

Strategic Mapping and Optimised Allocation of Automated External Defibrillators in Urban Areas

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ABSTRACT

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Background: Out-of-hospital cardiac arrest (OHCA) is a leading cause of death and is regarded as a significant public health issue. Immediate treatment with an automated external defibrillator (AED) increases OHCA patient survival potential. For AEDs to be used and fulfil their lifesaving potential, they need to be in close proximity to the victim and accessible at the time of a cardiac arrest. The current paper sheds light upon an optimized location-allocation method achieving full coverage with immediate accessibility in an urban context given a limited number of available AEDs for deployment using GIS. The case study is the Region of Western Macedonia (RWM) in Greece for a pilot AED placement program for the Governance of RWM. The focus of the current study is the capital city of RWM, Kozani. The initial number of the defibrillators (120) that are needed to be distributed is very small and cannot cover the needs for every major city or rural area in the region. Out of the 120 AEDs, the challenge is to find the minimum required number of AEDs to allocate in the city providing full coverage and accessibility. This paper focuses only on one city, however, the same methodology was applied to allocate AEDs in the other selected cities of the region. The rural dimension and methodology are not in the scope of this paper.

Methods: Road network data, spatio-temporal analysis of accessibility network, digital elevation model, land uses, population density, seasonal fluctuations and socio-demographic variables were used. GIS algorithms such as spatial analysis, kernel density, hot spot analysis, maximal covering location problem (MCLP) tests, proximity algorithms, buffer zoning, were a few of the tests made in order to find the most efficient positions and maximize coverage keeping in mind that access to an AED until defibrillation time must not exceed the time range of five minutes.

Results: Based on our methodology for optimised sites and allocated AEDs in urban areas we managed to achieve full city coverage with 17 AEDs. In every

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part of the city, people can have access to a nearby AED with its critical radius of less than or equal to 250m achieving defibrillation in the critical period of 5 minutes. The results are promising for the establishment and expansion of optimised AED deployment in cities.

Conclusions: The progress of the project must be monitored and there are still unresolved problems that need to be tackled to provide a robust allocation of future defibrillators. Further research to enhance our understanding on public access defibrillation and optimize the accessibility and functionality of the medical health care services is needed. A network of engaged and informed citizens ready to act is required for a successful public access defibrillation program.

Keywords : Urban Areas, Geographic Information Systems, Automated External Defibrillator

I. INTRODUCTION

Out-of-hospital cardiac arrest (OHCA) is a leading cause of death and is regarded as a significant public health issue [1]. Immediate treatment with an automated external defibrillator (AED) increases out-of-hospital cardiac arrest patient survival potential. Over the years an increased focus on public access defibrillation has led to widespread AED dissemination. While an increased AED dissemination has been linked with higher AED use, the trade-off between the number of deployed AEDs and the coverage of cardiac arrests in real-life settings remains unclear [2].

Albeit the considerable attention that has been given to determining optimal public AED locations, spatial and temporal factors such as time of day and distance from emergency medical services (EMSs) are understudied [3]. In Europe alone about 275,000 people experience an OHCA each year [4].

In order for AEDs to be used and fulfil their lifesaving potential, they need to be in close proximity to the victim and accessible at the time of a cardiac arrest. In addition, in a matter of minutes in the event of a

cardiac arrest, bystanders must be able to locate and bring the AED to the victim. Hence, the utility of an AED depends on its position and accessibility and on bystanders' knowledge of these factors. Such conditions inflict challenges to the AED use, and failure to overcome these challenges may be the main limitation to the lifesaving potential of AEDs in community settings [5].

The utility of spatial analytical methods has been discussed in research on the spatial patterns of medical services. While studies on the locations of AED placement have been performed over the years, the spatial and temporal variations of OHCA occurrence and the availability of emergency medical services have not been considered thoroughly [6]. Thus, the appropriate placement of automated external defibrillators does not have standardized approaches. According to the revised ERC guidelines in 2015 the installation of an automated external defibrillator should be based on previous OHCA sites but as with the guidelines of the American Heart Association of 2015 and International Liaison Committee on Resuscitation, point out significant gaps in knowledge about the best development strategies of public AEDs

and underline the need for scientific evidence and data [7].

