Visualization and Analysis of Historical OHCA Occurrences and Other Risk Factors for Improved Placement of AEDs

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This is an abridged version of the bachelor thesis *Visualization and Analysis of Historical OHCA Occurrences and Other Risk Factors for Improved Placement of AEDs* written at the Royal Institute of Technology in Stockholm and presented June 2014.

**Abstract**

When an out of hospital cardiac arrest (OHCA) occurs, time is of the utmost importance. For every minute that the arrest goes untreated, the chance of survival decreases rapidly. The most common treatment, that is also the most known, is Cardiopulmonary Resuscitation (CPR). Thanks to new technology, the defibrillator is no longer a tool only available to hospital personnel but to anyone who knows where they are located.

The objective of this study is partly to visualize OHCA occurrences as well as visualize the differences in OHCA occurrences. The study will analyze where the optimal locations of AEDs are based on a number of variables such as location and year, which is referred to as risk analysis. The analysis was performed by using daytime and nighttime population data from Statistics Sweden (SCB) in combination with heart disease statistics from the national patient register of Socialstyrelsen. Along with that data, AED locations at the end of 2013 and OHCA data from 2006 up until 2013 was used in visualizations and risk analysis. In order to determine the final optimal placement through the risk analysis, a GIS tool named MCE was used. This tool enabled the weighting of the different parameters against each other, which was integral for the final result.

The results implied that the recommended locations of AEDs while using daytime population data were located in commercial areas. Recommended AEDs using the nighttime population data were clustered in residential areas.

**Keywords:** MCE, AED, OHCA, Stockholm, GIS, Cardiac Arrest, Defibrillator
Acknowledgments

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We would also like to thank David Fredman and Martin Jonsson from Södersjukhuset for promptly providing us with data, ideas and giving us input about the medical side of this two-pronged study.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AED</td>
<td>Automatic External Defibrillator</td>
</tr>
<tr>
<td>CA</td>
<td>Cardiac Arrest</td>
</tr>
<tr>
<td>CPR</td>
<td>Cardiopulmonary Resuscitation</td>
</tr>
<tr>
<td>HLR</td>
<td>Svenska rådet för hjärt-lungräddning (Swedish Resuscitation Council)</td>
</tr>
<tr>
<td>OHCA</td>
<td>Out of Hospital Cardiac Arrest</td>
</tr>
<tr>
<td>SCB</td>
<td>Statistiska Centralbyrå (Statistics Sweden)</td>
</tr>
<tr>
<td>SÖS</td>
<td>Södersjukhuset</td>
</tr>
</tbody>
</table>
1. Introduction

1.1 Background

From the year 2006 until the end of the year 2013, 7268 OHCA cases have occurred in Stockholm County. Every minute OHCA goes untreated, the survival rate decreases NHLBI (2011). While most of these cases occur at home, the OHCA that do happen in public can be quickly treated with the aid of publicly available AEDs. Therefore, finding the optimal placements for AEDs can reduce the waiting time for treatment of an OHCA.

The Swedish Resuscitation Council (HLR) works to spread the knowledge about cardiac arrest and how it can be treated effectively. This includes the creation of guidelines and manuals, as well as education and training in the effective use of CPR and AEDs (HLR, 2014).

While taking the HLR guidelines into account, the optimal locations for future AEDs are to be determined. By using already existing AED locations, an analysis of whether the existing arsenal of AEDs follow the guidelines or if they are less than optimally placed.

1.2 Objectives

The objective of the study is to find the optimal placements for AEDs based on statistics about Cardiac Arrests (CA) and the location of groups that have a higher risk of suffering CA.

The following research questions are to be answered:

- Is there a difference between the locations for OHCA occurrences during the day and during the night?
- Where are the optimal locations for new AEDs in Stockholm County?
2. Cardiac Arrest

2.1 Definition

Cardiac Arrest is defined in the Utstein guidelines, which is a standardized guideline for reporting OHCA occurrences, as “the cessation of cardiac mechanical activity, confirmed by the absence of a detectable pulse, unresponsiveness, and apnea (or agonal, gasping respirations)” (Cummins et. al 1991). The cause of the arrest is usually a problem with the electrical system within the heart (Mayoclinic, 2012). A CA is fatal if not treated promptly, but with the right treatment survival is a possibility. Each minute of arrest increases the mortality rate by ten percent (NHLBI, 2011).

