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Strategic Mapping and Placement of Automated External Defibrillators in Remote Areas. The case of the Region of Western Macedonia Greece

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ABSTRACT

Background: In Europe, sudden cardiac arrest is one of the dominant causes of death. Considering the fact that defibrillation within 3-5 minutes of collapse can cause survival rates as high as 50-70%, programs for public access defibrillation should be actively implemented. So far, the international research is focused on optimised methods for Automated External Defibrillator (AED) placements in cities and densely populated areas but there is not any concrete approach in connection with geographic information systems to covering the remote rural areas which have different dynamics, demographics and of course accessibility to medical care. This gap is what this paper will try to fill. The work of the current study unfolds in the Region of Western Macedonia (RWM) in Greece for a pilot AED placement program for the Governance of RWM. The initial number of the defibrillators (120) that are needed to be distributed is very small and by far it cannot cover the needs for every major town or rural area. This paper focuses only on the rural dimension for the allocation. Methods: All existing Regional Medical facilities, Health centers and Hospitals were identified and mapped. Subsequently, all types of road network were mapped and classified, which differ in conditions and maintenance, in order to do a network analysis. In addition, the type of land uses, demographics, population densities and seasonal dynamics were also taken into consideration in the mapping process in order to do a priority ranking for the allocation of the AEDs. Results: Based on the methodology the optimised sites and allocated AEDs covered the major rural areas that are most in need for immediate relief in the event of a cardiac episode. The results show a promising future for the foundation and expansion of optimised AED placements in rural areas. Conclusions: The progress of this pilot project must be monitored and there are many problems and obstacles that need to be tackled in order to provide a robust allocation of future defibrillators. Further research is needed to deepen our understanding on optimization approaches to enhance the functionality of the medical services as well as create a stable network of engaged and informed citizens ready to act.

Keywords : Automated External Defibrillator, Geographic Information Systems, Rural Areas, Cardiac Arrest

I. INTRODUCTION

The occurrence of Out-of-Hospital Cardiac Arrest (OHCA), is a life-threatening event all around the world. Each year in the United States 424,000 people experience an OHCA, about 275,000 in Europe, 60,000 in Japan and 20,000 in Taiwan [1]. Regarding Europe, Sudden Cardiac Arrest (SCA) is one of the leading causes of death [2]. Out-of-hospital cardiac events can be categorized as cardiac arrests occurring in public areas, which 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. Residential locations, housing for the elderly or health care accommodation also fall under the definition [3].

Since the mid-1990s, there has been a growing global emphasis on the availability of automated external defibrillators (AEDs) for use by citizens, a process known as Public Access Defibrillation (PAD). The effectiveness of a PAD program is directly related to the number of people witnessing a heart attack episode as well as how often and in which way they can receive, implement and activate the AED [4].

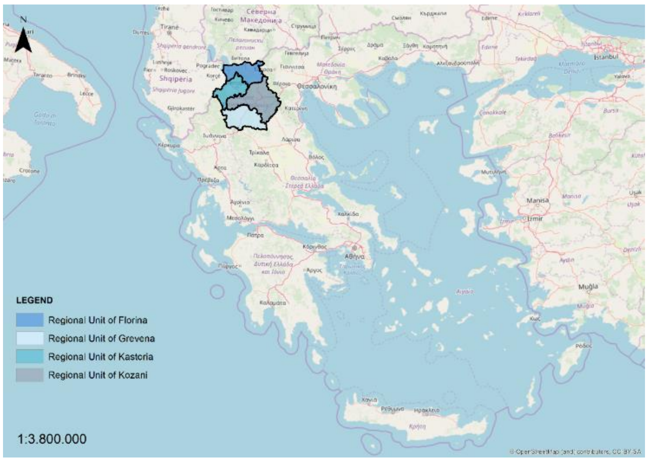
The European Resuscitation Council (ERC) and the American Heart Association (AHA) vary in their recommendations for strategic development of automated external defibrillators and this has been seen in their guidelines for public access defibrillation since 2005. The ERC suggests the employment of AED in areas with at least 1 cardiac arrest every five years [5] and the AHA proposes the placement of AED in areas with at least 1 cardiac arrest every two years [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].