In an urban context placing an AED in every corner of the city is financially not feasible and not cost-effective. Deployment strategies should be based on multi-criteria approaches that will allow identification of the optimum number and placement positions of outdoor automated external defibrillators in urban areas. The purpose of this study was to develop an optimized AED method with the use of geographic information systems for the allocation of a limited number of public access automated defibrillators in the Region of Western Macedonia Greece. More specifically, this study focuses on one city candidate to the pilot project (Kozani) for part of the AED deployment and shows the methodology and results of how an optimised model was able to achieve full city coverage. The novelty of this study lies in the achievement of a fully available public access AED network throughout the city in a matter of minutes, a fact that enhances the potential positive results of early defibrillation.

This paper focuses on the methodology for AED deployment in urban areas. AED allocation in the rural areas is not in the scope of the current study. [8] have already worked on an optimised methodology on AED deployment in rural areas in the region.

A. The Situation

OHCA events could be defined as all areas accessible to the general public, all outdoor areas, public transport areas, schools, outpatient clinics, and commercial and residential centers. The residential locations, housing for the elderly or health care accommodation are also included [9]. In addition, for every minute between cardiac arrest and defibrillation survival decreases by 7-10% [10]. Achieving defibrillation within 3-5 minutes of collapse can cause survival rates as high as 50-70%. At the same time, premature defibrillation can be accomplished through people with knowledge of cardiopulmonary

resuscitation (CPR) using public access automated defibrillators. AED programs for public access should be implemented in public places with a high density of citizens [11].

On a regional city level, there is not an established framework for public access automated defibrillators, which makes the regional medical system even more vulnerable to existing deficiencies. The lack of publicly available defibrillators, especially in urban areas, the lack of awareness as well as knowledge of the operation of these devices are important inhibitors of the proper and efficient functioning of the medical system.

Our study area is the Region of Western Macedonia in Greece which is divided into four administrative regional units: the Regional Unit of Florina, the Regional Unit of Kozani, the Regional Unit of Kastoria and the Regional Unit of Grevena with Kozani being the head governing unit for the Region of Western Macedonia (RWM). RWM has a population of 283.689 people based on the 2011 census and covers an area of 9.451 km². For the purposes of this paper we will focus on the capital city of the regional governing unit of RWM, Kozani with a population of 41.006 people based on the 2011 census.

The Governance of RWM is about to acquire 120 AEDs for a pilot program which are needed to be distributed in the major cities of the regional units (the cities of Florina, Kastoria, Kozani, Ptolemaida and Grevena) and among their remote and rural areas. The number of the defibrillators is limited and it is not in a position to cover the needs for every major city or remote area, but it is a pilot program that will be the inaugurating point for a solid framework of AED deployment and awareness program in the Region of Western Macedonia. This paper focuses only on the mapping methodology for the placement of AEDs in urban areas and explains the steps and results of such approach. The paper focuses more on the analytical

results and it does not explain the technical part of the already existing algorithms that have been used. By the time of this writing the Regional Governance had already accepted the proposal of the candidate sites in the cities for the pilot program.

