Investigating the Relationship between Out-of-Hospital Cardiac Arrest Risk and the Distribution of AEDs in the Municipality of Enschede

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Table of Contents

Abstract

Background – Globally, the out-of-hospital cardiac arrest (OHCA) survival rates are low, with only 10% of survival. However, with the presence of readily accessible automated external defibrillators (AEDs), survival rates can become significantly improved. To ensure quick access to AEDs, it is crucial to effectively distribute the available number of AEDs across a given area. A strategy for AED distribution is that more AEDs are placed in high OHCA risk areas, and less in low risk areas. One example of such high OHCA risk area is the municipality of Enschede, which is therefore used as the study area for this study. This study aims to find the relationship between the spatial distribution of OHCA risk and the coverage of AEDs in the municipality of Enschede.

Methods and Results – For this observational cross-sectional study, all AEDs in the municipality of Enschede were included (n=169). The percentage area covered by AEDs was calculated for each neighborhood of Enschede. Besides that, seven OHCA risk factors were included; socioeconomic status (SES), smoking, BMI greater than 25, population density, non-western background, elderly people and low-education level, which together form the overall OHCA risk score. With a two sample t-Test ($P < 0.05$) and by making boxplots, the relationship of AED coverage and OHCA risk was determined. No significant relation was found between AED coverage and overall OHCA risk score (P=0.25) in the municipality of Enschede. Taking all factors separately, the neighborhoods with a higher OHCA risk on education level (P=0.036*), population density (P=0.00*), smoking (P=0.001*), high BMI (P=0.291), not-western background (P=0.067) and SES-score (P=0.059) are more likely to be fully covered by AEDs. On the other hand, neighborhoods with a higher OHCA risk on elderly people are less likely to be fully covered by AEDs.

Conclusion – In conclusion, neighborhoods with a higher overall OHCA risk do have the same coverage rate as neighborhoods with a low overall OHCA risk score in the municipality of Enschede. This indicates that AEDs are not effectively distributed over the area of Enschede. More research on a broader scale is needed to implement OHCA risk in AED distribution models and to generalize it to other areas.

1. Introduction

Out-of-hospital cardiac arrests (OHCA) are globally one of the main causes of death. [1] In the Netherlands, the incidence of an OHCA is 1 per 1000 inhabitants per year. [2] An OHCA involves a problem in the heart's electrical system, which causes the ventricles to vibrate irregularly and fast. As a result, the heart can no longer pump blood to vital organs, which then no longer receive oxygen. This mainly happens to someone unexpectedly. The victims are identified by their abnormal breathing, not having a pulse, collapsing, and losing consciousness. [3] The chance of surviving an OHCA is low throughout the world, and varies by country. [1, 4] Globally, 8 to 12% of the OHCA victims survive to hospital discharge. [4] However, the survival rates can significantly become improved when the out-of-hospital cardiac arrest Chain of Survival is deployed to the victim. [5] The Chain of Survival contains of six steps that needs to be executed to help the victim and increase survival. A crucial step in the Chain of Survival is defibrillating, where automated external defibrillators (AEDs) are used to restart the electrical system of the heart through electric shocks. A fast deployment of an AED to the victim, contributes to a higher effectiveness of the AED treatment, which will increase the chance of survival. In fact, an early AED deployment, which is the case when an AED is already deployed before the emergency medical service (EMS) arrives, will almost doubles the chance of survival. [6, 7] And, every minute a patient needs to wait longer for an AED deployment, the chance of survival decreases with 7 to 10%. [8, 9]

In the Netherlands, the EMS arrival time averages within 9 minutes in cases of an OHCA. [2] This takes too long for the victim to survive an OHCA. So, to shorten the AED deployment time, the Dutch Heart foundation 'HartslagNu' asks bystanders and nearby living trained inhabitants (who followed a cardiopulmonary resuscitation and AED deployment course) to deploy the AED before EMS arrives. This, has significantly improved the deployment time, since trained inhabitants are able to help the OHCA victim on average 2.5 minutes earlier than the arrival of EMS. [10] However, helping the victim is only possible when there are actually enough bystanders or trained inhabitants present. Moreover, it also requires a quick accessibility to AEDs. To improve quick access, geographical accessibility to AEDs is an important factor. This, is the physical distance or travel time from the OHCA victim to the closest AED. [11] The smaller the time or distance range is to an AED, the higher the chance is to save an OHCA victim. In fact, a previous study showed that with every 100 meters an AED is further away from the OHCA victim, the mortality increases with 10%. [12] In the Netherlands, HartslagNu aims for a 'six-minute zone'. This means that an OHCA victim can be defibrillated within six minutes, which corresponds with a 500 meters radius, from any location in the Netherlands. However, areas do not always have the capacity (money and materials) to provide a full number of AEDs to cover all OHCAs. Moreover, in the Netherlands the AED placements are mostly driven by political or local initiatives, which may result in the risk of inhabitants not having AED access while living in a high OHCA incidence area. [13] Therefore, high demand AED areas must be found in order to distribute AEDs on a more effective way as a result to improve the geographical accessibility to AEDs.

Several studies were done to identify high demand AED areas, in order to optimize AED distribution. Early studies found a higher AED demand in higher population density areas (Figure 1-I), or in higher building density areas (Figure 1-II). As well as the room density, defined as the number of rooms per floor inside a building, which is applicable to high-rises (Figure 1-III). But, not all buildings have the same OHCA risk. So, another study found AED demand based on certain high risk building types, which often were buildings with a high population flow such as train stations, casinos and sport venues. An other study, which however subsequently considered to be not cost-effective, focused on creating more awareness around AEDs by placing them next to fire extinguishers, so they would be more conspicuous in public places (Figure 1-IV). [14] However, these studies were limited to indoor OHCAs, and did not include OHCA cases outside buildings. [6, 13, 15, 16] An often-used model, which is also applicable to cover outdoor cardiac arrests, is based on the Maximum Covering Location Problem (MCLP). [13, 17-21] This, is a mathematical model that measures a maximized amount of covered demand under a limited amount of health facilities (AEDs) using historical spatial cardiac arrest data. [22] So, high demand areas were found by using the locations of previous occurred cardiac arrests. An optimization model was then based on an input of a given number of AEDs, dependent on capacity, obtaining a maximum amount of covered OHCAs as an output (Figure 1-V). [22] This model is also useful for finding AED demand in non-urban areas. [23] Often, studies are using MCLP as a base model and expanded it with other factors. For example, by adding a socioeconomic deprivation factor to the model. [24] Or by adding temporary factor to the model by including opening hours of placed AEDs (Figure 1. [17, 25]

Although previous studies evaluated AED demand by finding high crowded areas, or identifying certain high risk building characteristics, this study evaluated AED demand by finding high OHCA risk areas through certain population characteristics. Several studies found a link between AED placement and population characteristics, such as a previous study that found a higher AED accessibility in ZIP code (postal code) areas with a higher salary, higher median household income, higher employment and areas that had a moderately populated residential area. [26] Another study found that AEDs are significantly more likely to be placed in more affluent areas with white ethic background inhabitants and inhabitants with a higher socio-economic status. [27] However, these findings are a mismatch with where AEDs are actually more needed. In fact, the population characteristics that are associated with a higher AED accessibility, do have a lower OHCA incidence. Notwithstanding, a higher OHCA incidence is associated with population characteristics as low income, low educational qualification, low socioeconomic status (SES) and a non-white background ethnicity. [28-32] Also other characteristics lead to a higher OHCA risk, such as areas with a higher percentage of elderly people (65 years and older), smoking or a body mass index (BMI) that is above 25 kg/m^2. [30-33] To distribute AEDs effectively over the area, it is important that areas with high rates of population at risk will have a high AED accessibility.

This study aims to determine if there is any relation between the spatial distribution of OHCA risk factors over an area, and how likely high risk areas are fully covered by AEDs compared to lower risk areas. As an example, this study uses the area of the Dutch municipality Enschede, since this area has a high OHCA risk by its poor socio-economic status, health behavior and by the high immigration rates, compared to other municipalities in the Netherlands. [34-36] The main objective for this study is to determine the relationship between the spatial distribution of out-of-hospital cardiac arrest risk and the coverage of automated external defibrillators in the municipality of Enschede.

