A DECISION MODEL FOR DETERMINING PUBLIC LOCATIONS SUITABLE FOR AUTOMATED EXTERNAL DEFIBRILLATOR (AED) DEPLOYMENT: A CASE STUDY IN THE CITY OF VALENCIA

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ABSTRACT

Automated external defibrillators (AED) offered a new perspective on resuscitation by enabling first-responders to deliver life-saving defibrillation within the critical first minutes after sudden cardiac arrest (SCA). This raised the question about where to place the AEDs. This study aims to provide a novel approach to the problem and to serve as a guideline for health policy decision makers in future projects. We used the Analytic Hierarchy Process (AHP) to form a decision model with four main criteria, and six sub-criteria. "Response time" was the most important criterion with an importance of 65.07%. Locations with the highest scores were a sports center, two stadiums, the central market, and the central bus station. A simple ranking of the alternatives would not be sufficient for the purpose of this study because the aim is to offer a guide for selecting locations for deploying AEDs rather than ranking the alternatives according to their suitability. Therefore, we formed priority groups. Sensitivity analysis showed that especially the alternatives in the first-priority group are not highly sensitive to changes, emphasizing their importance.

Keywords: automated external defibrillator (AED); public access defibrillation (PAD); sudden cardiac arrest (SCA)

1. Introduction

Early treatment is the key success factor for resuscitation of Sudden Cardiac Arrest (SCA) patients since survival chances decrease by about 10% with every minute without defibrillation (Nolan et al., 2010). Automated external defibrillators (AED) have proven to be safe and effective for use by not only healthcare professionals but also laypeople. Public-access defibrillation (PAD) is critical for improving survival rates of out-of-hospital SCA (Folke et al., 2009). A recent study shows that even the lay AED response without any CPR may increase survival rates (Capucci et al., 2016). The appropriate placement of AEDs is the key to improving the effectiveness of PAD programmes (Nielsen et al., 2013).

Locating AEDs has been an important topic in emergency medicine. However, most studies are retrospective and the topic has not been studied thoroughly in the multi-criteria decision making (MCDM) domain. In this study, we aim to provide a guideline by using the Analytic Hierarchy Process (AHP), a well-known and widely used MCDM technique (Saaty, 1977). Section 2 provides an overview of previous studies, and Section 3 discusses the methodology used. Section 4 elaborates on the case study and the decision model while Section 5 presents our findings. Section 6 draws some conclusions and provides suggestions for future research.

2. Background

2.1 Locating AEDs

Studies about AEDs mainly focus on determining the cost-effectiveness of the units or equitable allocations of the AEDs (Myers & Mohite, 2009; Cram et al., 2003; Rauner & Bajmoczy, 2003). These mostly analyze the cost per QALY (quality-adjusted life-year) gained (Folke et al., 2009; Nichol et al., 2009). The literature reviewed suggests that this issue has not been studied thoroughly in the MCDM domain. We did not find any study using AHP for determining suitable AED locations. Most studies focus on historical data of SCA incidents and propose these high-risk locations for AED deployment (Folke et al., 2009; Nielsen et al., 2013; Chan et al., 2013; Gilchrist et al., 2010; Muraoka et al., 2006; Page et al., 2013). There are also studies focusing on specific locations such as university campuses, basketball arenas, and public gardens (Myers & Mohite, 2009; Motyka et al., 2005; Imai et al., 2008).

2.2 Criteria

SCA risk is the most common criterion used for determining AED locations in the literature as it is intuitional to link high SCA risk with the need of having an AED in that location. Many researchers link this criterion to historical data of SCA incidents and advise a location type for AED installation if there is a past incidence of SCA in that location (Folke et al, 2009; Nielsen et al, 2013; Muraoka, 2006; Brooks et al., 2013; Norton & Norton, 2008). Tsai et al. (2012) determine not only the location, but also the time of SCA incidents throughout the city to match high-risk locations with the shops of a market chain with the aim of finding which shops are suitable for AED deployment. Motyka et al. (2005) focus merely on the possible response time of a cardiac arrest