II. METHODOLOGY

In a wider context, placing automatic external defibrillators in positions with the highest probability of future heart attacks would maximize cost-effectiveness and survival rates [10]. However, before evaluating the placement of automated external defibrillators, it is important to consider multi-criteria parameters for placing an AED in densely populated areas and not focus only on one parameter especially in dynamic places like cities. With this in mind, mapping the history of sudden cardiac events in all residential areas or where data is available is not sufficient in order to justify an AED placement. Existing defibrillators outside of hospitals that may exist in private areas, private clinics, mobile and outpatient clinics, public agencies and industries should also be recorded. Cities with a high population density and cities with a smaller population differ in the probabilities of possible heart attacks or the number of previous OHCA based on various factors (quality of life, health factors, environmental etc.). However, the challenge of this study is to find a robust way to distribute a part of the initially small number of available automated defibrillators throughout the city of Kozani without obscuring and depriving the other cities from the minimum number of AEDs for their optimal coverage. In addition, if we map the events of cardiac episodes, adopting the definition of [9] including sudden cardiac events confirmed by the absence of consciousness, pulse and breathing, that needed defibrillation through the database of the first responders medical department we could not compare for obvious reasons the need for defibrillators in high population cities and in low population urban areas.

Variables used
Data of all road network categories
Spatio-temporal analysis of accessibility network
Digital Elevation Model
Land uses
Population density
Seasonal Fluctuations
Socio-demographic variables

Table 1. Multivariable selection for AED allocation.

In Figure 1 we introduce the methodological framework of data used and the steps taken to reach the desired results for the pilot program in urban areas. Concerning the allocation and placement of AEDs in the rural and remote areas a different approach and methodology was followed, however, this will not be discussed in this paper.

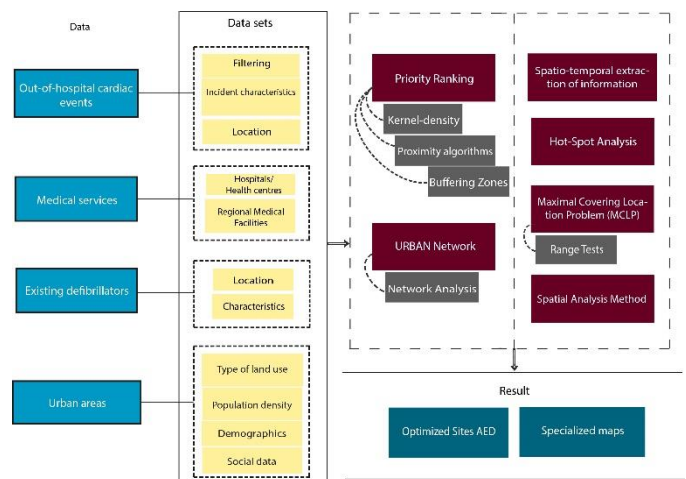


Figure 1. Complete framework for optimised AED placement in urban areas.

B. The Framework

[12] applied a mathematical modelling and optimization method for the prioritization of AED deployment in Toronto, Canada. They estimated an AED placement as appropriate when it was placed within 100m of an OHCA event. Such mathematical modelling and optimization in AED allocation could increase cardiac arrest coverage and decrease the distance to the closest AED. In our study the inherent problem is the limited number of available AEDs. Only 120 are available for the current pilot study and these must be optimally allocated in 5 major cities and

remote areas of the RWM. Hence, our approach is to have an optimised allocation in the cities by finding the minimum number of AEDs required with an effective coverage to cover all parts of the city.

Based on the findings of [13] and provided that a person required to carry the defibrillator moves to the nearest AED position at a speed of 10 km/h (2.78 m/s) and assuming it will take him/her 4 minutes to return with the AED, a critical radius must be defined. This critical radius varies depending on the proximity of the device, the incident and is defined as the minimum distance within which the use of AED can be effective. Furthermore, it must be taken into consideration that with every minute delay in cardiopulmonary resuscitation and defibrillation after a heart attack the patient's chance of survival significantly reduces [14]. The optimal scenario where a person can access and use the automatic defibrillator in less than five minutes is feasible when one is found early in the event and provided that the automated defibrillator is available at a close perimeter. In order to find the optimal radius in the cities, the digital elevation model was taken into account for inclination differences, which play an important role to the degree of difficulty and the access times.