AED development strategies should enhance their evidence-based criteria that will allow identification of the optimum number and placement positions of outdoor automated external defibrillators in urban areas as well as rural communities. The purpose of this study was to develop an optimized approach with the use of geographic information systems for the allocation of a limited number of public access automated defibrillators in Western Macedonia Greece by calculating variables such as spatial and temporal accessibility as well as coverage and density ranges. The novelty of this study lies in the fact that so far the international research is focused on optimised methods for AED placements in cities and densely populated areas but there is not any concrete approach in connection to geographic information systems to attempt a method that will cover the remote areas of the different regions which have different dynamics, demographics and of course accessibility to medical care. This is what this paper will try to cover.

A. The Situation

For every minute between cardiac arrest and defibrillation survival decreases by 7-10% [8]. Cardiopulmonary resuscitation improves the outcome of out-of-hospital cardiac arrest, but early defibrillation remains crucial in the rescue effort [9]. 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 actively implemented in public places with a high density of citizens [2]. However, even with the currently wide dissemination, the use of AEDs in communities is limited and more so in remotely accessed areas. For this reason, emphasis should be placed on a holistic public access program taking into consideration the remote areas which are also in need of immediate relief in the event of a cardiac episode.

The situation in the Region of Western Macedonia, Greece, in terms of emergency medical care runs into obstacles when it comes to areas without any medical facilities nearby. Especially ambulances that need to arrive in a remote area in time, face many difficulties and problems not only because of the distance but also because of the topographic differences of these areas. At a regional level, there is no coordinated and well-established framework for public access automated defibrillators, which makes the regional medical system even more vulnerable to existing deficiencies. The lack of readily available defibrillators, especially in rural 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.



Map 1. Region of Western Macedonia in Greece and its four administrative units.

The Region of Western Macedonia is divided into four administrative regional units which are: 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. Currently 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 capital cities of Florina, Kastoria, Kozani and Grevena) and among their remote and rural areas. The number of the defibrillators is very small and by far it cannot cover the needs for every major city or remote area, but it is a pilot program that will be the starting point for a concrete framework of AED deployment and awareness program in the Region of Western Macedonia. This paper focuses only on the mapping methodology for the installation of AEDs in the remote and rural areas and explains the steps and why these areas were chosen as candidates for an AED deployment. 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 for the pilot program.

II. METHODOLOGY

In order to justify the distribution and placement of automated external defibrillators, an assessment should be made about the cost effectiveness of the program. In general, 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 that the parameters for placing an AED in remote villages and rural areas differ from those in cities and densely populated areas. 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 and remote areas with a very small population differ in the probabilities of possible heart attacks or the number of previous OHCA. 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 to the remote places so that it can optimally cover the rural areas most in need. Thus, considering the guidelines of ERC for the historical accumulation of cardiac arrest in those rural areas would not be of much help since in these places a cardiac arrest could have happened less frequent than every two or five years. In addition, if we map the events of cardiac episodes, adopting the definition of [3] 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 rural villages. However, as we will explain later there are villages for example that an ambulance can take over 30 minutes to reach because of its high-altitude position and its mountainous road considering also the difficulties of such villages in wintertime.

Below (Figure 1) we introduce the methodological framework of data used and the steps taken to reach the desired results for the pilot program. Concerning the allocation and placement of AEDs in the urban areas a different approach and methodology was followed for the four major cities of RMW but this will not be discussed in this paper.

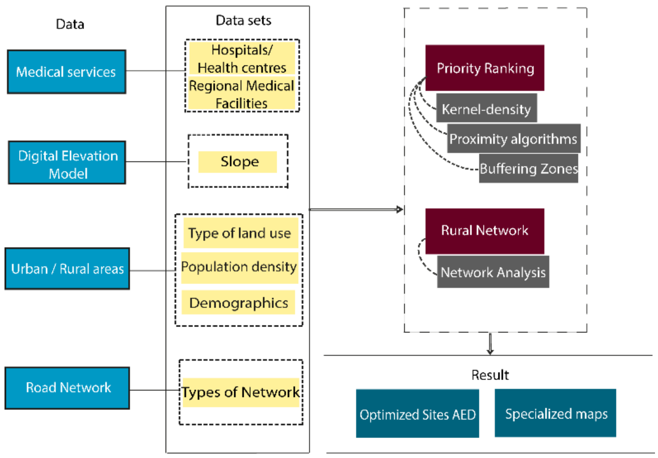


Figure 1. Framework for optimised AED placement for the rural areas.

