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THESIS

USING UNMANNED AERIAL VEHICLES FOR AUTOMATED EXTERNAL DEFIBRILLATOR DELIVERY IN THE SEATTLE KING COUNTY REGION FOLLOWING OUT-OF-HOSPITAL CARDIAC ARREST

by

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September 2018

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ABSTRACT

Using an automated external defibrillator (AED) to deliver a shock to a cardiac arrest patient before emergency medical services arrive increases the likelihood that the patient will survive. This thesis explores the possibility of using unmanned aerial systems (UASs, or drones) to deliver AEDs to patients experiencing out-of-hospital cardiac arrest (OHCA) in Washington's Seattle/King County region—particularly in suburban and rural areas where traditional emergency response may be delayed. The researcher collected qualitative data on OHCA incidents in the region over a five-year period and ran simulated models to determine whether an AED-equipped UAS could arrive to a cardiac arrest patient faster than a traditional ground response. The research concluded that such UASs could be launched and maintained by a single organization, and could significantly decrease response times to the suburban and rural areas of the Seattle/King County region.

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TABLE OF CONTENTS

I. INTRODUCTION 1

II. LITERATURE REVIEW AND BACKGROUND 5
- A. OUT-OF-HOSPITAL CARDIAC ARREST 5
  - 1. Defibrillators 5
  - 2. The Importance of Early Defibrillation 6
  - 3. Public Response to Cardiac Arrest 7
- B. NATIONAL CPR TRAINING STUDY 9
- C. CARDIAC ARREST STATISTICS 12
- D. UAS AND AED DEPLOYMENT STRATEGIES 13
  - 1. Stockholm, Sweden 13
  - 2. Salt Lake City, Utah 15
  - 3. Toronto, Canada 17
  - 4. Reno, Nevada 17
- E. LEGAL AND REGULATORY FRAMEWORK CONSIDERATIONS 18
  - 1. Legal Issues 18
  - 2. Public and Private Partnerships 18

III. OHCA IN SEATTLE / KING COUNTY 21
- A. EMERGENCY RESPONSE MODEL 22
  - 1. Tiered Response 22
  - 2. High-Performance CPR 23
- B. CARDIAC ARREST HISTORICAL DATA 24
- C. PUBLIC ACCESS TO AEDS 28
- D. CARDIAC ARREST STATISTICS BY GEOGRAPHIC AREA AND GEOCODE 30
- E. RESPONSE TIME ANALYSIS 31
  - 1. 9-1-1 Call Received to Unit Dispatch 35
  - 2. Unit Dispatch to Unit En Route 36
  - 3. Unit En Route to Unit on Scene 38
  - 4. Unit on Scene to Unit with Patient 39
- F. ALTERNATIVE DEPLOYMENT STRATEGIES 40
  - 1. King County Medic One Stations 41
  - 2. Public Safety Answering Points (Dispatch Centers) 41
  - 3. Hospital Locations 41
  - 4. Private Industry 41

5. King County UAS Launch Site Data 42
G. SUMMARY 43

IV. RESEARCH DESIGN 45
A. METHODS FOR ASSESSMENT 45
B. DATA ELEMENTS 46

V. DATA ANALYSIS 49
A. SINGLE-ORGANIZATION DEPLOYMENT 49
B. UAS PERFORMANCE 55

VI. DISCUSSION 59

VII. RECOMMENDATIONS AND CONCLUSION 61
A. CONCLUSIONS 61
B. LIMITATIONS AND CONSIDERATIONS FOR FUTURE RESEARCH 62
C. CONSIDERATIONS FOR OTHER COMMUNITIES RESEARCHING UAS DEPLOYMENT 65

LIST OF REFERENCES 67

INITIAL DISTRIBUTION LIST 75

LIST OF FIGURES

Figure 1. King County Geocode Map Example 30

Figure 2. Cardiac Arrest by Geocode Location 31

Figure 3. Unit Dispatch to Patient's Side Median Time by Geocode 32

Figure 4. Time Interval: Unit Dispatch to Unit with Patient by Geocode 34

Figure 5. 9-1-1 Call Received to Unit Dispatch 36

Figure 6. Unit Dispatch to Unit En Route 37

Figure 7. En Route Time 38

Figure 8. En Route Times Map 39

Figure 9. Unit on Scene to "At Patient's Side" 40

Figure 10. UAS Launch Points for All Locations 43

Figure 11. King County Medic One Medic Units 49

Figure 12. Hospital Locations 50

Figure 13. Dispatch Centers 51

Figure 14. Private Industry Locations 52

Figure 15. Patients Affected: UAS Placed at Medic Locations, 25 mph 53

Figure 16. Patients Affected: UAS Placed at Medic Locations, 80 mph 54

Figure 17. Patients Affected: UAS Placed at Medic Locations, 100 mph 54

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LIST OF TABLES

Table 1. Characteristics of U.S. Counties by Rates of CPR Training.....11

Table 2. Factors Associated with Low Rates of CPR Training 12

Table 3. Utstein Sub-set: Survival to Hospital Discharge for Arrests Due to Heart Disease, Witnessed by Bystanders, with an Initial Rhythm of VF 26

Table 4. Utstein Sub-set: CPR Initiated by Bystanders, Limited to Arrest before Arrival of EMS Personnel 26

Table 5. Cardiac Arrest Data from 2012–2017.....27

Table 6. Seattle King County Community AED Program.....28

Table 7. AED Locations in King County.....29

Table 8. Time Interval: Unit Dispatch to Unit with Patient by Geocode.....33

Table 9. UAS Performance and Effect on Cardiac Arrest Cases.....56

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LIST OF ACRONYMS AND ABBREVIATIONS

ACLU	American Civil Liberties Union
AED	automated external defibrillator
ALS	advanced life support
BLS	basic life support
BVLOS	beyond visual line of sight
CASS	Cardiac Arrest Surveillance System
EMS	emergency medical services
EMT	emergency medical technician
FAA	Federal Aviation Administration
NFPA	National Fire Protection Agency
OHCA	out-of-hospital cardiac arrest
UAS	unmanned aerial system
VF	ventricular fibrillation
VT	ventricular tachycardia

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EXECUTIVE SUMMARY

Using an automated external defibrillator (AED) to deliver a shock to a cardiac arrest patient before the arrival of emergency medical services (EMS) increases the chance of the patient's survival. Studies both within the United States and abroad have explored using unmanned aerial systems (UASs, also known as drones) to deliver AEDs to cardiac arrest patients. By exploring similar research and legal restrictions and evaluating historical cardiac arrest data, this thesis examines a UAS solution for suburban and rural areas in which traditional emergency response may be delayed. Ultimately, the thesis seeks to determine if a UAS solution can be deployed in Washington's Seattle/King County region to reduce morbidity and improve survival rates for patients experiencing out-of-hospital cardiac arrest.

To test this approach, the researcher gathered historical data from the Seattle/King County region on traditional EMS responses for 4,233 cardiac arrest cases that occurred between January 1, 2012, and December 31, 2017. The data evaluated the emergency response from the moment a 9-1-1 call was placed to the moment the emergency responder made contact with the patient to begin resuscitative care.

Models were then constructed and run to evaluate if a UAS could respond to the patient faster than a traditional ground unit. The models were run for four different sets of potential UAS launch points to determine which would provide the best coverage for King County: King County Medic One Medic unit stations, 9-1-1 dispatch centers, hospitals, and private industry locations (commercial package delivery organizations with potential UAS delivery systems). The models evaluated UASs flying at 25 mph (40 km/h), which is what current off-the-shelf technology can offer; 80 mph (129 km/h), which is what current experimental airframes can perform; and 100 mph (161 km/h), which is currently the full speed at which the Federal Aviation Administration allows UASs to operate. The model tests showed that response times can, indeed, be reduced using UASs; response times per test site and UAS speed are shown in Table ES 1.

Table ES 1. UAS Performance and Effect on Cardiac Arrest Cases[1]

UAS Speed (mph)	Cardiac Arrest Cases of 4,233	King County Medic Units	Hospitals	Dispatch Centers	Private Industry
25	Cases Affected	1,743	254	229	151
	Median UAS Response Time for Cases Affected (Min:Sec)	11:55	11:48	11:42	11:59
	Median Reduction in Response Time for Cases Affected	1:31	1:38	1:44	1:27
80	Cases Affected	4,139	1,772	1,656	1,848
	Median UAS Response Time for Cases Affected (Min:Sec)	4:04	4:18	4:10	4:13
	Median Reduction in Response Time for Cases Affected	1:39	1:25	1:33	1:30

[1] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

UAS Speed (mph)	Cardiac Arrest Cases of 4,233	King County Medic Units	Hospitals	Dispatch Centers	Private Industry
100	Cases Affected	4,198	2,346	2,261	2,394
	Median UAS Response Time for Cases Affected (Min:Sec)	3:22	4:06	4:08	4:12
	Median Reduction in Response Time for Cases Affected	2:54	1:38	1:40	1:44

Of the four locations tested, King County Medic One stations would provide the most effective coverage for the suburban and rural areas of King County. If the UASs were placed at these locations, 1,743 of the 4,233 cardiac arrest cases (41 percent) that were researched could have had a median improvement in response time by 1 minute and 31 seconds with a UAS traveling at 25 mph, and 4,198 of 4,233 of the cardiac arrest cases (99 percent) could have had a median time improvement of 2 minutes and 54 seconds with a UAS traveling at 100 mph.

Although this shows significant response time reductions in the rural areas of King County, it is possible that the deployment of UASs with AEDs may have a greater impact in the suburban areas of King County. For a patient in cardiac arrest, the chances of survival decrease cumulatively by about 10 percent for each minute that passes without

intervention.[2] A reduction in response time from 6 minutes to 4 minutes could therefore conceivably increase the patient's chance of survival by 20 percent. However, in a rural setting, the difference between a response time of 18 minutes and 11 minutes might not have any impact on survival.

Because the data and models show that the UAS approach can reduce response time to patients in cardiac arrest, the next step—after addressing the considerations and limitations discussed in this thesis—is to explore the actual implementation process in King County and begin live testing.

[2] Monique L. Anderson et al., "Rates of Cardiopulmonary Resuscitation Training in the United States," *JAMA Internal Medicine* 174, no. 2 (February 1, 2014): 194, https://doi.org/10.1001/jama internmed.2013.11320.

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I. INTRODUCTION

Every day in the United States, people experience medical emergencies for which immediate care can improve their likelihood of survival. Sudden cardiac arrest is one of the leading emergencies for which mere seconds can make a lifesaving difference. Every year in the United States, approximately 326,000 people experience out-of-hospital cardiac arrest (OHCA).[1] Of those, 23 percent experience a potentially lethal heart rhythm, ventricular fibrillation (VF) or ventricular tachycardia (VT).[2] Either of these cardiac rhythms have a high probability of conversion back to a normal heart rhythm if a shock can be delivered with an automated external defibrillators (AED). First responders such as firefighters, emergency medical technicians (EMTs), paramedics, and law enforcement officers have been using AEDs for several decades.[3] In an effort to achieve even earlier defibrillation, AEDs are now being deployed into public spaces, and are even mandated in many public buildings around the United States.[4]

In the state of Washington's Seattle/King County area, studies have examined different techniques that may increase an OHCA patient's chance of survival. This region's overall cardiac arrest survival rates from 2012–2016 were 24 percent, and patients with a cardiac rhythm that was shockable by an AED had a survival rate of 55 percent during that same time period.[5] There is a strong consensus that "time is tissue"—that defibrillation can produce an organized rhythm with spontaneous circulation. Ultimately, survival declines

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[1] Emelia J. Benjamin et al., "Heart Disease and Stroke Statistics—2017 Update: A Report from the American Heart Association," *Circulation* 135, no. 10 (March 2017): 5, https://doi.org/10.1161/CIR.0000000000000485.

[2] Steven P. Keller and Henry R. Halperin, "Cardiac Arrest: The Changing Incidence of Ventricular Fibrillation," *Current Treatment Options in Cardiovascular Medicine* 17, no. 7 (July 2015): 392, https://doi.org/10.1007/s11936-015-0392-z.

[3] Kenneth Gundersen et al., "Development of the Probability of Return of Spontaneous Circulation in Intervals without Chest Compressions during Out-of-Hospital Cardiac Arrest: An Observational Study," *BMC Medicine* 7, no. 6 (2009), https://doi.org/10.1186/1741-7015-7-6.

[4] "Public Access Defibrillation Guidelines," U.S. Department of Health and Human Services, accessed February 20, 2018, https://foh.psc.gov/whatwedo/AED/HHSAED.ASP.

[5] Helen Chatalas and Tracie Jacinto (eds.), "2017 Annual Report to the King County Council" (report, Public Health – Seattle & King County, September 2017), 45, https://www.kingcounty.gov/depts/health/~/media/depts/health/emergency-medical-services/documents/reports/2017-Annual-Report.ashx.

as the interval between initial collapse and AED shock increases. Without early defibrillation, patients who suffer OHCA at home or in an area without access to an AED lose precious seconds, and their chance of surviving declines.[6]

According to the U.S. Census Bureau, only three percent of the land mass in the United States is classified as urban.[7] While most of the population lives in urban and suburban areas, 19 percent (roughly 60 million people) live in rural areas.[8] Responding to medical emergencies in rural areas in a timely manner is often a challenge.[9] National Fire Code section 1710 from the National Fire Protection Agency (known as NFPA 1710) stipulates that the first arriving emergency medical services (EMS) unit should be on scene following a 9-1-1 call within 4 minutes.[10] However, a recent study by the American College of Emergency Physicians showed that the average response time for EMS to rural areas was at least 13 minutes, and 10 percent of the time the patient waited over 30 minutes for help to arrive.[11] With life-threatening emergencies such as uncontrolled bleeding, anaphylaxis, and cardiac arrest, the patient's chance of survival decreases significantly with every minute that passes.[12]

Delayed emergency response times are not just a problem for rural residents in the United States. Urban and suburban areas can experience heavy 9-1-1 call volumes that deplete emergency resources, heavy vehicle traffic, and inclement weather, all of which

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[6] David Carlbom et al., "Strategies to Improve Survival from Sudden Cardiac Arrest" (report, Resuscitation Academy, April 2013), 5.

[7] "New Census Data Show Differences Between Urban and Rural Populations," U.S. Census Bureau, December 8, 2016, https://www.census.gov/newsroom/press-releases/2016/cb16-210.html.

[8] U.S. Census Bureau.

[9] U.S. Census Bureau.

[10] National Fire Protection Agency, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, NFPA 1710 (Quincy, MA: National Fire Protection Association, 2016), https://codesonline.nfpa.org/code/01ae8631-3d82-47d4-a689-9d088b2517d4/60a88fe0-47fc-4b6d-a02b-ec08d3656814/.

[11] "Rural Patients Wait Longest for EMS," American College of Emergency Physicians, July 19, 2017, http://newsroom.acep.org/2017-07-19-Rural-Patients-Wait-Longest-for-EMS.

[12] "Every Second Counts: Rural and Community Access to Emergency Devices," American Heart Association, accessed August 7, 2018, 2, http://www.heart.org/idc/groups/heart-public/@wcm/@adv/documents/downloadable/ucm_462242.pdf.

prevent emergency services from reaching patients quickly. While a myriad of factors contributes to emergency response times, there are two overarching primary issues: time and distance. Many factors play into both. Deployment models for emergency vehicles and their placement are constantly being refined and evaluated to ensure that response times are as short as possible. Emergency responders have little to no control over traffic conditions, weather, time of day, and distance, among other variables. With this in mind, are there technologies that can reduce the time it takes to get help to those who need it?

Individual homeowners can increase their family's preparedness by purchasing an AED on their own with a prescription from a medical provider or family doctor. However, AEDs vary in cost from several hundred to several thousand dollars and require routine maintenance to ensure they will operate effectively during an emergency. A recent study by the Louisville School of Medicine in Kentucky showed that 21 percent of all public access AEDs failed at least one phase of testing needed to make the unit effective in treating cardiac arrest, and five percent had batteries that were completely dead when tested.[13] AEDs both in public venues and in the home need to be monitored at regular intervals. AEDs that are being routinely maintained and monitored by emergency responders are the gold standard for OHCA response.

Emergency services have begun to use unmanned aerial systems (UASs), commonly referred to as drones, as part of their mission response plans. Police agencies now use UASs to help with surveillance, and fire departments around the world are beginning to use them to monitor large-scale fires and inform tactical decisions.[14] Can UASs be used to deliver a critical piece of equipment to OHCA patients until trained EMS providers arrive? And could the resulting reduction in response time decrease morbidity and mortality for patients who are in cardiac arrest? Several fire and EMS agencies from around the world are studying the use of UASs to increase patient survival rates during

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[13] "University of Louisville Researchers Find Readiness of Public Access AEDs Alarmingly Low," Sudden Cardiac Arrest Foundation, April 24, 2017, http://www.sca-aware.org/sca-news/university-of-louisville-researchers-find-readiness-of-public-access-aeds-alarmingly-low.