2.2 Risk Factors

HLR also publishes an annual report on CAs in Sweden. In this report they also publish probable causes for CA, from which the causes were grouped into several categories. These figures are presented in Table 1 (HLR, 2013).

<table>
<thead>
<tr>
<th>Cause</th>
<th>Amount of cases</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart disease</td>
<td>41405</td>
<td>66%</td>
</tr>
<tr>
<td>Lung disease</td>
<td>3808</td>
<td>6%</td>
</tr>
<tr>
<td>Non-medical causes†</td>
<td>5228</td>
<td>8.3%</td>
</tr>
<tr>
<td>Other causes</td>
<td>12317</td>
<td>19.7%</td>
</tr>
</tbody>
</table>

† This includes accidents, overdoses, suffocation, suicide, sudden infant death syndrome and drowning
2.3 Treatment

An AED is a compact, lightweight and easy-to-use device that monitors the heart rate and if needed, tries to correct an eventual arrhythmia. By connecting the attached electrodes to the body, the AED then decides whether a shock is needed or not, depending on the type of arrhythmia (NHLBI, 2011). See Figure 1 for an AED.

Figure 1: An AED located in the L-building, KTH. Photo taken by the authors

3. Study Area and Data Collection

Lantmäteriet, SCB, Södersjukhuset (SÖS), Sveriges Hjärtstartarregister and Socialstyrelsen were the primary sources of data used in the study. Data from Lantmäteriet was used as a primary map over Stockholm County, which was the geographical scope of the study. The data from SCB was census data about the daytime population in the city of Stockholm. SÖS provided statistics about previously occurred OHCAs between the years 2006 and 2013. Sveriges Hjärtstartarregister provided data about the location of public available AEDs. Socialstyrelsens statistical database was used to extract information about in-patient care diagnoses between 2006 and 2012 and their relative frequency for different age groups and genders.
3.1 Data Collection

3.1.1 SCB data
SCB is the Swedish authority responsible for collection and production of statistics which they mainly supply to companies, authorities and researchers.

Daytime and nighttime population data from the year 2012 were used to represent the population of Stockholm County. The coordinate system SWEREF99 was utilized for the census data and was acquired, in vector format, as polygons in 250 by 250 meters and 1000 by 1000 meters grid. 250 by 250 meters grid was used where the population density was high while the 1000 by 1000 meters grid was used where the density was lower. The age groups for the populations can be seen in Table 2.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime</td>
<td></td>
</tr>
<tr>
<td>16-39</td>
<td></td>
</tr>
<tr>
<td>40-44</td>
<td></td>
</tr>
<tr>
<td>45-49</td>
<td></td>
</tr>
<tr>
<td>50-54</td>
<td></td>
</tr>
<tr>
<td>55-59</td>
<td></td>
</tr>
<tr>
<td>60-64</td>
<td></td>
</tr>
<tr>
<td>65-67</td>
<td></td>
</tr>
<tr>
<td>Nighttime</td>
<td></td>
</tr>
<tr>
<td>0-39</td>
<td></td>
</tr>
<tr>
<td>40-44</td>
<td></td>
</tr>
<tr>
<td>45-49</td>
<td></td>
</tr>
<tr>
<td>50-54</td>
<td></td>
</tr>
<tr>
<td>55-59</td>
<td></td>
</tr>
<tr>
<td>60-64</td>
<td></td>
</tr>
<tr>
<td>65-69</td>
<td></td>
</tr>
<tr>
<td>70-74</td>
<td></td>
</tr>
<tr>
<td>75+</td>
<td></td>
</tr>
</tbody>
</table>

3.1.2 SÖS data
The data collected from SÖS contained statistics about OHCAs occurred in Stockholm County during the years between 2006 and 2013 which consisted of 7268 OHCA occurrences. The data contained coordinates of the locations of the previously occurred OHCAs, given in the coordinate system RT90, age and gender of the victim, etiology and some information that was not utilized in the study.