B. The Framework

This stage encompasses the initial attempts for the pilot AED deployment in rural areas and here we will only focus on the rural dimension. Before we begin with our mapping analysis, an explanation of the medical distinctions of the RWM is necessary. The major medical categories are the hospitals which are all located in the four capital cities of each regional unit plus one more hospital in the city of Ptolemaida in the regional unit of Kozani. For the next subcategory there are four health centers in RWM which are smaller than hospitals and with fewer medical departments. Lastly, there are the regional medical facilities which are dispersed around the regional units, serving their surrounding villages or towns and are far less equipped and smaller than the health centers.

As an initial step all the existing regional medical facilities, the health centers and the hospitals were identified and mapped. Subsequently, all the types of road network were put together which differ in conditions and maintenance. Regarding the network types the categories are the primary and secondary national road network, the primary and secondary regional road network, and the community-municipal road network. Considering these differences and incorporating the digital elevation model and terrain data of the region we evaluated the various distances between the hospitals, the different regional medical facilities and the different villages of each Regional Unit. Using Proximity and Network Analysis algorithms the shortest path between a set of points (in our case medical units) 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 Regional Medical Facility to a maximum diameter of 5 km allowed the identification of places that not only were cut off from any medical care access within five-ten minutes but also based on the proximity methods were far out of reach from the health centers and hospitals.

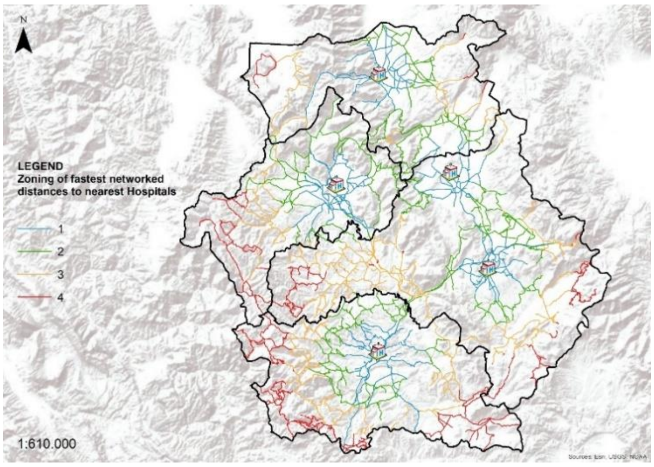
According to [11] provided that a person required to carry the defibrillator moves to the nearest AED position at a speed of 10 km/h (2.78 m/s) and assuming it will take him/her 4 minutes to return with the AED, a critical radius must be defined. The critical radius varies depending on the proximity of the device, the incident and is defined as the minimum distance within which the use of AED can be effective. In addition, with every minute delay in cardiopulmonary resuscitation and defibrillation after a heart attack the patient's chance of survival significantly reduces [12]. The optimal scenario where a person can reach and use the automatic defibrillator in less than five minutes is feasible when one is found early in the event and provided that an automated defibrillator is available at a close perimeter. The problem is magnified when the incident takes place in remote areas where first aid needs to be given immediately and the ambulance will take more than 10 minutes to reach and with an AED being unavailable.

C. Placement of AEDs in Remote Areas

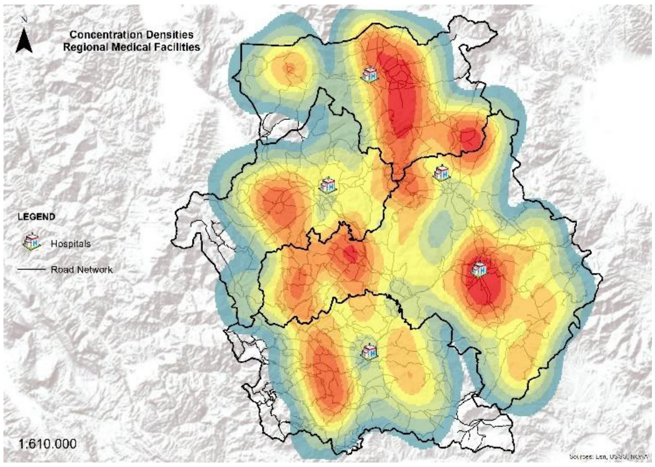
As shown in Map 2 based on the road network we made a zoning approach of four categories from 1-4 with each zone indicating how fast and close to the nearest hospital each zone is. Zone 1 which is the blue coloured network is the zone with the fastest networked distances to the nearest hospitals. As we move to zones 2 until 4 the networks become slower in terms of time accessibility and driving difficulty. Map 3 shows the density of existing regional medical centers based on a kernel density algorithm. The circles and their colour indicate high or low concentration of points of interest, in our case regional health centers that are the closest medical care to the surrounding villages. The intense red circles indicate a high concentration of regional health centers around the area. As the circles move outwards of these high-density areas the colours lose their intensity or change colour of light red, orange and yellow indicating lower occurrences of regional medical centers. In areas covered by the blue circles not only are there no available regional medical centers around but also these places are far less accessible to the nearest hospital or health center.