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incident for determining suitable AED locations in a basketball arena. Studies focusing on university campuses suggest using coverage capability, response time, or a combination of both (Myers & Mohite, 2009; Timmons & Crosbie, 2014; Whitney-Cashio et al., 2012). Siddiq et al. (2013) introduce the term "effective range", defined as "the maximum straight-line distance between the AED and the cardiac arrest such as that there is a reasonable probability of retrieval and use prior to EMS arrival", and they run a mathematical model to achieve the highest coverage based on retrospective incident data and pre-defined AED effective range values. Some studies focus on first-aid responders (i.e. potential users of the AED in case of an emergency) and the importance of a trained user being available (Lubin et al., 2004; Myerburg et al., 2005; Schneider et al., 2004).

Some studies use a combination of criteria such as "high population density or high rate of previous SCA incidents", "population density, risk level of people and response time", "high population density, emergency medical services (EMS) response time being longer than 5 minutes and the expectance of at least one SCA incident in 5 years", or "high population, SCA risk and availability of user" (Becker et al., 1999; Balady et al., 2002; Gilchrist et al., 2010; Colquhoun et al., 2008).

2.3 Alternatives

AEDs in airports, airplanes and casinos have proven to be effective in prior studies, and major train stations, public squares and pedestrianized areas are places of frequent incidents of SCA (Folke et al., 2009). In a research study, covering a 28-month period, sports facilities, transportation facilities and other public areas were the locations with most SCA incidents (Nielsen et al., 2013). Brooks et al. (2013) state that retail stores, offices, shopping centers, industrial areas, race tracks/casinos, jails, hotels, hostels/shelters, convention centers, railway stations, campuses, sports arenas, swimming pools, and golf courses have high SCA risk. Muraoka et al. (2006) recommend railway stations, hospitals, elderly homes, playgrounds and golf courses for AED deployment. A study covering six major cities in the Netherlands shows that shops, catering facilities, hotels, museums, municipality buildings, cinemas, companies, office complexes, and educational institutions were locations most frequently chosen for AED deployment (Huig et al., 2014). According to a retrospective study, railway stations, nursing homes, medical facilities, and fitness facilities are the places where AED use is most frequent (Sasaki et al., 2011). Another study states that it would be reasonable to deploy AEDs in schools, fitness centers, sports arenas, stadiums, and locations of temporary sports events (Myerburg et al., 2005). Shopping malls, work places, exhibition halls, airports, harbor terminals, railway stations, sports arenas, fitness centers, golf courses, community centers, elderly homes, and jails are locations of relatively frequent SCA incidents, and would benefit from AED deployment (Becker et al., 1999).

It was reported that AEDs were installed in public locations, airports, sports arenas and golf courses in Los Angeles (Eckstein, 2012). A study reviewing the early results of the national defibrillator program in UK and Wales states that busy public places such as airports and major railway stations, sports facilities, workplaces, shopping centers, exhibition halls and major sporting venues are equipped with AEDs (Colquhoun et al., 2008).

There are also studies focusing on a particular location type and assessing risks and benefits of AED deployment in these locations, such as fitness facilities and sports

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venues, schools, subway stations, and university campuses (Page et al., 2013; Muraoka et al., 2006; Norton & Norton, 2008; Balady et al., 2002; Berger, 2009; Sweoret al., 2013; Watson et al., 2013; Gianotto-Oliveira et al., 2015; Myers & Mohite, 2009; Whitney-Cashio et al., 2012; Aragonés-Beltrán et al., 2014).

3. Methodology

Determining appropriate locations for AEDs is a problem of a complex nature with multiple criteria and alternatives, requiring a multi-criteria decision making (MCDM) approach to solve it. The Analytic Hierarchy Process (AHP) is an MCDM method developed by Saaty (Saaty, 1977). It structures the decision problem as a hierarchy consisting of multiple levels: the goal, criteria (together with sub-criteria if necessary) and alternatives. Saaty and Vargas (2012) explain the rationale of AHP as the hierarchical decomposition of complex systems being a basic device which is already used by the human mind to cope with diversity. For this reason, the AHP was chosen as the method to be used in this study.

