Strategic Placement of Ambulance Drones for Delivering Defibrillators to Out of Hospital Cardiac Arrest Victims

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**Sammanfattning**

Varje år inträffar det extretna många hjärtstopp utanför sjukhus i Sverige och det är väldigt få överlevande. Vid ett hjärtstopp förlorar hjärtat sin normala rym och för att återfå den måste hjärtat få en elektrisk stöt inom några minuter.


Området som studerats är Stockholms län och datan som används innehåller hjärtstopp utanför sjukhus mellan 2006 och 2013 samt tiden det tog för ambulansen att nå olycksplatsen.


Resultaten visade att den bästa platsen för drönaren skulle vara den absoluta stadskärnan eftersom det är där de flesta fallen uppstår, men också de norra delarna av skärgården på grund av den långa tiden det tar för ambulansen att komma dit.
Abstract
The number of out of hospital cardiac arrest (OHCAs) that occur in Sweden every year is really high and there are very few survivors. When a cardiac arrest happens the heart loses its original rhythm and to find it again the heart needs to be shocked within minutes.

There is on going research to see what can be done to improve the survival rate. Publicly accessible defibrillators are one thing that is being implemented. Another solution being considered right now is the possibility of delivering a defibrillator by a drone, especially to places that are difficult to be reached by the ambulance. A test flight with this kind of drone will take place in Stockholm, Sweden in June 2015 and the purpose of this thesis was to analyze where the most suitable place would be to start the drone from for a test flight.

The area studied was Stockholm County and the data used contained Out of Hospital Cardiac arrest occurrences between the years of 2006 and 2013 including the time it took for the ambulance to arrive at the scene.

The analysis was done with Multi Criteria Evaluation. Multi Criteria Evaluation is a power spatial analysis tool that considers multiple criteria in decision-making environments. With Multi Criteria Evaluation suitable places can be found by adding different data and weighing them according to their importance. In this study a raster with interpolated values was produced from ambulance arrival times and this was weighed against a raster created from the density of previous OHCA cases.

Results showed that the best place for a drone like this would be the city center since that is where most OHCAs occur but also the northern parts of the archipelago because of the time it takes for the ambulance to get there.
Acknowledgements

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A big thank you to PhD student Jan Haas for distributing the data but above all for the input in how this kind of problem can be solved with the help of GIS tools.

Last but not least I would like to thank Fredrik Hilding and Ella Syk for sharing their experience from similar projects, their knowledge of the workings of different GIS tools and for great support.
# Contents

Sammanfattning .................................................................................................................. II

Abstract ............................................................................................................................... III

Acknowledgements .............................................................................................................. IV

List of figures ....................................................................................................................... 3

List of Tables ....................................................................................................................... 3

List of abbreviations .......................................................................................................... 4

1 Introduction ..................................................................................................................... 5
   1.1 Background .................................................................................................................. 5
   1.2 Objectives .................................................................................................................... 5

2 Literature overview ......................................................................................................... 6
   2.1 Cardiac arrest ............................................................................................................. 6
   2.2 AED ............................................................................................................................. 6
   2.3 Ambulance Drone ..................................................................................................... 6
      2.3.1 The Deficopter ..................................................................................................... 6
      2.3.2 Drone flying regulations ...................................................................................... 6
   2.4 Earlier and similar studies ........................................................................................ 7
      2.4.1 Publicly accessible defibrillators ......................................................................... 7
      2.4.2 AED coverage and accessibility .......................................................................... 7
      2.4.3 Analysis of using a drone for delivering a defibrillator to OHCA victims ........... 8

3 Study area and data collection ....................................................................................... 9
   3.1 Study area .................................................................................................................. 9
   3.2 Data collection .......................................................................................................... 10
      3.2.1 OHCA cases from 2006 to 2012 ....................................................................... 10
      3.2.2 OHCA cases from 2013 ..................................................................................... 10
      3.2.3 Gas station placement ........................................................................................ 10
      3.2.4 Fire departments and Swedish Sea Rescue Society ......................................... 10
      3.2.5 Base map ............................................................................................................ 10

4 Methodology .................................................................................................................. 11
   4.1 GIS ............................................................................................................................. 11
   4.2 Data preparation ....................................................................................................... 11
   4.3 MCE .......................................................................................................................... 11