Sub-questions for this study are:

a) Where are automated external defibrillators located, and how are they spatially distributed over the municipality of Enschede?
b) How are out-of-hospital cardiac arrest population characteristic risk factors spatially distributed over the municipality of Enschede?
c) How are automated external defibrillators currently spatially distributed, based on out-of-hospital cardiac arrest risk factors in the municipality of Enschede?

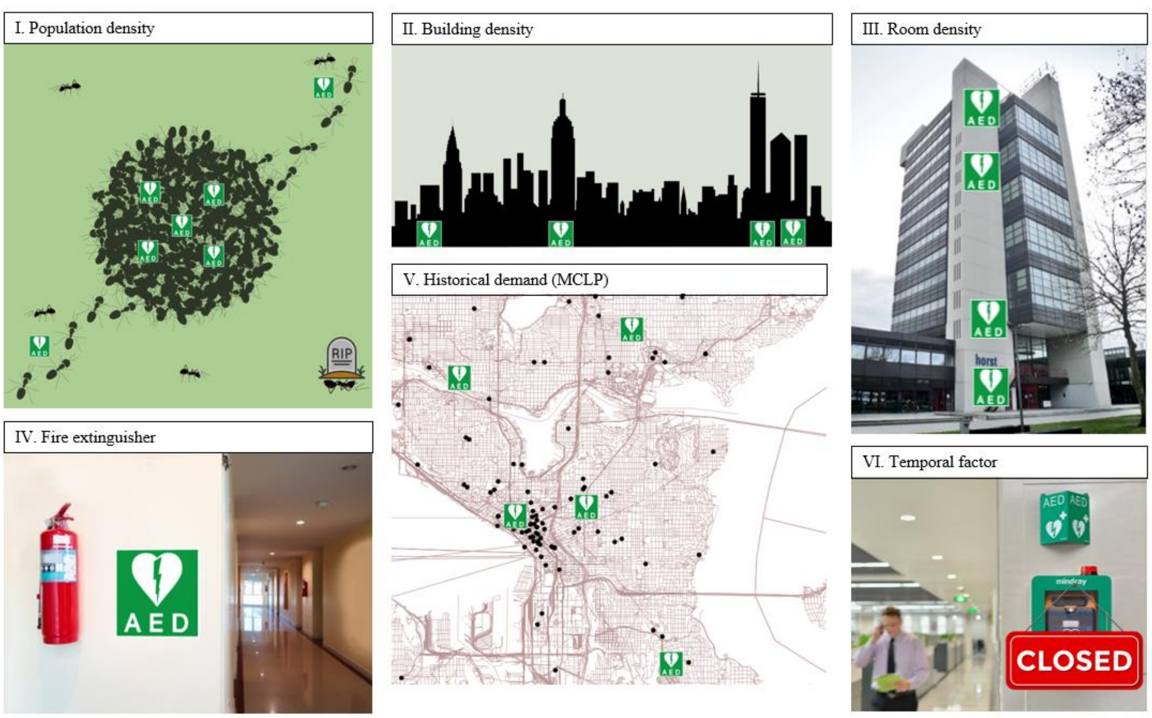

Figure 1: AED distribution optimization models

2. Methods

2.1 Study design

The research question and sub-questions were answered by the use of data that was analyzed on the same moment. Hence, this is an observational study using cross-sectional research.

2.2 Study area

This study will be specified to the area of the Dutch municipality Enschede. Enschede covers an area of 142.72 km^2. [37] The municipality is divided into ten districts, and 70 neighborhoods. Enschede has a growing population that reached 160640 inhabitants in 2022, ranking it as the 15th biggest population size among all 342 Dutch municipalities. [38-40] The population density is 1141 inhabitants per km^2, which is above the average of 383 inhabitants per km^2. [40, 41]

2.3 Software

All analyses were conducted using ArcGIS Pro version 3.0 and Microsoft Excel 2019.

2.4 Data

2.4.1 AEDs

AED data collection

This study includes both registered and unregistered AEDs. Registered AEDs, are AEDs from owners who registered their AED in the application ‘MijnHartslagNu’ from HartslagNu. Unregistered AEDs on the other hand, are AEDs from owners who did not register their AED in the application.

For this study, the locations of all registered AEDs in the municipality of Enschede were collected through the MijnHartslagNu application, which visualizes a map showing all registered AEDs in the users’ area within a two km^2 radius. In order to collect all registered AEDs in Enschede, the data in the app were obtained from eight different locations through the municipality (Figure 2). The data of a total of 167 registered AEDs were obtained. These were collected on the 2nd of April 2023.

In addition, data on unregistered AEDs were obtained using citizen science data collection. Twelve volunteer inhabitants of Enschede participated. They got the question which AED locations in Enschede they knew. All answers were collected and cross-checked with the registered AEDs. Only the unregistered AEDs were kept and combined with all registered AEDs. A total of 2 unregistered AEDs were identified and used for this analysis.

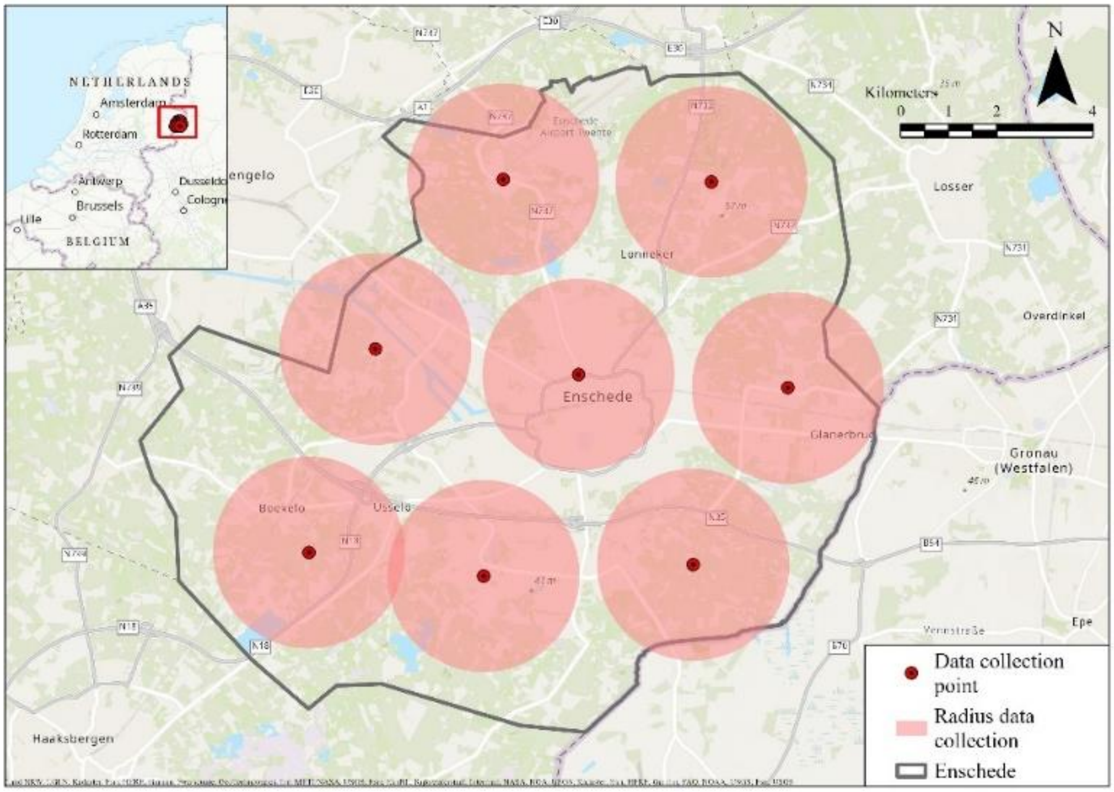

Figure 2: Registered AED data collection points

AED data cleaning

There were no AEDs found outside the borders of municipality Enschede, so all 169 AEDs were included. The location of each AED contained a street address and a ZIP code. To map the AEDs in ArcGIS, the latitude longitude coordinates were obtained for each address using the ArcGIS Pro Geocode Addresses tool. The points were projected to a RD New coordinate system.