AHP is considered an easy-to-use tool by many researchers, and is used in various domains such as marketing, finance, education, public policy, economics, medicine, and sports (Wu et al., 2007). AHP is preferred mainly because it allows decision makers to analyze complex problems with a systematic approach that breaks down the problem into levels which make it simpler and more affordable (Aragonés-Beltrán et al., 2014). The main strong point of AHP is that it enables handling not only tangible but also intangible criteria. On the other hand, AHP has also been subject to criticism, mainly because of the time it requires for a decision maker to make pairwise comparisons in complex models containing many levels (Wu et al., 2007).

AHP may also be used for rating alternatives according to their compliance to an "ideal". Instead of pairwise comparisons, each alternative is associated with a performance category such as "excellent", "average", or "poor". The importance of each alternative is obtained by multiplying the importance of the criterion and the compliance degree of the alternative. The ratings technique is recommended when there are a large number of alternatives (Saaty, 2006).

4. A real-life case study

4.1 Selected city and decision maker

Public access defibrillation has been a topic of interest in Valencia, and Valencia Polytechnic University (UPV) already has its own AED program. For years, the authorities responsible for the health policies of the City of Valencia and UPV have been sensitive about training non-medical staff in the use of AEDs, a process which is organized and standardized through the Valencian School of Health Studies. Trainings are regulated by a decree published in the Official Journal of the Generalitat Valenciana (Decree 220/2007 dated 02.11.2007).

UPV has trained 25% of its staff and 6 AEDs have been installed throughout the campus according to population density and distance criteria. The plan in the future is to equip two mobile security guards with AEDs based on a study that shows that their response

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time is less than three minutes. Because of the success of the UPV's AED program the decision was made to extend the MCDM-based model to determine suitable AED locations in the city of Valencia.

The decision maker (DM) was the coordinator of the AED program in UPV, a cardiologist and professor in Healthcare Technology and Biomedical Engineering programs in the School of Business Administration and Management of the UPV. A senior lecturer of Project Management in the Department of Engineering Projects of the UPV supervised and facilitated the decision making process.

4.2 Constituents of the decision model

A specific decision making process was designed for this case study (see Figure 1), based on the decision making process suggested by Topcu (2000).

