Journal of the Operational Research Society (2009) 60, 869–872

www.palgrave-journals.com/jors/

Locating automated external defibrillators in a university community

DC Myers* and M Mohite

Bowling Green State University, Bowling Green, OH, USA

Automated external defibrillators (AEDs) use smart technology to determine whether a victim of cardiac arrest requires defibrillation and will deliver a shock only if one is needed. These portable devices are becoming increasingly more available in such places as airports, shopping malls, and sports facilities. This article reports on a model for determining appropriate locations for AEDs in a university community. Additionally, we describe difficulties encountered when attempting to implement the results obtained from the model.

Journal of the Operational Research Society (2009) **60,** 869–872. doi:10.1057/palgrave.jors.2602615
Published online 28 May 2008

Keywords: risk management; covering; location problems; health

Introduction

Cardiovascular disease is a major public health problem and is the leading cause of death in the United States. Between 300 000 and 400 000 Americans die each year due to cardiac arrest, a sudden and unexpected loss of heart function. When cardiac arrest occurs inside a hospital, medical personnel administer an electric shock to the patient in an attempt to restore the heart to a normal rhythm. If this is done early enough, there is a high probability (50–90%) that the patient will survive. The survival probability shrinks quickly with the passing of time (about 10% per minute) (Toeppen-Sprigg *et al*, 2003).

Automated external defibrillators (AEDs) are portable devices designed to use smart technology that automatically determines whether a victim's heart requires a shock and will only deliver a shock if one is needed. Voice instructions guide the user throughout the procedure. For ease of access, these devices are usually located in a wall cabinet similar to those housing fire extinguishers (see Figure 1). AEDs have been shown to be a safe and effective method of defibrillating a victim even when used by children (Gundry *et al*, 1999).

In June of 1999, Chicago's O'Hare and Midway Airports installed AEDs in sufficient numbers so that the response time to reach the victim is 1 min (Chicago HeartSave™ Program (Bond, 1999)). As of 11 April, 2004, a Federal Aviation Administration (FAA) rule went into effect requiring every big jet in the US fleet to have a defibrillator on board (Davis, 2004). The FAA had been debating the rule for 4 years.

The cost of AEDs has reached a level where these devices are affordable even for home use. One manufacturer offers a home defibrillator with 'technology identical to those in use on airplanes and in airports, workplaces, and communities around the world' (http://www.heartstarthome.com). While individual purchases for home use require a prescription in most states, thousands of the devices have been purchased by shopping malls, golf courses, and, more recently, universities.

Problem description

This article reports on a model developed at a mid-western United States university for locating AEDs obtained from a grant. The Director of Risk Management was given the task of determining appropriate locations for the AEDs to provide timely response capability for medical emergencies requiring defibrillation. Medical authorities report that a victim of cardiac arrest has the best chance of survival without neurological damage if care is received within 3–5 min of occurrence (American Heart Association, 2001). (Actually, this time is a source of contention. Various sources use anywhere from 3 to 8 min, although shorter times are clearly better for the victim.) Thus, the goal of our analysis was to determine the location of the AEDs so that every member of the university community would be within 4 min of one of the devices. Certain of the locations were easy to determine since those areas were either isolated from other areas of the university (greater than 4 min from the nearest other facility) or was an area with an increased likelihood of having a need for these devices (such as the golf course, recreation centre, and football stadium complex).

Related research

The mathematical model developed is known in the literature as a covering model. We wanted to provide 'coverage'

Correspondence: DC Myers, Department of Applied Statistics and Operations Research, Bowling Green State University, Bowling Green, OH 43403, USA.
E-mail: myers@bgsu.edu

Figure 1 AED in wall-mounted storage cabinet.

to all university areas with the available AEDs. The covering problem is a well-known problem in management science and numerous practical applications of set covering methodology have been documented. Plane and Hendrick (1977) used a set covering model to locate fire companies in Denver. Current and O'Kelly (1992) developed set covering models for locating emergency sirens to warn citizens of approaching severe weather. In 1979, Sweeney *et al* used a similar model to determine the number of banking facilities required to permit a regional banking firm to do business in all counties of a mid-western state. Brotcorne *et al* (2003) recently reviewed 30 years of ambulance location and re-location model research.

Previous research in the management science literature involving AEDs includes determining the cost effectiveness of the units and equitable allocations of AED units. Rauner and Bajmoczy (2003) investigate cost effectiveness of AEDs for the Austrian Red Cross. Mandell and Becker (1996) use a multi-objective integer programming model to assist decision makers in determining which basic life support companies to equip with AEDs in order to achieve an equitable survival rate.