2.4.2 Neighborhood characteristics

Neighborhood characteristics data collection

Eight OHCA risk factor population characteristics were found in literature; elderly people, low educational qualification, high BMI, higher population density, non-white ethnic background, low income, low SES, and smoking. [28-32] Seven of eight characteristics were included to this study. Low income however, was not directly included, but is partly included in the socio-economic status score. The included OHCA risk factors were obtained from open datasets from the Statistics Bureau of the Netherlands (CBS) and the National Institute for Public Health and the Environment (RIVM). An overview of all used data for this study is listed in Table 1.

Table 1: Summary of data used in this study

Source	Year	Data	URL
CBS Wijk- en buurtkaart	2021	Education level	https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/wijk-en-buurtkaart-2021
	2022	Neighborhood and municipality shapefile	https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/wijk-en-buurtkaart-2022
		Population density neighborhoods	
		Ethnicity	
		Age 65+	
CBS 100 x 100 meters map	2022	Population density tiles	https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/kaart-van-100-meter-bij-100-meter-met-statistieken
CBS Sociaal-economische status	2019	Socio economic status	https://www.cbs.nl/nl-nl/cijfers/detail/85163NED
RIVM	2020	Smoking	https://www.rivm.nl/media/smap/rokers.html
		High BMI	https://www.rivm.nl/media/smap/overgewicht.html
HartslagNu	2023	Registered AEDs of Enschede	https://mijnhartslagnu.nl
Citizen science	2023	Unregistered AEDs of Enschede	-

The included population characteristics:

1) **Education level** – Education level is split up into three groups: low, middle and high education. The low education group contains people between 15 and 75 years old, that achieved an education level of primary education, pre-vocational secondary education (VMBO), the first three years of senior general secondary education (HAVO) or pre-university education (VWO), Secondary vocational education level 1 (mbo1) or practical education. These data were obtained from the district and neighborhood map of 2021 from CBS. [42]
2) **Population density** –
    i. Neighborhoods: Population density is expressed in the mean number of inhabitants per square kilometer. These data were obtained from the district and neighborhood map of 2022 from CBS. [43]
    ii. Tiles: Population density is expressed in the number of inhabitants per squares of 100 m^2 (hectare). Only the tiles with at least five inhabitants living in that hectare are mapped. These data were obtained from the 100 by 100 meters map of 2022 from CBS. [44]

3) **Ethnicity** – For ethnicity data are used of inhabitants with a non-western migration background. This includes people with a migration background from Turkey, Africa, Latin-America and Asia. Japan and Indonesia were excluded, since these people are considered having a 'Western' migration background because of their socioeconomic status and cultural position. These data were obtained from the district and neighborhood map of 2022 from CBS. [43]
4) **Age** – The dataset of age splits age up into five different groups. The highest group contains data of the older age group, 65 years and older, per neighborhood. This group was 65 years and older on the 1st of January 2022. These data were obtained from the district and neighborhood map of 2022 from CBS. [43]
5) **Socio economic status** – The SES-scores per neighborhood are based on welfare, education and employment. The mean score in the Netherlands is zero. Under zero means a lower SES-score, which indicates a lower score on welfare, education and employment, and above zero means a higher SES-score. The mean score of Enschede municipality is -0.268, which belongs to the lowest category (Figure 3). These data were obtained from the socioeconomic status map of 2019 from CBS. [34]
6) **Smoking** – These data includes the percentages of inhabitants over 18 years old that smokes per neighborhood. Vaping is excluded. These data were obtained from RIVM of 2020. [35, 45]
7) **BMI** – These data includes the percentages of inhabitants over 18 years old with a Body Mass Index (BMI) greater than 25 kg/m^2 per neighborhood. These data were obtained from the dataset overweight map of 2020 from RIVM. [45, 46]

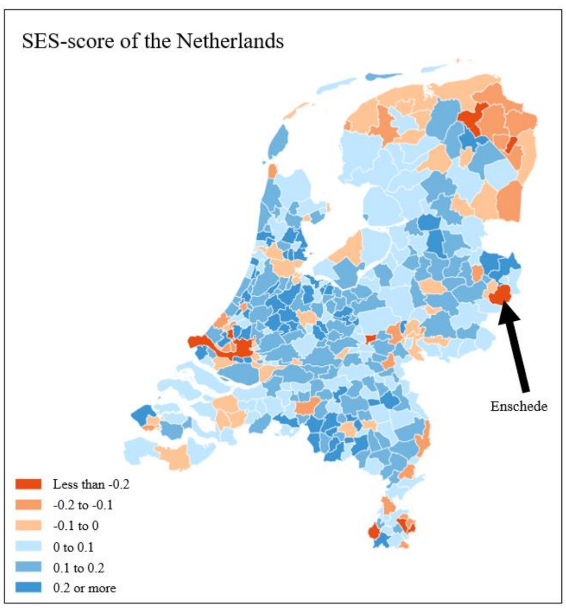

Figure 3: Source CBS socio economic status. SES-score of the Netherlands [34]

Neighborhood characteristics data cleaning

From the three datasets, CBS 2021, CBS 2022 and RIVM, only the data about the municipality Enschede were retained. Then, the 'municipality' and 'districts' fields were excluded, so only the 'neighborhoods' fields were retained. For every population characteristic separately, the no data fields were eliminated. For all the risk factors histograms were made to visualize the statistical distribution, Figure 4. Most risk factors are distributed normally. However, overweight rate, population density and non-western population rate are not. This knowledge is essential in order to choose a reliable test for identifying a correlation between AED coverage and OHCA risk.

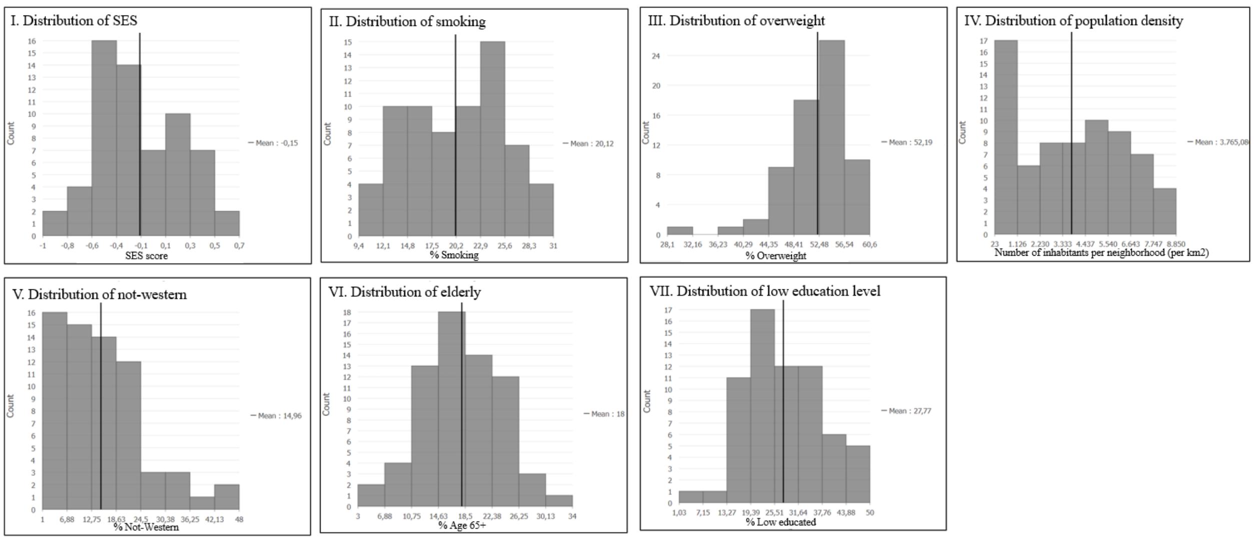

Figure 4: Histograms of population characteristics - (I) SES. (II) Smoking. (III) Overweight. (IV) Population density. (V) Not-Western. (VI) Elderly people. (VII) Low education level

2.5 Analysis

Part 1: Location and distribution of AEDs in Enschede

The AEDs were mapped in points, so the locations and the distribution is visualized. Besides that, the AED density distribution is visualized using a Kernel Density Analysis. To investigate how the AEDs are distributed over the area, in clusters, random or dispersed, an Average Nearest Neighbor Analysis was used. Therefore an area of 142700000 m^2 was chosen, which is the total area of the municipality of Enschede. The null hypothesis for this analysis was H_0: AEDs in the municipality of Enschede are not distributed in clusters. The alternative hypothesis was H_1: AEDs in the municipality of Enschede are distributed in clusters. The null hypothesis was rejected when $P < 0.01$ and $Z < -2.58$ (Figure 5). Also, the Nearest Neighbor Index was calculated. If this index < 1 the AEDs exhibits clustering, if not AEDs are distributed as dispersion or competition.