Regarding the distribution of AEDs in cities, also applied in Kozani, based on the digital elevation model (DEM), each city was divided into zones according to their slope. The slope zones for each city were classified into areas with high slopes, medium slopes and almost flat areas. Calculating the slope is important because based on the slopes the time it takes for someone to reach a nearby AED and return will change based on the area within the city in which the person is located. Given this parameter, there was a need to find a critical radius that could be reached in all areas in less than five minutes. We found a possible efficient radius that matches this situation at 250m taking into account the number of defibrillators. If the radius is reduced, the number of defibrillators will have to change to cover the different parts of the city.

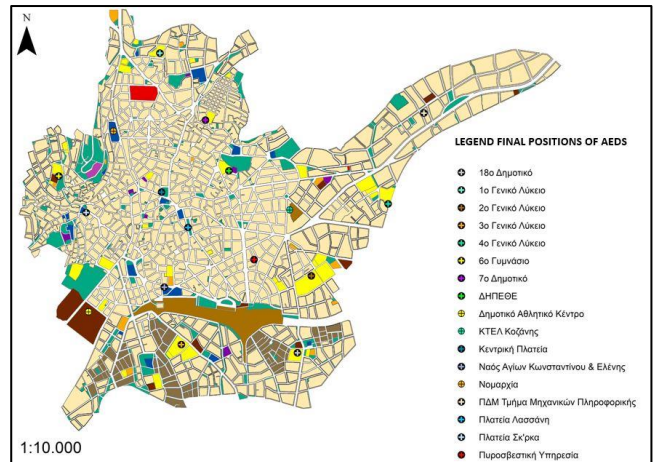
This way, every citizen anywhere within the critical range has the same opportunity to reach the AED in a very short time. Using proximity and network analysis algorithms the shortest path between a set of points was found as well as finding polygons defining the area at a given distance along a network across directions from one or more locations. Buffering each set of points' potential position to a range of maximum-minimum diameter allowed the identification of coverage ranges and places that were included or excluded from a quick AED access in the critical time period.

C. Allocation of AEDs in the city

As shown in Map 1 based on the digital elevation model we made a zoning approach of three categories with each zone indicating how flat or steep each area on the city is. Red zones indicate steep terrain, orange zones medium steepness and green zones indicate almost flat areas inside the city. Map 2 shows the buffer zones around each centre point which indicate the effective critical radius for quick access to an AED. Based on the analysis of the framework and various tests we found these positions as shown in Map 2 to be the optimum ones for full city coverage. Furthermore, the effective coverage range is not constant and in this case one of the variables that play a role in this is the small number (120) of automatic defibrillators that are available for deployment in the region. Therefore, we needed to use for one city not only a minimum number but also an optimum allocation strategy for full coverage. Trying to approach the possibility of covering the city with the minimum number of devices and calculating the morphology along with all other variables, we found a radius of 250m to be the most suitable. As shown in Map 2, each centre of a circle represents a potential AED position. The yellow buffer around each circle represents a 150m radius from the centre point and each blue area of the circles represent a 250m radius from the centre point of the circle. With the current ranges and calculated positions it is possible to obtain full city coverage with 17 AEDs. It is of essential importance during an

OHCA event to achieve defibrillation in less than 6 minutes. In our current method even if an event occurs on the edge of a circle and a bystanders has to go the centre of the circle to get the AED and travel back to the edge they can achieve defibrillation in the critical period of 5 minutes.