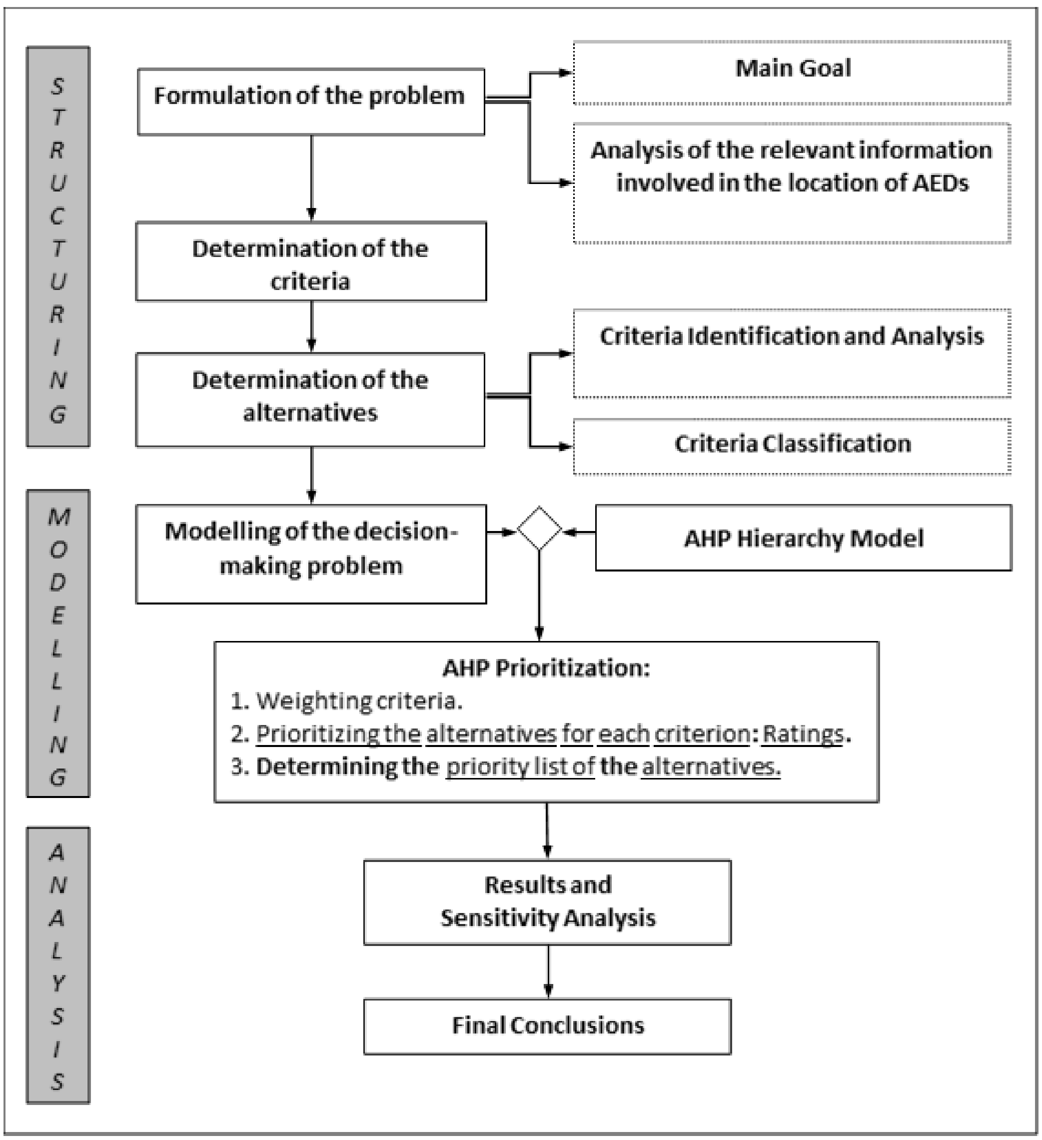

Figure 1. The decision making process.

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4.2.1 Evaluation criteria

After reviewing previous studies (as explained in detail in Section 2.2) four main criteria were agreed on:

1. Coverage Capacity: Number of people and the size of the area covered by the AED. It has two sub-criteria: 'Population Coverage' (i.e. the number of people the AED will serve) and 'Physical Coverage' (i.e. the physical area the AED will serve).
2. SCA Risk: Likelihood of witnessing SCA in the premises. It consists of two sub-criteria: 'Risk Level of People' and 'Risk Level of Activities'.
3. Response Time: Time needed to arrive at the victim's location. It has two sub-criteria: 'Time to Place' (i.e. the time it takes for an ambulance to arrive at the place from the moment it is called) and 'Time to Furthest Point' (i.e. the time it takes for the medical professionals to reach from the parking spot of the premises to the furthest point in the building, which reflects the "vertical response time" mentioned in previous studies).
4. Availability of an assigned user: Likelihood of a trained person to be near and able to recognize the need for AED.

Literature review on criteria affecting selection of locations for AED deployment shows that previous research agrees on the effect of criteria on the goal:

- An alternative with higher population coverage is a more suitable location for AED deployment (Balady et al., Becker, 1999; Gilchrist et al., 20012; 2002, Whitney-Cashio et al., 2012). "Population coverage" is a benefit attribute.
- An alternative with higher physical coverage is a more suitable location for AED deployment (Motyka et al., 2005; Myers & Mohite, 2008). "Physical coverage" is a benefit attribute.
- People with higher SCA risk make an alternative more preferred for AED deployment (American Heart Association, 2001; Balady et al., 2002; Becker et al., 1999; Brooks et al., 2013; Folke et al., 2009; Muraoka et al., 2006; Nielsen et al., 2013; Tsai et al., 2012). "Risk level of people" is a benefit attribute.
- Locations where high-risk activities are performed are more preferred alternatives for AED deployment (American Heart Association, 2001; Norton & Norton, 2008; Page et al., 2013). "Risk level of activities" is a benefit attribute.
- Longer response time of emergency medical services is linked to higher preference as an alternative for AED deployment (American Heart Association, 2001; Balady et al., 2002; Gilchrist et al., 2012). "Time to place" is a benefit attribute.
- Longer response time within the premises is linked to higher preference as an alternative for AED deployment (American Heart Association, 2001; Whitney-Cashio et al., 2012). "Time to furthest point" is a benefit attribute.