Model

Prior to model construction, data had to be collected regarding the estimated travel times between pairs of buildings. Student teams from the first author's management science class were assigned the duty of determining these times. The times were obtained by actually walking (at a hurried pace) from building to adjacent building. The collected times were then used to estimate times between non-adjacent buildings. For some of the buildings, this was essentially an additive process. For other pairs of buildings, the actual walking distance was used. These times were then used to create a coverage matrix. A Microsoft® Excel spreadsheet was set up with one array containing the actual building-to-building time estimates and another array containing binary values indicating whether the buildings are 'reachable' within the desired 4 min time limit.

Using the binary coverage matrix, a spreadsheet model was constructed with a cell allocated for each campus building in which AEDs could be located. These cells would eventually contain a binary value indicating whether the building was selected or not. Dormitories, fraternities, and sororities were not considered as acceptable locations for AEDs due to the potential for misuse by building occupants. (These facilities were included as buildings that must be reachable within the time limit.)

In the initial model, x_i is a binary variable which will have a value of 1 if an AED is located in area i and a value of 0 otherwise. Also, y_i is a binary variable which will have a value of 1 if university area i is covered by an AED (within the required time limit) and a value of 0 otherwise. The model is given as

$$\text{Max} \quad \sum_{i=1}^{B} y_i \tag{1}$$

$$\text{s.t.} \quad \sum_{j=1}^{B} x_j = D \tag{2}$$

$$\sum_{j \in C_i} x_j \geqslant y_i, \qquad i = 1, \ldots, B \tag{3}$$

$$x, y \text{ binary} \tag{4}$$

where B is the number of buildings on campus, D is the number of defibrillating devices available, and C_i is an index set indicating that areas are within the maximum time limit of area i. The Director of Risk Management identified 107 university facilities that were to be covered by the AEDs and 58 viable locations for the units. Thus, the model had 165 binary variables and 107 constraints.

Grant funds were considered sufficient for the purchase of nine additional AEDs to go with the three the university already had (thus, $D = 12$). The initial model above involved maximizing the number of facilities reachable within the desired time limit by appropriate placement of the 12 AEDs. The results indicated that the entire campus community could, indeed, be covered with these 12 AEDs. However, campus security officials felt that, instead of locating each of the AED units in a specific building, the campus community would be better served by reserving three of the units for use in campus police patrol cars. This led to the consideration of

Table 1 Maximum coverage with fixed number of AEDs

# of AEDs	*# Campus locations covered (within 4 min)*
1	64
2	84
3	94
4	99
5	102
6	104
7	106
8	107
9	107
10	107
11	107
12	107

a variation of the original model to determine the minimum number of AEDs needed to provide timely coverage for all campus facilities. This model is shown below:

$$\text{Min} \quad \sum_{j=1}^{B} x_j \tag{5}$$

$$\text{s.t.} \quad \sum_{j \in C_i} x_j \geqslant 1, \qquad i = 1, \ldots, B \tag{6}$$

$$x \text{ binary} \tag{7}$$

Since some campus buildings are open for longer periods of time and/or may serve a larger part of the campus community (eg student union, recreation centre), a third model variant was constructed to allow consideration of such issues. This involved attaching weights to each building variable to reflect the relative size and composition of the campus population served by the building. This did not affect the number of AEDs needed, but it did generate AED placements more acceptable to the Director of Risk Management.

Discussion of results

The solution to the initial model indicated that, given the freedom to objectively determine the AED locations, the entire campus community could be covered within the desired 4 min with 12 AEDs. In fact, Table 1 shows that this coverage is achievable with as few as eight units. However, as mentioned earlier, the university already had three of these devices. These had been provisionally placed and the university was reluctant to move them. One of these had been purchased with non-university funds for placement in a specific location and its removal would be particularly problematic. Further, the Director of Risk Management had previously been advised by an oversight committee where six of the soon to be purchased AEDs should be placed. This was determined by identifying campus locations frequented by relatively large numbers of people, in particular, athletic facilities. Added to this was the insistence by campus security officials that three of the devices be earmarked for installation in campus security cruisers. Thus, it seems that all of the locations for the AEDs had been pre-determined.

Table 2 Coverage provided by preliminary AED locations

# of Minutes	*# locations covered*
4	84
5	91
6	92
7	93
8	99
9	104
10	106
11	107

Running the covering model with these restrictions showed that this configuration would provide 4 min coverage for only 84 of the 107 campus facilities. Some campus facilities would require as long as 9–11 min to be reached from this pre-determined placement of the AEDs. Table 2 summarizes this analysis. It was further determined that to reach the entire university community within 4 min while maintaining these pre-determined placements would require the acquisition of five more AEDs beyond those currently approved. Additional runs of the model showed that moving just one of the AEDs would increase the coverage from 84 to 96, and placing only two AEDs (instead of the three requested) in campus security cruisers would provide an identical improvement in coverage. Making both of these changes simultaneously would provide coverage to 101 of the 107 campus facilities. After some discussion with the oversight committee, it was decided to re-locate these two devices. Campus coverage thus increased from 78.5 to 94.4%. However, the committee could not be convinced to rearrange other AEDs in order to reach 100% coverage. Re-solving the model with the re-located devices indicated that two additional devices would be necessary to provide complete campus coverage (instead of the five originally thought to be needed). The committee agreed to place subsequently obtained devices in the locations determined by the computer model.