5 Results and Discussion .................................................................................................. 14
   5.1 Overview maps ......................................................................................................... 15
      5.1.1 Density of cases .................................................................................................. 16
      5.1.2 Ambulance times ............................................................................................... 17
5.2 Drone placement: The 50/50 weighing results ........................................ 18
  5.2.1 Visualizations .................................................................................. 18
  5.2.2 Time saved and cases covered ...................................................... 22
5.3 Drone placement: The 80/20 weighing results .................................... 25
  5.3.1 Visualizations .................................................................................. 25
  5.3.2 Time saved and cases covered ...................................................... 29
5.4 Possible error sources ........................................................................ 32
6 Conclusions and future research ........................................................... 33
  6.1 Conclusions ....................................................................................... 33
  6.2 Future research .................................................................................. 33
References ................................................................................................. 34
List of figures
Figure 1: Map of Stockholm County with municipality names.............................................. 9
Figure 2: OHCA cases within Stockholm County between the years of 2006 and 2013................................................................. 15
Figure 3: Density of OHCA cases that occurred between the years of 2006 and 2013................................................................. 16
Figure 4: Ambulance arrival times in different parts of the county......................................... 17
Figure 5: The resulting layer after weighing the point density layer with the IDW layer of ambulance arrival times........................................... 18
Figure 6: Most optimal placements of ambulance drones................................................... 19
Figure 7: Most optimal placements of ambulance drones and the OHCA cases covered................................................................................ 20
Figure 8: The optimal placements of the drone at a service station and the harbors of the sea rescue society......................................................... 21
Figure 9: The average ambulance response times of the optimal places compared to drone flight time of 8.5 minutes ........................................ 22
Figure 10: The number of cases the drone would have covered within a 5 minute radius............................................................................. 22
Figure 11: The average ambulance response times of the optimal places compared to drone flight time of 5 minutes...................................... 23
Figure 12: The number of cases the drone would have covered within a 5 minute radius............................................................................. 23
Figure 13: The resulting layer after weighing the point density layer with the IDW layer of ambulance arrival times........................................ 25
Figure 14: Most optimal placements of ambulance drones................................................. 26
Figure 15: Most optimal placements of ambulance drones and the OHCA cases covered................................................................................ 27
Figure 16: The optimal placements of the drone at service stations and the harbors of Swedish sea rescue society ........................................ 28
Figure 17: The average ambulance response times of the optimal places compared to drone flight time of 8.5 minutes ........................................ 29
Figure 18: The number of cases the drone would have covered within a 8.5 minute radius............................................................................. 29
Figure 19: The average ambulance response times of the optimal places compared to drone flight time of 5 minutes ........................................ 30
Figure 20: The number of cases the drone would have covered within a 5 minute radius............................................................................. 30
Figure 21: The average ambulance response times of the optimal places compared to drone flight time of 3 minutes ........................................ 31
Figure 22: The number of cases the drone would have covered within a 3 minute radius............................................................................. 31

List of Tables
Table 1: Coordinates for the most optimal places for the 50/50 scenario......................... 19
Table 2: Coordinates for the most optimal places for the 80/20 scenario......................... 26
# List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AED</td>
<td>Automated External Defibrillator</td>
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<tr>
<td>CA</td>
<td>Cardiac Arrest</td>
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<td>CPR</td>
<td>Cardiopulmonary Resuscitation</td>
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<td>EMS</td>
<td>Emergency Medical Services</td>
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<td>GET</td>
<td>Geographical extraction tool</td>
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<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>IDW</td>
<td>Inverse Distance Weighed interpolation</td>
</tr>
<tr>
<td>KI</td>
<td>Karolinska Institutet</td>
</tr>
<tr>
<td>KTH</td>
<td>Kungliga Tekniska Högskolan (Royal Institute of Technology)</td>
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<tr>
<td>MCE</td>
<td>Multi Criteria Evaluation</td>
</tr>
<tr>
<td>OHCA</td>
<td>Out of Hospital Cardiac Arrest</td>
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<tr>
<td>SÖS</td>
<td>Södersjukhuset</td>
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<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
</tr>
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</table>
1 Introduction

1.1 Background

Every year sudden cardiac arrests lead to death. When a sudden cardiac arrest happens outside of a hospital the survival chance is low. In Sweden there are about 10 000 sudden cardiac arrests per year and less than 500 survivors (Hjärt-Lungfonden, 2014a). For a person to survive, they have to be shocked with a defibrillator within minutes, thus time is a primary aspect (American Heart Association, 2014a). The survival rate is said to be 74% if a person is shocked within 3 minutes of the arrest (Valenzuela et. al. 2000). It is also said that for every minutes that goes by the chance of survival decreases with 10%, meaning that after only 5 minutes the chance of survival is down to 50% (Hjärtstartarregistret, 2015). To increase survival chances there are now AEDs (Automated External Defibrillators) placed in different places available to the public. Even though the AEDs are often stored in places where there are a lot of people, for example shopping malls, golf courses, businesses, airports, airplanes, casinos, convention centers, hotels, sports venues, and schools most of them are placed in buildings that are not accessible at all times (Malta Hansen et. al. 2013). Ambulances do off course carry defibrillators and today even some firefighters and the police force have them (Nordberg et. al. 2015), but the average ambulance arrival time in Stockholm is about 13 minutes and since Stockholm consists of a lot of Islands there are places where the ambulance has trouble getting to, for example the archipelago of Stockholm (Hellekant, 2015). For this there are ideas that a drone, positioned in a good place, could carry an AED to these otherwise inaccessible places. In June 2015 there will be a test flight for this kind of drone in Stockholm, Sweden, organized as a cooperation between the German Aerospace center, Karolinska institutet and rescue coordination center of Stockholm, amongst others (DLR, 2015).

1.2 Objectives

The main objective for this thesis is to analyze where within Stockholm County the best place would be to start the drone from for a test flight.

The questions to be answered are the following:
• Where are the hotspots of cardiac arrest occurrences that are difficult to be reached by ambulances?
• In how many of the chosen historical OHCAs does the drone arrive before the EMS system?
• Are there any particular areas where the time benefit of using a drone equipped with an AED is the greatest?
• In how many cases can a drone reach the OHCA victim within 5 minutes?
2 Literature overview

2.1 Cardiac arrest
When a sudden cardiac arrest happens it is usually because the normal rhythm of the heart is replaced by electrical chaos. The heart starts to beat irregularly (arrhythmia) and cannot pump the blood to the rest of the body (Medtronic, 2011). One kind of arrhythmia is Ventricular fibrillation. When Ventricular fibrillation occurs the lower chambers of the heart, the ventricles, start to contract fast and unsynchronized. They fibrillate instead of beating (American Heart Association, 2014b). For the heartbeat to become regular again an electrical chock is necessary. CPR should be performed while waiting for defibrillation. It does not start the heart back up again but it keeps the circulation of the blood going while waiting for defibrillation. Brain damage can occur already after 3-4 minutes if no CPR is preformed (Hjärt-Lungfonden, 2014b).