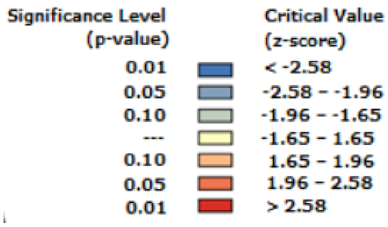

Figure 5: Nearest Neighbor Analysis P-value and Z-score

Based on the HartslagNu recommendation, an OHCA is covered, which means that an AED is close enough to defibrillate the OHCA victim on time, when an AED is located within a maximum distance of 500 meters from the OHCA victim. Therefore, all AEDs were buffered with a 500 meters radius. The resulting area is the covered area. The not-covered area, represents the area in which an OHCA victim cannot be defibrillated on time. Then, by using the buffered area, the AED coverage rates per neighborhood were determined. This indicates to what extent AEDs are geographically accessible for the neighborhood. The higher the AED coverage rate, the more likely an OHCA in the neighborhood is covered by an AED. This is determined firstly by calculating the ‘km^2 covered’ per neighborhood, which is the total of the buffered area per neighborhood. This was calculated by union of the AED buffered area with the neighborhoods of Enschede. Then, in the union attribute the records of the not-covered area were deleted, so only the records of the covered area remained. Secondly, the km^2 total area of AED coverage per neighborhood was determined using the calculate geometry tool. Then, the AED coverage rate per neighborhood was determined using Equation 1. Coverage rate per neighborhood was mapped in a choropleth map with five classes and a natural breaks (Jenks) method. [47]

Equation 1: Coverage rate per neighborhood

$$\left(\frac{Km^2\ covered}{Km^2\ total\ area}\right) \times 100\ = \%\ covered\ area\ per\ neighborhood$$

Besides the area coverage, also the population that is served, and not served, by AEDs was determined. By using the 100 x 100 meters data tiles, population density was visualized. The number of inhabitants inside the covered area and outside the covered area were calculated. Tiles that are located on the border of covered area were counted as covered population.

Part 2: Distribution of cardiac arrest risk factors in Enschede

Firstly, all neighborhood cardiac arrest risk factors were analyzed separately. The data of population density, ethnicity, elderly people, SES, smoking and high BMI were in relative numbers and could be directly projected on a map. The education level data on the other hand, were in absolute numbers and firstly needed to be converted in percentages to be able to compare between the different neighborhoods. Using Equation 2, the percentage of low educated people relative to all people in that neighborhood was calculated. All seven characteristics are now in relative quantities. Based on Bertin's theory on visual variables these data were mapped on a choropleth map and divided into five classes so that color differences between classes were still visible. [48] The Jenks method was used as classification method since then real classes become identified. The factor high BMI does not have a large variance, so a Jenks method may not be the optimal method for this factor. However, to stay consistent on type of method for all factors (including high BMI) the Jenks method was used. [47] The darker a neighborhood is colored, the higher the OHCA risk is for the inhabitants in that neighborhood.

Equation 2: Equation for calculating % low education

$$\left(\frac{Low\ education}{(Low + Middle + High)}\right) \times 100 = \%\ Low\ educated\ people$$

Besides that, an overall risk score was calculated per neighborhood based on the seven different risk factors. Each risk factor value per neighborhood was divided into a '1' whether the value of the boxplots made in part 3 is above the Q3 median (high risk), or a '0' whether this value was under the Q3 median (low risk). Then, the sum of all factors was calculated, so each neighborhood got a risk score between zero (low risk) and six (high risk). These scores were mapped out in a choropleth map. Neighborhoods that missed one or more risk factor values were excluded from this map.

Part 3: AED coverage based on OHCA risk factors

The link between AED coverage in the municipality and the cardiac arrest risk factors was investigated on neighborhood level, because this is more detailed than districts. Therefore the AED coverage rates per neighborhood (calculated in part 2) were used. These data are not distributed normally, so cannot directly be used for finding a relation between AED coverage and OHCA risk factor (Figure 6-I). Therefore, the data were transferred from continuous to dichotomous values (Figure 6-II). A value '0' was given to all neighborhoods with a coverage rate of less than 95%, and a value '1' was given to all neighborhoods with a coverage rate of 95% or more. Value 1 initiates a fully AED covered neighborhood, while the value 0 initiates a non-fully covered neighborhood.

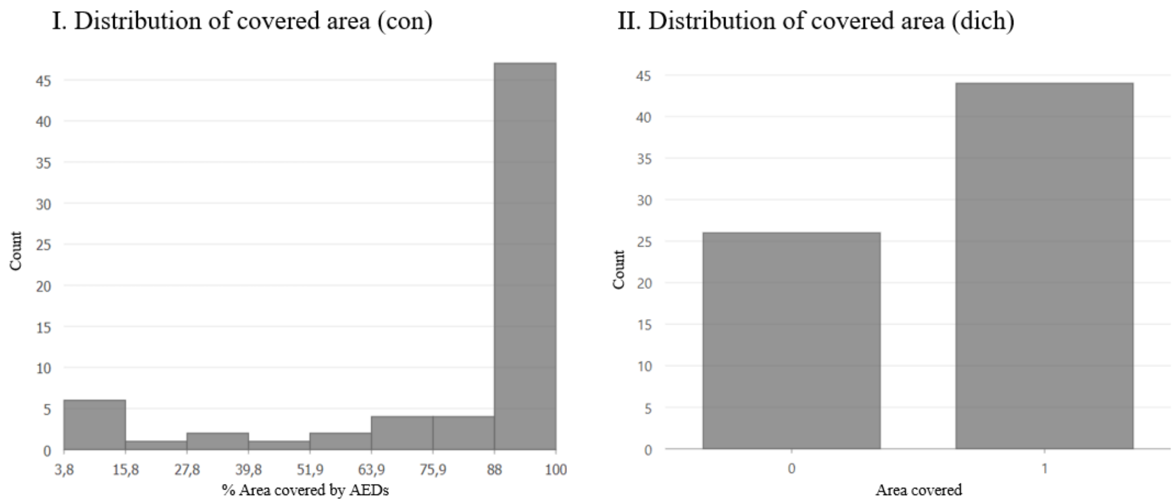

Figure 6: Histogram of area covered by AEDs – (I) Continuous distribution. (II) Dichotomous distribution.

By the use of the AED coverage values, all separate OHCA risk factor data and the overall OHCA risk score data, boxplots were made to visualize the difference in OHCA risk between neighborhoods that are fully covered (0), and neighborhoods that are not-fully covered (0). From all boxplots, the minimum, maximum, first (Q1) and third quartile (Q3) were obtained. Also the median was obtained, which is the center value. With these values the total range and the interquartile range (IQR) were determined:

$$Total\ range = Maximum - minimum$$
$$Interquartile\ range = Q3 - Q1$$

Outliers are shown as dots, but will be excluded from the boxplot. A value becomes an outlier when this is 1.5 times the IQR below Q1 or above Q3. Then, P-values were calculated for determining if there is a significant difference in OHCA risk factor between a fully covered neighborhood (1) or a not-fully covered neighborhood (0). Therefore, a two-sample t-Test was used with a significance level of $P < 0.05$. This was done for all seven different factors separately as well as for the overall OHCA risk score.