In addition to determining the AED locations, the oversight committee has established guidelines for their use. An area coordinator assigned to each AED location is responsible for maintaining sufficient personnel trained in their use. At least two certified employees (certified in AED usage as well as cardio-pulmonary resuscitation (CPR)) are to be available at each AED site whenever the facility is open.

We (the authors) were somewhat disappointed at our inability to convince the oversight committee to adopt the AED placements that achieve 100% campus coverage. This unfortunate outcome is due mostly to the lateness of our participation in the decision-making process. Our involvement began after reading in the campus newspaper about the receipt of the grant for obtaining the AEDs. Apparently, this was already too late. The university already had three AEDs in place around campus. No consideration was seriously given to the possibility of re-locating these. Also, the oversight committee had already met to discuss the placement of the incoming devices. Some locations were chosen due to some committee members' perception of them as 'high-risk' areas. They deemed it more important to have an AED in each of these critical areas than to have one in a nearby facility even though some of the critical areas could be easily reached from a nearby facility within the time limit. While the committee was impressed by the model(s) later presented by the authors (and some members expressed surprise that such models are available), it should come as no surprise to OR/MS practitioners that it is very difficult to change decisions once they are already made. The good news, however, is that this project started a dialogue between the authors and campus security officials regarding other campus situations that may benefit from an OR/MS approach. On a higher level, even better news is that the availability of the AEDs on campus has already resulted in one life being saved.

Summary

This article describes a model (and several variations) for determining appropriate locations for AEDs in a campus community. The appropriateness of a location depends on several factors, which include time and population considerations. Solutions obtained for each model varied and disagreed with some of the pre-determined locations identified by an oversight committee. While the models identified locations that assure 100% coverage within the desired time, the pre-determined locations had been selected due to some committee members' perception of them as 'high-risk' areas and there was some reluctance by these members to consider alternative sites. After an extended discussion of the model results, the committee agreed to re-locate two of the devices to locations identified by the model. This increased campus coverage from 78% to nearly 95% with the further benefit of reducing the need for additional AEDs (to achieve 100% coverage) from five to two.

With the prices of the devices decreasing and liability suits becoming more prevalent, more university communities may consider purchasing AEDs for their campuses as part of their risk management strategy. Models such as those described herein can be useful in guiding them on purchase and location issues. Given the authors' experience, it is important that campus officials be made aware of the potential for such models early in the decision-making process.

References

American Heart Association (2001). Placing AEDs—where and how many? Available at http://www.americanheart.org/downloadable/heartsmart/10957144473924Bplaceaed.pdf.

Bond M (1999). Chicago Airport System Unveils HeartSave™ Program—first publicly available lifesaving device in country. http://www.flychicago.com/doa/avi_news/doa_avi_news_pr_1.shtm.

Brotcorne L, Laporte G and Semet F (2003). Ambulance location and relocation models. *Eur J Oper Res* **147**: 451–463.

Current J and O'Kelly M (1992). Locating emergency warning sirens. *Decision Sci* **23**: 221–234.

Davis R (2004). U.S. jets must now have defibrillators on board. *USAToday* Online Edition, http://www.usatoday.com/travel/news/2004-04-11-jets-defibs_x.htm.

Gundry J, Comess K, DeRook F, Jorgenson D and Bardy G (1999). Comparison of naïve sixth-grade children with trained professionals in the use of an automated external defibrillator. *Circulation* **100**: 1703–1707.

Mandell M and Becker L (1996). A model for locating automatic external defibrillators. *Socio-Econ Plan Sci* **30**: 51–66.

Plane D and Hendrick T (1977). Mathematical programming and the location of fire companies for the Denver fire department. *Opns Res* **25**: 563–578.

Rauner M and Bajmoczy N (2003). How many AEDS in which region? An economic decision model for the Austrian Red Cross. *Eur J Oper Res* **150**: 3–18.

Sweeney D, Mairose R and Martin R (1979). Strategic planning in bank location. *Proceedings of the Annual Meeting, American Institute of Decision Sciences, New Orleans, LA*. Home Office: Atlanta, Georgia.

Toeppen-Sprigg B, Hudson W, Konicki D, Dilorio C and Kennedy P (2003). Utilization and impact of AEDs in the workplace: A survey of occupational health physicians. *Am Coll Occup Environ Med*, October. Available at http://www.acoem.org/AEDSurveyResults.aspx.

Received May 2007;
accepted February 2008 one revision