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Research Article

Geosimulation Based Deployment of Automated External Defibrillator (AED) Equipped Mobile Responders for Optimizing the Survival Rate of Out-of-Hospital Cardiac Arrest at the Example of the City of Bangkok

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Abstract

It is still one of the main problems of out-of-hospital cardiac arrest (OHCA), that laypersons can´t help in a sufficient quota to perform adequate Cardio-Pulmonary-Resuscitation (CPR). Either their willingness to help, their training or their equipment is just not sufficient to do so. Therefore, different elements have been setup by emergency managers: Starting from telephone guided CPR assistance over continuous training of laypersons one element is the IT-supported delivery or guidance of resources like AEDs or CPR trained personnel over means of IT-Guided persons and resources by foot, vehicles or drones. This study evaluated the impact on OHCA of one specific setting at the example of Bangkok. A simulated case study for the city of Bangkok was done. Therefore, the study generated a Google-Maps-API geosimulation model for AED equipped mobile responders. The case study could show for what effort such an approach could add value to the rescue chain in the given city: For the scenario a minimum of 3.5 mobile responders with AEDs per square kilometer would be able to improve the given rescue situation compared to the classical ambulance. Given an auto rickshaw (Tuk Tuk) usage time of 15 hours per day, a density of 1 Tuk Tuk per 700 inhabitants and an achievable quote of 20% AED equipped vehicles with trained drivers, the approach would make sense for 5 of the 50 districts of Bangkok. The developed case study model is capable of adapting to different other scenarios like other cities, other vehicles or other resources to bring to the site of OHCA. Due to the integration of a real-live Google Maps API, the work allows the integration of individual traffic and street situations in a specific city or setting. Therefore, the work could be valuable for the standardized evaluation of different other supportive OHCA CPR support Cases on the base of an extended IT-supported logistics scenarios. For the specific scenario of Bangkok only a very focused usage in 5 high density suburban areas would be feasible and adding value to the rescue chain.

Keywords: *First-Responder; Recue-Chain; App; Geosimulation; SCD; OHCA CPR; AED Distribution; Healthcare Digitalisation*

Background

The outcome of patients with out-of-hospital cardiac arrest (OHCA) remains on a low level. Many resuscitation or cardiac arrest registries have been established to evaluate the epidemiology of OHCA. Data from the recently published European Registry of Cardiac Arrest registry (EuReCa TWO) demonstrated an incidence of OHCA in Europe between 84 to 87 per 100.000 person years [1,2]. Overall, in one third of cases (33%) ROSC was achieved and 8% of patients were discharged from hospital alive. Survival to hospital discharge was higher in patients when a bystander performed CPR with ventilations, compared to compression-only CPR (14% vs. 8% respectively) [2].

An early CPR and defibrillation are important in the context of the chain of survival. The reduction in the out-of-hospital defibrillation response interval below the in earlier trials proposed 8 minutes should be a target for improving cardiac arrest survival, since each one-minute reduction in the defibrillation response interval leads to a 23% relative improvement in survival [3]. In 54,3% of cases the collapse was witnessed by bystanders, however only in 47.4% of cases cardiopulmonary resuscitation (CPR) were initiated by a bystander. A shockable initial rhythm was reported in 22.2% of patients [4]. In earlier studies about 25 - 50% of patients with OHCA have ventricular fibrillation (VF) in the initial heart rhythm analysis. However, more patients may initially have VF or ventricular tachycardia (VT) at the time of collapse but prior to the first analysis of the rhythm. When the rhythm is recorded immediately after collapse e.g. by an automated external defibrillator (AED), the proportion of patients with VF can increase until 76% [5,6]. Moreover, the usage of static AEDs can significantly improve the neurological outcome [5]. Current guidelines for resuscitation recommend an immediate bystander CPR and early defibrillation since defibrillation within 3 - 5 minutes of collapse can produce survival rates up to 50 - 70% [7].

However, the availability of static AEDs or traditional emergency medical services (EMS) equipped with AEDs or manual defibrillators differ between countries and depend on structural and economic circumstances. Using contemporary digital technology, improvement of response times can be achieved using different solutions, e.g. 1) optimized positioning of AEDs using predictive model inputs, 2) building trained citizen volunteer responder network, 3) using a mobile responder network and 4) drone delivery of AEDs for remote areas.