3. Results

3.1 Location and distribution of AEDs in Enschede

The AEDs cover 50.50 km² area, which roughly is one-third (50.50 / 142.72) of Enschede area (Figure 7-I). The AEDs are serving 151250 of 160640 inhabitants, which means that 9390 inhabitants do not have access to AEDs on time in Enschede (Figure 7-IV). AEDs were mostly found in the center of the municipality and close to the border with Germany (Figure 7-II). The Average Nearest Neighbor Analysis gave a P-value of 0.00 and a Z-score of -11.78. So, the null hypotheses is rejected, which means that AEDs in the municipality of Enschede are clustered (Table 2). This indicates AEDs are distributed unevenly through the area, as a result that some areas have a higher AED density than other areas. This means that the municipality has areas that are not covered by AEDs (Appendix-A). Also the Nearest Neighbor Ratio confirms clustering, since the Ratio is 0.53 which is less than 1. The mean distance between AEDs is 241.72 meters. This is about 200 meters less than the expected mean distance (458.10) which also indicates AEDs are clustered (Table 2).

Table 2: Summery Average Nearest Neighbor Analysis

Observed Mean Distance	241.7191 meters
Expected Mean Distance	458.0971 meters
Nearest Neighbor Ratio	0.527659
z-score	-11.781782
p-value	0.000000

The 70 Neighborhoods within the municipality Enschede are on average for 81.5% covered by AEDs, which means that AEDs are not geographically accessible for one-fifth of the neighborhood area (Figure 7-III). The neighborhood with the lowest coverage rate is covered for 3.8%. The top three neighborhoods with the lowest coverages are listed in Table 3. On the other hand, 23 of 70 neighborhoods scored a coverage percentage of 100%. These neighborhoods are fully covered by AEDs, which means that they are fully geographically accessible for AEDs.

Table 3: Top 3 neighborhoods with lowest AED coverage rates

Worst AED coverage	
Neighborhood	*Score (%)*
Buurtschap Twekkelo	3.75
Boekelerveld	5.86
Buurtschap Broekheurne	8.02

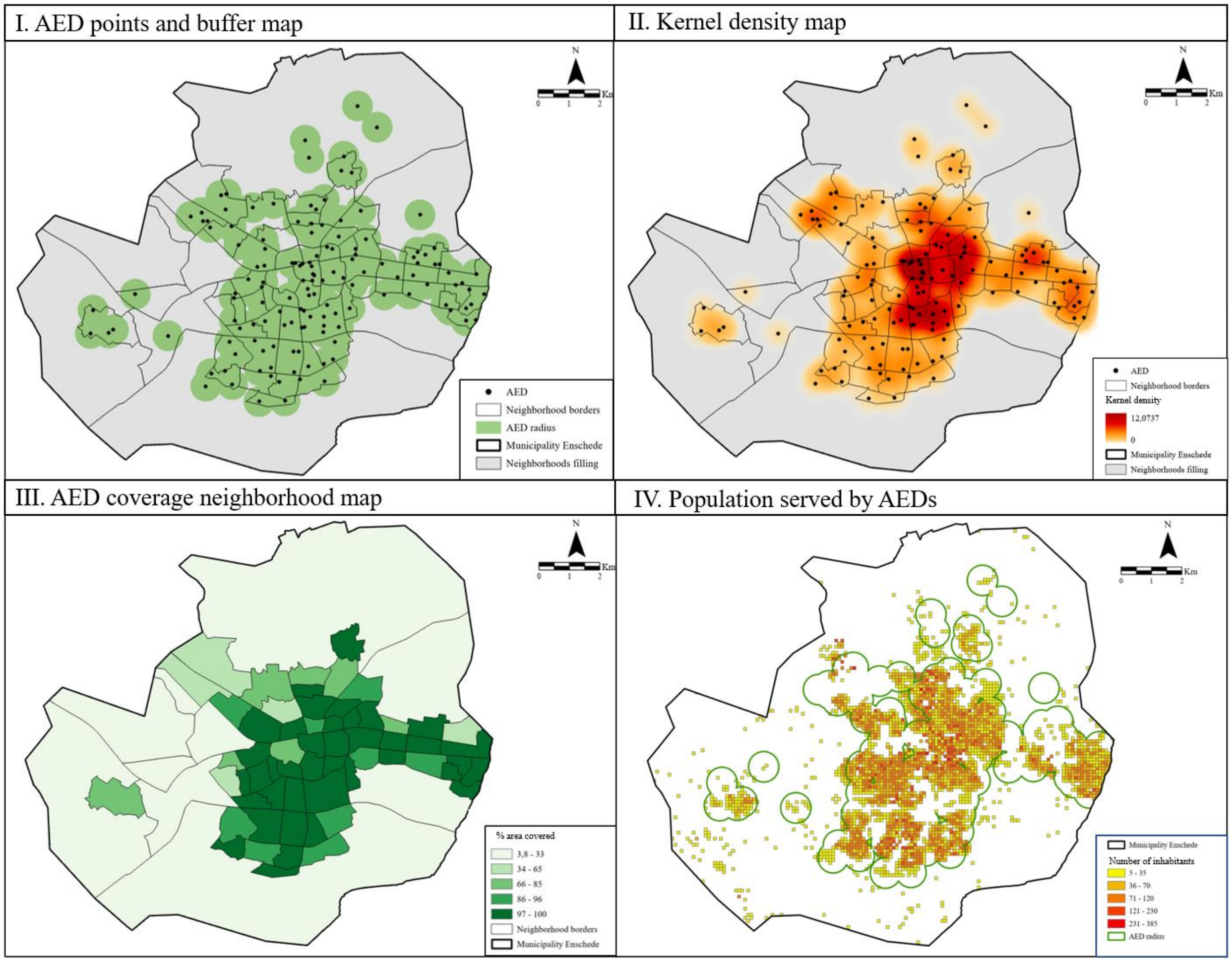

Figure 7: (I) AED point map with buffer analysis. (II) Kernel density map of AEDs in Enschede. (III) Percentage of area covered by AEDs per neighborhood. (IV) Population served by AEDs

3.2 OHCA risk factors distribution in Enschede

OHCA risk factors are visualized in Figure 8 and Figure 9. Notably, the OHCA risk is generally lower in the north of Enschede, and higher in the center and east-side of the municipality. Conversely, the risk factor for elderly people is lower in the center, and higher in the border neighborhoods. The overall OHCA risk score map is visualized in Figure 10. The upper side of the center and the north side of the municipality received a low-risk score. Two neighborhoods received the maximum attainable high-risk score. The highest risk neighborhoods are listed in Table 4.