4.2.2 Potential locations

After reviewing previous studies and making meetings with the experts, 80 locations were selected as alternatives for the model. These locations were marked on a map using Google Maps and were sent to the decision maker to ensure that he had detailed knowledge on each. The map is accessible at https://www.google.com/maps/d/edit?mid=zCY0EY5RkUmE.kdqoLNSMHK8M.

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4.2.3 Decision hierarchy

A hierarchy of the decision model was constructed as seen in Figure 2.

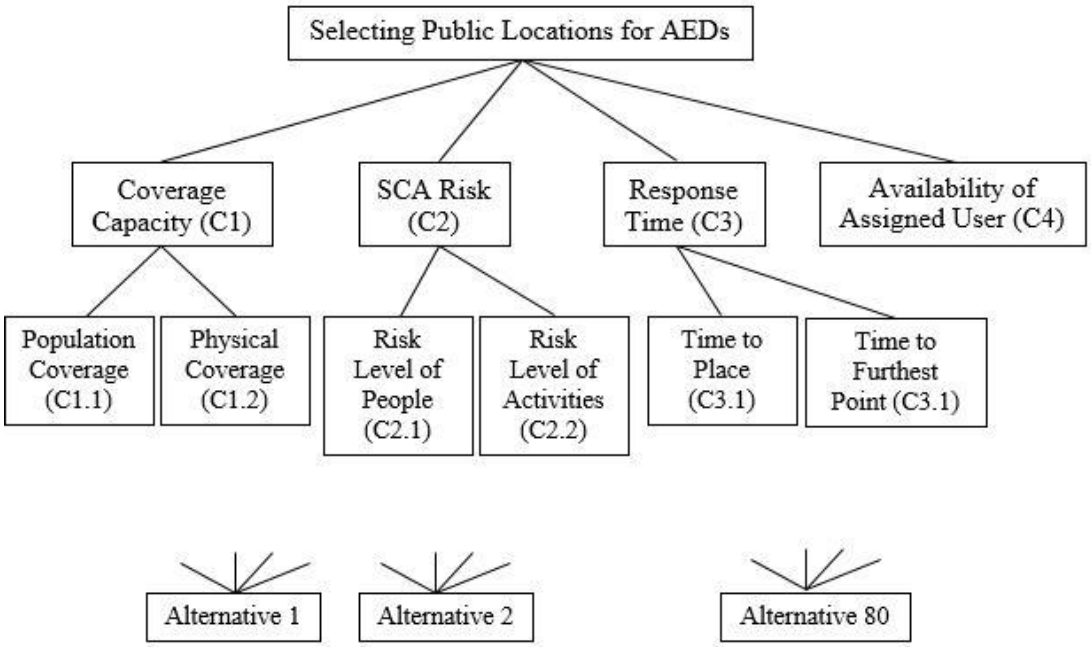

Figure 2. Hierarchy of the decision model

A 1-to-5 scale from very low to very high was used for rating the alternatives according to criteria population coverage, physical coverage, risk level of people, and risk level of activities; while a 1-to-5 scale from very short to very long was used for time to place and time to furthest point, and a 1-to-3 scale (not available, possible, available) was used for availability of assigned user.