Methods

The aim of this project was to perform a reproduceable Case Study to evaluate the feasibility of a previously developed geosimulation of AED equipped mobile responders based on a predictive model for reduction of the overall response time and to discuss the feasibility. For that purpose, the developed model case integrated real-live data and traffic densities over the Google Maps API. It allows the real-world simulation of a fleet of first responders based on real-world traffic and navigation data. Different densities of first responders in real-world map data allows simulated reaction times on emergencies and gives hint on dependencies from parameters like day-time, traffic density and other means of the local setting.

Bangkok, the capital of Thailand, is subdivided into 50 districts and comprises 15.687 square kilometers. Almost 8 million people (12.6% of the entire population) are living in this fast-growing city. However, the significant car usage and lack of efficient infrastructure led to chronic constipated traffic, especially during rush hours. Hence, in some cases of OHCA, traditional EMS equipped with AEDs cannot provide the mandatory short defibrillation response time. The usage of using network-integrated smaller vehicles like auto rickshaws equipped with AEDs may shorten this time interval.

Therefore, we conducted a geosimulation case study based on a predictive model to evaluate the feasibility and parameter settings of mobile responders (auto rickshaws) in the setting of Bangkok. For each simulation an equal distribution of the auto rickshaws was taken on the given map according to different given densities per SQM.

How was the data generated and analyzed in single steps?

1. With a function for random seeds in Excel first a location on the given map was generated over GPS coordinates for the virtual cardiac arrest event (incident location).
2. Additionally random positions were generated on the map with the varying given density of dots per SQM for the auto rickshaws.
3. The dots of the ambulance vans were given in the map due to fixed locations.

After plotting the dot for the Cardiac Arrest and the dots for the ambulances and rickshaws the Excel function selected the nearest dot for an ambulance and the three nearest dots for the rickshaws. The Google Map API was then requested for each dot to calculate a time and distance with real world traffic and map data. The returned values were then processed for the given graphs.

This was done 10 times over the same map for each auto rickshaw density distribution and an average value was taken from the simulated run. For the comparison of ambulances and auto rickshaws the same setup times for the activation were taken and it was assumed, that both entities move at the same speed of normal cars. The geosimulation itself was based on traffic data and potential traffic jam delays from the geographic information system (GIS) *Google Maps* application programming interface (API) and computes these datasets comprising the location, time and distance to reach a destination on the prespecified map. Using combined datasets of the described incident location and a starting point for a rescuer, this geosimulation case study provided comprehensive information about the distance, the time-dependent duration and the optimal density of the assumed AED equipped mobile responder in comparison to AED equipped traditional ambulances. The gathered data was then submitted to an Excel Sheet with simple average calculations of e.g. 10 simulated rounds.

Bangkok itself consists of 50 different areas comprising to 1.568 SQM. The areas vary in their population density from 0,417 thousand inhabitants per SQM (Nong Chok) up to 29,841 (Samphanthawong) [8]. For this case study simulation, we selected an exemplary 10 square kilometer area in Bangkok comprising 8 hospitals, each of them providing one AED equipped ambulance. During the first phase of calculation we evaluated the optimal density of the mobile responder. The location of the mobile responder and the place of OHCA were assigned in a random manner, whereas the ambulances were always located at the dedicated hospitals. We defined 8 mobile responder density values from 0.5 to 4.0 per square kilometer. For each mobile density value, we conducted 10 calculation runs for the 3 nearest mobile responders and the nearest ambulance. The second phase of calculation evaluated the impact of daytime on duration and distance of the mobile responder in comparison to the ambulances. We assumed different mobile responder density values ranging from 0,5 up to 4 auto rickshaws equipped with drivers and AEDs per square kilometer. The location of the mobile responder and the place of OHCA were assigned in a random manner, whereas the ambulances were always located at the dedicated hospitals. As stated, we conducted 10 calculation runs for the 3 nearest mobile responders and the nearest ambulance for every hour from 7 am until 10 pm. As all other values like speed and preparation time of the two different vehicle types were the same, the main advantage of the mobile rescuers network was therefore the geographic distribution of the mobile responder auto rickshaws versus the stationary situated ambulances. After each round of simulation, the data was collected in a simple Excel calculation sheet and calculated with simple average value formulas for data points.