By adding restrictions based on the cause of the OHCA, a number of cases were removed. In addition, incorrect data were another factor for dismissal. By removing these OHCA, the number of OHCA cases was reduced to 6768. See Figure 2 for a visualization of the locations of the OHCAs in Stockholm County.
3.1.3 Sveriges Hjärtstartarregister data

The data collected from Sveriges Hjärtstartarregister contained coordinates, delivered in the coordinate system WGS84, of the locations of currently available AEDs in the end of the year 2013. Incorrect or missing data led to the exclusion of some AEDs. Therefore, a total of 1063 AEDs and their locations were utilized in the study. See Figure 3 for a visualization of the locations of AEDs in Stockholm County.
3.1.5 Socialstyrelsen

These selections were discussed with a fifth year medical student and were based on whether the heart is the primary organ involved in the diagnosis or not. The diagnoses used are presented in Table 3. Data was limited to Stockholm County between the years 2006 and 2012 for both male and female patients.

<table>
<thead>
<tr>
<th>ICD-codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I05-109</td>
<td>Chronic rheumatic heart disease</td>
</tr>
<tr>
<td>I11</td>
<td>Hypertensive heart disease with heart failure</td>
</tr>
<tr>
<td>I20-125</td>
<td>Ischemic heart disease</td>
</tr>
<tr>
<td>I30-152</td>
<td>Other types of heart disease (Cardiomyopathy, inflammations etc)</td>
</tr>
</tbody>
</table>
4. Methodology

4.1 Visualization

Since the main study consists of finding the most suitable locations for AEDs based on daytime population, a comparison between the OHCAs occurred during the night and day was performed. In order to split up the data into daytime and nighttime OHCA occurrences, the definition of these two time intervals were set as 06:00-18:00 for daytime and 18:00-06:00 as nighttime. After exclusion of missing or incorrect data, 6471 cases were included.

4.2 Risk analysis

An MCE was performed in order to determine the spots by giving raster layers weights according to collected statistics. Statistics from Socialstyrelsen were utilized in order to determine which age groups suffer from prior heart disease while statistics from SÖS provided which age groups have been affected from OHCA previously. A tool provided by ArcMap, ModelBuilder, performed the analysis for determining the optimal placements.

The cells with the highest suitability scores were the chosen spots. These chosen locations can perhaps be used as recommended locations for future added AEDs.

4.2.1 Age distribution

Because the SCB data was delivered in two different age group intervals for daytime and nighttime, two separate tables were created for each time of the day. By extracting the genders and age groups from the data used in the comparison between nighttime and daytime OHCA occurrences, Tables 4 and 5 were created.

<table>
<thead>
<tr>
<th>Age groups</th>
<th>0-39</th>
<th>40-44</th>
<th>45-49</th>
<th>50-54</th>
<th>55-59</th>
<th>60-64</th>
<th>65-69</th>
<th>70-74</th>
<th>75+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>5%</td>
<td>2%</td>
<td>4%</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
<td>10%</td>
<td>9%</td>
<td>50%</td>
</tr>
<tr>
<td>Male</td>
<td>6%</td>
<td>2%</td>
<td>4%</td>
<td>6%</td>
<td>8%</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Table 4: Nighttime statistics for both genders and age groups

<table>
<thead>
<tr>
<th>Age groups</th>
<th>16-39</th>
<th>40-44</th>
<th>45-49</th>
<th>50-54</th>
<th>55-59</th>
<th>60-64</th>
<th>65-67</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>13%</td>
<td>5%</td>
<td>9%</td>
<td>12%</td>
<td>16%</td>
<td>26%</td>
<td>19%</td>
</tr>
<tr>
<td>Female</td>
<td>12%</td>
<td>6%</td>
<td>9%</td>
<td>12%</td>
<td>21%</td>
<td>25%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 5: Daytime statistics for both genders and age groups