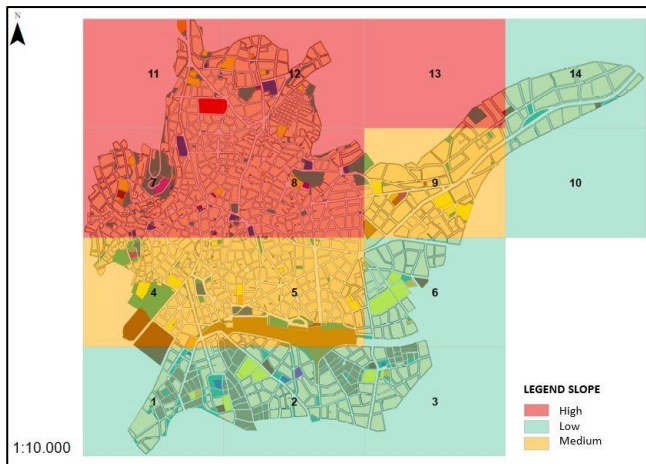
Map 3 shows the final positions of the AEDs. In these positions based on the land uses we identified which places were publicly accessible land uses such as administrative buildings, schools, open green spaces etc in order to suggest the exact location around the optimum calculated positional area. It is easier to install AEDs outside these public spaces rather than privately owned spaces even if the position its outdoors to minimize legal concerns.



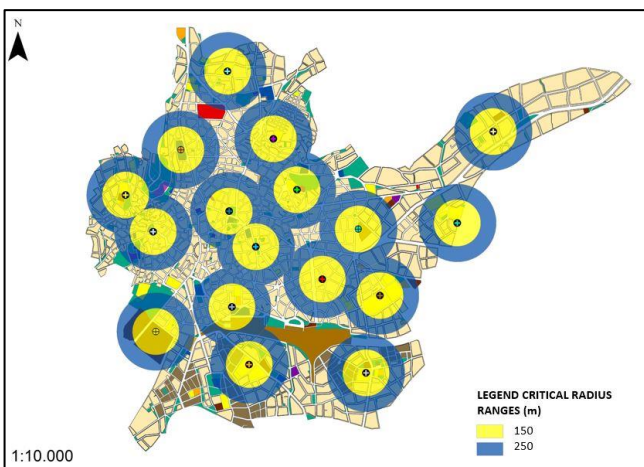
Map 3. Final optimised allocations of 17 AEDs in the city.

III. RESULTS AND DISCUSSION

The same framework explained in this paper was applied to the other four major cities of RWM and the optimised sites and allocated AEDs covered all the major parts of these urban areas. Each defibrillator can be accessed in a very short time in order to achieve potential high survival rates. The results show a promising future for the foundation and expansion of optimised AED placements in urban areas. It is important to consider the dynamic differences of these urban areas. Geographic information systems play a significant role not only for optimizing strategic mapping methods but also for creating a real-time active network of citizen/rescuers. As a next step a mobile application will be developed to contain information of all the available defibrillators, including these allocated ones, their current functioning status and availability. This will give the citizens and first responders the opportunity to be real time informed as well as become themselves geo-citizens and provide on a constant basis data about the defibrillators and any medical event that needs immediate attention. There are a lot of issues from legal to technological that the research community still needs to shed light upon, however, based on the existing literature positive steps and outcomes can be seen around the world.



Map 1. Slope zoning of the city.



Map 2. Critical Radius ranges for each allocated defibrillator around the city.

IV. CONCLUSIONS

Citizens need to be aware of the location of the devices in any given time and especially how such device can be used in times of an OHCA event. Campaigns for awareness and first aid provision in the region are making small steps to achieve the desired levels of citizens' engagement and awareness. Such education especially for emergency first aid should start from schools and the regional governance should give a priority to such an effort.

As a final remark, there are still many problems, missing data and obstacles that need to be tackled in order to provide a robust allocation of future

defibrillators. Monitoring of the project is essential and a thorough planning for the security of the AEDs must be elaborated if we want to eliminate any potential malicious attempts and property damage, especially in the urban areas. Further research to enhance our understanding on public access defibrillation and optimize the accessibility and functionality of the medical health care services is needed. A network of engaged and informed citizens ready to act is required in order to have a successful public access defibrillation program. We also encourage the other university departments to enrich the research with socio-technological advancements to amplify the efficiency and effectiveness of the current regional pilot project.

V. ACKNOWLEDGMENTS

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VII. DISCLOSURES

Conflicts of Interest: None