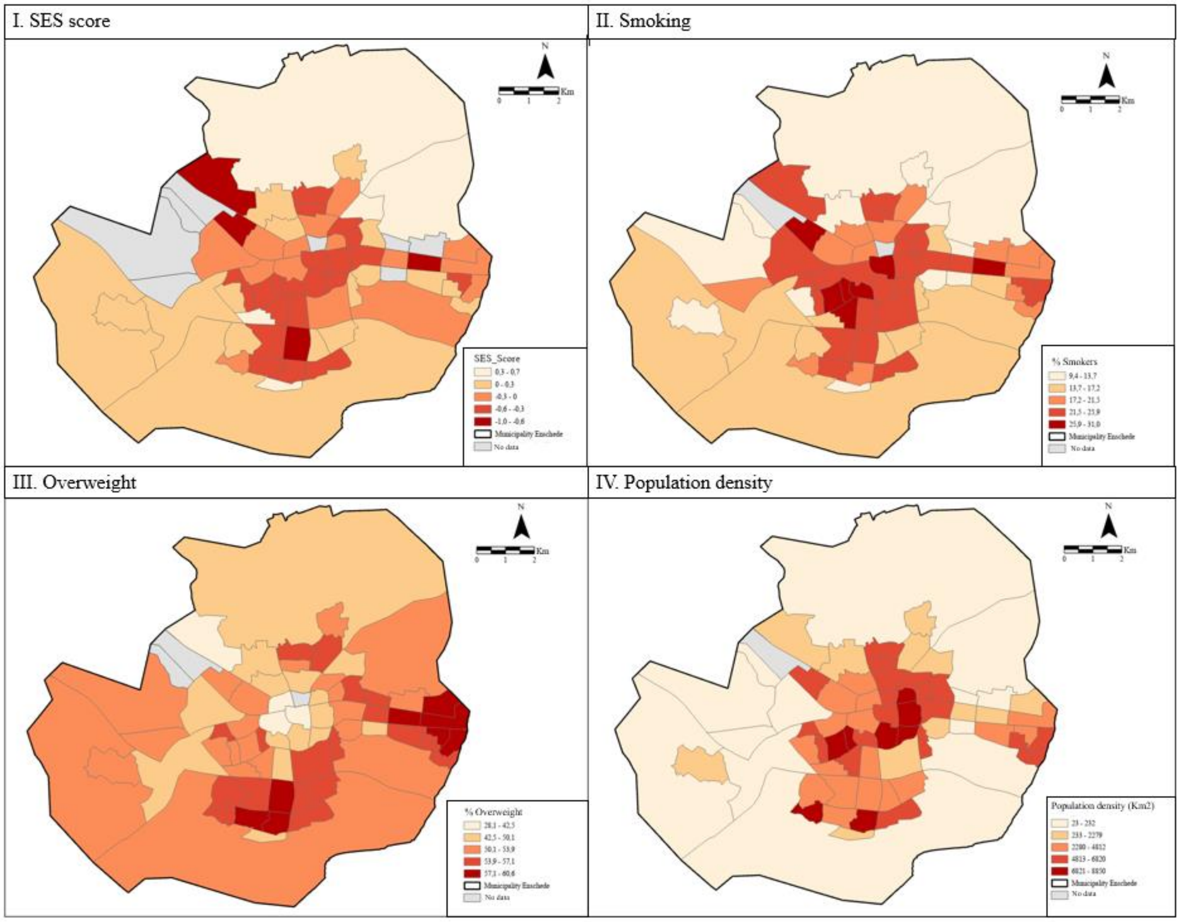

Figure 8: Population characteristics of Enschede - (I) SES-score. (II) Smoking. (III) Overweight. (IV) Population density.

Figure 9: Population characteristics of Enschede - (V) Ethnicity. (VI) Elderly. (VII) Education level.

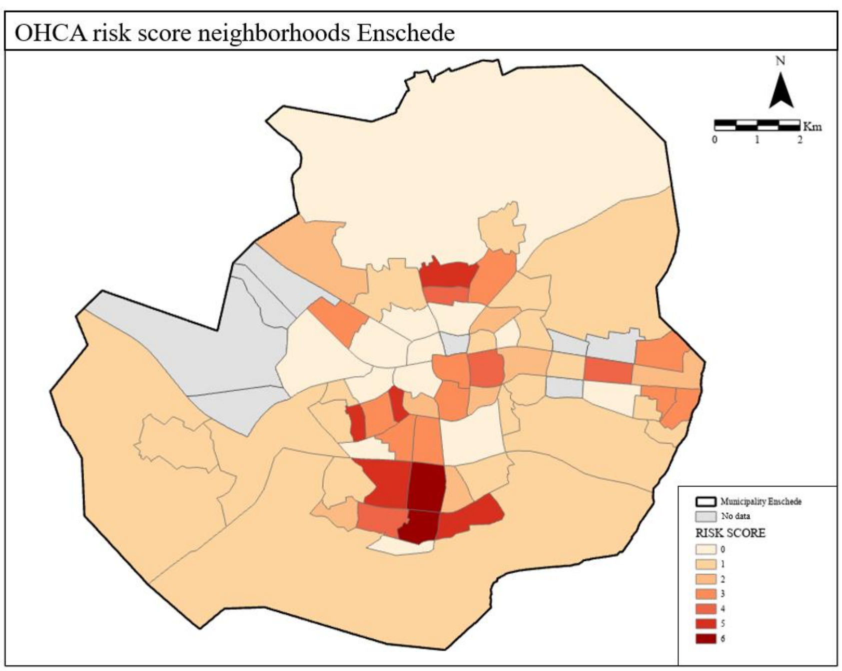

Figure 10: OHCA risk map Enschede

Table 4: Neighborhoods with the highest OHCA risk score

Neighborhoods with highest OHCA risk score	
Risk score	*Neighborhood*
6	Wesselerbrink Zuid-Oost
	Wesselerbrink Noord-Oost
5	Deppenbroek
	Pathmos
	Wesselerbrink Noord-West
	Stroinkslanden-Zuid
	Stadsveld-Zuid

3.3 AED coverage based on OHCA risk factors

The boxplots of Figure 11 are visualizing the difference in OHCA risk factor between not-fully covered (0) and fully covered neighborhoods (1). The results of the two-sample t-Test with their P-values are listed in Table 5.

SES-score – Figure 11-I shows the boxplot of SES-score and AED coverage. In the not-fully covered neighborhoods the minimum SES-score is -0.98, Q1 is -0.33, the median is 0.03, Q3 is 0.31 and the maximum score 0.55. In the fully covered neighborhoods is the minimum SES-score is -0.78, Q1 is -0.48, median is -0.29, Q3 is 0.10 and the maximum SES-score is 0.69. The total range is 1.53 in not-fully covered neighborhoods and 1.47 in fully covered neighborhoods. The IQR is also higher in not-fully covered neighborhoods (0.65) than in fully covered neighborhoods (0.58). So, neighborhoods are more fully covered at a lower SES-score. The P value is 0.059 so no significant relation is found between AED coverage and SES-score.

Smoking – Figure 11-II shows the box plot of smoking rate and AED coverage. In the not-fully covered neighborhoods, the minimum smoking rate is 9.4, Q1 is 13.45, the median is 17.1, Q3 is 22.95 and the maximum smoking rate is 25.1. In the fully covered neighborhoods, the minimum smoking rate is 11.4, Q1 is 18.5, the median is 22.4, Q3 is 25.60 and the maximum rate is 31. The smoking rate total range is larger in fully covered neighborhoods (19.6) than not-fully covered neighborhoods (15.7), but the IQR is smaller (7.1) is fully covered neighborhoods than not-fully covered neighborhoods (9.4). So, neighborhoods with a high smoking rate are more fully covered than neighborhoods with a low smoking rate. With a P value of 0.001 this relation is found to be significant.

BMI – Figure 11-III shows the boxplot of the overweight rate and AED coverage. In the not-fully covered neighborhoods, the minimum overweight rate is 42.50 (excluding outliers), Q1 is 49.48, the median is 51.95, Q3 is 55.58 and the maximum rate is 60.50. The fully covered neighborhoods have a minimum rate of 42.30 (outliers excluded), Q1 is 49.80, median is 53.70, Q3 is 55.50 and the maximum rate is 60.60. The total range is 18 in not-fully covered neighborhoods and 18.3 in fully covered neighborhoods. Besides, the IQR is 6.1 in not-fully covered neighborhoods and 5.7 in fully covered neighborhoods. So, neighborhoods with a higher overweight rate are more fully covered, although this has a minor difference and is not significant (P = 0.291).

Population density – Figure 11-IV shows the boxplot of population density and AED coverage. In the not-fully covered neighborhoods, the minimum population density is 23, Q1 is 60, the median is 1086, Q3 is 3126 and the maximum density is 6352 inhabitants per km^2. In the fully covered neighborhoods, the minimum density is 231, Q1 is 3350, median is 5252, Q3 is 6602 and the maximum density is 8850. The total range is 6329 and IQR is 3066 in not-fully covered neighborhoods, and total range is 8619 and IQR is 3252 in fully covered neighborhoods. So, neighborhoods with a higher population density are more fully covered by AEDs than neighborhoods with a low population density. The P value is zero, so the relationship is significant.

Non-western – Figure 11-V shows the boxplot of non-western rate and AED coverage. Three outliers were found and excluded in the boxplot. In the not-fully covered neighborhoods, the minimum rate is zero, Q1 is 3, median is 5, Q3 is 18 and maximum is 34. In the fully covered neighborhoods, the minimum rate is 2, Q1 is 10, median is 15, Q3 is 21 and the maximum rate is 33. The total range is 34 in not-fully covered neighborhoods and 31 in fully covered neighborhoods. The IQR in not-fully covered neighborhoods is 15 and in fully covered neighborhoods 11. So, neighborhoods with a higher not-Western background ethnicity rate has a higher AED coverage. However, the P value is 0.067 so no significant relationship is found.