2.2 AED
AED stands for Automated External Defibrillator. It is a defibrillator that is light and easy to carry. When you attach the electrodes to the victim the AED registers the heart rhythm and if necessary it sends a chock to the heart in order to restore the normal rhythm (American Heart Association, 2012). The AEDs available to the public are easy to use and guides the user through the process. No previous training is necessary.

2.3 Ambulance Drone

2.3.1 The Deficopter
A drone, also called UAV (Unmanned Aerial Vehicle) is a small helicopter that can be operated from the ground. The drone that will be used for the test flight is a drone produced by the German company Height-Tech. In cooperation with the non profit group Definetz they have come up with what they call the Deficopter, which is a drone carrying an AED (The verge, 2015). The Deficopter can travel at a speed of 70 km/h and within a radius of 10 km. When the emergency call is received the Deficopter will be loaded with data and navigated to the emergency place. The Deficopter is equipped with a camera so that the emergency personnel can spot the scene and know when to drop the AED. The AED falls to the ground with a parachute.

2.3.2 Drone flying regulations
Flying a drone in Sweden cannot just be done by anyone, anywhere; there are legal regulations (Transportstyrelsen, 2015). The Swedish Transport Agency divides drones into several categories in their regulations. To serve its purpose the ambulance drone needs to able to fly out of sight of the pilot, which puts this kind of drone in a special category. According to the regulations, when operating a drone in this category a whole organizational structure behind it is needed. There are also protocols regarding the planning of each flight and areas restricted from flying.
2.4 Earlier and similar studies

2.4.1 Publicly accessible defibrillators

Outcomes of rapid defibrillation by security officers after cardiac arrest in casinos
This study was done to analyze the outcomes of rapid defibrillation by others than medical personnel. Security officers working in casinos were instructed to use AEDs in cases of OHCA. The results showed that 53% survived to discharge from the hospital in total. The survival rate was 74% for those who received their first defibrillation no later than 3 min after the cardiac arrest and 49% for those who got shocked after 3 min. The conclusion reached was that rapid defibrillation by non medical personnel can improve survival rate and less than 3 minutes between cardiac arrest and defibrillation is necessary to achieve high survival rates (Valenzuela et. al. 2000).

Survival after Public Access Defibrillation in Stockholm, Sweden – A striking success
There is both a first responder system and a Public Access Defibrillation program implemented in Stockholm. Alongside registered AEDs there are also unregulated AEDs available to the public. This study did an evaluation of the survival rate depending on defibrillation strategies in cases of OHCA available for public access defibrillation. Results showed that survival to one month was 70% when defibrillated with a public AED. Both the structured AED program as well as the spread of unregulated AEDs was associated with very high survival rate (Ringh et. al. 2015).

2.4.2 AED coverage and accessibility

Visualization and Analysis of Historical OHCA Occurrences and Other Risk Factors for Improved Placement of AEDs
This bachelor thesis was about visualizing OHCA occurrences and analyze the optimal placements of AEDs in Stockholm County, Sweden. The data used was daytime and nighttime population data, heart disease statistics and socio economic data along with the locations of AEDs at the end of 2013 and OHCA cases that happened between 2006 and 2012. The method used was a Multi Criterias Evaluation (MCE) with GIS tools. The results showed that the best placement of AEDs during daytime was commercial areas and for nighttime a bit different but closely together in residential areas (Hilding and Ilethag, 2014).

Automated External Defibrillators Inaccessible to More Than Half of Nearby Cardiac Arrests in Public Locations During Evening, Nighttime, and Weekends
This article was about the AED accessibility affected coverage of cardiac arrest in public locations. Coverage was defined as an AED within 100 meters of the cardiac arrest. Results showed that 61.8% of all cases occurred during nighttime or weekends, whereas only 9.1% of the AEDs were accessible at all times, while 96.4% where accessible during daytime and weekdays. The conclusion reached was that limited AED accessibility at time of CA decreased coverage by 53.4% (Malta Hansen et. al. 2013).
Temporal Trends in Coverage of Historical Cardiac Arrests Using a Volunteer-Based Network of Automated External Defibrillators Accessible to Laypersons and Emergency Dispatch Centers

This article investigated how volunteer based AED dissemination affected public cardiac arrest coverage in high and low risk areas. All cases of OHCAs and AEDs in Copenhagen were geocoded. Results showed that most of the AEDs were placed in low risk areas or areas where no OHCAs had occurred. The AEDs that were placed in high risk areas were placed in offices and not in areas that were previously identified as high-risk, such as train or bus stations. The conclusion was that between 2007 and 2011 the AED coverage increased from 2.7% to 32.6% in total and in high risk areas from 5.7% to 51.3% (Malta Hansen et al. 2014).

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

The purpose of the study was to determine the effects of dual dispatch on response times and outcome in differently populated regions. The study concluded that Dual dispatch of fire fighters and EMS reduced response time in all regions. 30-day survival increased significantly in downtown populations while limited impact was seen in rural areas. There was a difference of survival from 15% in downtown area compared 5.3-7.0 % in rural areas (Nordberg et al. 2015).