[14] Ben, "Drones Used by Police, Fire, and Other Emergency Services," *Drone UAV* (blog), July 10, 2015, http://www.droneuav.co.uk/drones-at-work/drones-used-by-police-fire-and-other-emergency-services/.

cardiac arrest emergencies. But issues involving their deployment, location, training requirements, legal implications, and the need for partnerships with the private sector still need to be addressed. However, their successful implementation could prove to be a key factor in further increasing OHCA survival rates. This thesis seeks to determine if emergency deployment of UASs can be used in the Seattle/King County region to reduce morbidity and improve cardiac arrest survival rates for patients with OHCA in suburban and rural areas when traditional emergency response may be delayed.

II. LITERATURE REVIEW AND BACKGROUND

This chapter discusses current national and international studies that have explored using UASs to deliver lifesaving equipment to cardiac arrest patients—including the limitations of those studies—as well as the legal issues surrounding drone use in both the public and private sector, and the training impacts on departments and organizations.

A. OUT-OF-HOSPITAL CARDIAC ARREST

1. Defibrillators

There are two types of external defibrillators that can be used on patients in cardiac arrest. The advanced life support (ALS) unit is used in hospitals by trained healthcare providers such as doctors and nurses, and by paramedics in out-of-hospital scenarios.[15] The ALS defibrillator allows the trained provider to intervene manually if a shock is required.[16] The second type, an AED, is an easy-to-operate unit that can be used by a layperson or healthcare provider who only has basic training.[17] AEDs instruct the rescuer to deliver the shock; some machines have the ability to deliver the shock automatically without any intervention from the rescuer.[18]

All defibrillator devices work by sending energy through the victim's chest wall. This stops the chaotic rhythms of both VF and VT by stunning the heart, which allows it to start beating normally again on its own.[19] The AED's built-in computer checks the cardiac arrest patient's heart rhythm through sensitive electrodes that are placed on the patient's chest.[20] If the computer in the AED determines that a shock is needed, an

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[15] Ananya Mandal, "Defibrillator Types," News-Medical.Net, March 11, 2010, https://www.news-medical.net/health/Defibrillator-Types.aspx.

[16] Mandal.

[17] Mandal.

[18] Mandal.

[19] Mayo Clinic, "Ventricular Fibrillation."

[20] "What Is an AED?," American Heart Association, accessed February 7, 2018, http://www.heart.org/idc/groups/heart-public/@wcm/@hcm/documents/downloadable/ucm_300340.pdf.

automated voice will instruct the rescuer to push a button that delivers an electrical shock to the patient's heart.[21]. The AED guides the user through the rescue process, including how to use the device, where to place the adhesive electrodes, when to stop and start CPR, and when to deliver a shock.[22]

2. The Importance of Early Defibrillation

For several decades, researchers have been studying the effects of early defibrillation on patients in cardiac arrest. In 1974, Dr. Richard R. Liberthson et al. from the University of Miami School of Medicine determined that early defibrillation increased cardiac arrest patients' chance of survival.[23] In an article published in the *New England Journal of Medicine*, Dr. David Callans stated, "most victims of cardiac arrest are initially found in ventricular fibrillation …. decades of experience in cardiac intensive care units have shown that immediate defibrillation is almost universally effective."[24] For a study in Olmstead County, Minnesota, long-term quality of life was measured on a group of patients who suffered an OHCA.[25] The study concluded that if a patient had an OHCA and was rapidly defibrillated, his or her long-term quality of life was the same as someone in the general population who had never suffered a cardiac arrest event.[26] Furthermore, the American Heart Association published a paper in February 2018 stating that if an AED is used prior to EMS arrival for a patient in cardiac arrest, the chances for survival double.[27]

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[21] American Heart Association.

[22] "How to Use an AED (Automatic External Defibrillator)," Australian Defibrillators, accessed February 7, 2018, www.aeds.com.au.

[23] Richard R. Liberthson et al., "Prehospital Ventricular Defibrillation," *New England Journal of Medicine* 291, no. 7 (August 15, 1974): 317–21, https://doi.org/10.1056/NEJM197408152910701.

[24] David J. Callans, "Out-of-Hospital Cardiac Arrest—The Solution Is Shocking," *New England Journal of Medicine* 351, no. 7 (August 12, 2004): 632–34, https://doi.org/10.1056/NEJMp048174.

[25] T. Jared Bunch et al., "Long-Term Outcomes of Out-of-Hospital Cardiac Arrest after Successful Early Defibrillation," *New England Journal of Medicine* 348, no. 26 (June 26, 2003): 2626–33, https://doi.org/10.1056/NEJMoa023053.

[26] Bunch et al.

[27] Ross Pollack, "Cardiac Arrest Survival Greatly Increases When Bystanders Use an Automated External Defibrillator," American Heart Association, February 26, 2018, https://newsroom.heart.org/news/cardiac-arrest-survival-greatly-increases-when-bystanders-use-an-automated-external-defibrillator.

3. Public Response to Cardiac Arrest

Of the 326,000 OHCAs annually in the United States, approximately 30 percent occur outside of the home, in a public place.[28] With the knowledge that AEDs can deliver a shock to a patient in cardiac arrest—and that the device gives verbal instructions to untrained laypeople—President Bill Clinton signed the Cardiac Arrest Survival Act in November 2000, U.S. Code H.R. 106-634.[29] The act required all federal buildings to have an AED onsite and provided "Good Samaritan" protections from civil lawsuits to AED users as well as building owners, renters, and others who make AEDs available for public use.[30] In May 2002, President George W. Bush signed the Community Access to Emergency Devices Act, H.R. 3462.[31] In June of that same year, President Bush signed a bill that authorized $30 million in federal funds to be spent on purchasing and placing defibrillators in public places where OHCAs are likely to occur.[32]

Thanks to these laws and growing public awareness, AEDs have now become prevalent in many public places. All federal and most state and local government buildings are now required to carry AEDs, and many businesses now have AEDs readily available should a patron suffer an OHCA in their facility. There are nearly 2.4 million AEDs registered in the United States, and an estimated total need of over 30 million.[33] Many states are now requiring certain private businesses to carry an AED onsite and be able to retrieve it within sixty seconds. In the state of Washington, dental offices and any private

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[28] Mozaffarian et al., "Heart Disease and Stroke Statistics."

[29] "State Laws on Cardiac Arrest and Defibrillators," National Conference of State Legislatures, January 2, 2017, http://www.ncsl.org/research/health/laws-on-cardiac-arrest-and-defibrillators-aeds.aspx; Cardia Arrest Survival Act of 2000, 106 Cong., H. Rept. 106-634, https://www.congress.gov/congressional-report/106th-congress/house-report/634/1.

[30] National Conference of State Legislatures, "State Laws."

[31] Lois Capps, "H.R.3462—Community Access to Emergency Defibrillation Act of 2001," U.S. Congress, December 28, 2001, https://www.congress.gov/bill/107th-congress/house-bill/3462.

[32] National Conference of State Legislatures, "State Laws."

[33] DXE Marketing, "2.4 Million Public Access AEDs in the US, At Least 30 Million Needed," *AED Blog*, August 1, 2013, http://www.aed.com/blog/2-4-million-public-access-aeds-in-the-us-at-least-30-million-needed/.

medical practice facility that administers anesthesia is required to have an AED.[34] In many states, gyms, educational facilities, sports venues, airports, and large shopping centers are also required to have an AED readily available.

In a study by Myron Weisfeldt et al., a group of cities belonging to the Resuscitation Outcome Consortium, which is made up of eleven cities in the United States and Canada, showed that AEDs in a public venues were only utilized 2.1 percent of the time over a seventeen-month period.[35] If AEDs had been applied and used for the OHCA incidents, the overall survival rate would have gone from 9 percent to over 24 percent.[36] This shows that using a properly maintained AED can increase the probability of survival in cardiac arrest; however, this only works if rescuers are willing to use the AED.

According to the American Heart Association, approximately 12 million people are trained in CPR/AED administration every year in the United States.[37] Most individuals who take a CPR class take the American Heart Association's Heartsaver CPR/AED course. The course is approximately three hours long and covers adult CPR, infant CPR, how to relieve choking in adults and infants, and the proper use of an AED.[38] For those who are not trained, or for those who have forgotten how to use an AED, however, all AEDs use voice prompts to guide the user through CPR and defibrillation.

Technological advances are now making it easier to help patients in cardiac arrest. Smartphone applications can teach anyone how to perform CPR and use an AED, give real-time instructions during a cardiac arrest, and even let trained rescuers know that there

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[34] "WAC 246-817-722: Defibrillator," Washington State Legislature, accessed February 8, 2018, http://apps.leg.wa.gov/WAC/default.aspx?cite=246-817-722.

[35] Myron L. Weisfeldt et al., "Survival after Application of Automatic External Defibrillators before Arrival of the Emergency Medical System," *Journal of the American College of Cardiology* 55, no. 16 (April 20, 2010): 1, https://doi.org/10.1016/j.jacc.2009.11.077.

[36] Weisfeldt et al., 5.

[37] "CPR Statistics," American Heart Association, June 2011, http://www.heart.org/HEARTORG/CPRAndECC/Whatis%20CPR/CPRFactsandStats/CPR-Statistics_UCM_307542_Article.jsp#.WnxWEJPwZsM.

[38] "Heartsaver CPR AED," American Heart Association, accessed February 8, 2018, http://cpr.heart.org/AHAECC/CPRAndECC/Training/HeartsaverCourses/HeartsaverCPRAED/UCM_473176_Heartsaver-CPR-AED.jsp.

is a cardiac arrest near their current location. In June 2009, the San Ramon Valley Fire Protection District in California, along with the College of Informatics at Northern Kentucky, developed the PulsePoint application for smartphones.[39] PulsePoint allows citizens who are trained in CPR to register on the company's website and receive a notification on their smartphone that a patient is in cardiac arrest somewhere in their immediate area.[40] The PulsePoint app also gives communities and businesses the ability to register an AED device that is located in one of their buildings.[41] This information is also registered with the local emergency dispatch center. When a 9-1-1 call comes into a dispatch center that has the PulsePoint app integrated into its system, a notification will go out to all registered responders who have the PulsePoint app, notifying them that there is a cardiac arrest near them, and identifying the closest registered AED.[42] In New Zealand, the New Zealand Health Navigator has also developed a smartphone app that helps the user quickly locate the nearest AED.[43] The app allows the user to browse the location of an AED on a map, search for the location by name and address to get details, obtain contact information, and determine hours of operation of any business that has an AED.

B. NATIONAL CPR TRAINING STUDY

It has been well documented that the sooner an OCHA patient receives CPR, the greater the patient's chance of survival. For every minute that passes without CPR or AED intervention, the patient's chance of survival falls by 10 percent.[44] According to a study published in the *Journal of the American Medical Association* in 2014, the rate of CPR

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[39] "PulsePoint Foundation," accessed February 12, 2018, http://www.pulsepoint.org/foundation/.

[40] PulsePoint, accessed February 12, 2018, http://www.pulsepoint.org/.

[41] PulsePoint.

[42] "PulsePoint AED," accessed February 12, 2018, http://www.pulsepoint.org/pulsepoint-aed/.

[43] The app was designed by BKE Digital Outfitters. See "AED Locations App," Health Navigator New Zealand, accessed February 12, 2018, https://www.healthnavigator.org.nz/app-library/a/aed-locations-app/.

[44] Monique L. Anderson et al., "Rates of Cardiopulmonary Resuscitation Training in the United States," *JAMA Internal Medicine* 174, no. 2 (February 1, 2014): 195, https://doi.org/10.1001/jamainternmed.2013.11320.

training in the United States is low, and varies widely by year and by county.[45] The study examined the variability in county-level rates of CPR training to try to determine why the rates are so low. The study defined tertiles by ordering all 3,142 U.S. counties—based on rate of CPR training—from highest to lowest, and grouped the counties into lower, middle, and upper tertiles. In an attempt to identify contributing factors for low rates, the study took into account gender, race, median household income, education level, a rural location, geographic rate of mortality due to heart disease, and number of physicians in the region (see Table 1).Over a one-year period, the study found that just over 15 million individuals in the United States had been trained in some form of CPR. The median annual CPR training rate in the United States was 2.39 percent in an individual county. The lower tertile ranged from 0 percent to 1.29 percent (median 0.51 percent) of the population trained, the middle tertile from 1.29 percent to 4.07 percent (median 2.39 percent), and the upper tertile was greater than 4.07 percent (median 6.81 percent).[46]

[45] Anderson et al., 194.

[46] Anderson et al., 196.

Table 1. Characteristics of U.S. Counties by Rates of CPR Training[47]

		Tertile of CPR Training			
Baseline of Characteristic	Overall (N=3143)	Lower Tertile (N=1047	Middle Tertile (N=1048)	Upper Tertile (N=1048)	P Value
Population density (# of persons per square mile)	42.8 (16.5-107.6)	24.0 (7.7-46.7)	44.1 (20.0-98.6)	92.7 (32.8-282.1)	<.001
Race					
White	89.1 (75.2-95.5)	89.1 (72.6-96.3)	90.4 (78.2-96.0)	87.8 (74.9-94.1)	.001
Black	2.0 (0.5-10.2)	1.3 (0.3-15.0	1.7 (0.5-7.1)	2.8 (0.8-9.8)	<.001
Hispanic	3.3 (1.6-8.2)	2.5 (1.4-6.2)	3.2 (1.6-8.5)	4.1 2.0-9.5)	<.001
Asian	0.5 (0.3-1.0)	0.3 (0.2-0.5	0.5 (0.3-1.0	0.9 (0.5-2.1)	<.001
Male sex	49.5 (48.9-50.4)	49.7 (49.0-50.7)	49.6 (49.0-50.3)	49.4 (48.7-50.1)	<.001
Median age	40.3 (37.4-43.4)	41.4 (38.9-44.8)	40.4 (37.6-43.4)	39.3 (36.1-41.9)	<.001
Rural residents	60.4 (35.8-90.2)	82.8 (60.3-100.00)	60.7 (38.8-82.3)	38.6 (18.0-60.0)	<.001
College degree	14.5 (11.2-19.3)	12.1 (10.0-15.4)	14.4 (11.3-18.8)	17.7 (13.7-24.8)	<.001
Median household income $	42,390 (36,518-49,241)	38,087 (33,551-43,693)	43,358 (37,630-50,332)	45,267 (40,135-52,386)	<.001
Living in poverty	14.3 (10.9-18.3)	16.3 (12.3-21.0)	13.5 (10.6-17.8)	13.5 (10.4-16.7)	<.001
# of physicians per county	20.0 (5.0-93.0)	6.0 (2.0-15.0)	22.0 (7.0-76.0)	94.0 24.5-405.5)	<.001
Heart disease mortality rate, persons per 100,000	197.4 (170.6-228.9)	208.0 (176.2-246.4)	195.8 (170.6-226.1)	191.2 (164.4-215.4)	<.001
Region					
West	14.3	11.1	14.4	17.3	<.001
South	45.3	57.0	43.9	34.9	
Midwest	33.6	31.1	34.6	34.9	
Northeast	6.9	0.8	7.1	12.1	

The study concluded that rates of CPR training in the lower tertile were directly associated with lower population densities. The study also showed that rural areas had lower rates of individuals trained in CPR. "For every 5-percentage point increase in rural population," the authors found, "the odds of being in a lower tertile level increased."[48] The study determined that although geographic location, household income, age, race, and ethnicity all caused variations in the number of people trained in CPR and which tertile each county would end up in, the largest determining factor was the percentage of rural residents in that particular county (see Table 2).[49] This is why alternative means need to be explored to try to increase cardiac arrest survival rates in rural areas.

[47] Adapted from Anderson et al., 197.

[48] Anderson et al., 196.

[49] Anderson et al., 197.