Age – Figure 11-VI shows the boxplot of the rate of elderly people and AED coverage. In the not-fully covered neighborhoods, the minimum rate is 3, Q1 is 15, median is 20, Q3 is 24 and the maximum rate is 34. In the fully covered neighborhoods, the minimum rate is 6, Q1 is 13, median is 17, Q3 is 20 and the maximum rate is 29. The total range is 31 in not-fully covered neighborhoods and 23 is fully covered. The IQR is 9 in not-fully covered and 7 is fully covered neighborhoods. So, neighborhoods that have a higher rate of elderly people are less likely to be fully covered by AEDs. The P value is 0.087 so there is no significant difference found between AED coverage and elderly people rate.

Education level – Figure 11-VII shows the boxplot of low education level rate and AED coverage. In the not-fully covered neighborhoods, the minimum rate is 1.03, Q1 is 16.65, median is 21.88, Q3 is 34.08 and the maximum rate is 44.81. In the fully covered neighborhoods, the minimum rate is 14, Q1 is 21.84, median is 26.53, Q3 is 36.59 and the maximum rate is 50. In the not-fully covered neighborhoods, the total range is 43.78 and the IQR is 17.43. In fully covered neighborhoods the total range is 36 and the IQR is 14.75. So, neighborhoods with a higher low-education rate are more covered than neighborhoods with a lower rate. And, with a P value of 0.036 this relation is significant.

Overall OHCA risk score – Figure 11-VIII shows the boxplot of OHCA risk score and AED coverage. In the not-fully covered neighborhoods, the minimum rate is zero, Q1 and the median is 1, Q3 is 3 and the maximum rate is 4 with an outlier of 5. In the fully covered neighborhoods, the minimum rate is zero, Q1 is 1, median is 2, Q3 is 3 and the maximum is 6. In the not-fully covered neighborhoods, the total range is 4 and the IQR is 2. In the fully covered neighborhoods, the total range is 6 and the IQR is 2. So, the range in risk score is the neighborhoods that are fully covered more divers compared to the neighborhoods that are not-fully covered by AEDs. The neighborhoods with a risk score of 6 (the highest score possible) are fully covered with AEDs. On average neighborhoods with a higher risk score are more likely to be fully covered compared to neighborhoods with a lower risk score. However, the P value is 0.25 so no significant relation is found.

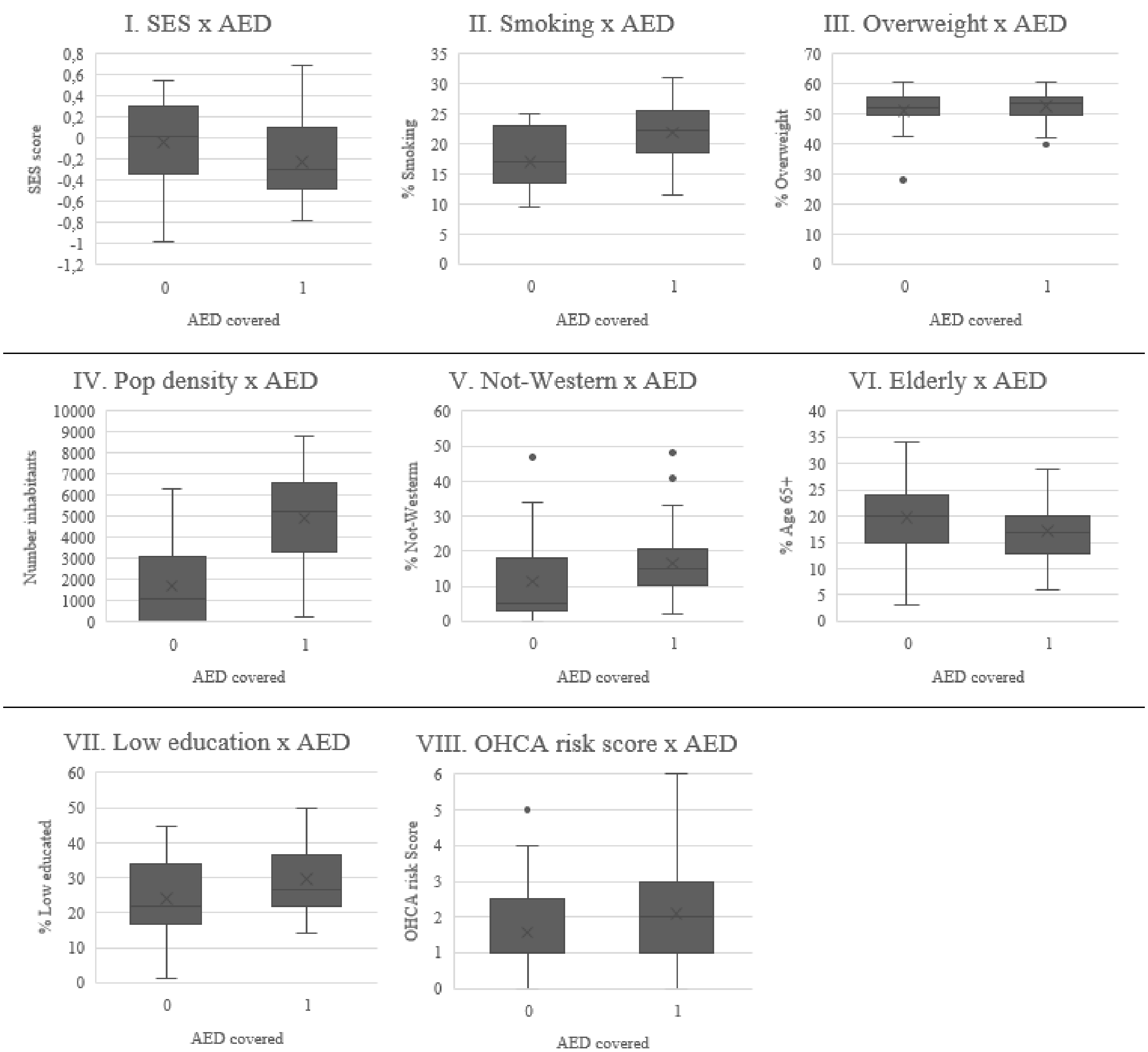

Figure 11: Boxplots AED cover and OHCA risk factors - (I) SES x AED. (II) Smoking x AED. (III) Overweight x AED. (IV) Population density x AED. (V) Not-Western x AED. (VI) Elderly x AED. (VII) Low education x AED. (VIII) OHCA risk score x AED.

Table 5: Two sample t-Test P-values of population characteristics and AED coverage

Characteristic	**P-value**
SES-score	0.059
Smoking	0.001*
Weight	0.291
Population density	0.000*
Not-Western	0.067
Elderly people	0.087
Low-education level	0.036*
OHCA risk score	0.250

* Significant

4. Discussion

4.1 Relationship risk factors and AED coverage

This study aimed to determine the relationship between the spatial distribution of out-of-hospital cardiac arrest risk and the coverage of automated external defibrillators. Neighborhoods with a higher overall OHCA risk score are not significantly more or less likely to be fully covered with AEDs. This means, there is no higher AED coverage in neighborhoods with a higher OHCA risk, which indicates that AEDs are not effectively distributed over the municipality of Enschede. Taking the risk factors separately, the neighborhoods with a higher OHCA risk on population density, smoking and low education level are more likely to be fully covered by AEDs. The other factors, SES, weight, ethnicity and elderly, do on the other hand not significantly differ in coverage between higher or lower risk. This means, high risk neighborhoods (because of low SES-score, high overweight, not-western or elderly people rate) do not contain a higher AED coverage. Neighborhoods with a higher elderly people rate do even have a lower coverage at a higher elderly people rate.

4.2 Reflect on results

A previous study has shown that an area wherein AED placement is driven by political or local initiatives can lead to unnecessarily placed AEDs, because they primarily become placed in low OHCA incidence places. [13] This study also investigated an area wherein AEDs become placed through political and local initiatives. New findings are that there is no significantly higher coverage in high risk areas compared to low risk areas. And, areas with a higher OHCA risk because of higher elderly people rates do have a lower AED coverage in a self-driven AED placement area. That means, AEDs are not effectively distributed in an area that is been driven by local and political initiatives.