Four raster layers, i.e. female age groups for nighttime, were created by using the weights produced in the tables viewed above. Standardization was performed by using map algebra and assigning the layers with the value range of 0 to 255. In order to generate the two final layers, one for nighttime and one for daytime, the gender distribution had to be taken into account. Therefore, while creating the daytime layer, the layers which consisted of male age groups were assigned a weight of 70% and female 30%. The nighttime layer was assigned with a weight of 66% for male and 34% for female. See Figure 4 for an example of how the weighted raster layer looks like while using statistics for female age groups from Table 5.
4.2.2 Prior heart disease

As it has already been established in section 2.2, prior heart disease is the number one factor causing OHCAs. Since there are a plethora of ethical restrictions involved in accessing an actual patient database, especially since this is not a medical study, another method to quantify the risk of an inhabitant having a prior heart condition was devised.

For each gender and age group in the Socialstyrelsen dataset of patients per 100 000 inhabitants, a year-by-year total of patients with any of the previously mentioned conditions within the heart disease definition is formed. These yearly sums are then
averaged to compensate for any fluctuations in the dataset. This process is then repeated to cover all age groups for males and females.

In order to utilize these percentages as weights in the MCE, they were linearly normalized so that the sum of the percentages for each gender amounts to 100%. The formula for this approximate method can be found in equation 2:

\[
\frac{\text{amount genderAgeGroup}}{\text{total Gender}} \quad \text{eq. 2}
\]

By applying the standardization formula on the prior heart disease data using the daytime age grouping, the final weighting percentages are listed in Table 6. The same calculations were also performed for the age groups for nighttime and the corresponding table can be found in Table 7.

<table>
<thead>
<tr>
<th>Table 6: Standardized statistics for using the same age groups as the daytime population data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7: Standardized statistics for using the same age groups as the nighttime population data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
</tbody>
</table>

Four raster layers, i.e. prior heart disease for female for nighttime, were created by using the weights produced in the table viewed above. Standardization was performed by using map algebra and assigning the layers with the value range of 0 to 255. In order to generate two the final layers, one for daytime and one for nighttime, the gender distribution had to be taken into account. Therefore, nighttime layer was assigned with a weight of 62% for male and 38% for female prior heart disease patients. The daytime layer was assigned weights of 69% for male and 31% for female.
4.2.3 Determining the optimal locations

In order to determine the optimal locations for AEDs, i.e. determine which cells have the highest suitability score, the built-in tool ModelBuilder was utilized. However, a restriction of the possible location of an AED was added to only include buildings. Figure 5 is the utilized model for this study. The algorithm identifies which pixels have the highest value in the suitability map and proceeds to isolate it by removing all other values. Thereafter it stores that pixel in a separate layer which will be used to plot the final recommendations. At the same time, the process creates a 200 meters buffer and removes it for further consideration. The final suitability map is then used as the input value for the next iteration. ModelBuilder was set to run 20 times for each scenario.

Figure 5: The flowchart of the algorithm in ModelBuilder
4.4.2.1 Daytime analysis

One scenario was performed by using the ModelBuilder while using the daytime population data. The data used were the prior heart diseased statistics and the age groups for both genders.

In this scenario, the prior heart disease layer received a weight of 66% and the age layer 34%. These weights were chosen based on the report found in Section 2.2, see Table 1. This scenario is mentioned in the results as Scenario II.

4.4.2.2 Nighttime analysis

One scenario was performed by using the ModelBuilder while using the nighttime population data. The data used were the prior heart disease statistics and the age groups for both genders.

The second scenario had a weight of 66% to prior heart disease and 34% age distribution. These weights were chosen in order to have a similar weight distribution as Scenario II. In the results, the scenario is named Scenario IV.

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2 In this abridged version, only two of the six scenarios are mentioned. For full explanation for each scenario, see the full work.
5. Results and Discussion

5.1 Comparison between daytime and nighttime OHCA locations

The final results were two raster layers where a high value, dark on the map, means more OHCA occurrences. The final result for daytime OHCA occurrences can be found in Figure 6 and nighttime occurrences in Figure 7.

