
Reducing Ambulance Response Times Using Geospatial–Time Analysis of Ambulance Deployment

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Abstract

Objectives: This study aimed to determine if a deployment strategy based on geospatial–time analysis is able to reduce ambulance response times for out-of-hospital cardiac arrests (OOHCA) in an urban emergency medical services (EMS) system.

Methods: An observational prospective study examining geographic locations of all OOHCA in Singapore was conducted. Locations of cardiac arrests were spot-mapped using a geographic information system (GIS). A progressive strategy of satellite ambulance deployment was implemented, increasing ambulance bases from 17 to 32 locations. Variation in ambulance deployment according to demand, based on time of day, was also implemented. The total number of ambulances and crews remained constant over the study period. The main outcome measure was ambulance response times.

Results: From October 1, 2001, to October 14, 2004, a total of 2,428 OOHCA patients were enrolled into the study. Mean \pm SD age for arrests was 60.6 ± 19.3 years with 68.0% male. The overall return of spontaneous circulation (ROSC) rate was 17.2% and survival to discharge rate was 1.6%. Response time decreased significantly as the number of fire stations/fire posts increased (Pearson $\chi^2 = 108.70$, $df = 48$, $p < 0.001$). Response times for OOHCA decreased from a monthly median of 10.1 minutes at the beginning to 7.1 minutes at the end of the study. Similarly, the proportion of cases with response times < 8 minutes increased from 22.3% to 47.3% and < 11 minutes from 57.6% to 77.5% at the end of the study.

Conclusions: A simple, relatively low-cost ambulance deployment strategy was associated with significantly reduced response times for OOHCA. Geospatial–time analysis can be a useful tool for EMS providers.

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Geographic information systems (GIS) are computer-based systems for the integration and analysis of geographic data. GIS is a multilayering mapping software that is able to portray multiple geographic–time information in an easy-to-read, graphical manner. “Geographic data” are spatial data that result from observation and measurement of phenomena referenced to their locations on the earth’s surface.

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Using GIS technology, we are able to depict such time-geographic patterns to aid planning for ambulance deployment.

Geographic information systems facilitate modeling of events in simulations and for planning.^{1,2} For example, system status management is a technique using GIS that matches the movement of ambulances in anticipation of where they will be needed.³

It has been noticed that acute medical events like cardiac arrests are not random events, but rather have definite time-geographic distribution patterns.⁴⁻⁶ This is related to the underlying population demographics and movement patterns.

Of the approximately 16,000 deaths that occur in Singapore every year, about 23% will be from a cardiac cause,⁷ of which some 30% to 40% will occur suddenly, outside of a hospital. The mechanism of death is usually a fatal arrhythmia, most often ventricular tachycardia or fibrillation.⁸

Out-of-hospital response intervals are an important factor affecting patient outcomes in any emergency medical services (EMS) system, especially for out-of-hospital cardiac arrest (OOHCA).^{9,10} The "chain-of-survival" concept¹¹ states that survival can be improved with early access, early cardiopulmonary resuscitation (CPR), early defibrillation, and early advanced care. There is currently good evidence that indicates the importance of delivering early defibrillation (<4 minutes).¹²⁻¹⁵

We aimed to determine if a deployment strategy based on geospatial-time analysis is able to reduce ambulance response times for OOHCA in an urban EMS system. This study was a part of the Cardiac Arrest and Resuscitation Epidemiology (CARE) project.¹⁶

METHODS

Study Design

This was an observational, prospective study examining the geographic location of OOHCA in Singapore, as well as the effect of increasing the number of ambulance satellite stations on response times. The study period was October 2001 to October 2004. Institutional review board approval was obtained from all participating institutions.

Study Setting and Population

Singapore is a city-state with a land area of 707.1 km² and a population of 4.6 million. The island's EMS system is run by the Singapore Civil Defense Force (SCDF), which operates the national 9-9-5 emergency telephone service. 9-9-5 is a nationwide, centralized, enhanced dispatching system, using computer-aided dispatch, medical dispatch protocols, global positioning satellite automatic vehicle locating systems, and road traffic monitoring systems.

At the time of the study, the SCDF operated 32 ambulances based in fire stations. It is primarily a single-tier system, able to provide basic life support and defibrillation with automated external defibrillators (AEDs). Private ambulances do not attend to emergencies like cardiac arrest. The system does not use fire or police first-responders; however, motorcycle paramed-

ics with AED capability are used to reach the patients in shorter time intervals than an ambulance. These motorcycles are deployed in fire stations and were treated like ambulances for the purpose of calculating response intervals for this study. There was no change in the number of motorcycles over the period of the study.