4.2.4 Pairwise comparisons

A questionnaire was prepared and sent to the decision maker. The questionnaire consists of seven sections as indicated below:

- Introduction: Brief explanation of the model and the survey.
- Explanation of Criteria: The definitions of the criteria and sub-criteria.
- Explanation of the Survey: Detailed explanation of how to answer the questions.
- Explanation of the Scale in Spanish: The Spanish translation of Saaty's fundamental scale to assist the decision maker.
- Part 1: Questions for pairwise comparison of the criteria.
- Part 2: Questions for determining rating intensities of the criteria.
- Part 3: Questions for determining attributes of alternatives.

In Part 1 of the questionnaire, the decision maker is asked to make pairwise comparisons of criteria according to the goal and also those of the sub-criteria according to the criteria. In this part, Saaty's fundamental scale is used. In Part 2, the decision maker is asked to assign points to each performance level (i.e. rating intensity) from 0 to 100, according to

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its compliance degree. For this study, using the rating intensities that were assigned by the decision maker is preferred rather than assigning equal intervals to the performance levels. In other words, instead of automatically assigning 0, 25, 50, 75, and 100 points for the five levels of the criterion population coverage (C1.1), the assigned points 10, 20, 50, 80, and 100 are used. In Part 3, the decision maker is asked to select performance levels of the criteria for each of 80 alternatives.

Before responding to the questions, AHP and the nature of the pairwise comparisons were explained in detail to the DM by the AHP expert, and the DM answered the questions under his surveillance.

5. Results and sensitivity analysis

According to the results of the study, response time is by far the leading criterion with an importance of 65.07%, followed by SCA risk with 23.13%, coverage capacity with 7.65%, and availability of assigned user with 4.14%. The sub-criteria of response time and SCA risk have equal importance with respect to the main criterion. The importance of physical coverage with respect to coverage capacity is 83.33% while population coverage has an importance of 16.67%.

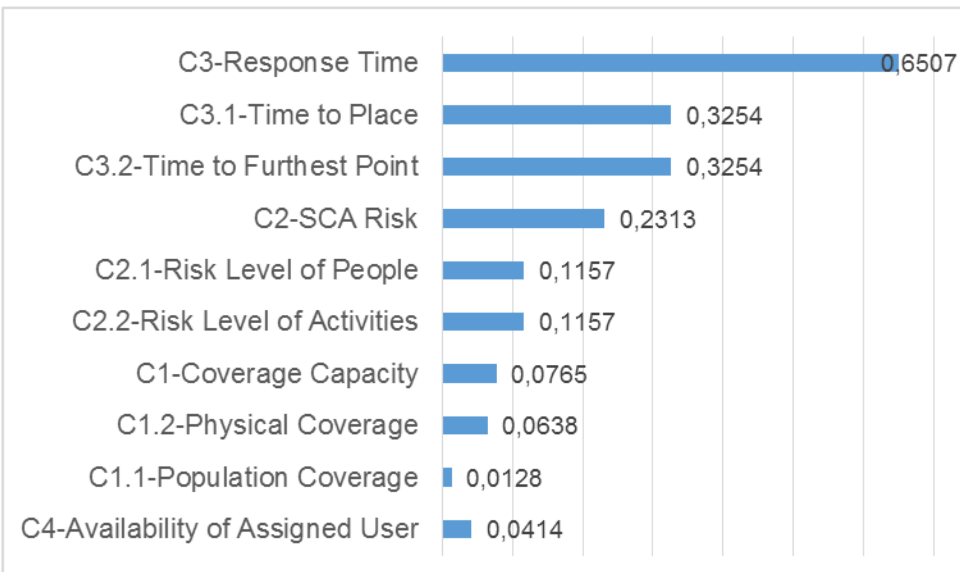

Figure 3. Importance of criteria according to the goal

Researchers agreed that a simple ranking of the alternatives would not be sufficient for the purpose of this study because the aim is to offer a guide for selecting locations for deploying AEDs rather than ranking the alternatives according to their suitability. Therefore, we formed priority groups. The global scores of all alternatives were plotted on a graph in descending order to determine possible separation points (see Figure 4). Observing these separation points, we divided alternatives into four priority groups.