2.4.3 Analysis of using a drone for delivering a defibrillator to OHCA victims

Increasing the Survival Rate of Out of Hospital Cardiac Arrests in Stockholm County

The project was about how it could be possible to increase survival rate of OHCAs by improving existing solutions of reaching OHCA cases. It consisted of two parts, where one was about using UAVs and the second one about improving the currently used SMS function.

The area studied was Stockholm County and the data used was data about location of fire stations, location of registered AEDs as well as data about previous OHCAs.

The analysis was done with an MCE and GIS tools.

Results showed the four most optimal fire stations to place the drone from, which were Johannes fire station, Kungsholmen fire station, Hägersten fire station and Farsta fire station (Hals et al., 2015).

A GIS project

This was a similar project as the one above, carried out by another group of students. The study area and given data were the same as well as the methodology, except that this study did not use fire stations as starting points for the UAV. There were several results presented of the optimal placement constellations of UAVs, depending on the input data. In every result presented the city center of Stockholm seemed to be one of the best places along with some suburbs (Alongi et al., 2015).
3 Study area and data collection

3.1 Study area

The area studied was the County of Stockholm, Sweden. Every year there are about 900 OHCA cases in Stockholm (HLR-Konsulent, 2015). The county has 2 205 105 inhabitants (SCB, 2015) in an area of 6522 square kilometers and thus a population density of 338 people per square kilometer (SCB, 2012). Stockholm County consists of a lot of Islands, some accessible by for example bridges and some only reachable by boat. More than half of the population of Stockholm County is considered islanders (SCB, 2014).

Figure 1: Map of Stockholm County with municipality names

Figure 1 is a map of Stockholm County with municipality names, which can be used as a guide and for orientation in the maps below.
3.2 Data collection

3.2.1 OCHA cases from 2006 to 2012
The main data used in the study came from the Centre of Cardiac arrest research (Hjärtstoppencentrum) represented by SÖS and KI. The data was presented in an excel file and included a lot of information for all registered cardiac arrest occurrences in Stockholm County. The most significant information for this study was the coordinates, in RT-90, for each case along with the registered date and time for when the ambulance accepted the case and the time the ambulance arrived at the scene. Aside from that, there was also knowledge about the probable cause behind the cardiac arrest, for example heart disease, accident, suicide and sudden infant death syndrome. After talking to David Fredman and Martin Jonsson from SÖS only the cases that were cardiac related were kept as useful data and the cases that were classified as “crew witnessed” were also removed since they meant that the EMS were already in place when the arrest happened.

3.2.2 OHCA cases from 2013
This data originated from the same source as the one above and included almost the same parameters. This too was delivered as an excel file but with the coordinates in WGS-84. OHCA cases from all over Sweden were recorded so to match the study area only the cases within Stockholm County were selected.

3.2.3 Gas station placement
This data included the coordinates for the placements of the gas stations that have personnel. The coordinates were downloaded from the gas stations respective websites (Shell, 2015)(Statoil, 2015). All data was represented in WGS-84 coordinates in Excel files.

3.2.4 Fire departments and Swedish Sea Rescue Society
The addresses of the Fire departments and volunteer fire departments around Stockholm County were found on the website brandforsvar.se after calling and emailing Storstockholms brandförsvar. Approximate coordinates were collected by typing in the address in Google maps since no exact coordinates could be found.

It has been suggested that the test flight will originate from one of the harbors of the Swedish Sea Rescue society and for that reason the coordinates of those two harbors were collected by typing there address into Google maps as well.

3.2.5 Base map
A base map was gathered with the help of the service GET (Geographical extraction tool). The purpose of GET is to distribute the geodata provided by Lantmäteriet to the universities all over Sweden. This makes it possible for anyone with a KTH login (or another registered university) to download data for free.
4 Methodology

4.1 GIS
The analysis will be carried out with the help of GIS tools. GIS stands for geographical information systems and with GIS it is possible to solve a lot of problems as long as they include a spatial component. Besides the objective of this thesis other questions that can be answered with the help of GIS can include (but are not limited to); Where is the nearest restaurant? Where in the city do people under the age of 25 live? Where can I find a hotel that has a pool and is located less than 100 meters from the beach? (Heywood et. Al., 2011)

4.2 Data preparation
The first step in this analysis was to prepare the raw data. For the excel file with the data that consisted of OHCA cases from 2006 to 2012 a new column had to be added to calculate the response time of the ambulance. The date and time when the ambulance responded to the call was subtracted from the date and time when the ambulance arrived at the scene. This time was then multiplied by 1440 to get a float number in excel. Some data needed to be reformatted and edited in excel as well.

4.3 MCE
MCE stands for multi criteria evaluation and is a way to find one optimal place by putting together several layers and ranking them by importance. Every layer gets multiplied by a weight and the layers are then added together. All the weights need to add up to 1. So for example if two layers that are of equal importance are to be weighed they should each me multiplied by 0.5 and then added together. Before creating the final MCE map for this analysis all layers needed to be prepared. The process and tools used are described in the following sub sections.

ArcMap
For this study the software ArcMap in ArcGIS 10 was used. It is a software created by the company ESRI. Similar software from other companies exists too. With the help of ArcGIS, analysis can be done on a lot of different data and final maps can be created to visualize and represent results.