Table 2. Factors Associated with Low Rates of CPR Training[50]

		Tertile of CPR Training			
Baseline of Characteristic	Overall (N=3143)	Lower Tertile (N=1047	Middle Tertile (N=1048)	Upper Tertile (N=1048)	P Value
Population density (# of persons per square mile)	42.8 (16.5-107.6)	24.0 (7.7-46.7)	44.1 (20.0-98.6)	92.7 (32.8-282.1)	<.001
Race					
White	89.1 (75.2-95.5)	89.1 (72.6-96.3)	90.4 (78.2-96.0)	87.8 (74.9-94.1)	.001
Black	2.0 (0.5-10.2)	1.3 (0.3-15.0	1.7 (0.5-7.1)	2.8 (0.8-9.8)	<.001
Hispanic	3.3 (1.6-8.2)	2.5 (1.4-6.2)	3.2 (1.6-8.5)	4.1 2.0-9.5)	<.001
Asian	0.5 (0.3-1.0)	0.3 (0.2-0.5	0.5 (0.3-1.0	0.9 (0.5-2.1)	<.001
Male sex	49.5 (48.9-50.4)	49.7 (49.0-50.7)	49.6 (49.0-50.3)	49.4 (48.7-50.1)	<.001
Median age	40.3 (37.4-43.4)	41.4 (38.9-44.8)	40.4 (37.6-43.4)	39.3 (36.1-41.9)	<.001
Rural residents	60.4 (35.8-90.2)	82.8 (60.3-100.00)	60.7 (38.8-82.3)	38.6 (18.0-60.0)	<.001
College degree	14.5 (11.2-19.3)	12.1 (10.0-15.4)	14.4 (11.3-18.8)	17.7 (13.7-24.8)	<.001
Median household income $	42,390 (36,518-49,241)	38,087 (33,551-43,693)	43,358 (37,630-50,332)	45,267 (40,135-52,386)	<.001
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# of physicians per county	20.0 (5.0-93.0)	6.0 (2.0-15.0)	22.0 (7.0-76.0)	94.0 24.5-405.5)	<.001
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Region					
West	14.3	11.1	14.4	17.3	<.001
South	45.3	57.0	43.9	34.9	
Midwest	33.6	31.1	34.6	34.9	
Northeast	6.9	0.8	7.1	12.1	

C. CARDIAC ARREST STATISTICS

According to the American Heart Association, the 2015 national average of non-traumatic OHCA patients in the United States who were discharged alive from the hospital was 10.6 percent.[51] Thomas D. Rea et al. published research on individual cities throughout the United States to show the vast differences in cardiac arrest survival rates: survivability ranged from 3.3 percent in Chicago to over 40 percent in Rochester, Minnesota.[52] Furthermore, Dariush Mozaffarian et al. showed that, in 2015, approximately 60 percent of cardiac arrests were treated by EMS personnel; 25 percent of patients treated by EMS had no reported symptoms prior to the cardiac arrest and 23 percent had an initial

[50] Adapted from Anderson et al., 199.

[51] Mozaffarian et al., "Heart Disease and Stroke Statistics," 208.

[52] Thomas D. Rea et al., "Incidence of EMS-Treated Out-of-Hospital Cardiac Arrest in the United States," *Resuscitation* 63, no. 1 (October 2004): 20, https://doi.org/10.1016/j.resuscitation.2004.03.025.

rhythm of VF or VT, which are shockable by an AED.[53] Cardiac arrest was witnessed by a bystander 38.7 percent of the time, by an EMS provider 10.9 percent of the time, and was unwitnessed in 50.4 percent of the cases.[54]

In 2016, the Seattle/King County region had a total of 1,246 OCHA incidents.[55] Of those, 21.4 percent of the patients survived. Patients who had an initial rhythm of VF (shockable by an AED) had an overall survival rate of 55 percent.[56]

D. UAS AND AED DEPLOYMENT STRATEGIES

1. Stockholm, Sweden

A 2016 study by A. Claesson et al. sought to determine if using UASs to deliver AEDs could reduce morbidity and mortality in Stockholm County, Sweden. With a total area of 6,488 km^2 (2,505 mi^2) and a population of 2.3 million people, Stockholm County is made up of urban, suburban, and rural areas.[57] The incidence of OHCA in Stockholm is 46 per 100,000 residents per year.[58] According to Claesson et al., the county has four dispatch centers and runs a tiered emergency response system that responds to both BLS and ALS calls. For OHCA cases in Stockholm, the average response time from collapse to defibrillation by an AED was 11 minutes, with an overall thirty-day survival rate of 31 percent when the first shock was delivered by EMS.[59] Claesson et al. reported that if a public access AED had been used prior to EMS arrival, survival rates for patients with a shockable rhythm would have increased to 70 percent.

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[53] "Mozaffarian et al., "Heart Disease and Stroke Statistics."

[54] Mozaffarian et al., 207.

[55] Helen Chatlas and Michele Plorde (eds.), "2015 Annual Report to the King County Council," (report, Public Health – Seattle & King County, September 2015), 45, https://www.kingcounty.gov/depts/health/emergency-medical-services/~/media/depts/health/emergency-medical-services/documents/reports/2015-Annual-Report.ashx.

[56] Chatlas and Plorde, 45.

[57] "Stockholm," City Population, February 22, 2018, http://www.citypopulation.de/php/sweden-admin.php?adm1id=01; A. Claesson et al., "Unmanned Aerial Vehicles (Drones) in Out-of-Hospital-Cardiac-Arrest," *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine* 24, no. 1 (December 1, 2016): 2, https://doi.org/10.1186/s13049-016-0313-5.

[58] Claesson et al., "Unmanned Aerial Vehicles," 2.

[59] Claesson et al., 2.

The Stockholm study used a spatial analysis global information system model to determine the best locations to deploy the AED-equipped UASs. The model weighted two factors: the OHCA, and the time it took for EMS to arrive.[60] In the urban areas of Stockholm, the OHCA and the response time were weighted equally—both were considered equally important in making a determination about if and where a UAS would be placed. In the rural areas of Stockholm, however, the OHCA was only weighted at 20 percent, while the amount of time it would take for an EMS unit to arrive on scene was weighted at 80 percent. Once they determined where to place the UASs, the researchers ran another model, which showed that—in urban settings—the UAS would arrive to the OCHA before the EMS crew in 32 percent of the cases, with an average decrease in response time of 1 minute and 30 seconds.[61] In the rural areas, the UASs were able to arrive faster than the EMS units in 93 percent of the OHCA cases, and had an average decrease in response time of 9 minutes.[62]

However, a separate study performed in Stockholm showed that a decrease in response time—when it comes to the patient's survival—does not make as big a difference for traditionally long response times as it does for already shorter response times.[63] The study showed that the relationship between time reduction and survival did not appear to be proportional, especially in rural areas. Because a cardiac arrest patient's chance of survival falls approximately ten percent each minute that passes without intervention, the *total* time to arrival is the most important factor, as the AEDs are most effective when used early.[64]

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[60] Claesson et al., 2.

[61] Claesson et al., 5.

[62] Claesson et al., 5.

[63] Per Nordberg et al., "The Survival Benefit of Dual Dispatch of EMS and Fire-Fighters in Out-of-Hospital Cardiac Arrest May Differ Depending on Population Density—A Prospective Cohort Study," *Resuscitation* 90 (May 2015): 5, https://doi.org/10.1016/j.resuscitation.2015.02.036.

[64] Anderson et al., "Resuscitation Training," 195.

Claesson et al. concluded that rural cases can theoretically be reached by a UAS within 8.5 minutes.[65] Data suggested that if the UAS carrying the AED could arrive within 7 to 10 minutes, the thirty-day survival rate could reach somewhere between 30 to 41 percent. Currently, the EMS response time to rural areas of Stockholm averages 21 minutes, with a correlating cardiac arrest survival rate of 0 to 8 percent.[66] The study further stated that the use of UASs may be safe and feasible, and that global information system study models could reduce the time to defibrillation for patients who suffer OHCA. It should be noted, however, that the study only included OHCA cases that occurred before EMS crews arrived; including all cases may have altered the results. Also, the technology and data used in the study did not have the ability to capture the time between notifications from the dispatch center and launch of the UAS, which may alter results. The study furthermore could not determine how UAS landing and deployment procedures would affect the overall response time. These limitations notwithstanding, the study did show that a UAS would reduce the amount of time it took to deliver an AED to a patient in cardiac arrest.

2. Salt Lake City, Utah

In the *Journal of Prehospital Emergency Care*, Aaron Pulver, Ran Wei, and Clay Mann published an article about reducing OHCA response time in Salt Lake County, Utah. Currently in Salt Lake County, the Salt Lake City Fire Department maintains a response time of 5 minutes or less to life-threatening emergency response calls.[67] The purpose of the study was to determine if OHCA response times could be reduced to less than one minute for 90 percent of cases. Using traditional ground-based EMS, Salt Lake County was able to arrive on scene within 1 minute of an OHCA 4.3 percent of the time.[68]

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[65] Claesson et al., "Unmanned Aerial Vehicles," 8.

[66] Claesson et al., 8.

[67] Jennifer Bruno, "Council Budget Staff Report" (report, City of Salt Lake City, 2014), 393, http://slcdocs.com/council/agendas/2014agendas/BudgetRelatedStaffReports.pdf.

[68] Aaron Pulver, Ran Wei, and Clay Mann, "Locating AED Enabled Medical Drones to Enhance Cardiac Arrest Response Times," *Prehospital Emergency Care* 20, no. 3 (May 3, 2016): 381, https://doi.org/10.3109/10903127.2015.1115932.

The authors studied three different scenarios: 1) using existing EMS stations as potential launch sites, 2) using only new locations as potential launch sites, and 3) using a combination of existing and new launch sites. In the first scenario—which used only the 66 existing EMS stations as launch sites—a UAS equipped with an AED could reach 80 percent of the county within 1 minute, and 94.1 percent of the county within 5 minutes. While this did not meet the study's goal (1 minute for 90 percent of cases), there was significant cost savings to utilizing existing structures owned by Salt Lake County. In scenario two, modeling software identified thirty-seven new facility locations that would achieve the study goal. If the goal time were changed from 1 minute to 5 minutes, only four launch facilities would have to be built in order to meet the goal. The down side to scenario two, however, is that no existing facilities could be utilized, and building thirty-seven new facilities would cost $2,590,000. For scenario three—using a combination of existing and new facilities—the study revealed that thirty-nine existing EMS stations could be used, and twelve could be constructed for an approximate cost of $2,010,000.[69]

The study concluded that a UAS network, strategically placed, could deliver lifesaving equipment faster than traditional ground EMS for patients with OHCA.[70] The study did not account for the amount of turn out time, or the time from when a unit or station was notified that there was a cardiac arrest to the time that the emergency response unit had "wheels rolling". There is also no data in Salt Lake County that shows the amount of time that traditionally transpires between a unit's arrival on location and responders' arrival at the patient's side. For example, in a high-rise building, it may take emergency responders several minutes—even once they arrive at the building—to reach a patient on the top floor.

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[69] Pulver, Wei, and Mann, 283, 381–82.

[70] Pulver, Wei, and Mann, 389.

3. Toronto, Canada

Justin J. Boutilier et al. published a study in 2017 that examined using AED-equipped UASs to increase OHCA survival rates in Toronto, Canada. The study evaluated almost 54,000 OHCA cases that occurred over a twelve-year period in the region.[71] The goal of the study was to reduce the amount of time that an AED would arrive on scene by 1, 2, or 3 minutes. The authors found that decreasing arrival time by as little as 13 seconds had statistical significance. The study also realized that for the AED program to work optimally, there would need to be at least two rescuers on scene with the patient—one to perform CPR and the other to retrieve the UAS. The Toronto study determined that UAS delivery of AEDs can not only reduce time to intervention during OHCA, but is also more cost effective than adding additional response units.[72]

4. Reno, Nevada

The Regional Emergency Medical Service Authority in Reno, Nevada, has partnered with UAS manufacturer Flirtey to deliver AEDs to patients in cardiac arrest.[73] Both organizations hope to increase survivability to patients in cardiac arrest by delivering AEDs via UASs.

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[71] Justin J. Boutilier et al., "Optimizing a Drone Network to Deliver Automated External Defibrillators," *Circulation* 135, no. 25 (June 20, 2017): 2454, https://doi.org/10.1161/CIRCULATIONAHA.116.026318.

[72] Boutilier et al., 2459, 2463, 2462.

[73] "Flirtey Partners with Pioneering Ambulance Service to Launch First Emergency Drone Delivery Program," PR Newswire, October 26, 2017, https://www.prnewswire.com/news-releases/flirtey-partners-with-pioneering-ambulance-service-to-launch-first-emergency-drone-delivery-program-in-united-states-300534046.html.

E. LEGAL AND REGULATORY FRAMEWORK CONSIDERATIONS

1. Legal Issues

The Federal Aviation Administration (FAA) restricts UASs from flying in certain areas, but does allow certain exemptions for emergency responders.[74] However, responders still must deploy and pilot drones, per FAA regulation, while keeping in constant visual contact with the UAS.[75] Thus, the UAS would not be able to fly autonomously to a residence based on global positioning satellite (GPS) coordinates. As of 2018, the FAA has been working to keep up with the booming UAS market in both the public and private sectors.

The American Civil Liberties Union (ACLU) has brought a secondary legal and civil issue to light, having filed numerous lawsuits against cities and police departments across the United States that are attempting to use drones for surveillance and emergency services.[76] The ACLU wants strict and transparent policies to regulate all government entities that operate drones over cities. In 2013, the ACLU was able to successfully stop the Seattle Police Department from deploying two drones it had acquired from a Department of Homeland Security grant.[77]

2. Public and Private Partnerships

Several large companies are attempting to use commercial drone delivery service throughout the United States. Amazon Prime Air, Google, and UPS are moving forward

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[74] "Certificates of Waiver or Authorization (COA)," Federal Aviation Administration, last modified March 9, 2018, https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/coa/.

[75] "FAA Regulations for Unmanned Aerial Vehicle (UAV) Drones UAV," Homeland Surveillance & Electronics, accessed February 9, 2018, http://www.hse-uav.com/faa_regulations.htm.

[76] "Protecting Privacy from Aerial Surveillance: Recommendations for Government Use of Drone Aircraft," American Civil Liberties Union (ACLU), accessed August 8, 2018, https://www.aclu.org/report/protecting-privacy-aerial-surveillance-recommendations-government-use-drone-aircraft.

[77] "Protect Privacy as Seattle Police Drones Take Off," ACLU of Washington, January 2, 2013, https://www.aclu-wa.org/blog/protect-privacy-seattle-police-drones-take.

with divisions on drone package delivery.[78] UPS may also partner with the Red Cross to fly its drones during disasters, to help disaster workers look for sick and injured people.[79] In private industry, organizations like Amazon, Google, and Flirtey have technology that most public emergency services do not; if emergency response agencies were to partner with private agencies, they could see great cost savings for UAS maintenance and upkeep.

A report from the National Defense University outlines the benefits of public–private partnerships from a Department of Defense.[80] However, many principles noted in the report can be applied to smaller government organizations as well. According to the report, public–private partnerships can further policy objectives, enhance operational capabilities, reduce costs, and grant government agencies access to nongovernmental expertise or assets.[81] It is also noted that, as governmental agencies try to keep up with ever-changing roles and missions with financial limitations, the expertise and involvement of the private sector, research institutions, and academia will be essential for government agencies to remain relevant.[82]

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[78] Julie Bort, "Google's Drone Delivery Project Just Shared Some Big News about Its Future," *Business Insider*, June 7, 2017, http://www.businessinsider.com/project-wing-update-future-google-drone-delivery-project-2017-6; "Amazon Prime Air," Amazon, accessed August 8, 2018, www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011; Eric Mandel, "UPS Testing Drones for Disaster Relief," *Atlanta Business Chronicle*, September 8, 2017, https://www.bizjournals.com/atlanta/news/2017/09/08/ups-partnership-tests-drones-for-disaster-aid.html.

[79] Mandel, "UPS Testing Drones for Disaster Relief."

[80] Linton Wells II and Samuel Bendett, "Public-Private Cooperation in the Department of Defense: A Framework for Analysis and Recommendations for Action," *Defense Horizons* no. 74 (October 2012): 1, http://www.dtic.mil/dtic/tr/fulltext/u2/a569572.pdf.

[81] Wells and Bendett, 2.

[82] Wells and Bendett, 2.

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III. OHCA IN SEATTLE / KING COUNTY

In the Seattle/King County region, OHCA data has been collected since 1976 by the Cardiac Arrest Surveillance System (CASS).[83] The King County CASS has been used since then to evaluate the effectiveness of both community and EMS CPR programs, and its data have been used by both national and international researchers.[84] Having spent nearly two decades as a King County paramedic, the author has intimate knowledge of the EMS system's processes and goals. Seattle King County is constantly striving to improve OCHA outcomes and has taken an interest in the UAS/AED program proposal.

King County, Washington, currently boundaries the Puget Sound to the west and the Cascade Foothills to the east.[85] The human geography of King County is diverse, with high population urbanization on the shores of the Puget Sound, suburban areas east of Lake Washington, and rural areas near the Cascade Foothills. The city of Seattle and King County, respectively, have the largest population in the state of Washington.[86] The county has thirty-nine cities and a population of 1.9 million, which is estimated to increase to 2.263 million people by the year 2030.[87] The county's current population density is 970.3 persons per square mile, with 863,700 single and multifamily dwellings.[88] The county covers a total of 2,132 square miles, 1,670 square miles of which is non-urban (rural, agricultural, and forested).[89]

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83 "Cardiac Arrest Surveillance System (CASS)," King County, last updated April 9, 2016, https://www.kingcounty.gov/depts/health/emergency-medical-services/planning/cass.aspx.