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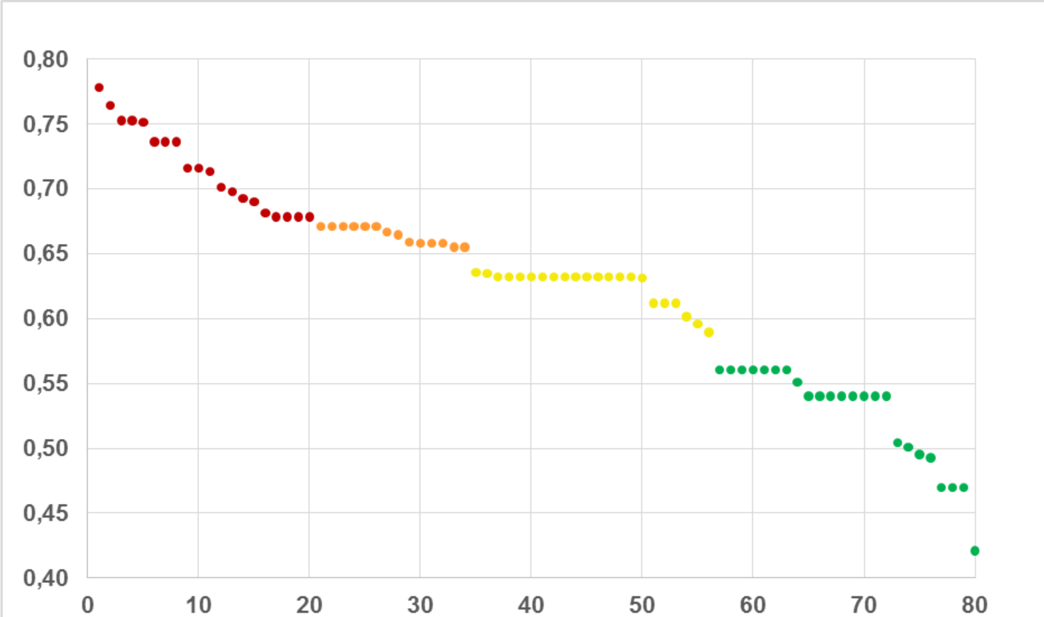

Figure 4. Grouping alternatives according to their global scores

The first-priority group consists of 20 alternatives with the highest global scores. This group represents the locations that should be considered as first priority or may be the subject of a pilot study. Other groups of descending priorities have 15, 21, and 24 alternatives respectively.

For a better and more sound understanding of the model, we performed a sensitivity analysis of the results to changes in the weights of the main criteria. Eight scenarios were tested and compared with the original results, each scenario representing the situation where one of the main criteria has either 100% or 0% importance.

For a better comparison in terms of priorities of the groups, the number of alternatives belonging to each priority group was not kept the same for all scenarios. Instead, the global scores of the alternatives belonging to each scenario were analyzed, similar to what had been done for the original results, and the alternatives were grouped accordingly. This caused differences in the number of alternatives in each group for different scenarios. The number of alternatives in each priority group of all scenarios is summarized in Table 1.

Table 1
Number of alternatives in priority groups for each scenario

	Orig.	Scn 1 (w_{C3} =1)	Scn 2 (w_{C3} =0)	Scn 3 (w_{C2} =1)	Scn 4 (w_{C2} =0)	Scn 5 (w_{C1} =1)	Scn 6 (w_{C1} =0)	Scn 7 (w_{C4} =1)	Scn 8 (w_{C4} =0)
First-Priority	20	67	20	16	22	21	19	58	23
Second-Priority	15	5	20	21	19	9	13	22	12
Third-Priority	21	6	19	26	18	31	29	-	18
Fourth-Priority	24	2	21	17	21	19	19	-	27

We believe that a closer look at the sensitivity of the first-priority group to the scenarios would be useful. The rankings and groups of the first 20 alternatives are shown in Table 2 with colors showing their priority groups: red for first priority group, orange for second, and yellow for third. These alternatives are mostly in the first-priority group for all scenarios. The first 10 alternatives especially show strong insensitivity to changes, illustrating their robustness.