Importing Data
If the data is already in shape file format, it is very easy to just import it as a layer into ArcGIS. If the data on the other hand is represented in for example an excel file a little more work has to be done. The first step is to add the X, Y data. When doing that it is important to choose which column from the excel file that represents the respective coordinates. You also need to choose the coordinate system for the coordinates. After that it is possible to export it as a shape file and then all operations can be done on that data.

Select by location and select by attribute
With the select by location tool it is possible to select features in different layers according to how they relate to each other. Since the data with the OHCA cases from 2013 included cases from all over Sweden this tool was needed to select only the cases that had happened within Stockholm County.
The select by attribute tool helps you select amongst the attributes within one layer. Since the data with OHCA cases between 2006 and 2012 included some cases that did not have a registered response time and some where the times were wrongly registered giving the response time a negative value, the select by attribute tool could be used to remove these.

**Project**

When working with data layers delivered in different coordinate systems it is important that they are projected the same so that operations can be preformed with the same parameters, for example the chosen cell sizes. With the project tool all layers got projected to SWEREF 99 TM.

**Merge**

To simplify the following steps the cases from 2006-2012 and the ones from 2013 were put in the same layer by merging. The Merge tool appends the entire attribute table of one layer to the bottom of the attribute table of another layer.

**IDW**

IDW stands for inverse distance weighed interpolation and is a tool that creates a raster layer from a point layer. It uses an inverse distance weighing formula to calculate the value of one cell. For one cell it looks at the closest known points’ values and from them calculates the supposed value of that cell, resulting in a raster layer with interpolated values for every cell. The IDW function was used on the OCHA cases layer with the response time as input attribute. The output cell size was set to 50 meters. When determining the value of one cell the number of nearby point to refer to is set to 12 by default and this was kept.

**Point density**

The point density counts the number of points within a certain area and delivers a raster layer with values representing the density. This was used with the entire OHCA cases layer and the output cell size was again set to 50 meters.

**Extract by mask**

A part of a raster layer can be extracted with the help of another layer representing the same shape that is to be extracted. With the help of the Stockholm county layer both the point density layer and the IDW layer for response times could be extracted to the shape of the county.

**Adding layers together**

Before the IDW layer and the Point density layer could be added together they needed to be represented on the same scale. For each of the two layers this was done by dividing the layer with its highest value and then multiply it by 255, which made both layers range from 0 to 255.

The adding was then done with two different sets of weights. In the first case scenario the layers got weighed equally, both by 0.5. For the second case scenario the IDW layer representing the ambulance response times got weighed a lot heavier, 0.8, leaving the point density layer with the weight of 0.2. The following steps where then carried out on both produced suitability layers.
**Finding the optimal pixel**

With the help of focal, local and zonal operations different statistics of a certain layer can be found. Focal sum takes an input radius and for each cell calculates the summarized value of all cells within this radius and assigns this summarized value to the cell. When doing this the radius was set to 10 kilometers to represent the maximum radius of the drone. The zonal statistics needs one zone layer and one value layer. A zone layer was created by reclassifying another layer of the same size and giving the entire layer the value of 1. Then the zonal maximum tool was used to find the maximum value of the focal sum layer. With the local tool “Equal to frequency” the cell representing the zonal maximum, and thus the best location, could be found. After finding the best location, this location was removed from the zone layer and the whole procedure could be done again to find the second best place and so on.

**Extract values to points**

In reality the drone needs to be placed somewhere it can be looked after and serviced and for that reason part of the analysis included finding some kind of optimal station as well. With the help of the “extract values to point” function it was possible to extract the values of the final layer and add them to the attribute table of the service stations layer. After that it could easily be determined which station got associated with the highest valued pixel.

**Raster to point**

After finding the highest valued pixels they can be converted into points so that vector operations can be preformed.

**Buffer**

Buffer layers of desirable size and shape can be put around points. All points got one circle buffer with the radius of 3500 meters, equal to 3 minutes flight time for the drone, one with the radius of 5800 meters, equal to 5 minutes flight time of the drone and one with the radius of 10000 meters, equal to 8.5 minutes flight time for the drone. In this way, by the help of selecting by location and attribute, it was possible to see how many cases each place covered and in how many cases the drone would have been faster than the EMS.
5 Results and Discussion

The results are presented and discussed in the following sections. Since most of the results are pretty self-explanatory and easiest represented with maps and other visuals such as graphs that is how they will be presented. When finding the 10 most suitable places the radius was set to 10 km, the reachable area for the drone. This radius when doing the focal sum can be set differently, to for example represent 5 minutes (5800 meters) and then maybe the most suitable places would be different ones. Although since the highest valued pixels are still in the same places, the results should not differ that much.

Results show that most OHCA cases occur in the center of the city, which can be seen in both figure 2 and 3. Figure 4 showing the ambulance arrival times indicate that there is a high average ambulance arrival time in Stockholm County, and very few places reachable within five minutes. For the 50/50 weighing scenario the risk zones and thus the most suitable places showed up mostly in the city core along with the Northern Archipelago and Ekerö. This is visualized in figures 5, 6 and 7 along with table 1 and in figure 8 it is possible to see how many cases each suitable place would cover. When extracting values to the points representing the stations, all 10 best stations showed up in the center city for the 50/50 weighing scenario, which can be seen in figure 9 along with the locations of the harbors of Swedish sea rescue society. For the 50/50 weighing scenario the average ambulance arrival time compared to the drone flight time and the amount of cases that would have been covered if using a drone are represented as graphs in figures 9 till 14, split into the buffers of 8.5 minutes, 5 minutes and 3 minutes.