84 King County.

85 Anneliese Vance-Sherman, "King County Profile," Washington State Employment Security Department, last updated September 2015, https://esd.wa.gov/labormarketinfo/county-profiles/king.

86 Vance-Sherman.

87 "Statistical Profile on King County 2016," accessed August 9, 2018, https://www.kingcounty.gov/~/media/depts/executive/performance-strategy-budget/regional-planning/Demographics/KC-profile2016.ashx?la=en.

88 King County.

89 King County.

A. EMERGENCY RESPONSE MODEL

The King County EMS system works with a number of partners to ensure that high-quality prehospital emergency management care is provided to the community. The King County EMS division believes that consistent, standardized medical care and collaboration are what allow the system to excel and to achieve the best possible outcomes for patients in cardiac arrest.[90]

1. Tiered Response

The Seattle/King County region 9-1-1 response system utilizes an emergency tiered response model.[91] The model, as described by the county's EMS division, has five major components:

- EMS system access: The response begins when a patient or bystander calls 9-1-1 for help. The call is answered by one of five emergency dispatch centers in King County.[92]

- Telecommunicator (dispatch) triage: Following medically approved guidelines, the emergency dispatcher who answers the call uses medical response assessment criteria to determine the type and number of emergency units that need to respond, whether basic life support (BLS) or advanced life support (ALS). Dispatchers will then guide the 9-1-1 caller through life-saving steps such as CPR, and use of an AED if available.[93]

- Tier one response—BLS: A minimum of one BLS unit responds to each emergency call; EMTs in King County respond to 100 percent of emergency medical calls and usually arrive first the on scene. Each unit

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[90] Chatalas and Jacinto, "2017 Annual Report to the King County Council," 8.

[91] "Overview of the Medic One/EMS System," Public Health – Seattle & King County Division of Emergency Medical Services, accessed August 9, 2018, https://www.kingcounty.gov/depts/health/emergency-medical-services/~/media/depts/health/emergency-medical-services/documents/EMSAdvisoryTaskForceOverview.ashx.

[92] Chatalas and Jacinto, "2017 Annual Report to the King County Council," 8.

[93] Chatalas and Jacinto, 8.

contains two to four firefighter EMTs who can stabilize a cardiac arrest patient. Approximately 4,200 EMTs—all certified by the state of Washington—are employed by the thirty fire departments in King County and, on average, BLS units arrive 5.5 minutes after the 9-1-1 call.[94]

- Tier two response—ALS: Paramedics from King County Medic One, a governmental third-service agency, respond to approximately 25 percent of 9-1-1 calls; they typically arrive after the fire department BLS unit and provide service for life-threatening emergencies. Five regional organizations provide Medic One services, and the county has a total of twenty-six ALS units. The paramedics are certified by the state of Washington and required to complete intensive education and ongoing training to maintain certification.[95]

- Additional medical care—transport to hospital: Once a patient is stabilized, EMS personnel determine whether transport to a hospital or clinic for further medical attention is needed.[96]

2. High-Performance CPR

All King County emergency responders are trained in high-performance CPR. According to the King County Resuscitation Academy, which trains the county's emergency responders, "quality CPR is a means to improve survival from cardiac arrest … scientific studies demonstrate that when CPR is performed according to guidelines, the chances of successful resuscitation increase substantially."[97] Continuing, the academy states, "minimal breaks in compressions, full chest recoil, adequate compression depth, and adequate compression rate are all components of CPR that can increase survival from

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[94] Chatalas and Jacinto, 8.

[95] Chatalas and Jacinto, 8.

[96] Chatalas and Jacinto, 8.

[97] Resuscitation Academy, "High Performance CPR Toolkit" (training document, Resuscitation Academy, March 2011), 3–4, http://www.resuscitationacademy.org/downloads/HPCPRToolkit110309.pdf.

cardiac arrest, and together, these components combine to create High Performance CPR."[98] The Resuscitation Academy has identified ten key components to successful resuscitation:

1. EMTs own CPR. [What used to be the role of the paramedic]
2. Minimize interruptions in CPR *at all times*.
3. Ensure proper depth of compressions (>2 inches).
4. Ensure full chest recoil/decompression.
5. Ensure proper chest compression rate (100–120/min).
6. Rotate compressors every two minutes.
7. Hover hands over chest during shock administration and be ready to compress as soon as patient is cleared.
8. Intubate or place advanced airway with ongoing CPR.
9. Place and intravenous or intraosseous line with ongoing CPR.
10. Coordination and teamwork between EMTs and paramedics.[99]

B. CARDIAC ARREST HISTORICAL DATA

Database managers from the Seattle/King County Public Health Department provided the historical data for this study, which include records of emergency response activities during calendar years 2012 through 2017. Individual records from the database were included in this study if they met the following criteria:

- Confirmed cardiac arrest, which by King County definition is a patient who is found to be both pulseless and breathless.[100]
- CPR continued after arrival of first responder.

[98] Resuscitation Academy, 3.

[99] Resuscitation Academy, 5.

[100] Chatalas and Jacinto, ""2017 Annual Report to the King County Council," 44.

No personally identifiable information is included in this study; the data were aggregated and depersonalized. Once the appropriate records were identified, the database manager provided a dataset with the following values:

- The year that the cardiac arrest occurred.
- Time that the dispatch center received the call.[101]
- Time that the unit was dispatched.
- Time that the unit was on scene.
- Time that the unit was at the patient's side.
- Time interval at the dispatch center (the amount of time it took for the call receiver to identify the cardiac arrest and dispatch the appropriate units).
- Time interval between when the call was received and the time that the unit was at the patient side.
- Time interval between when the call was received and the time that the unit was on scene.
- Time interval between when the unit was dispatched to the time the unit was at the patient's side.
- Geocode location.[102]
- Initial cardiac arrest rhythm.

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[101] 9-1-1 calls can originate from one dispatch center and then be transferred to a more appropriate center; this value is considered the time that the final dispatch center—the one that dispatched the response unit—received the call.

[102] The location identified on a map of King County by a one-quarter square mile by one-quarter square mile grid.

- Utstein model: The Utstein model was created by the European Resuscitation Council in June 1990.[103] The name Utstein was derived from the historic Utstein Abbey, located on a small island near Stavanger Norway, where the European Resuscitation Council holds its annual meeting.[104] The model created uniformity in reporting in cardiac arrest; it allows specific data and information to be collected and analyzed. The information listed in Tables 3 and 4 are examples of Utstein-specific information from the King County data retrieved for this study.

Table 3. Utstein Sub-set: Survival to Hospital Discharge for Arrests Due to Heart Disease, Witnessed by Bystanders, with an Initial Rhythm of VF[105]

Year	2016	2012-2016
Survival Rate	111/197 (56%)	520/947 (55%)

Excludes EMS-witnessed events

Table 4. Utstein Sub-set: CPR Initiated by Bystanders, Limited to Arrest before Arrival of EMS Personnel[106]

Year	2012	2013	2014	2015	2016
Bystander CPR	662/982 (67%)	657/998 (66%)	734/1,093 (67%)	666/985 (68%)	791/1,086 (73%)

[103] Richard Cummins et al., "Recommended Guidelines for Uniform Reporting of Out-of-Hospital Cardiac Arrest: The Utstein Style," *Circulation* 84, no. 2 (August 1991): 960, www.ncbi.nlm.nih.gov/pubmed/1860248.

[104] Cummins et al., 960.

[105] Adapted from Chatalas and Jacinto, "2017 Annual Report to the King County Council," 45.

[106] Adapted from Chatalas and Jacinto, 45.

Between January 1, 2012, and December 31, 2017, there were 4,233 OHCA incidents in the King County region, excluding the city of Seattle. Table 5 shows the data that was requested for the study. Any incomplete data that could not be rectified through imputation was excluded from this study.

Table 5. Cardiac Arrest Data from 2012–2017[107]

When Known, Plus Imputation						
	Included		Cases Excluded		Total	
	N	Percent	N	Percent	N	Percent
Year Cardiac Arrest Occurred	4,233	100.0%	0	0.0%	4,233	100.0%
Time Dispatch Center Received Call	4,231	100.0%	2	0.0%	4,233	100.0%
Time Unit Dispatched (Overall)	4,232	100.0%	1	0.0%	4,233	100.0%
Time Unit on Scene (Overall)	4,232	100.0%	1	0.0%	4,233	100.0%
Time Unit with Patient (Overall)	4,220	99.7%	13	0.3%	4,233	100.0%
Time Interval—Dispatch Center Received Call to Unit with Patient	4,231	100.0%	2	0.0%	4,233	100.0%
Time Interval—Dispatch Center Received Call to Unit on Scene	4,219	99.7%	14	0.3%	4,233	100.0%
Time Interval—Unit Dispatch to Unit on Scene	4,232	100.0%	1	0.0%	4,233	100.0%
Time Interval—Unit Dispatch to Unit with Patient	4,220	99.7%	13	0,3%	4,233	100.0%

[107] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

C. PUBLIC ACCESS TO AEDS

Within the 863,700 private homes in King County, only 435 AEDs are registered for private residences.[108] The numbers in Tables 6 and 7 show that the odds are very low that a person having an in-home cardiac arrest would have immediate access to an AED. Furthermore, one-third of these AEDs reside in the 84 square miles of the city of Seattle. Currently, only one study has examined where AEDs should be placed based on where cardiac arrest cases have historically occurred, and this study excluded cardiac arrests that occurred in private residences.[109] The study concluded that although it has been well documented that AEDs decrease morbidity and mortality in cardiac arrest patients, there is no best practice for determining how many AEDs a community should have in public spaces.

Table 6. Seattle King County Community AED Program[110]

2018 1st Quarter Report		
Overall Number of AEDs Placed		
Program	**Number of Sites**	**Number of AEDs**
City of Seattle	447	1,071
King County	882	2,215
Totals	**1,329**	**3,286**

[108] King County, "Statistical Profile"; Public Health – Seattle & King County, "Community AED Program" (1st quarter report, Public Health – Seattle & King County, March 2018).

[109] Benjamin Dahan et al., "Optimization of Automated External Defibrillator Deployment Outdoors: An Evidence-Based Approach," *Resuscitation* 108 (November 2016): 69, https://doi.org/10.1016/j.resuscitation.2016.09.010.

[110] Adapted from Public Health – Seattle & King County, "Community AED Program."

Table 7. AED Locations in King County[111]

Locations	Number of AED Places per Category
Private Includes private citizens, participants of the Family Heart Savers Program, & At Home AED study	435
Government Includes police/sheriff department, fire departments, detention facilities, transit, public health centers, and various offices	714
Airports	164
Athletic Facilities	62
Business	1204
Golf/Country Club	41
Marine Aquatic Includes Port of Seattle marine devices	49
Medical Facility	70
Non-profit	87
Retail/Grocer	21
School	424
Senior Center/Retirement	15
Total	**3286**

[111] Adapted from Public Health – Seattle & King County, "Community AED Program."

D. CARDIAC ARREST STATISTICS BY GEOGRAPHIC AREA AND GEOCODE

The Department of Public Health gathers the locations of cardiac arrest calls based on data input from King County Fire and EMS agencies.[112] To map the location of the calls, the Seattle/King County region uses a unique mapping model known as a geocode map, which divides the county into a grid containing 1,403 one-quarter mile by one-quarter mile boxes (see Figure 1).[113] Data on individual cardiac arrests can be matched to a unique identifier—or box—on the map, known as a geocode. This allows for the number of cardiac arrest calls in a particular map box to be identified for resource deployment.

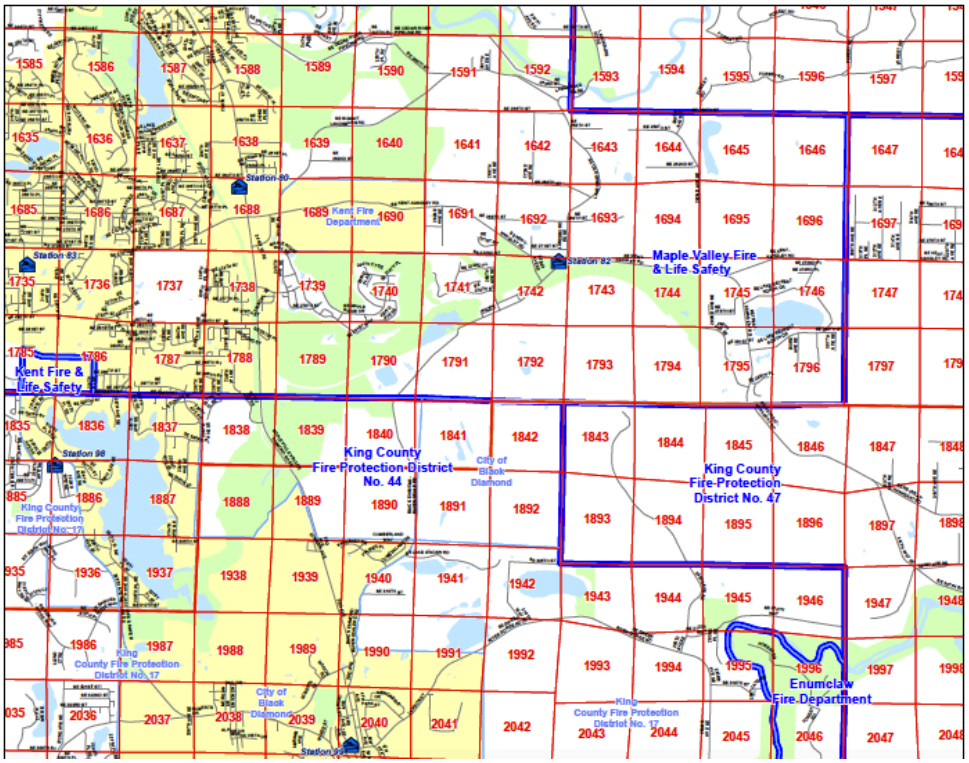

Figure 1. King County Geocode Map Example[114]

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[112] D. Sharkov, "King County Geocode Map," EMS Online, accessed August 9, 2018, http://www.emsonline.net/mirfeducation/assets/geocodeatlas/atlas%202009_36.pdf.

[113] Sharkov.

[114] Source: Sharkov.

The 4,233 cardiac arrests were captured and plotted on the King County geocode map. Figure 2 shows the locations and number of cardiac arrests by geocodes during the study period (January 1, 2012, to December 31, 2017). As would be expected, there were more cardiac arrests in areas with higher population densities.

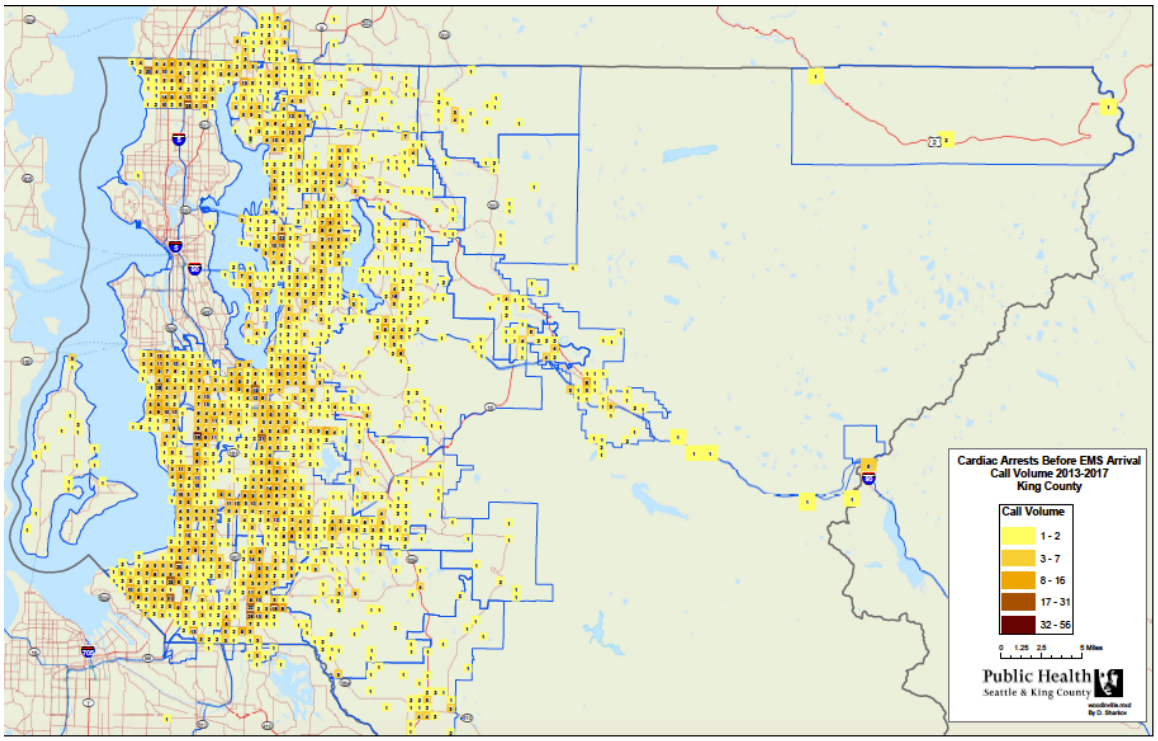

Figure 2. Cardiac Arrest by Geocode Location[115]

E. RESPONSE TIME ANALYSIS

Historical response times in the study period for emergency ground units were evaluated against the simulated response time of a UAS to the same geocode location. The response times were broken down into the following segments and each segment was evaluated: call to dispatch, dispatch to en route, en route to on location, and on location to "at patient's side."