Because AEDs in the municipality of Enschede are often collectively purchased through local initiatives, it is questionable if neighborhoods with a lower SES, which initiates a lower income, are able to afford AEDs for the neighborhood. This study however indicates no difference in SES-score between fully covered neighborhoods and not-fully covered neighborhoods. This can mean that neighborhoods with lower SES-scores are as likely to pay for an AED for the neighborhood as higher SES-score neighborhoods. This may be due to higher social cohesion in low SES-score neighborhoods, which makes the step smaller to spread the awareness of the importance for AEDs through the neighborhood. Another theory for this could be that AEDs in lower SES neighborhoods become subsidized by the municipality.

This study can bring a new light to the study of optimizing the distribution of AEDs. Previous studies made an optimization model based on risk areas, by finding high population flows through high building density areas or by finding certain crowded areas like train stations or shopping malls. In those models each person counts equally. For example, when there is a choice between putting an AED in area A with five people or area B with seven people, the AED will be placed in the area with most people, so area B. However, this study looked at population at risk. Therefore, not every person counted as one. By way of contrast, people with a higher OHCA risk will be counted higher than people with a lower OHCA risk. This will prevent redundantly placed AEDs in low risk areas, and allowing to place them in areas where they are actually needed.

4.3 Strengths and limitations

This study has some limitations. First, the chosen study area may be too small to be reliable and to be generalizable to other areas. Second, for determining the overall OHCA risk score per neighborhood, the sum of all factors was taken. Each factor counted with the same weight, but that may be not accurate because some factors can lead to a higher OHCA risk than others. A more accurate way for calculating an overall risk score, all separate risk scores should be weighted to how big their influence is on OHCA risk, based on literature. Third, in the calculation of the population served by AEDs with the 100 x 100 meters data tiles, tiles were counted as 'served' while they are located on the border of covered area. However, there is a chance that a part of the population inside the border tiles do not have access to AEDs. This results in an overestimation of the number of people covered by AEDs. Fourth, the AED coverage is based on a two-dimensional area. However, the area is mostly three-dimensional, especially in places with high flats or office buildings. This should have been considered as well. Fifth, in this study there is no distinction made between AEDs that are 24/7 accessible, and AEDs that are not always accessible, for example AEDs in office building or sports clubs. However, according to Red Cross, 50% of all AEDs in the Netherlands were not 24/7 accessible in 2016. So, neighborhoods may not always be as covered as is shown in this study. [49]

The main strengths of this study are firstly that the municipality of Enschede was used as a study area. This municipality has a low SES and a high non-western population rate compared to other municipalities of the Netherlands. And, within the municipality the risk factor ranges are wide and varies between neighborhoods. That makes this area a good area for finding a correlation between the two variables. Second, to be able to compare the AEDs between different neighborhoods, and to avoid only looking inside the neighborhood border areas, coverage rates per neighborhood were calculated. This is a strength because AEDs that are serving two or more neighborhoods (when the radius is covering several neighborhoods) will be counted as serving for several neighborhoods instead of counting only the neighborhood where the AED is located in.

4.4 Future research

Further research can be done to consider a weighted factor to the risk factors. In this study all risk factors were weighted with the same weight, so the same amount of risk. However, it may be that the presence of risk factor A leads to a much higher OHCA risk than the presence of risk factor B. When that is investigated, a more accurate map of the high and low risk areas can be created. Also further research must be done to include OHCA risk factors in the AED distribution policy plan to the extent that there is a significantly higher AED coverage in areas with a higher OHCA risk because of higher rates in overweight people, non-western people, lower SES-score and especially elderly people. Additionally, further research is required to investigate the potential applicability for developing the AED distribution optimization model. The effectiveness of placing AEDs on the basis of population risk factors can be tested through historical cardiac arrest data points, so the amount of covered OHCAs can be calculated.

5. Conclusion

To increase OHCA survival rates in the municipality of Enschede, the geographical accessibility to AEDs should be optimized, especially for areas with a higher OHCA risk. This study shows that currently there is no difference in the extent of AED coverage between low OHCA risk neighborhoods and high OHCA risk neighborhoods. Furthermore, neighborhoods with high rates of elderly people, who are at higher OHCA risk, are currently less fully covered than neighborhoods with low rates. Therefore, this study shows that AEDs are not yet optimally distributed over the municipality of Enschede. More research on a broader scale is needed to implement OHCA risk in AED distribution models and to generalize it to other areas.

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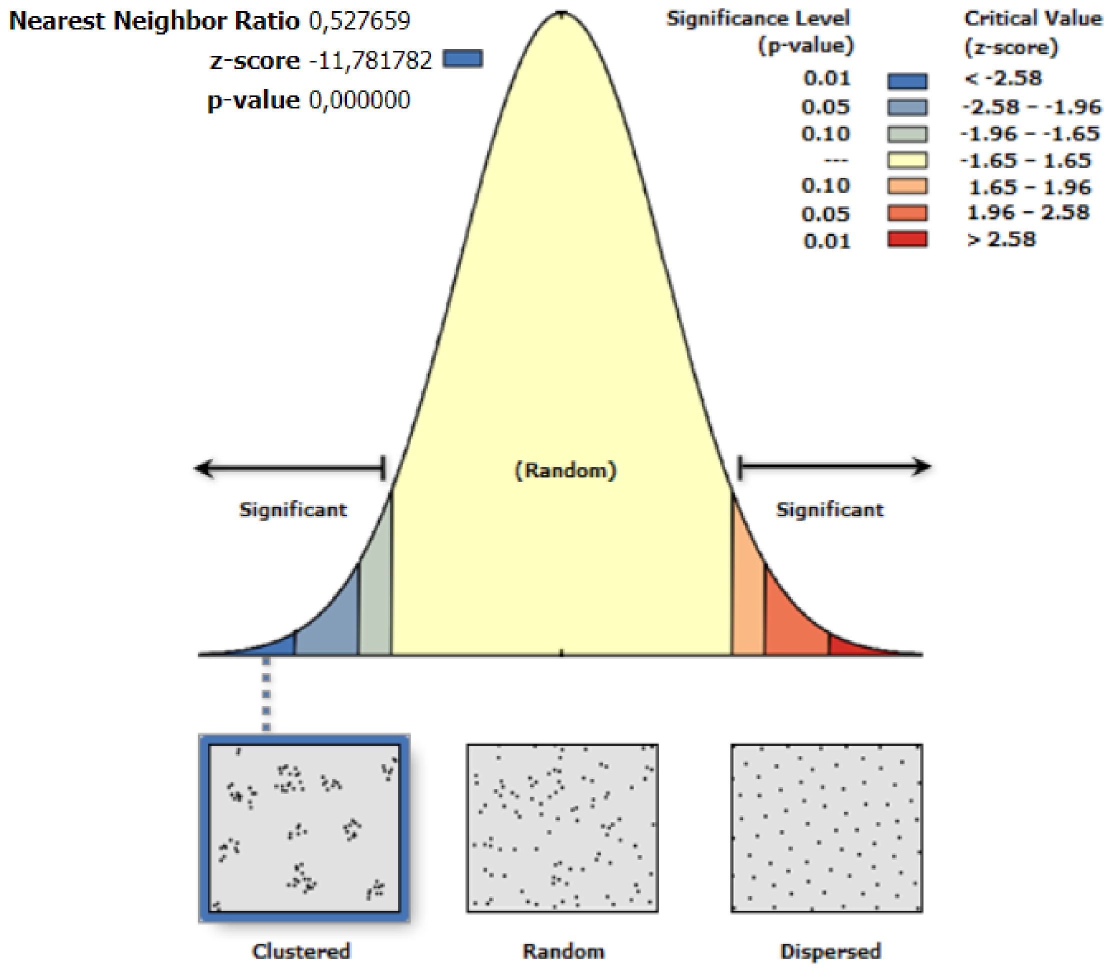
Appendix

A: Average Nearest Neighbor analysis summery



Given the z-score of -11.781782, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.