For the 80/20 weighing scenario the risk zones and 10 most suitable places can be found in figures 15, 16 and 17 as well as table 2. As for the optimal stations for the 80/20 scenario they were mostly located in connection to the most suitable places, see figure 18. For the time saved and cases covered the same kind of graphs were put together as for the 50/50 weighing and are presented in figures 19-24.
5.1 Overview maps

Figure 2: OHCA cases within Stockholm County between the years of 2006 and 2013.

As seen in figure 2 the OHCA cases are clustered around the city center, which could be excepted since that is where most people are located, both by living, working and running errands.
5.1.1 Density of cases

The outcome of the density of OHCA cases that can be seen in figure 3 could have been assumed already by looking at the previous map (figure 2) since the density is pretty easy to spot with the naked eye. The highest density of registered OHCA cases between 2006 and 2013 is found in the absolute center of the city and from there it subsides the further away you get.
5.1.2 Ambulance times

By looking at figure 4 one can easily tell that there are very few areas where the ambulance can reach the victim within five minutes. Since the chance of survival for an OHCA victim is much higher if defibrillated within 5 minutes, this could be considered a critical problem. The area covered within ten minutes is larger but for more than half of the county area it still takes the ambulance over ten minutes to arrive. The longest ambulance response times are seen in the outskirts of the city, especially islands and other areas surrounded by water which could have been predicted due to the difficulty of driving there.
5.2 Drone placement: The 50/50 weighing results
How the layers should be weighed was really difficult to decide and therefore a 50/50 weighing felt like a reasonable approach. The original thought was that a high density of cases along with long ambulance arrival times should yield a result of the most optimal placement of the drone.

5.2.1 Visualizations

5.2.1.1 Risk zones

Figure 5: The resulting layer after weighing the point density layer with the IDW layer of ambulance arrival times

The risk zones that show up in figure 5 are first and foremost the center city. This is not strange since the absolute highest density of cases is in the city center and when looking closely at figure 4 with the ambulance arrival times it is possible to see a small number of spots in the inner city that also have long arrival time. These would probably be the highest valued points. The other red parts in figure 5 are perhaps red because of their long ambulance arrival times.
5.2.1.2 Most optimal places calculated by ArcGIS

Figure 6: Most optimal placements of ambulance drones

Table 1: Coordinates for the most optimal places for the 50/50 scenario

<table>
<thead>
<tr>
<th>Place</th>
<th>X-coordinate</th>
<th>Y-coordinate</th>
<th>Approximate place</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>18.011430</td>
<td>59.330876</td>
<td>Kristineberg, Kungsholmen.</td>
</tr>
<tr>
<td>2nd</td>
<td>18.148685</td>
<td>59.278828</td>
<td>Älta, Bagarmossen subway station</td>
</tr>
<tr>
<td>3rd</td>
<td>18.164371</td>
<td>59.372857</td>
<td>Lidingö, Oxelvägen</td>
</tr>
<tr>
<td>4th</td>
<td>17.995743</td>
<td>59.236731</td>
<td>Huddinge, Lännavägen</td>
</tr>
<tr>
<td>5th</td>
<td>17.960449</td>
<td>59.414785</td>
<td>Sollentuna, kummelbyvägen</td>
</tr>
<tr>
<td>6th</td>
<td>17.834959</td>
<td>59.348874</td>
<td>Lovön, Koviksvägen</td>
</tr>
<tr>
<td>7th</td>
<td>17.825156</td>
<td>59.488534</td>
<td>Äpplarö</td>
</tr>
<tr>
<td>8th</td>
<td>17.583978</td>
<td>59.366862</td>
<td>Munsö, fägelsången</td>
</tr>
<tr>
<td>9th</td>
<td>18.874176</td>
<td>59.536284</td>
<td>Outside of Lagnö</td>
</tr>
<tr>
<td>10th</td>
<td>17.976135</td>
<td>59.312868</td>
<td>Vinterviken/Stora Essingen/Älsten</td>
</tr>
</tbody>
</table>

Figure 6 and table 1 show that the 6 most optimal places were all located in the city center and its closest areas. Points 7 through 9 indicates that the optimal places outside of the city core are the northern parts of the archipelago, a bit south of Norrtälje along with some islands in Mälaren; Ekerö, Munsö and Adelsö. Ending up around the islands was expected since those should be the most troublesome places for the ambulances to get to.
Illustrated in figure 7 are the most optimal places and the previous OHCA cases they would have covered. It is easy to see that the most optimal places outside of the city center do not cover a lot of historical cases and must therefore have had a really high ambulance arrival time to still be considered an optimal place.
5.2.1.3 Most optimal stations

The harbors of the sea rescue society (Sjöräddningssällskapet) are marked in figure 8. According to this Brygga Hammarby slussen might actually be a good starting position for the drone. Other than that the most optimal stations are all placed around the number one optimal point.
5.2.2 Time saved and cases covered
The following charts were put together to answer the questions regarding in how many cases the drone would have been faster than the EMS and in how many cases the drone can reach the victim within five minutes. For all 10 places there was a 8.5 minutes buffer, a 5 minutes buffer and a 3 minutes buffer put around them to easier distinguish in how many cases the drone would have been faster.