[115] Source: King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

Response times were calculated by the number of cardiac arrest responses in an individual geocode. The response time was considered the amount of time that passed between when the unit was notified by the dispatch center, and when emergency personnel arrived at the patient's side to deliver care. When there was more than one response in a specific geocode, the median response time was used. Figure 3 shows the King County response times by geocode. As expected, higher-density population areas, where fire stations are closely located, had shorter response times than the rural and suburban areas.

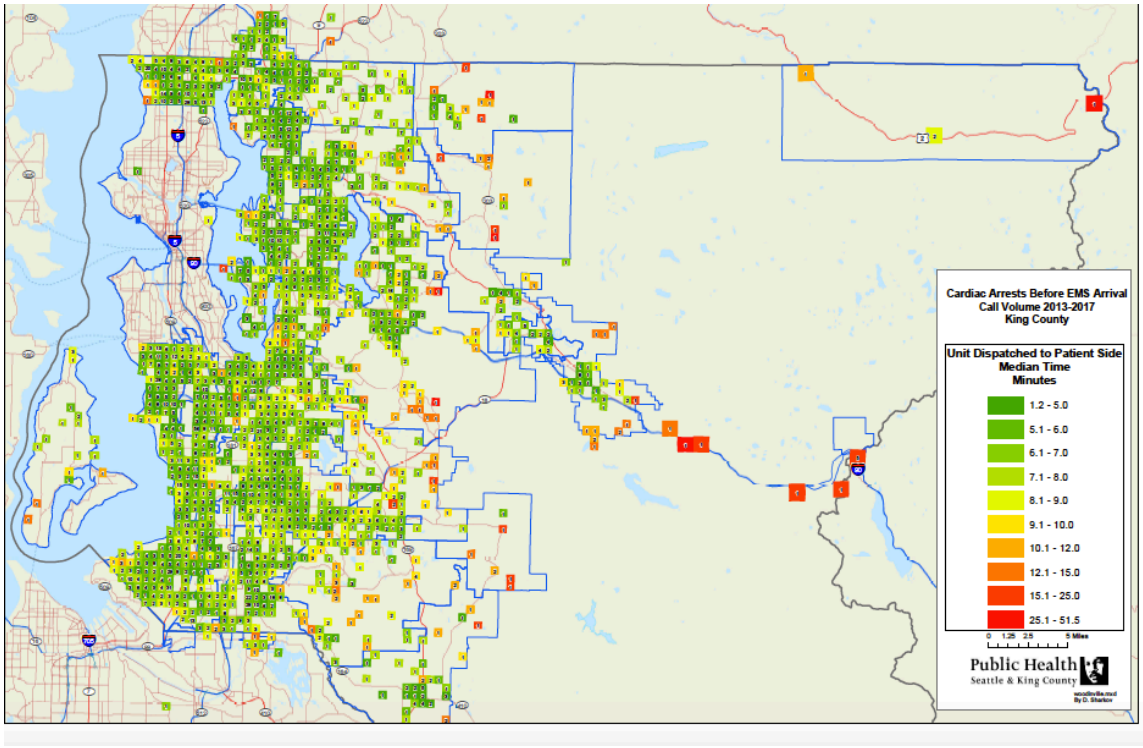

Figure 3. Unit Dispatch to Patient's Side Median Time by Geocode[116]

[116] Source: King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

The response map shows that, of the 1,403 geocode map boxes (excluding the city of Seattle) where King County Fire and EMS agencies respond to a cardiac arrest, emergency units were only able to arrive on location in less than 5 minutes 16 percent of the time. Table 8 and Figure 4 show that, 23 percent of the time, it took longer than 8 minutes for the first emergency unit to arrive at the patient's side to begin resuscitative care. In a study by Mary Larsen at el. performed in King County, it was shown that a patient that has no intervention for 10 minutes during cardiac arrest has no possibility of survival, and survivability after 8 minutes was less than 10 percent.[117]

Table 8. Time Interval: Unit Dispatch to Unit with Patient by Geocode[118]

Time Interval	Time Interval—Unit Dispatch to Unit with Patient	% Time Interval—Unit Dispatch to Unit with Patient
< 5 Minutes	227	16%
5–6 Minutes	357	26%
6–7 Minutes	318	23%
7–8 Minutes	202	14%
8–9 Minutes	124	9%
9–10 Minutes	49	4%
> 10 Minutes	123	9%
Total	1,400	100%

[117] Mary Larsen et al., "Predicting Survival from Out-of-Hospital Cardiac Arrest: A Graphic Model," *Annals of Emergency Medicine* 344 (November 1993): 1654.

[118] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

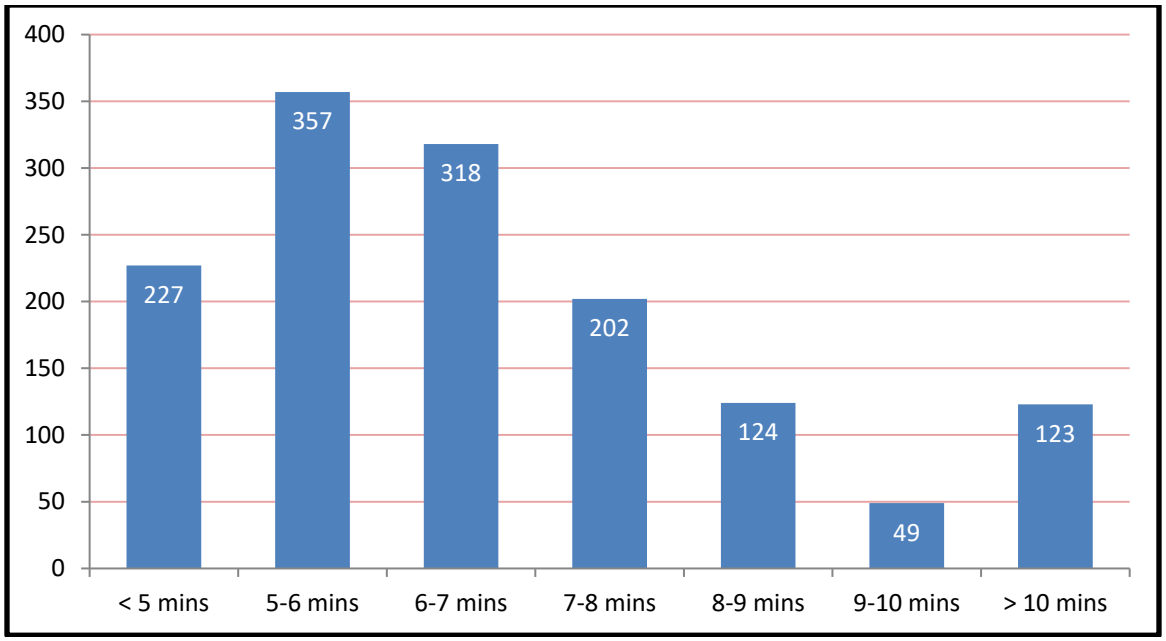

Figure 4. Time Interval: Unit Dispatch to Unit with Patient by Geocode[119]

Each aspect of the response was evaluated individually as well to determine if a significant delay occurred at a particular time, and if a UAS solution may be beneficial based on that timing. The response was broken down into the following categories.:

- *Call to unit dispatch*: This segment measured the amount of time that it took for the call receiver at the dispatch center to notify the emergency responder, in this case the first due fire station, that there was a cardiac arrest in their response area.

- *Unit dispatch to unit en route*: the amount of time that it takes the emergency responders, in this case the fire station in the response area, to be notified of the call and to be physically responding to the call, or have "wheels rolling."

[119] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

- *Unit en route to unit on scene*: the amount of time it takes the first responders to travel from their starting point to the location of the cardiac arrest.

- *Unit on scene to unit with patient*: the amount of time that it takes the first responders to arrive at the location, exit their response vehicle, gather their equipment, and arrive at the patient's side to begin delivering care.

1. 9-1-1 Call Received to Unit Dispatch

When a 9-1-1 call is placed to a dispatch center, the call must be processed so that the appropriate agency and discipline can respond to the emergency. For example, a 9-1-1 call may only need a law enforcement response, or only a fire and EMS response. However, there are occasions, such as a vehicle accident, where both law enforcement and fire/EMS need to respond to the emergency. The National Fire Protection Agency, which sets the standards that fire/EMS agencies must attempt to meet, states that 90 percent of all emergency calls must be processed in 60 seconds or less, and 99 percent of all emergency calls must be processed within 90 seconds or less by a dispatch center.[120]

Figure 5 shows the King County cardiac arrests between January 2012 and December 2017 that were processed by the dispatch center. For the 4,233 cardiac arrests that were dispatched inside the 1,403 geocodes, the dispatch centers were able to successfully dispatch the emergency call in less than 60 seconds 74 percent of the time, and able to dispatch a call in less than 90 seconds 93 percent of the time. Delays in dispatch are usually due to language barriers, 9-1-1 callers who are a second or third party (not directly with the patient), or callers who do not know the address or location of the emergency.

[120] Robert Upson and Kathy A. Notarianni, *Quantitative Evaluation of Fire and EMS Mobilization Times* (New York: Springer, 2010), 30, https://doi.org/10.1007/978-1-4614-4442-8.

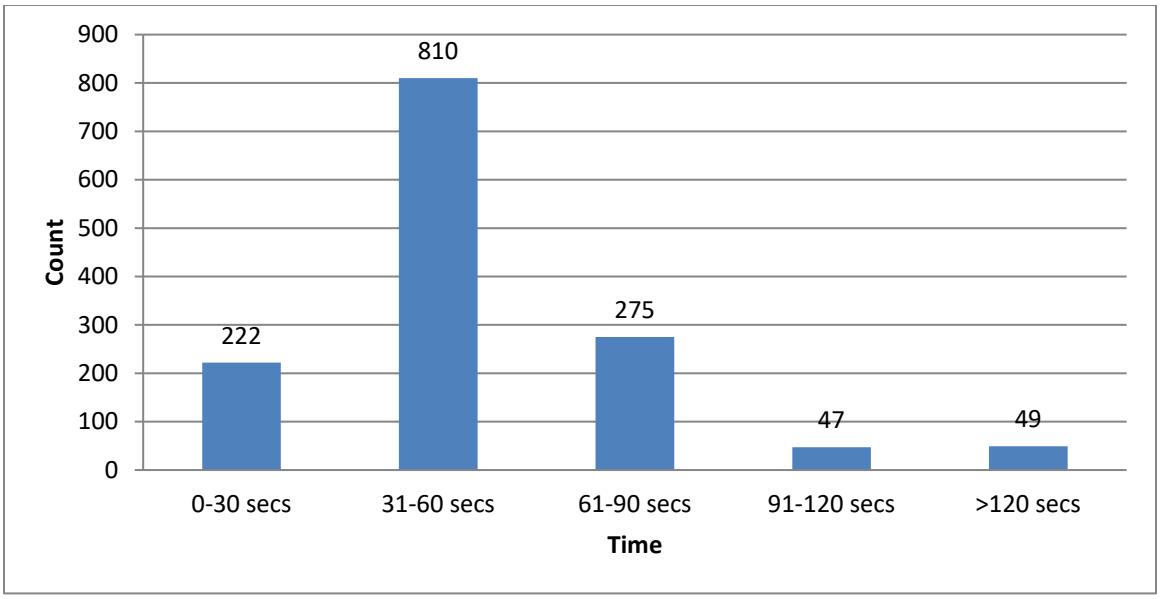

Figure 5. 9-1-1 Call Received to Unit Dispatch[121]

2. Unit Dispatch to Unit En Route

According to NFPA 1710, nine steps occur in the time it takes for emergency responders to begin to the alarm:

1. Notification from the dispatch center.
2. Gathering critical response information.
3. Disengagement from tasks in process.
4. Travel within the station to the response vehicle.
5. Donning appropriate personal protective equipment.
6. Mounting the response vehicle and securing seatbelts.
7. Opening the apparatus bay doors.

[121] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

8. Starting the response vehicle.

9. Signaling "en route."[122]

NFPA 1710 stipulates that 90 percent of all emergency response to fire calls must turnout, or be responding to the alarm, within 80 seconds or less, and 90 percent of all emergency response to EMS calls must turnout within 60 seconds or less.[123] Figure 6 shows that, King County emergency responders were able to go en route, or begin responding in the emergency vehicle, in less than 60 seconds 30 percent of the time, and responded in 90 seconds or less 65 percent of the time. The data did not differentiate between calls dispatched during the day and those dispatched at night, and it did not separate career departments that have emergency responders on duty twenty-four hours a day, seven days a week—the data show career, all-volunteer, and combination emergency response departments, including those that have emergency responders coming from home.

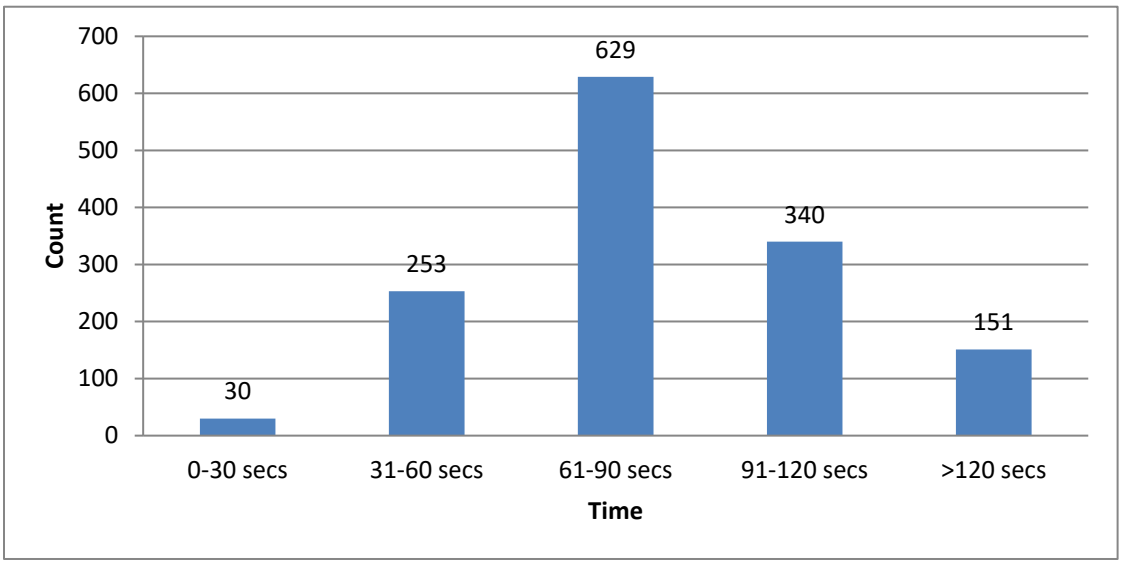

Figure 6. Unit Dispatch to Unit En Route[124]

[122] Upson and Notarianni, *Fire and EMS Mobilization Times*, 37–38.

[123] Upson and Notarianni, 37.

[124] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

3. Unit En Route to Unit on Scene

In King County, the benchmark travel time, or en route time, is 4 minutes and 15 seconds from the time the unit has "wheels rolling" to the time that the unit arrives on scene.[125] Volunteer stations, by national standards, are expected to be on scene within 16 minutes.[126] Figure 7 shows the amount of time it took the unit with "wheels rolling" to arrive at the dispatched address or location. Variables such as weather, traffic, time of day, and type of fire department (career, combination, or volunteer) were not considered in this research. Figure 8 is the map associated with those response times by geocode. In Figure 8, longer response times are evident in the suburban and rural parts of the region, as expected.