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Table 2
Ranking of first-priority group for each scenario

Alt. #	Name	Rank	Scn 1	Scn 2	Scn 3	Scn 4	Scn 5	Scn 6	Scn 7	Scn 8
A27	**Nazaret Sports Center**	**1**	**1**	**14**	**4**	**1**	**31**	**1**	**1**	**1**
A30	**Valencia City Stadium**	**2**	**2**	**1**	**1**	**2**	**1**	**2**	**1**	**2**
A01	**Central Market**	**3**	**2**	**3**	**4**	**2**	**1**	**4**	**1**	**3**
A07	**Valencia Central Bus Station**	**3**	**2**	**3**	**4**	**2**	**1**	**4**	**1**	**3**
A29	**Stadium on Av. de les Corts Vlc.**	**5**	**2**	**7**	**1**	**5**	**8**	**2**	**1**	**5**
A08	**City Hall (Ayuntamiento)**	**6**	**2**	**8**	**4**	**7**	**12**	**4**	**1**	**6**
A15	**Malvarrosa Beach**	**6**	**2**	**8**	**4**	**7**	**12**	**4**	**1**	**6**
A18	**UPV Vera Campus**	**6**	**2**	**8**	**4**	**7**	**12**	**4**	**1**	**6**
A16	**UV Blasco Ibáñez Campus**	**9**	**2**	**12**	**4**	**19**	**12**	**10**	**59**	**6**
A17	**UV Tarongers Campus**	**9**	**2**	**12**	**4**	**19**	**12**	**10**	**59**	**6**
A28	UV Sports Center Av. Pr. Reig	11	2	14	4	23	31	4	1	11
A21	Cabanyal Sports Center	12	2	16	17	7	12	13	1	13
A25	School of San José	13	2	17	17	12	22	13	1	15
A20	Sports Center in Garden Turia	14	2	19	4	53	31	10	59	11
A52	Cabanyal Train Station	15	2	20	28	7	12	20	1	16
A24	Alboraya Industrial Zone	16	2	21	17	19	12	28	59	13
A26	Nazaret Football Pitch	17	2	22	17	23	31	13	1	17
A69	Patacona Sports Complex	17	2	22	17	23	31	13	1	17
A76	Mercavalència Wholesale Center	17	2	22	17	23	31	13	1	17
A77	Barri de la Llum Sports Center	17	2	22	17	23	31	13	1	17

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6. Conclusions and further suggestions

The aim of this study was to provide a novel approach to the problem of selecting suitable locations for AEDs by using the Analytical Hierarchy Process (AHP), and to utilize the decision model on a case study, aiming to serve as a guideline for health policy decision makers in future projects.

After reviewing previous studies on this topic, the criteria and alternatives were determined. The decision problem consisted of four main criteria, six sub-criteria, and 80 alternatives. Ratings were done by a decision maker who is an expert on AED programs under the supervision of a professor who is an expert on AHP.

Response time was the most important criterion with an importance of 65.07%, followed by SCA risk (23.13%), coverage capacity (7.65%), and availability of assigned user (4.14%). However, it was interesting to observe that remote locations such as public gardens did not have high preferences. This shows that although the criterion response time dominates the selection, other criteria play an important role since most locations do not differ much in terms of response time.

We believe that a simple ranking of the alternatives is not sufficient for the purpose of this study. We formed priority groups instead. Global scores of all alternatives were analyzed and four groups with descending priorities were formed. Sensitivity analysis showed that especially the alternatives in the first-priority group are not highly sensitive to changes, illustrating their robustness. This is particularly true for the first ten locations as shown in Table 2.

Although providing a novel approach, this study may be further improved. The first step would be expanding the geographical area of the survey. Using multiple decision makers might also provide valuable results. Additionally, different decision making models might be used to compare results. Finally, yet importantly, it is obvious that having one AED would not be enough for some locations, considering that the size and physical structure of locations such as a stadium or a shopping mall make it impossible for a responder to bring the AED to the patient in less than 10 minutes, which is the rule of thumb in the literature. A valuable contribution to this study would be determining the number of AEDs needed in each location.

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