The CARE study group includes representatives from the six major public hospitals in Singapore, the SCDF, Health Sciences Authority, and the Clinical Trials and Epidemiology Research Unit. CARE phase I found survival from OOHCA in Singapore to be 2.0%.¹⁶ Mean (\pm SD) EMS response time was 10.2 (\pm 4.3) minutes. Mean (\pm SD) time from call to defibrillation was 16.7 (\pm 7.2) minutes.

All patients with OOHCA as confirmed by the absence of a pulse, unresponsiveness, and apnea were included. Exclusion criteria were those "obviously dead" as defined by the presence of decomposition, rigor mortis, or dependent lividity.

Study Protocol

A progressive strategy of satellite ambulance deployment was implemented, increasing ambulance bases from 17 (2001) to 32 (2004) locations while keeping the overall number of ambulances constant (Figures 1 and 2). This means that new fire posts were added at intervals over the period of the study according to a schedule.

At the beginning of the study, an average of two to three ambulances were deployed at each fire station. A team was set up to plan a redistribution of ambulances according to geographic location of demand (cardiac arrest as well as all 9-9-5 calls), location of population centers, and availability of land and space for satellite fire posts. The team examined a map and simply moved resources to higher concentration areas according to demand. No geospatial statistical analyses or simulation testing were performed during this study.

Over the period of the study, ambulances were redeployed at satellite fire posts according to geographic location and spread out to cover a wider area. Satellite fire posts were usually located at the empty spaces of residential public housing blocks and community centers. Variation in ambulance deployment according to demand on time of day was also implemented. Initially, the number of ambulances deployed during the day (7 a.m.–7 p.m.) and night shifts (7 p.m.–7 a.m.) was the same. This was gradually changed to have more ambulances cover the day shift than at night. The total number of ambulances and crews remained constant over the study period, with the same total number of shifts staffed in each phase of the study.

Out-of-hospital cardiac arrest patients were prospectively identified by the attending paramedics, who had to fill out a standardized cardiac arrest clinical form. This was used for routine clinical purposes, and a copy was collected for the research database. Patient characteristics, cardiac arrest circumstances, electrocardiogram rhythms, and EMS response times were prospectively recorded in a standard report according to the Utstein style. Geographic location of cardiac arrests (including postal code) and type of location



Figure 1. Ambulance deployment strategy of the study.

(house, office, public place, shopping mall, school, etc.) was also recorded. EMS timings were automatically recorded by the computerized central dispatch system. All watches and timings were synchronized with the central dispatch clock at the beginning of each shift.

Outcome Measures

The main outcome measure was ambulance response time, defined as the interval from the time the 9-9-5 call is received to the time the vehicle arrives at scene. In addition to overall response time to OOHCA cases, we also examined the proportions of calls with response intervals of < 11 minutes (our system's current response time target) and < 8 minutes (our future response time target). Secondary outcome measures were return of spontaneous circulation (ROSC) and survival to either hospital discharge or 30 days post-cardiac arrest, whichever came first. We used the definition for survival to 30 days as equivalent to surviving the primary event. It was assumed that deaths after 30 days were not related to the primary event.

Data Analysis

Data management was carried out using the Clintrial application software version 4.4 (Phase Forward Inc., Waltham, MA). All data analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL), presenting

descriptive statistics and frequencies. Location of cardiac arrests was spot mapped using GIS technology (ArcGIS9, ESRI, Redlands, CA). This was graphically displayed according to postal codes and correlated with other cardiac arrest factors including time of day, day of week, mean age of the cardiac arrest patients, and ambulance response times.

The Pearson chi-square was used to check the association between response time (grouped) and number of stations. A log-normal regression line was used to investigate the effect of the number of stations to response time. An F-test analysis of variance was used to assess the overall fitting of the regression line. A binomial logistic regression line was used to investigate the effect of response time to ROSC and survival to hospital discharge. The binomial logistic model was adjusted to covariates age, sex, collapse witnessed, initial rhythm, bystander CPR, and defibrillation. Assessment of goodness of fit was done by the Hosmer-Lemeshow test.