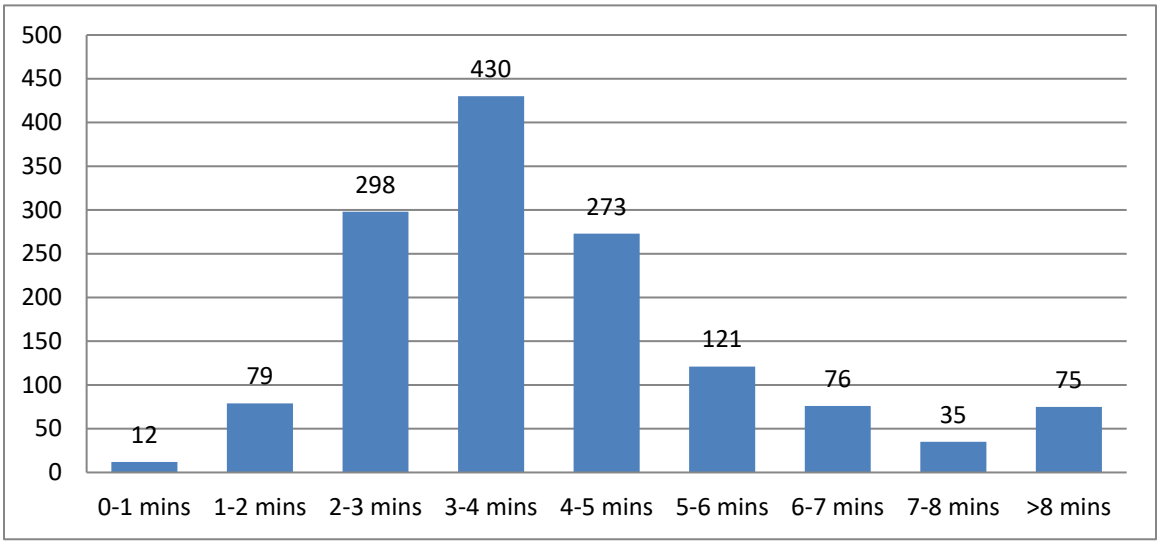

Figure 7. En Route Time[127]

[125] Kent Fire Department, "Kent Fire Department Regional Fire Authority: Standard of Cover" (standard, Kent Fire Department, May 2015), 83, http://pugetsoundfire.org/wp-content/uploads/2016/12/Standard-of-Cover.pdf.

[126] NFPA, NFPA 1710.

[127] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018."

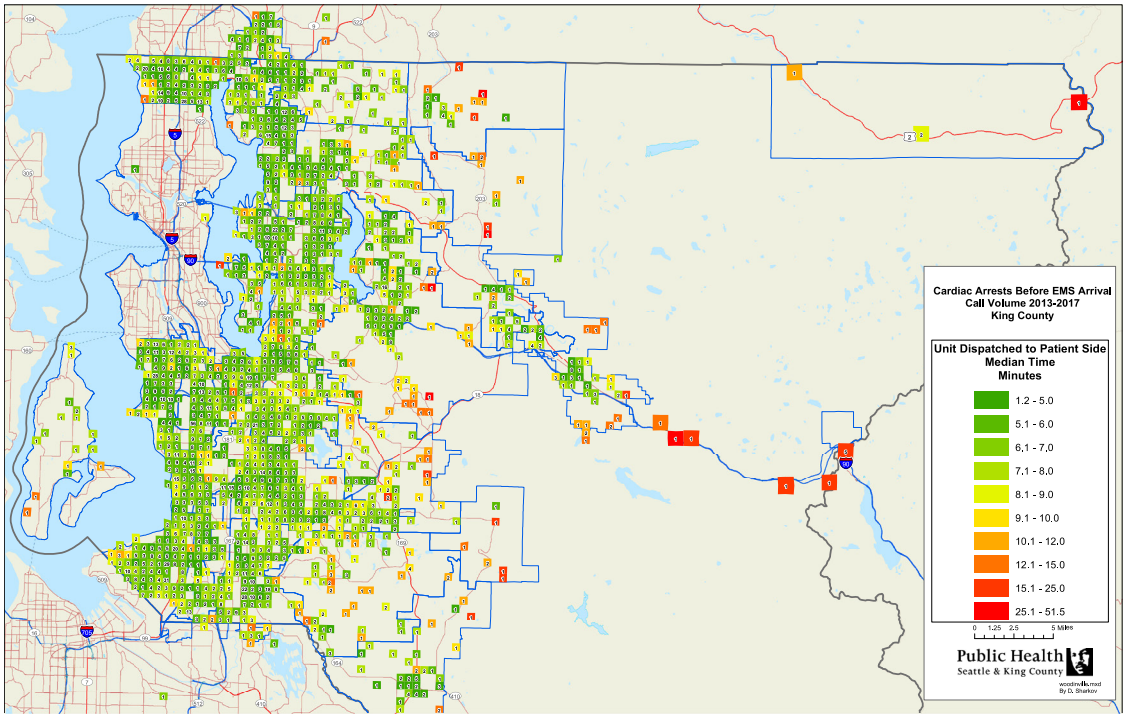

Figure 8. En Route Times Map[128]

4. Unit on Scene to Unit with Patient

In 2012, King County Medical Director Dr. Mickey Eisenberg initiated a policy to have first responders announce on the radio to the dispatch centers that they were "at patient's side."[129] This policy was initiated because units were arriving "on location," but several more minutes might pass before first responders were actually with the patient, administering resuscitative care. There are no national criteria for the length of time that it should take for an emergency responder to be at the patient's side. Figure 9 shows the length of time it took for first responders to arrive at the patient's side after arriving at the dispatched location. The graph shows that, overwhelmingly, an additional 1 to 1.5 minutes can pass before emergency responders actually reach the patient.

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[128] Source: King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

[129] Mickey Eisenberg, email to author, April 21, 2018.

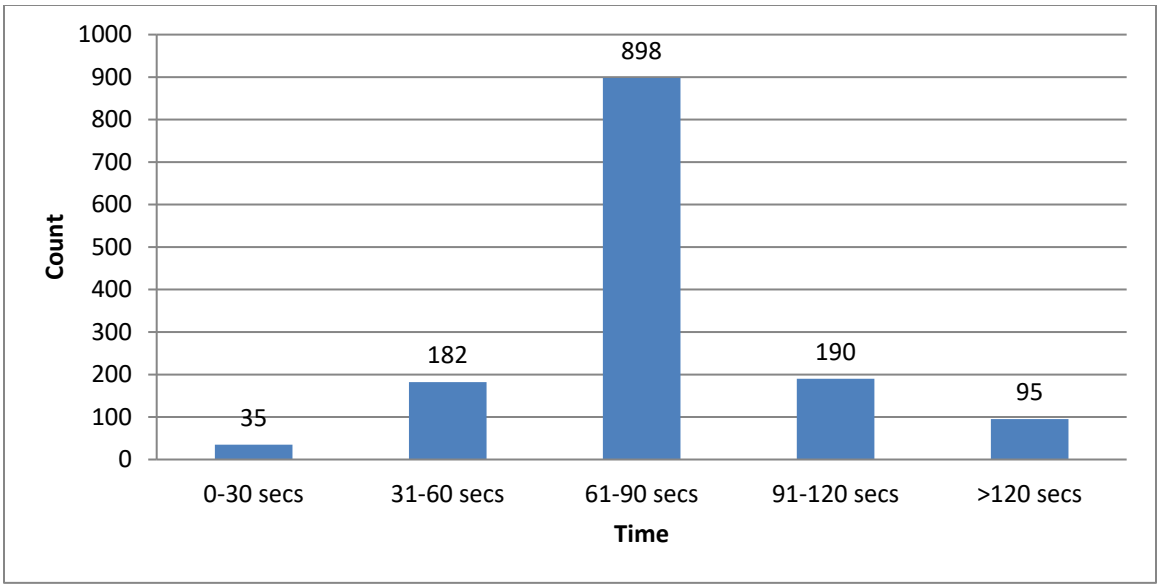

Figure 9. Unit on Scene to "At Patient's Side"[130]

F. ALTERNATIVE DEPLOYMENT STRATEGIES

As illustrated previously, there are a limited number of AEDs registered in private homes; options need to be explored for getting AEDs to patients in cardiac arrest quickly. The data from the previous sections show that most elements of the emergency response are meeting both regional and national standards; en route times, or the "wheels rolling" time, appears to be the only element of the response where significant time saving could potentially occur. This element of the response is where a UAS equipped with an AED could potentially save additional lives in the Seattle/King County region.

Where the AED-equipped UASs should be located—and who should operate and maintain them—was a crucial part of this investigation. The data examined where the UASs could be deployed from to provide maximum coverage of King County with the smallest number of units. Ideally, a location would be staffed twenty-four hours a day, seven days a week. There would need to be a trained technician on site that could evaluate the readiness of the UAS and the AED. Once the UAS was dispatched on an emergency

[130] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

response, redeployment and readiness of the UAS would need to be evaluated so the UAS could be response-ready for the next emergency. Four different locations were considered ideal: King County Medic One stations, dispatch centers, hospitals, and private industry locations.

1. King County Medic One Stations

King County Medic One paramedic units have been strategically placed throughout King County based on call volume and demand for service. Most fire stations are located in a specific area to cover a particular geographic location, regardless of the number of calls. King County Medic One medic units are staffed all day, every day, 365 days a year by career paramedics who are responsible for daily checks and evaluation of the equipment that they carry on the medic units, as well as the equipment in the stations.

2. Public Safety Answering Points (Dispatch Centers)

King County emergency dispatch centers are also staffed 24/7 with technicians who could ensure readiness of the UAS and AED. The dispatch center would likely know when a UAS was launched the their site, since the center is also dispatching the cardiac arrest.

3. Hospital Locations

Local area hospitals in King County would also be considered ideal launch sites. In King County, hospitals are geographically spread out far enough that adequate coverage could be attained with a UAS. One issue is that most hospitals in King County are privately owned and operated, and would require additional bureaucratic steps for implementation.

4. Private Industry

Currently there are several large package delivery companies in the Seattle/King County region, and package delivery giant Amazon has four large sorting and distribution centers in King County.[131] Currently, Amazon is exploring utilizing UASs for package

[131] "Amazon Fulfillment Center Locations," Avalara TrustFile, accessed August 9, 2018, https://www1.avalara.com/trustfile/en/resources/amazon-warehouse-locations.html.

delivery in the United States, and trials are being conducted in the United Kingdom.[132] One distinct advantage of dispatching a UAS from a private facility that specializes in UAS delivery is that the facility will have technical support on site for day-to-day operations; as technology continues to improve, and UAS units themselves continue to improve, the UAS AED program would benefit from the advances realized from the private industry.

5. King County UAS Launch Site Data

In order to evaluate where a UAS would need to be launched from to reach the majority of cardiac arrest locations, algorithms were run at the following locations: King County Medic One stations, public safety answering points (dispatch centers), hospitals, and private industry locations with UAS capabilities. Figure 5 showed a combination of all of these locations based solely on distance; 1-, 5-, and 10-mile Boolean Venn diagrams were created to ensure maximum coverage. Figure 10 clearly demonstrates that if UASs were placed at all of these locations there would be an incredible amount of overlap. The number of UASs needed to cover all of these sites would also make it cost prohibitive for the model to work.

[132] Amazon, "Amazon Prime Air."

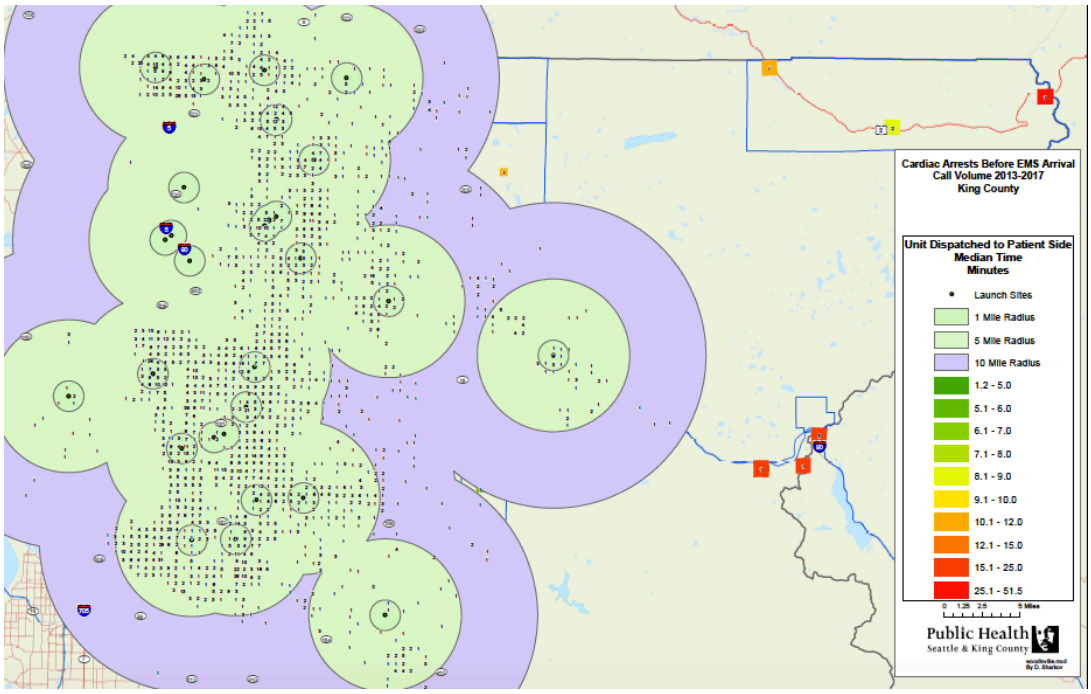

Figure 10. UAS Launch Points for All Locations[133]

G. SUMMARY

The data show that, during emergency responses in King County, dispatch centers are processing calls and emergency responders are "turning out" within an acceptable range of time, per national standards. The only place where Seattle/King County fire and EMS responders can reduce the amount of time that it takes to arrive at a cardiac arrest t, is during the response. This is where UASs may be valuable.

There are a number of implementation decisions to be considered for this study, such as appropriate UAS launch sites. Once the sites are determined, however, how much training would be required for the site employees? How and by whom would the UAS be maintained? Once the UAS is launched with an AED, who will retrieve the UAS and enable it for redeployment? What are the limitations of the UAS? Do weather, payload, and flight restrictions need to be considered when evaluating where to place the UASs? The next chapter focuses on the best locations for the UASs.

[133] Source: King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

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IV. RESEARCH DESIGN

This chapter describes the research design that was used for the analysis. As mentioned, the data showed that the en route time, or the "wheels rolling" time, appears to be the only response element where improvements can be made. Equipping UASs with AEDs that can be deployed to cardiac arrest patients is one way to achieve that improvement. This portion of the research attempted to determine the best locations from which to launch the UASs.

A. METHODS FOR ASSESSMENT

(1) Data Source: CASS and Geocodes

This portion of the research relied on the same CASS data described in Chapter III: all cardiac arrest patients included in the King County CASS over the five-year period between January 1, 2012, and December 31, 2017, regardless of outcome. King County Public Health database managers were able to provide 4,233 confirmed cardiac arrest cases over the timeframe requested. As fully described in Chapter III, this portion of the research also relied on the location of each cardiac arrest by geocode, as well as the response time of the first emergency unit that arrived at emergency location.

(2) UAS Deployment Locations

It was important to consider whether the UASs should be launched from a single organization's locations throughout King County (such as Medic One stations), or if launch sites should be chosen based solely on geographic locations—even if the final locations include several disciplines or organizations.

(3) UAS Estimated Performance

The UASs' performance and capabilities were evaluated based only on the aircraft's potential top speed. The data did not account for payload, weather, legal, or airspace restrictions in particular areas of the Seattle/King County region. UAS response times were calculated by having the UAS respond to the center of the particular geocode from the actual address of the UAS deployment strategy locations.

B. DATA ELEMENTS

The individual data elements were evaluated in detail to determine UAS launch locations. For all of the potential UAS launch points—Medic One unit stations, dispatch centers, hospitals, and private industry locations—the individual geocode location of the launch point address was plotted, and then a ten-mile Boolean circle was used to determine how far each UAS could potentially fly.

Current off-the-shelf UAS technology, like the Phantom 3 quadcopter, flies at an average speed of 25 mph (40 km/h).[134] An experimental airframe octocopter is currently being evaluated that can sustain flight at 80 mph (129 km/h) with a maximum payload of 20 pounds. The data in this chapter also consider a theoretical UAS that can travel at 100 mph (161 km/H), which is the current maximum speed allowed by the FAA.[135] These specifications do not account for wind, foul weather, or nighttime operations.

The data were measured from the time the dispatch center notified the emergency unit—in this case the first due fire station—to the time the emergency unit arrived on scene. Thirty seconds were added to the response time to account for the UAS needing time to launch from the site, and to have time to slow down as it approached the emergency site. The median time was used instead of a mean time to account for exceptionally long or short response times. This calculation was: *Total response time + 15 seconds for launch + 15 seconds for landing including a reduction in speed for approach.* In a similar study performed in Stockholm, Sweden, with field experimentation, a launch time of 10 seconds was achieved.[136]

When the models were run with the UAS, there was no delay from the moment of dispatch to the UAS was airborne, and the models had the UAS immediately traveling at top speed all the way to the target address. For all three speed variables that were modeled, the data was manipulated as: *15 seconds for launch + modeled UAS response time + 15*

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134 "Phantom 3 4K Specs," DJI, accessed August 10, 2018, https://www.dji.com/phantom3-4k/info.