Figure 6: OHCA density for daytime occurrences
The dark shade of red can mainly be seen in the inner city of Stockholm, which indicates that more OHCA occurrences happen during the day in the city as seen in Figure 6. People are more active during the day due to work and school, with the location of those mainly in the city. As viewed in Figure 7, the location of OHCA occurrences during the night does not seem to differ that much compared to daytime but seems to have a smaller cluster of high density.
5.2 Scenario II

Scenario II was assigned a weight of 66% to the prior heart disease layer and 34% to the age layer. The result can be seen in Figure 8.

In Scenario II, a total of 21 locations were recommended for a placement of an AED. Once again, a substantial amount of the suggested locations end up in the city center. These locations are expected since many of the inhabitants in Stockholm commute in to the center to work.
5.3 Scenario IV

Scenario IV was assigned a weight of 66% to the prior heart disease layer and 34% to the age layer. The result can be seen in Figure 9.

Scenario IV also produced 23 suggested locations for AED placements. A majority of the locations are in the most populated areas in the center of Stockholm or in locations previously discussed, but a new cluster of locations has appeared in the north part of the map. These locations are all in various places in Täby, which is one of the municipalities with the highest socio-economic status.
5.4 Comparison between suitability maps and existing AEDs

No recommendation of new locations can be performed without first analyzing the suitability maps with an overlay consisting of the existing AED coverage areas. This analysis will show where the coverage area is incomplete and what if any risk level those areas have.

Most of the very high-risk areas in the city center are already covered by the existing AEDs, but there are a few gaps in the coverage and these areas are top priority for new placements as seen in Figure 10. In the region near Stadshuset and the central station there is a considerable gap in coverage despite the areas being of the high and very high type. Finally, there are high risk and very high risk areas near Medborgarplatsen on Södermalm and Karlaplan on Östermalm with incomplete coverage areas, making them optimal candidates for further expansion.
For the nighttime scenarios, shown in Figure 11, there is a considerably larger amount of high risk and very high risk areas that have no AED coverage. The largest very high risk area is the western parts of Vasastan, near Torsgatan and Sankt Eriksgatan. These areas are mainly residential and therefore were not as visible in the daytime analysis in Figure 10. Other very high risk areas include Gärdet and Karlaplan on Östermalm as well as Hornstull and Reimersholme on the western part of Södermalm. There are also gaps in the coverage on Södermalm around Södra station and along Hornsgatan, which would require at least a few AEDs to fill the gaps.
5.5 Final recommendations

Figure 12: Recommended locations for AEDs in Stockholm County

Figure 13: Recommended locations for AEDs in the inner city of Stockholm
After removing all the suggestions from scenarios I to V that fall inside the existing AED coverage area, the final suggestions for AED placements are found in Figures 12 and 13 for Stockholm County and the city center respectively.

Some of the inner-city suggestions have just barely managed to find spots between the coverage areas. They should perhaps be seen more as indicators that the coverage area in the inner city is not total, rather than actual location recommendations.

There are several locations mentioned in the previous results that the ModelBuilder did not suggest in the allotted 20 runs. That means that the locations in Figures 12 and 13 are by no means the only AEDs needed, but at least some of the locations with the most urgent need of additional AED coverage.
6. Conclusions

6.1 Conclusions

In general, the results appear credible and the differences in locations vary in accordance with the expected impact of the population dataset used. With more insight as to how the different criterions should be weighed against each other, the overlaps could have been avoided. However, the overlaps are still useful as they indicate that even with two differently weighted scenarios, the locations are important in both and therefore should be considered as reliable recommendation.

Some coordinates received for AED locations were incorrect since the locations were in water. Furthermore, the AED data was not up to date since half a year passed between collection of the data and the production of the study.

Data of heart disease patients was not accessed during the study, which is a limiting factor since the alternative, using statistics from Socialstyrelsen, lacks reliability and accuracy. Since the main cause of OHCA is prior heart disease, a more precise way to measure and control for heart disease patients will produce a more accurate result. Therefore, the result cannot be taken as an absolute truth but rather a good indication of where additional AED coverage is needed.

With relatively few AEDs available in society, it is harsh criticism to say that some are incorrectly placed and should be moved. However, when considering future placement, perhaps a stricter adherence to the guidelines from HLR would lead to a better and larger coverage area.
References