Results

As the first part of the analysis, we evaluated the optimal density of mobile responders. Table 1 and figure 1 provide the calculated response interval of the mobile responders and the ambulance depending on the density of mobile responders. The density per square kilometer reflects the number of mobile responders in the area of one square kilometer. The more mobile responders are in this area the higher is the probability to reach an emergency and the faster the mobile responder can arrive in average. The ambulance has a fixed density, as the number of ambulances isn´t altered in this case study simulation. For example, at a given mobile responder density of 0.5 per square kilometer, the nearest mobile responder needed 451.4 seconds to reach the location of the assumed OHCA, whereas the nearest ambulance needed 304.9 seconds. As the main finding, the analysis of the prespecified density values of the mobile responders showed that beginning from a mobile responder density of 2.5 per square kilometer, the duration for the nearest mobile responder to reach the location of the assumed OHCA (236.2 seconds) was shorter than the nearest ambulance (273.7 seconds), whereas lower density values clearly showed a benefit towards the ambulance.

Density of mobile responder (per square kilometer)	Response Interval of mobile responder 1 (sec)	Response interval of mobile responder 2 (sec)	Response interval of mobile responder 3 (sec)	Response interval of ambulance (sec)
0,5	451,4	556,1	658,2	304,9
1	291,1	384,7	483,6	247,6
1,5	318,5	401,7	449,3	272,2
2	240,4	377,5	456,5	236,1
2,5	236,2	299,6	378,7	273,7
3	174,2	278,8	345,9	261,2
3,5	165,75	270,9	331,7	280,2
4	157,3	263	317,5	269,6

Table 1: *Duration depending on density of mobile responder and vehicle.*

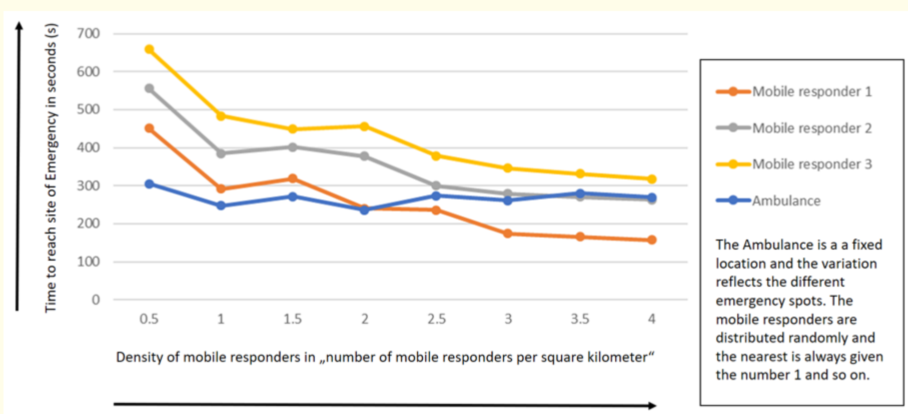

Figure 1: *Case Study simulation outcome - with each data point calculated as average of 10 rounds of simulation: response interval depending on density of mobile responder and vehicle.*

Table 2 and figure 2 provide the calculated distances of the mobile responders and the ambulance depending on the density of mobile responder. The analysis showed that at a density of 2.0 mobile responders per square kilometer, the distance to the assumed location of OHCA was shorter (986.2 meters) for the nearest mobile responder in comparison to the nearest ambulance (1100.6 meters). Moreover, at the density of 3.5 mobile responders per square kilometer, two responders showed a shorter distance than the ambulance to the assumed location of OHCA.

Density of mobile responder (per square kilometer)	Distance of mobile responder 1 (meter)	Distance of mobile responder 2 (meter)	Distance of mobile responder 3 (meter)	Distance of ambulance (meter)
0,5	2231,6	2778,3	3792,2	1448,3
1	1309,7	1829,4	2093,3	939,8
1,5	1357,3	1748,7	2089,4	1271
2	986,2	1617,4	1978,3	1100,6
2,5	872,7	1251,3	1554,3	1125,1
3	888,1	1380,3	1551,7	1044,8
3,5	707,95	1166,9	1381,7	1176,84
4	527,8	953,5	1211,7	1051,44