135 "Summary of Small Unmanned Aircraft Rule (Part 107)," FAA, June 21, 2016, www.faa.gov/uas/media/Part_107_Summary.pdf.

136 Claesson et al., "Unmanned Aerial Vehicles," 8.

seconds for landing = total UAS response time. If a cardiac arrest fell within two Boolean circles, the UAS launch point closer to the cardiac arrest was used. When a cardiac arrest fell within the Boolean circle of the UAS launch location, the historical response time data were compared from the time the ground emergency response unit was dispatched to the time that the ground unit was on scene, to that of a UAS flying 25 mph, 80 mph, and 100 mph.

For all launch locations and speed variables, a cardiac arrest case was included as "affected" if the UAS would have made it to the emergency location at least 60 seconds faster than the ground unit (according to historical data). The comparative response time was from the moment that the dispatch center notified the emergency responder, to the time that the emergency ground unit was "on location," or at the scene of the cardiac arrest.

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V. DATA ANALYSIS

A. SINGLE-ORGANIZATION DEPLOYMENT

As previously mentioned, deploying all the UASs from a single organization or discipline is the best way for the UAS program to operate with consistency and continuity. The maps in Figures 11, 12, 13, and 14 show the one-, five-, and ten-mile Boolean Venn diagram circles for King County Medic One Medic unit locations, hospitals, dispatch centers, and private industry locations with UAS deployment capabilities.

Because King County Medic One Medic Units are located strategically based on call volume and need, if UASs were deployed from these stations, they would provide the greatest coverage of the entire county, as demonstrated in Figure 11.

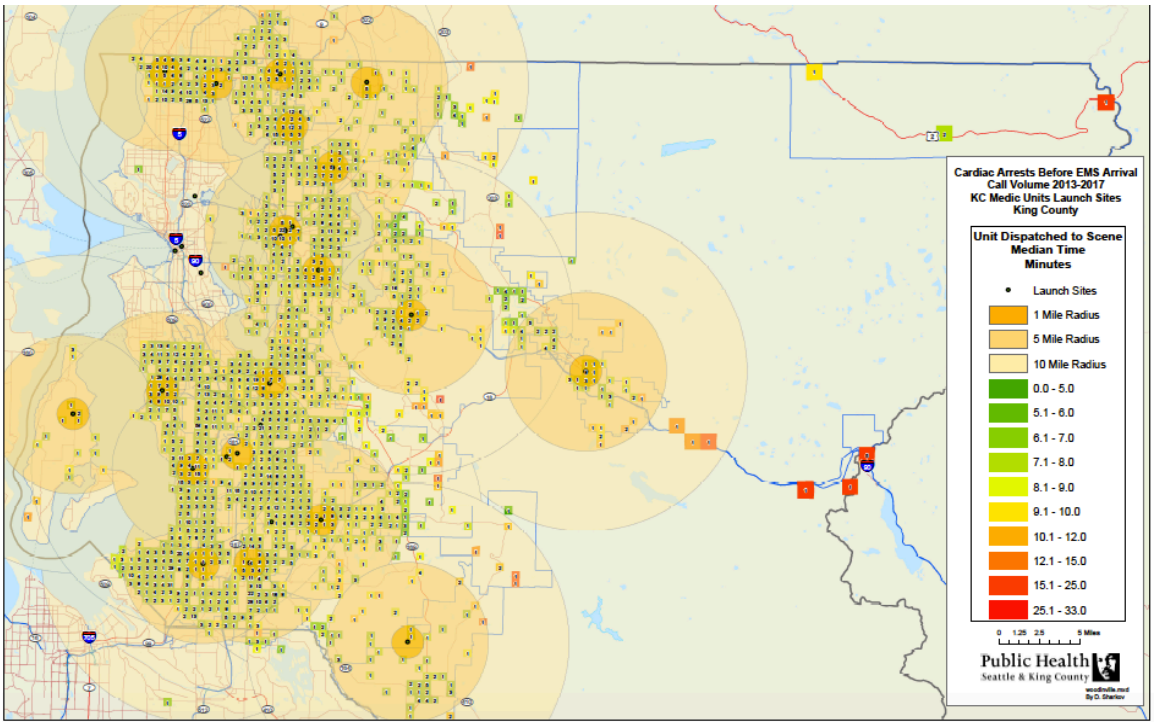
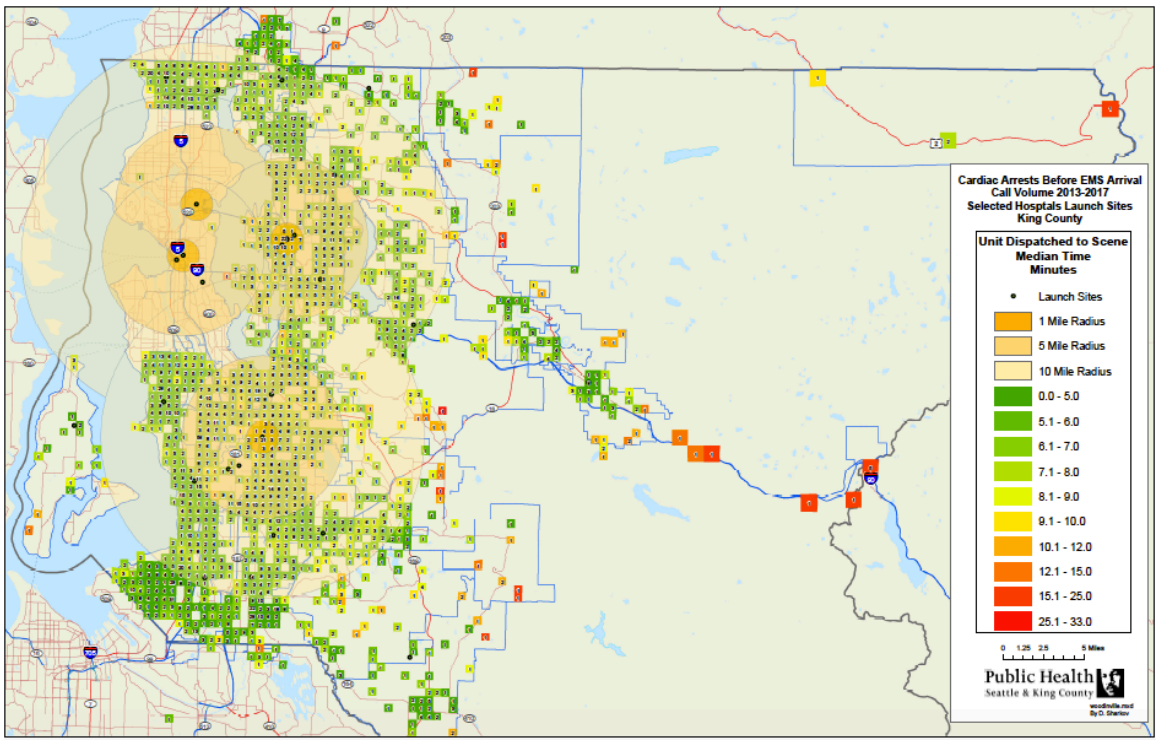


Figure 11. King County Medic One Medic Units[137]

[137] King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

As shown in Figure 12, if the UASs were launched from hospital locations, they would provide coverage for the suburban and urban areas of King County; however, they would provide practically no coverage in the rural areas.



Note: Hospital locations in the city of Seattle were included, though the study did not include cardiac arrest data from the city.

Figure 12. Hospital Locations[138]

[138] King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

If the UASs were placed at a dispatch centers, as shown in Figure 13, they would not provide coverage for all urban and suburban areas in the county, nor the rural areas.

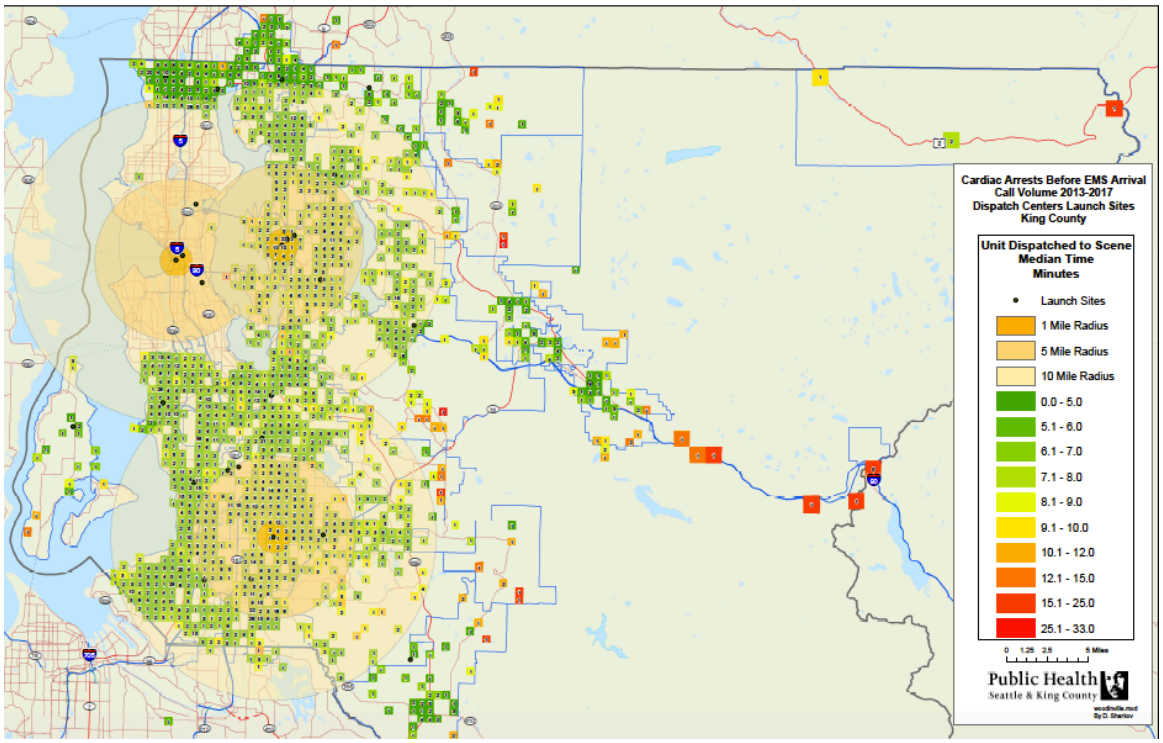


Figure 13. Dispatch Centers[139]

[139] King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

Figure 14 shows that if the UASs were placed at a private industry location, they would face similar limitations as the dispatch centers. The coverage would be adequate to meet the needs of the community and have no effect on the rural areas of King County.

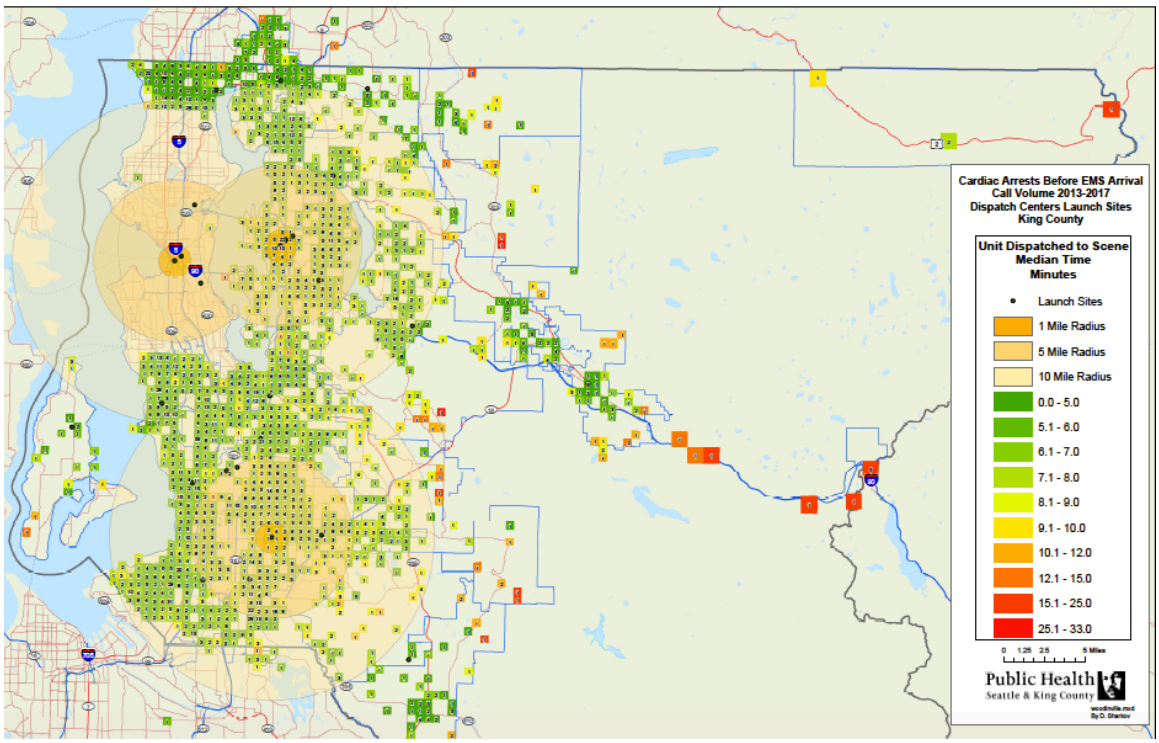


Figure 14. Private Industry Locations[140]

[140] King County Public Health's Cardiac Arrest Surveillance System, accessed April 1, 2018.

Medic One Medic unit locations appear to provide the best coverage for the documented cardiac arrest cases studied, while also allowing for a single discipline to oversee and manage the program.

Using King County Medic One Medic unit locations, models were run with UASs with 25 mph, 80 mph, and 100 mph capabilities (see Figures 15, 16, and 17). A 30-second delay was added for launch time, and time for the UAS to slow when arriving at the cardiac arrest destination. The data also consider the number of patients that would be impacted, and the reduction in response time (how much sooner the UAS would arrive than the first emergency unit). As expected, the faster the UAS is able to travel, the faster it arrived on scene; therefore, the faster UASs would be able to get an AED to a greater number of patients in cardiac arrest.