5.2.2.1 Within a drone flight time of 8.5 minutes

![Figure 9: The average ambulance response times of the optimal places compared to drone flight time of 8.5 minutes](chart)

![Figure 10: The number of cases the drone would have covered within a 5 minute radius](chart)

As seen in figures 9 and 10, showing the outer radius of 10 kilometers of the drone’s reachable area, the drone would be useful but the effect is not overly extreme. In some of the places the average time of the EMS system is lower than the drone flight time and even though there are a great number of cases in which the drone would have been faster, most of the cases are covered by the EMS.
5.2.2.2 Within a drone flight time of 5 minutes

![Drone Flight Time vs Ambulance Response Time](image)

**Figure 11**: The average ambulance response times of the optimal places compared to drone flight time of 5 minutes

![Number of Cases Covered](image)

**Figure 12**: The number of cases the drone would have covered within a 5 minute radius

From figure 11 one can tell that the drone flight time is now lower than the average ambulance response time for all ten places and although the difference is not huge, the drone flight time is about 3-5 minutes shorter which could mean life or death.

Figure 12 shows that in this scenario even though the EMS reached a lot of cases within five minutes, in more than half of the cases the drone would have been faster. For the first place there were 579 lives that could not be reached by the ambulance in five minutes and would have been reached by the drone.
5.2.2.3 Within a drone flight time of 3 minutes

Figure 13: The average ambulance response times of the optimal places compared to drone flight time of 3 minutes

Figure 14: The number of cases the drone would have covered within a 3 minute radius

Figure 13 shows that a drone flight time of 3 minutes is a lot faster than the average ambulance arrival time for all ten places. From figure 14 we can see that for most of the cases the drone would have been faster than the EMS.
5.3 Drone placement: The 80/20 weighing results
Since the data included a lot of registered cases in the city center, it was assumed that a 50/50 weighing would show that the drone was best located in the city center, which was also the results as seen above. Getting a permit to test fly in the city center and densely built up areas might be tough due to the drone flying regulations. For this reason and because part of the study was to find the areas inaccessible to the EMS, the IDW layer with ambulance arrival times got weighed a lot heavier in the second scenario with the goal to find out which would be the most optimal locations outside of the city core.

5.3.1 Visualizations

5.3.1.1 Risk zones

As guessed figure 15 shows that there are a lot more hot spots outside of the city core for this scenario.
5.3.1.2 Most optimal places calculated by ArcGIS

Figure 14: Most optimal placements of ambulance drones

Table 2: Coordinates for the most optimal places for the 80/20 scenario

<table>
<thead>
<tr>
<th>Rank</th>
<th>Place</th>
<th>X-coordinate</th>
<th>Y-coordinate</th>
<th>Approximate place</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td></td>
<td>18.724827</td>
<td>59.481909</td>
<td>Outside of Äpplarö</td>
</tr>
<tr>
<td>2nd</td>
<td></td>
<td>18.881695</td>
<td>59.530153</td>
<td>Outside of Husarö and Lagnö</td>
</tr>
<tr>
<td>3rd</td>
<td></td>
<td>17.585152</td>
<td>59.365842</td>
<td>Munsö, Ekerö</td>
</tr>
<tr>
<td>4th</td>
<td></td>
<td>18.740751</td>
<td>59.970057</td>
<td>North of Norrtälje, outside of Ålmsta</td>
</tr>
<tr>
<td>5th</td>
<td></td>
<td>17.497785</td>
<td>59.071974</td>
<td>Outside of Järna</td>
</tr>
<tr>
<td>6th</td>
<td></td>
<td>18.320248</td>
<td>59.759527</td>
<td>Close to Rimbo</td>
</tr>
<tr>
<td>7th</td>
<td></td>
<td>18.266770</td>
<td>58.950905</td>
<td>Utö</td>
</tr>
<tr>
<td>8th</td>
<td></td>
<td>18.712419</td>
<td>59.207382</td>
<td>Nämdö</td>
</tr>
<tr>
<td>9th</td>
<td></td>
<td>18.920389</td>
<td>59.849184</td>
<td>North-East of Norrtälje, Vätö</td>
</tr>
<tr>
<td>10th</td>
<td></td>
<td>18.688651</td>
<td>60.060412</td>
<td>East of Hallstavik</td>
</tr>
</tbody>
</table>

As seen in figure 16 and table 1 all hotspots showed up in the outskirts of the city. Foremost in the archipelago followed by the islands in Mälaren eg Ekerö and Adelsö. It might be worth mentioning that the places ranked 1-3 in this scenario are pretty much the same places that made the top ten in the 50/50 weighing scenario.
Figure 15: Most optimal placements of ambulance drones and the OHCA cases covered.

In figure 17 we can see the 10 most optimal places and all the cases each place would cover.
5.3.1.3 Most optimal stations

Figure 16: The optimal placements of the drone at service stations and the harbors of Swedish sea rescue society

Figure 18 shows that most of the optimal stations end up being located in pretty much the same area as the optimal points. The best thing might be to just choose an optimal point and then it will probably be possible to find some kind of station nearby that can be used as a hub. The one thing noticeable is that there is no station in the very northern part even though there were actually three places in figure 17 that were considered optimal. There might not be any kind of fire station or a Statoil or Shell gas station there but there is probably some kind of station that would be considered usable for this area. The harbors of Swedish sea rescue society are marked in figure 18 as well, and for this scenario Brygga Österskär might work as a good starting point since it is relatively near point 1 and 2.
5.3.2 Time saved and cases covered
Since the IDW does an interpolation where it appoints a value to every cell, even areas with no previous cases registered will get a value assigned according to the closest points. The IDW function was set to looking at the 12 closest points for all pixels, which means that even if there is no case that is really close to the cell that is to be determined, it will interpolate a supposed value of how long it would take the ambulance to get there if there was to be a case. It is impossible to know where the future cases will be, but if we consider them happening approximately where they have before an optimal location including no previously registered cases might not actually be optimal.