RESULTS

From October 2001 to October 2004, a total of 2,428 patients were enrolled into the study. Table 1 shows the characteristics of patients in the study. The mean \pm SD

Table 1
Study Patients' Characteristics

Characteristic	All Patients (N = 2,428)
Mean \pm SD age, yr (n = 2,413)	60.6 (\pm 19.3)
Male	1,652 (68.0)
Race	
Chinese	1,687 (69.5)
Malay	365 (15.0)
Indian	267 (11.0)
Others	109 (4.5)
Arrest location	
Residential homes	1,629 (67.8)
Other	772 (32.2)
Collapse witness (n = 2,418)	
Bystander	1,318 (54.5)
EMS witnessed	255 (10.6)
Not witnessed	845 (34.9)
Bystander CPR	478 (19.7)
Initial rhythm (n = 2,197)	
Ventricular fibrillation	424 (19.3)
Ventricular tachycardia	12 (0.5)
Asystole	1,162 (52.9)
Pulseless electrical activity	599 (27.3)
Defibrillated	525 (21.6)
Call receipt to arrive at scene, min (n = 2,261)	9.0 (6.8–11.4)
Arrived at scene to leave location, min (n = 2,253)	10.0 (7.0–12.6)
Leave location to arrive at hospital, min (n = 2,251)	10.0 (7.0–14.2)
ROSC	417 (17.2)
Survival to admission	215 (8.9)
Survival to discharge	38 (1.6)

Data are reported as n (%) or median (IQR), unless otherwise noted.
IQR = interquartile range; ROSC = return of spontaneous circulation.

Table 2
Quarterly Progressive Strategy of Ambulance Deployment

Time Period	No. of Fire Stations and Fire Posts	No. of Cases	% Defibrillated	Median (IQR) Response Time (min)	% Response Time	
					<8 minutes	<11 minutes
Oct 01–Dec 01	19	224	17.0	10.0 (8.0–13.0)	22.3	57.6
Jan 02–Mar 02	21	223	25.6	10.1 (7.6–12.7)	25.6	56.1
Apr 02–Jun 02	21	198	20.7	8.8 (6.8–11.6)	38.4	68.7
Jul 02–Sep 02	22	191	24.6	9.0 (6.9–10.9)	38.7	76.4
Oct 02–Dec 02	24	186	27.4	8.5 (6.3–11.3)	42.5	71.5
Jan 03–Mar 03	25	164	19.5	8.9 (6.9–11.0)	40.9	76.8
Apr 03–Jun 03	25	169	24.9	9.3 (6.7–11.2)	37.3	68.0
Jul 03–Sep 03	26	139	18.7	8.7 (6.8–10.8)	38.1	79.1
Oct 03–Dec 03	27	176	19.9	8.1 (6.0–10.4)	44.3	78.4
Jan 04–Mar 04	31	220	22.3	8.6 (6.7–12.1)	41.4	70.9
Apr 04–Jun 04	32	157	26.1	8.6 (6.3–11.7)	43.3	71.3
Jul 04–Oct 04	32	222	22.1	8.0 (6.0–10.7)	47.3	77.5

age for arrests was 60.6 ± 19.3 years with 68.0% male. The overall ROSC rate was 17.2% and the survival-to-discharge rate was 1.6%. Of these 2,428 patients, 159 patients were conveyed by either private ambulances or private vehicles, and these cases were excluded from the analysis.

Table 2 shows the quarterly progressive strategy of ambulance deployment. We found that response times for OOHCA decreased from a monthly median of 10.1 minutes at the beginning to 7.1 minutes at the end of the study. Similarly, the proportion of cases with response times < 8 minutes increased from 22.3% to 47.3% and < 11 minutes increased from 57.6% to 77.5% at the end of the study.

Figure 2 shows the median response time and number of fire stations and fire posts by month. Response time decreased significantly as the number of fire stations and fire posts increased (Pearson $\chi^2 = 108.70$, $df = 48$, $p < 0.001$). Results of log-linear regression to response time also suggested that as the number of stations increased, response time significantly decreased (estimated $\beta = 0.011$, 95% confidence interval [CI] = -0.015 to -0.008 , $p < 0.001$). Figure 3 shows the distribution of yearly cardiac arrest cases by time of day.

A binary logistic regression was fitted to ROSC including all factors to the model (Hosmer and Leme-

show test: $\chi^2 = 4.09$, $df = 8$, $p = 0.849$). From the fitted model, we found that response time had no significant effect on ROSC (odds ratio [OR] = 1.0, 95% CI = 0.96 to 1.01), but sex and witnessed arrest were found to be significant factors to the outcome. It was found that females were two times more likely to have ROSC than males (OR = 2.1, 95% CI = 1.65 to 2.62). Patients whose collapse was witnessed were 1.6 times more likely to have ROSC (OR = 1.6, 95% CI = 1.22 to 2.17). Among the variables, age (OR = 1.0, 95% CI = 0.99 to 1.00), initial rhythm (OR = 1.0, 95% CI = 0.52 to 1.93), bystander CPR (OR = 1.3, 95% CI = 0.98 to 1.80), and defibrillation (OR = 1.1, 95% CI = 0.80 to 1.55) were not significant for ROSC.