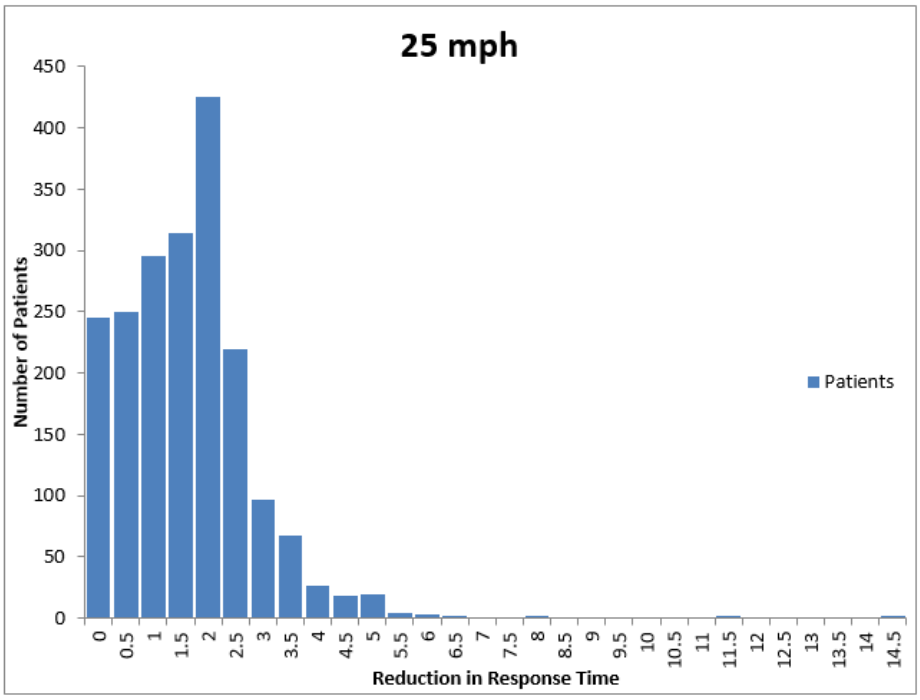


Figure 15. Patients Affected: UAS Placed at Medic Locations, 25 mph

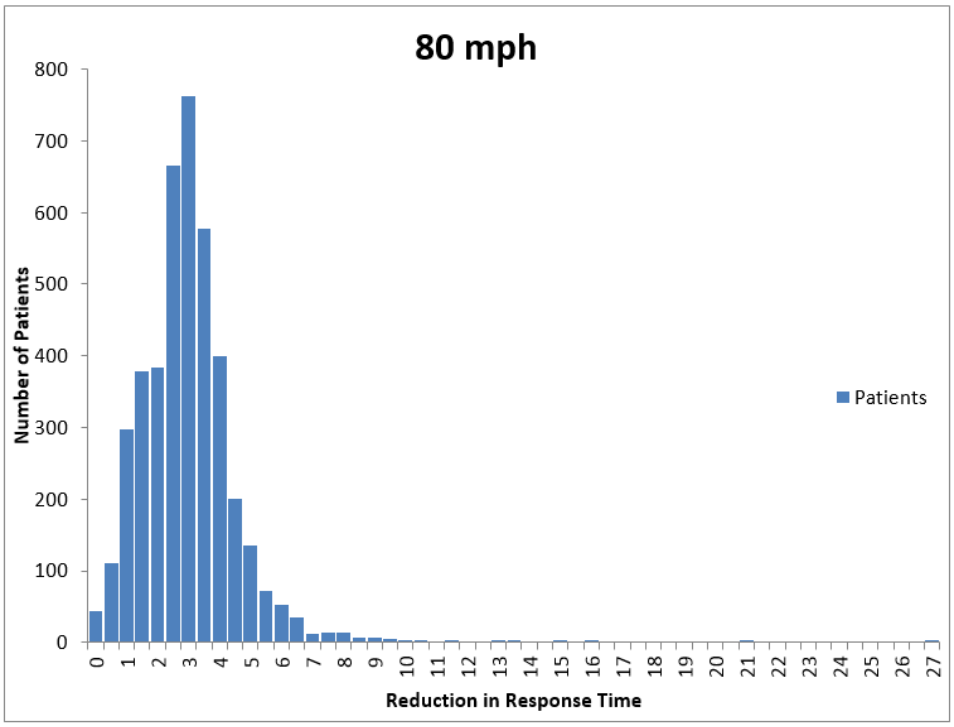


Figure 16. Patients Affected: UAS Placed at Medic Locations, 80 mph

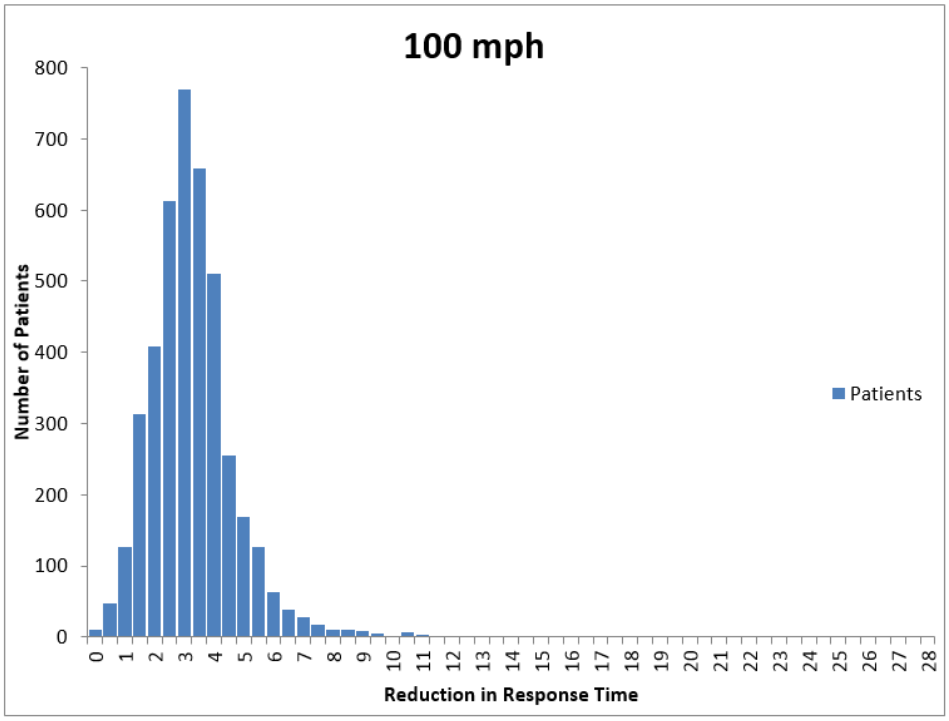


Figure 17. Patients Affected: UAS Placed at Medic Locations, 100 mph

B. UAS PERFORMANCE

Table 9 demonstrates the number of cardiac arrest cases of the 4,233 from the data set that would see decreased response time when using current off-the-shelf quadcopters—which fly at 25 mph—the experimental octocopter that can fly at 80 mph, and a theoretical UAS that can travel at 100 mph. In the table, the speed of the UAS is in the first column, and the cases affected by the UAS were compared to the total number of cases. For example, if a UAS flying 25 mph were to launch from one of the designated sites, and the ground EMS or fire unit were to arrive before the UAS, that particular case was not included.

There were some expected outcomes. The faster that the UAS was able to fly, the quicker it was able to arrive on scene. Median reduction in response times were also similar to the Stockholm. Stockholm has a similar size, demographic population, and geography of rural, suburban, and urban areas.[141] As mentioned, the faster the UAS was able to fly, the more cases were affected. Table 9 also shows that launching from a King County Medic One unit station had the greatest effect on cardiac arrest cases.

[141] Claesson et al., "Unmanned Aerial Vehicles," 2; Vance-Sherman, "King County Profile."

Table 9. UAS Performance and Effect on Cardiac Arrest Cases[142]

UAS Speed (MPH)	Cardiac Arrest Cases of 4,233	King County Medic Units	Hospitals	Dispatch Centers	Private Industry
25	Cases Affected	1,743	254	229	151
	Median UAS Response Time for Cases Affected (Min:Secs)	11:55	11:48	11:42	11:59
	Median Reduction in Response Time for Cases Affected	1:31	1:38	1:44	1:27
80	Cases Affected	4,139	1,772	1,656	1,848
	Median UAS Response Time for Cases Affected (Min:Secs)	4:04	4:18	4:10	4:13
	Median Reduction in Response Time for Cases Affected	1:39	1:25	1:33	1:30

[142] Data obtained from King County Public Health's Cardiac Arrest Surveillance System, April 1, 2018.

UAS Speed (MPH)	Cardiac Arrest Cases of 4,233	King County Medic Units	Hospitals	Dispatch Centers	Private Industry
100	Cases Affected	4,198	2,346	2,261	2,394
	Median UAS Response Time for Cases Affected (Min:Secs)	3:22	4:06	4:08	4:12
	Median Reduction in Response Time for Cases Affected	2:54	1:38	1:40	1:44

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VI. DISCUSSION

For the 4,233 OHCA cases that were evaluated in the 1,403 geocodes in the Seattle/ King County region from January 1, 2012, to December 31, 2017, as expected, traditional ground response times by fire and EMS agencies took considerably longer in suburban and rural areas of King County. The number of cardiac arrest cases per Geocode was higher in areas with higher population densities. In 23 percent of the evaluated cases, emergency responders were not able to arrive on scene within 8 minutes of the call. When the response times were broken down into individual segments (call to dispatch, dispatch to unit en route, etc.), it was discovered that the time for a dispatch center to process the call and alert the emergency agency was appropriate and within acceptable national standards. The amount of time it took for the emergency responders to turn out, or have wheels rolling, was also within national standards.[143]

En route times, or the time measured from when the emergency responding unit had wheels rolling to the time that the emergency unit arrived on scene at the cardiac arrest, were within 5 minutes 22 percent of the time per geocode location. For 5 percent of the calls, the response took longer than 8 minutes to arrive.

In 64 percent of the cardiac arrest cases that were evaluated, once the emergency unit arrived on scene it took an average of 61–90 seconds for the emergency responders to arrive at the patient's side to begin resuscitative care. Only 15 percent of the time were emergency responders able to reach the patient in under 1 minute, and 20 percent of the time it took longer than 91 seconds.

The data show that although 9-1-1 calls are being processed in a timely manner, and emergency crews are getting to the emergency vehicle and beginning the response to the cardiac arrest within national standards, it is the amount of time that it takes the emergency responders to drive, arrive on scene, and be at the patient's side to begin resuscitative care that can be improved.

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[143] As previously mentioned, the data did not differentiate between the type of response unit—whether career, volunteer, or a combination.

The research evaluated four different configurations for UAS launch points: King County Medic One unit stations, hospitals, dispatch centers, and private industry locations. With the goal of having a single organization responsible for the UAS and AED, it was found that Medic One units would give the most coverage for King County with the fewest number of UASs.

When models were run with UASs operating at 25 mph, 80 mph, and 100 mph from King County Medic One medic unit locations, the UASs were able to arrive faster than traditional emergency ground units for 41 percent, 98 percent, and 99 percent of the cardiac arrest cases, respectively. As expected, the faster the UAS was able to fly, the more cases affected. For the cases affected, the UASs traveling at 25 mph showed a median reduction in response time by 1 minute and 31 seconds; this reduction went to 1 minute and 39 seconds at 80 mph, and 3 minutes and 22 seconds at 100 mph.

With these predictions, King County can now determine if further testing is needed with current technology to begin writing policy and addressing legal, operational, and logistical issues to move closer to implementation.

VII. RECOMMENDATIONS AND CONCLUSION

A. CONCLUSIONS

This thesis asked if emergency deployment of UASs could be used in the Seattle/ King County region to reduce morbidity and mortality for patients with OHCA—particularly in suburban and rural areas where traditional emergency response may be delayed. The research showed that if UASs were placed at King County Medic One units, 1,743 of the 4,233 cardiac arrest cases that were researched see a median improvement in response time by 1 minutes and 31 seconds with a UAS traveling at 25 mph, and 4,198 of 4,233 of the cardiac arrest cases would see a median time improvement of 2 minutes and 54 seconds with a UAS traveling at at 100 mph.

It is possible that the deploying AED-equipped UASs may have a greater impact in the suburban areas of King County. The models did show significant time savings in the rural areas of King County; however, as mentioned, for every minute that passes without intervention for a patient in cardiac arrest, the chances of survival decrease by about 10 percent per minute.[144] So, a reduction in response time from 6 minutes to 4 minutes could conceivably increase the patient's chance of survival by 20 percent. However, in a rural setting, the difference between a response time of 18 minutes and 11 minutes could potentially have little impact on the patient's survival. There are other variables that need to be considered as well, such as the quality of CPR being performed while the patient waits for emergency responders, the overall health of the patient prior to cardiac arrest, and the proximity to specialized tertiary healthcare following the cardiac arrest.

Because the data do show improvement in response times—and therefore patient outcomes—the next step will be to explore the actual implementation process and begin live testing. However, considerations and limitations must first be addressed.

[144] Anderson et al., "Resuscitation Training," 195.

B. LIMITATIONS AND CONSIDERATIONS FOR FUTURE RESEARCH

(1) Weather

In the Seattle/King County region, on average, there are 308 days of cloud cover, 226 days of heavy cloud cover, and 150 days of rain annually.[145] UAS technology and response times will need to address the variable weather conditions in the region.

(2) Airspace Restrictions

Currently, the Seattle/King County region has airspace restrictions with two international airports, Seattle Tacoma International Airport and Boeing King County International Airport, that will need to be considered.

(3) Multistory and High-Rise Buildings

For patients in cardiac arrest who are in a multistory building (an apartment complex, for example) or a high-rise building, the UAS would only be able to land near the building. In a multistory building, it may take several minutes to retrieve the AED from the UAS and make it back to the patient. An AED would be better suited for buildings with a large number of residents or patrons.

(4) UAS Configuration

There are several UAS configuration considerations to account for. Should the UAS deliver the AED remotely—by parachute, for example—or should the UAS land and stay on location? Should the UAS be compartmentalized, so that the UAS and AED are two separate pieces, or should the UAS and AED be integrated so that they can operate as a single device? An integrated unit could also have two-way communication capabilities, allowing trained personnel to have visual capabilities while being able to communicate with the rescuer(s) who is providing CPR.

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[145] Liz Osborn, "Cloudiest Cities in U.S.—Current Results," Current Results Weather and Science Facts, accessed August 10, 2018, https://www.currentresults.com/Weather-Extremes/US/cloudiest-cities.php.

(5) Medical Considerations

A medical consideration that needs to be addressed is for the lone rescuer performing CPR on a patient. At what time interval does leaving the patient and stopping CPR to retrieve the AED from the UAS prove to be more detrimental than waiting for the first arriving emergency unit? And how often is there only one rescuer on scene with a patient in cardiac arrest?

(6) Retrieval and Redeployment

After a UAS is dispatched and arrives at an address with the AED, the UAS and the AED will need to be retrieved and redeployed. The King County EMS division tracks all cardiac arrests in King County, and downloads data from AEDs used in the field for research purposes. Currently, firefighters will take their AED back to their station and download the cardiac arrest case to King County EMS. There will need to be a mechanism to retrieve both the UAS and the AED in order to put them back in service for the next cardiac arrest in the area.

(7) Expanded Scope

Although studies on the use of UASs to deliver AEDs is limited, there is evidence of UASs being used for other critical interventions. Zipline is a California-based company that is using UASs in the country of Rwanda to deliver donated blood to mothers experiencing postpartum hemorrhage.[146] Using traditional means, it takes an average of 4 hours to get blood to a patient in this part of the world; with the Zipline UAS, patients are receiving blood in as little as 15 minutes.[147] Other potential medical interventions that could be deployed by a UAS include medications such as Narcan, which is used for patients who have overdosed on opiates such as heroin and Oxycodone; epinephrine for patients who are experiencing anaphylaxis; and glucagon for diabetics with low blood sugar.

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[146] Zipline, "Zipline in Rwanda," YouTube Video, uploaded May 13, 2016, www.youtube.com/watch?v=OnDpE8uSb7M.

[147] Zipline.

(8) Legal Considerations

There are several legal considerations when deploying and flying a UAS. Currently, the FAA controls and dictates when and from where a UAS can be deployed, and rules associated with flight.[148] The FAA has allowances for emergency flights; however, waivers need to be attained beforehand.[149] Organizations like the ACLU also have a vested interest in protecting the rights of the American public and ensuring that government officials are not using UASs that interfere with the public's civil liberties.[150] In an interview with the *Wall Street Journal*, FAA Chief Michael Huerta acknowledged that UAS technology is outpacing policy produced by the FAA, and that they needed to increase the speed of changing regulatory efforts to keep up with demand.[151] Huerta also added that the primary focus on UASs was to ensure the public's safety without stifling creativity and innovation.[152]

The FAA does not currently allow UASs to be operated beyond visual line of sight. (BVLOS)[153] In an effort to expand UAS capabilities, the White House is instating a UAS testing program that will allow UASs to operate BVLOS.[154] Companies like Drone

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148 "Fly under the Small UAS Rule," FAA, last modified December 14, 2017, www.faa.gov/uas/getting_started/part_107/.

149 "Waivers and Authorizations Supporting Emergency UAS Operations," FAA, February 22, 2018, https://www.faa.gov/uas/getting_started/emergency_approval/.

150 ACLU, "Protecting Privacy from Aerial Surveillance."

151 Andy Pasztor and Robert Wall, "Drone Regulators Struggle to Keep up with the Rapidly Growing Technology," *Wall Street Journal*, July 10, 2016, http://www.wsj.com/articles/drone-regulators-struggle-to-keep-up-with-the-rapidly-growing-technology-1468202371.

152 Pasztor and Wall.

153 FAA, "Small Unmanned Aircraft Rule," 1.

154 Marco Margaritoff, "Trump Administration Expands Drone Use to Beyond Visual Line of Sight," The Drive, October 25, 2017, http://www.thedrive.com/aerial/15458/trump-administration-expands-drone-use-to-beyond-visual-line-of-sight.

Delivery Canada, and Matternet in Sweden, are testing practical everyday uses for UASs that will be used in BVLOS applications.[155]

C. CONSIDERATIONS FOR OTHER COMMUNITIES RESEARCHING UAS DEPLOYMENT

Although the Seattle/King County region is unique to itself, the restrictions and limitations should be similar in any community considering using UASs for emergency deployment of any resource. A critical component in other regional research will be historical data. Whether it be cardiac arrests, allergic reactions, or overdoses, a strong data set will help determine if the UAS will actually be able to reduce response times and have a positive impact on patients, and if it will be beneficial to the patient or rescuer. A strong data set will also help a community develop a good cost-benefit analysis to consider the number of patients a UAS program could positively impact against the total cost of the program. As UASs are becoming a more viable option for emergency responders, agencies should begin to explore policy, procedure, legal restrictions, and logistical implementation considerations.

UAS launch locations will be a critical consideration as well. As technology improves, so should the range and speed of the UAS. Launch locations will need to be considered based on population and call density, historic and predicted calls for service of the type of emergency intervention needed, and UAS capabilities.

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[155] "Drone Delivery Canada to Expand Testing Program to the United States of America," January 15, 2018, http://www.dronedeliverycanada.com/news/press-releases/drone-delivery-canada-to-expand-testing-program-to-the-united-states-of-america/; Marco Margaritoff, "Matternet Station Drone to Deliver Lab Samples in Switzerland," The Drive, September 20, 2017, http://www.thedrive.com/aerial/14493/matternet-station-drone-to-deliver-lab-samples-in-switzerland.

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