Table 2: *Distance depending on density of mobile responder and vehicle.*

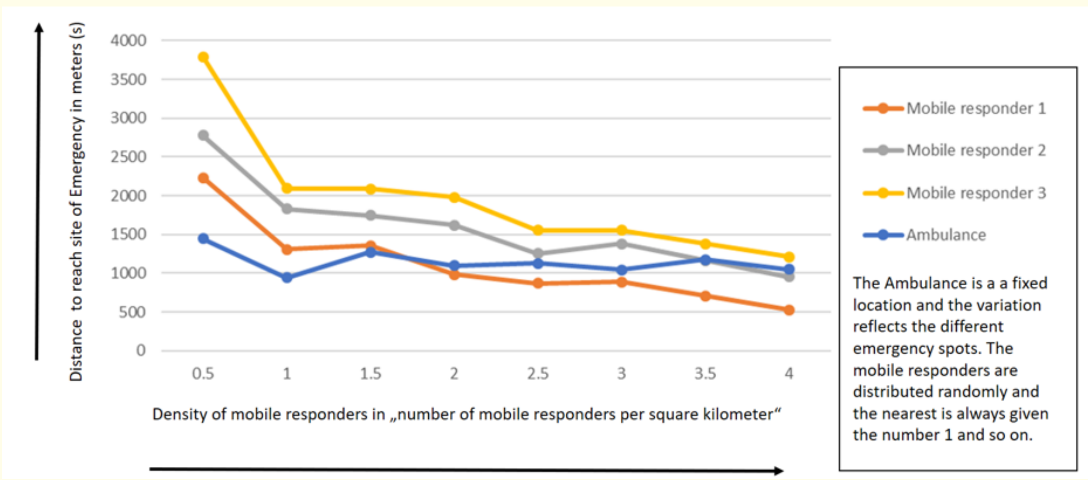

Figure 2: *Case Study simulation outcome - with each data point calculated as average of 10 rounds of simulation: distance depending on density of mobile responder and vehicle.*

As a second part of the analysis, we did a sensitivity analysis, at what thresholds of trained and equipped Tuk Tuks a feasibility of the approach for what number of districts of Bangkok can be reached. We assumed a number of 9.000 auto rickshaws in Bangkok and a projected density of 1 Tuk Tuk per 700 inhabitants from the media reports [9]. Depending on the different inhabitant densities of the districts and an assumed working time of 15 hours of each auto rickshaw figure 3 shows, how many districts would reach the optimal density of 3.5 mobile responders per SQM at different rates of educated and AED-equipped drivers. At the range of 20 - 40% trained and equipped auto rickshaws it turns out, that 5 (10%) to 18 (36%) Bangkok districts could be equipped at a benefit for the rescue chain.

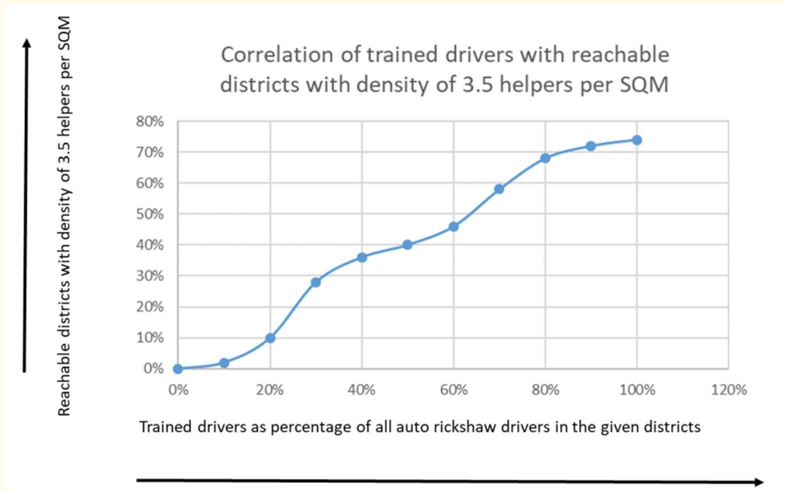

Figure 3: *Correlation of percentage of trained and AED equipped auto rickshaws to districts reaching the density of 3.5 per SQM for a feasible mobile responder rescue chain.*

Discussion

This study evaluated the geosimulation of AED equipped mobile responders and their impact on duration and distance to assumed locations of OHCA in Bangkok, the capital of Thailand. The first part of the analysis comprised the determination of the optimal density of the mobile responder to shorten the defibrillation response time. The main finding was that a minimum density of 2.5 mobile responders per square kilometer is required to obtain a shorter defibrillation response time for the nearest mobile responder and a minimum density of 2.0 mobile responders per square kilometer led to shorter distances without major improvement of the duration. At 3.5 mobile responders per square kilometer the distances of two mobile responders were shorter than the ambulance and led to these two responders arriving earlier than the ambulance.

The second part of the analysis projected this finding on the different districts of Bangkok taking different assumptions on the reachable percentage of AED equipable Tuk Tuks and their working hours. With a reasonable working time of 15 hours and a percentage of 20% equipped vehicles 5 of the districts seemed to be reachable at a reasonable impact for improvement, if these 20% of Tuk Tuks drivers are trained and equipped with an AED and the Smart Phone based coordination software.