Similarly, a binary logistic regression was fitted to survival to discharge (Hosmer and Lemeshow test: $\chi^2 = 7.45$, $df = 8$, $p = 0.489$). From the fitted model, we found that response time was not significant to the outcome (OR = 0.9, 95% CI = 0.79 to 1.05). Age, bystander CPR, and defibrillation were found to be significant factors to the outcome and younger patients were more likely to survive to discharge than older ones (OR = 1.0, 95% CI = 0.94 to 0.99). Those with bystander CPR (OR = 4.3, 95% CI = 1.39 to 13.09) and defibrillation (OR = 6.3, 95% CI = 1.91 to 20.58) were more likely to survive to discharge than those without. Among the

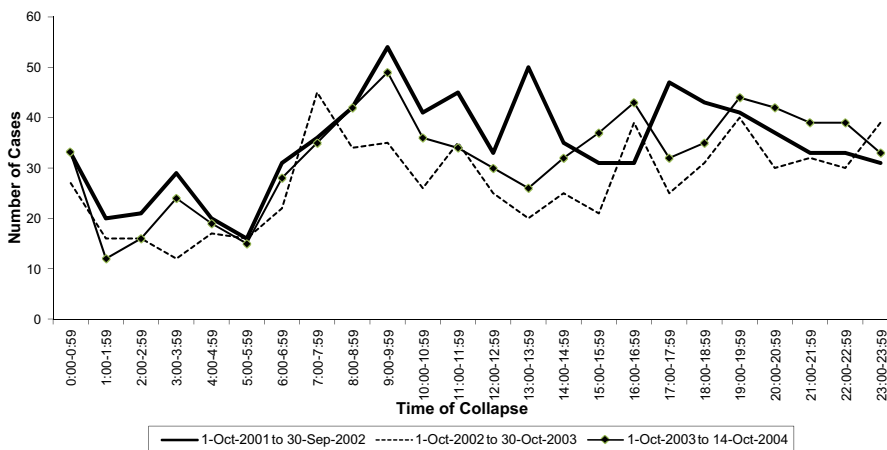


Figure 2. Median response time and number of fire stations and fire posts by month.

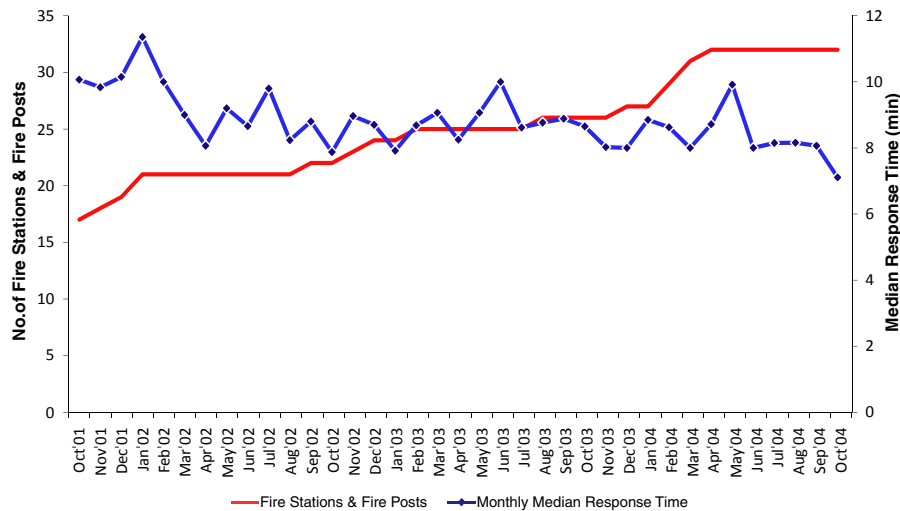


Figure 3. Yearly cardiac arrest cases by hour.

variables, sex (female: OR = 2.1, 95% CI = 0.68 to 6.58), witnessed arrest (OR = 1.1, 95% CI = 0.33 to 3.68), and initial rhythm (OR = 0.00) were not found to be significant for survival to discharge.

DISCUSSION

In this study, we found that a simple, relatively low-cost change in ambulance deployment strategy based on geospatial-time analysis, was associated with significantly reduced response times for OOHCA. This demonstrates the utility of using GIS in cardiac arrest research and for planning interventions. The second intervention in this study was the use of peak load staffing patterns (that is, more crews on duty during higher volume times and fewer on duty at lower volume times). This would also affect response time intervals even without increasing staffing levels.