5.3.2.1 Within a drone flight time of 8.5 minutes

![Figure 17: The average ambulance response times of the optimal places compared to drone flight time of 8.5 minutes](image)

Even though 8.5 minutes can seem like quite a long time, figure 19 shows that the average ambulance response time is at 20 to 38 minutes, meaning that a lot of time could be saved using a drone. Visible in blue in figure 20 is the number of cases where the drone would have been faster than the Ems, which is almost all of them.
5.3.2.2 *Within a drone flight time of 5 minutes*

![Graph showing the average ambulance response times of the optimal places compared to drone flight time of 5 minutes](image1)

*Figure 19: The average ambulance response times of the optimal places compared to drone flight time of 5 minutes*

![Graph showing the number of cases the drone would have covered within a 5 minute radius](image2)

*Figure 20: The number of cases the drone would have covered within a 5 minute radius*

Figure 21 and 22 shows that a radius of 5 minutes flight time instead of 8.5 minutes will not cover as many cases as 8.5 minutes but the time saved will be great, about 15-27 minutes.
5.3.2.3 Within a drone flight time of 3 minutes

The average flight time is based on only a few cases, with most of them having a very long response time, which makes for a very high average. As seen in figures 23 and 24, the drone would be faster than the EMS in all but one case and the time saved would be great, between 15 and 30 minutes. As mentioned above, the IDW assigns values to every cell in the raster and since the ambulance arrival time was weighed really heavy in this scenario even pixels that do not cover any previous cases might be considered the best ones since they have an assumed high ambulance arrival time, which can be seen in figure 24 for places 1, 2, 5, 7, 8 and 10.

Comparing the 3- and 5-minutes scenarios shown in figures 21-24 with the 8.5 minutes in figure 20 a lot more cases are covered in the 8.5 minutes, which could be expected since the radius is greater and therefore can include more cases. Even though fewer cases are covered in the 80/20 weighing than the 50/50, the stats in figures 19-24 shows that the drone would be faster than the EMS in almost all the cases, which means that a lot of lives would be saved.
5.4 Possible error sources
There are both pros and cons with using MCE as an analytic tool. How the weights of the layers are chosen is up to the analyst and thus the results may vary a lot depending on who is doing the analysis and what they find important.

Almost all tools in ArcGIS have several input parameters that can be altered. The way they were chosen did off course effect the results as well.

Calculating the average ambulance arrival time in the areas where only a few cases where registered does not give a very accurate result. To get a reliable average there need to be a lot of cases to base the calculations on.

When deciding whether or not the drone would be faster than the EMS the calculations were not exact. For example when a buffer of 3 minutes was put around the point it was possible to see how many of the cases within the entire radius that had an ambulance arrival time that exceeded 3 minutes but it was not taken into account how far within this radius the OCHA case was from the optimal place. This means that a case with a registered ambulance response time of 2 minutes will not be selected even though the true scenario might be that the case is located really close to the point and would actually be reached by the drone in one minute.
To get a more justified comparison the drone flight time from the optimal place to each point needs to be calculated separately and then compared to the registered ambulance time.

Since the coordinates of the fire departments were found by typing the address into Google maps, they are probably not completely accurate. For some of the stations not even an address could be found, only a place or an island, which makes the approximation of coordinates even rougher.
6 Conclusions and future research

6.1 Conclusions

The results show that there are very few places in Stockholm County that have an ambulance response time below 5 minutes, so unfortunately the chances of surviving an OHCA today are very low.

Since most OHCA cases happen where people are i.e. the inner parts of Stockholm city, placing a drone there would probably save the most lives. To be able to get the kind of permission required for ambulance drones to be taken into actual use, the regulations would have to be altered somewhat. Perhaps emergency drones could have their own regulation category or some kind of special permission.

Even though most OHCAs happen in the city, the average arrival time for the ambulance there is around 8-10 minutes compared to an average of 25-30 minutes in the outskirts and the archipelago. Consequently, an ambulance drone placed in the archipelago would increase the survival chance for the victims there tremendously.

For the test flight that will take place outside of the city, the islands of Äpplarö, Husarö and Lagnö in the Stockholm archipelago would be the most optimal places. In addition, the islands in Mälaren; Ekerö, Adelsö and Munsö could be good places for the test flight as well.

6.2 Future research

When finding an optimal place for a drone, other factors than only previous OHCA cases could be looked at for more accurate results. Perhaps risk groups and population density, even though where people live does not necessarily represent where they are when they suffer a cardiac arrest. The locations of AEDs available at all hours could be considered in the analysis as well.

If the drones are to be taken into use more research might need to be done looking into the regulations and how they can be altered.
References


Hilding, F and Ilehag, R. (2014). Visualization and Analysis of Historical OHCA Occurrences and Other Risk Factors for Improved Placement of AEDs B.Sc Royal Institute of Technology, Stockholm