Many different registries reported outcome data of OHCA in different continents (e.g. European Registry of Cardiac Arrest registry (EuReCa), the Cardiac Arrest Registry to Enhance Survival (CARES), the Resuscitation Outcomes Consortium (ROC) Epistry-Cardiac Arrest, All-Japan Utstein Registry, and the Pan-Asian Resuscitation Out-comes Registry (PAROS) [2,10-13]. The PAROS registry reported a proportion of unwitnessed arrests between 26.4% to 67.9% and the incidence of a shockable rhythm between 4.1% to 19.8%. However, bystander cardiopulmonary resuscitation (CPR) rates varied from 10.5% to 40.9%. Moreover, under 1.0% of these arrests received bystander defibrillation. The survival rate to hospital discharge were up to 31.2% in patients with witnessed arrest and VF, whereas the overall survival to hospital discharge varied from 0.5% to 8.5% [13]. Overall, the usage of EMS in Thailand in patients with OHCA is very low. A study revealed that the prevalence of EMS usage in this setting was at 14.5%, whereas the main reason for this low rate was the unawareness of any EMS numbers [14]. Since an early CPR and defibrillation play a major key role in the chain of survival, the enhancement of the EMS system may improve the overall outcome. However, the EMS systems in many Asian countries still need development and depend on regional and economic circumstances leading to incomplete coverage especially of remote areas [14]. On the other side, the prolonged response time (RTI) in combination with prolonged scene time interval (STI) is associated with a poor survival rates using the scoop-and-run EMS model [15]. The PAROS registry reported a median response time interval of 6.0 minutes. Our geosimulation calculated slightly lower median duration values for the ambulances (4.46 minutes without setup time). Since each one-minute reduction of the defibrillation response time will lead to a 23% relative improvement in survival, every AED equipped mobile responder may contribute to better survival of patients presenting with OHCA. On the one hand, our work showed the "sensitive" number of equipped and trained Tuk Tuk drivers needed in the exemplary Bangkok districts to improve outcome. On the second hand, target of our work was also to prove the usability of a simulation setting with standard Google Tools for real world simulations of a specific OHCA AED setting.

The developed geosimulation allows to judge different settings and needed densities of e.g. first responder networks to support a network of professional ambulance settings.

Nevertheless, the system is not able to judge the different efficiencies between different ways to provide OHCA help, which could be integrated into the simulation over experience values from countries with active first responder app systems.

The approach of simulating the distribution of different OHCA help settings by teaching, AED distribution or IT-supported coordination of helpers and/or drones/vehicles etc. is a technique being used by several other authors to apply guidelines and theoretical cases to a real world scenarios. E.g. in the work of Y. Wei [16], simulation techniques are used on a more macroscopic level to optimize a budget utilization for best outcome over comparison of 4 different scenarios. In the work of C. Mackle [17] a simulation of the best sites of AED drones in Northern Ireland was accessed, but a more high level simulation not tied to specific areas was performed.

Our approach is more easy to implement due to its connection to a standard Google API and due to a more specific "real world" linkage to individual street settings a specific area and the possibility to use real world traffic situations in the simulation. It may be another piece of the "puzzle" to tie guideline outcomes to a real world feasibility and could help to optimize resource allocation in OHCA settings in different countries and areas more easy.

Limitations of the Study

First, we used a case study geosimulation model for the calculation based on several assumption or prespecifications: the chosen area of interest, the current traffic situation, the parameters of the mobile responders (dispatch delay time, driving speed and random location), the parameters of the ambulance (chute time and driving speed), the random place of OHCA and the limited counts of calculation runs.

Second, we assumed that every OHCA will be reported in time by bystanders etc.

Third, we assumed that there are enough well-trained mobile responders who are willing to carry and operate an AED during their work time.

Last, the usage of AED is expensive and requires financial funding. However, not every region can bear this financial burden.

Conclusion

In our study we were able to show in a case study for Bangkok, that a density of 2 - 3.5 AED equipped mobile responders per square kilometer may improve the defibrillation response time in comparison to the ambulances in a highly densely populated area. Furthermore, it may improve the subsequent survival rate in patients presenting with OHCA in countries with developing EMS. The use of simulations could be something, that helps to differ semi-automated detection of areas and settings with high potential for interventions with combined approaches for resuscitation teaching and other measures for automated and IT supported crowd based help structures.

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