Although no cost analysis was done for this study, the cost for implementing satellite ambulance stations was relatively low. This is because new satellite posts were implemented in existing community facilities, with minimal renovation and retrofitting (communication equipment). No new construction was needed.

Unfortunately, we were unable to show a significant monthly increase in survival rates as the numbers involved were small. We note that response times in this single-tier AED system were still well over 4 minutes, and this might result in the unchanged survival statistics. Further efforts are in the pipeline to decrease response time. Also, many factors might affect cardiac arrest survival other than ambulance response times.^{9,17,18}

There has been a growing understanding that OOHCA is not a random event, but occurs in patterns and trends that can be observed historically. This is related to movement patterns of people according to time of day, as well as geographical epidemiology of the population. For example, about twice as many arrests occurred during the day (0700 hr to 1859 hr) compared to night (1900 hr to 0659 hr; Figure 3). Also, the day cases were more clustered in the southern commercial and business areas.

System status management is a technique for matching the movement of ambulances in anticipation of where they will be needed next by using historical temporal and geographic ambulance response data. It is also a key tool for high-performance ambulance or EMS systems.¹⁹ This is then combined with flexible, real-time management of the deployment of resources to meet response time performance requirements. Our results show potential for application of such theories, keeping in mind that ambulance deployment must be planned in response to all 9-9-5 calls and not only cardiac arrest cases. A specific challenge in our high-rise, urbanized city is the delay in reaching the patient associated with arrests occurring in high-floor buildings, which we have previously described.²⁰

Pell et al.,¹⁰ in a Scottish study, calculated that a reduction in target response to 90% of calls from 14 to 8 minutes would increase cardiac arrest survival from 6% to 8%, and a response of 5 minutes would increase survival up to 11%. Faster response times mean earlier initiation of CPR and earlier defibrillation. Survival after OOHCA has been shown to be determined mainly by time from onset of ventricular fibrillation to electrical defibrillation.¹³ Emergency ambulances in Singapore are equipped with the AED, which allows paramedic personnel to perform prehospital defibrillation.^{14,21} Survival rates of 74% have been reported where defibrillation has been performed within 3 minutes from collapse.¹² Likewise, early initiation of CPR has been shown to improve survival.^{13,22,23}

We intend to follow-up with this study by developing a system status plan for ambulance deployment, based on real-time ambulance demand data. This will include a mobile ambulance deployment strategy based on priority posting of ambulances. We intend to measure the effects of further enhancement of deployment strategy on ambulance response times. A larger sample size is also planned to measure the effect on outcomes such as survival to discharge. A crew satisfaction survey is another possible future study. A discrete events simulation for ambulance deployment is also being planned.

LIMITATIONS

Limitations of this study include that the response times reported are for call receipt to the time the vehicle arrives at scene. This does not reflect the additional time required to reach the patient's side. We note that our developing ambulance deployment strategy was based on retrospective historical data, rather than real-time ambulance demand data. Also note that although there was improved ambulance coverage from our strategy of satellite fire posts, this was still a fixed deployment model. This means that each ambulance was still based at a particular station, to which it returned after delivering a patient to the hospital. We did not use a mobile ambulance deployment strategy in this study.

As far as we are aware, there was minimal effect of secular changes, such as better roads, improved communication modalities, and enhanced quality improvement processes in EMS response to cardiac arrest, which may also account for decrease in response time over the study period. However, this should be a consideration to temper our results. We also note that the paramedics were not blinded to the objective to decrease response times, and there should therefore be some consideration for the Hawthorne effect.

It should also be noted that our primary outcome measure of response time, while showing a statistically significant decrease, may not necessarily be clinically significant in terms of survival outcomes. However, while patient-centered outcomes, such as survival to hospital discharge, would be ideal, many factors affect survival and a large sample size might be required to show statistically significant differences in clinical outcomes. We also feel that for the purposes of our hypothesis, our results demonstrate the utility of geospatial-time analysis to reduce ambulance response times.

We also note that in this study, we were only tracking response times for cardiac arrests. While any effect on response times for other conditions is not known, we are unaware of any adverse effects on response times for less severe conditions.

Finally, there were minor fluctuations in the number of ambulance staff and operational ambulances over the period of the study, due to staff turnover and vehicle maintenance. However, on the whole, the numbers of staff and ambulances were constant over the period of the study.

CONCLUSIONS

In this study, an ambulance deployment strategy based on geospatial-time analysis was associated with significantly reduced response times for out-of-hospital cardiac arrest, although we were not able to demonstrate a survival benefit in this small sample. This study demonstrates the utility of using geographical information systems in cardiac arrest research and for planning ambulance deployment and might serve as a useful tool for improving EMS response times in other systems.

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