However, we need to point out that in the blue regions and outside of them it could also be the case that there are only mountainous or non-inhabited areas.

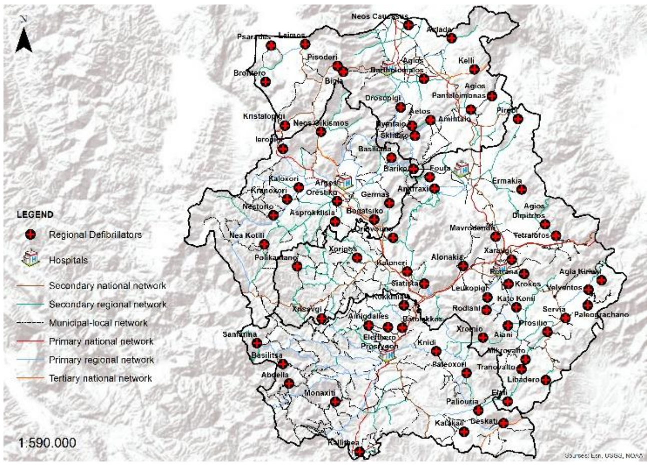
Taking all this into consideration as well as the type of road network with its analysis, the demographic dynamics (such as age composition), and seasonal conditions of each village and their time distance to each different medical facility the allocation of the automated external defibrillators was made. According to the Hellenic Statistical Authority a village has a size of 50 to 2.000 people. In total 71 AEDs of the total 120 were allocated to the rural areas as shown in Map 4 and the rest were allocated in the cities following a different approach than the current framework. A final step resulting from this study was the proposal of the exact positional placement of the AEDs inside the villages that could be publicly accessible 24/7 and as much as equidistant as possible inside the village.



Map 2. Zoning of road network to indicate fastest distances to nearest hospital



Map 3. Concentrations densities of Regional Medical Centers



Map 4. Final AED allocations in rural areas.

III. RESULTS AND DISCUSSION

Based on our methodology the optimised sites and allocated AEDs covered the major rural areas that are most in need for immediate relief in the event of a cardiac episode. 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 rural areas. It is important to consider the dynamic differences of the rural areas. For example, seasonal popuation changes affect the demands of these areas, their organizational planning as well as the needs for possible medical attention. Geographic information systems play a significant role not only for optimizing location-allocation methods but also for creating a real-time active network of citizen/rescuers that could provide information about the needs and statuses of each of these areas. As a next step creating an application that will contain information of all the available defibrilators, including these allocated ones, their current functioning status and availability will give the citizens and first responders the opportunity to be informed at all times as well as become themeselves geo-citizens and provide the system 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 will need to shed light upon, however, based on the existing literature positive steps and outcomes can be seen around the world.

IV. CONCLUSION

A mapping attempt of automated external defibrillators for public use is incomplete if the citizens themselves are not aware of the location of the devices at all times and how such a device is used in times of emergency. Awareness and first aid campaigns that have already been in existence in the region for years could not reach the desired levels of citizens' engagement and awareness. Such education especially for first aid should start from schools and the regional governance should prioritize such an effort. Information sessions and training seminars on cardiopulmonary resuscitation knowledge and AED use should be provided all year round in all regions to any interested citizen wishing to become a volunteer/rescuer. The progress of this pilot project must be monitored and there are many problems, missing data and obstacles that need to be tackled in order to provide a robust allocation of future defibrillators. A thorough investigation and planning about the security of the AEDs must be elaborated if we want to eliminate any potential malicious attempts or property damage, especially in the rural areas where the security dimension is weak. Further research is needed to deepen our understanding on public access defibrillation and optimize the accessibility and functionality of the medical health care services as well as create a stable network of engaged and informed citizens ready to act. We also encourage the technological departments to enhance the research and complementing it with technological advancements to increase the efficiency and effectiveness of the current project.

V. ACKNOWLEDGMENTS

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VII. DISCLOSURES

Conflicts of Interest: None

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