Sudden cardiac arrest and the role of crowd tasking apps for risk mitigation

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ABSTRACT

Sudden cardiac arrest (SCA) is among the three most prominent causes of death in industrialized nations. Therefore, experts are calling for solutions, including smartphone-based systems to mobilize volunteers.

German researchers are developing a crisis response system with a crowd tasking app. It aims to help reduce the effects of large-scale events, but also of ad-hoc incidents including SCA. This paper describes an approach to determine the potential of the system to increase the survival rate of SCA illustrated by an example. Its concept was analyzed by five experts from three countries and benefited from their feedback.

Keywords

Risk mitigation, crowd tasking, benefit analysis, warning apps, sudden cardiac arrest

INTRODUCTION

Modern societies are increasingly threatened by a wide range of natural and man-made risks. In this context, 'mitigation' is an important concept (Van de Walle and Turoff, 2008). According to Labaka (2013), mitigation/prevention 'refers to the actions taken to identify risks, avoid their occurrence and reduce possible negative effects on human life and personal property'. Van de Walle and Turoff (2008) consider specific large-scale events with a significant impact on life and property. Labaka's (2013) definition also allows for referring to large numbers of small risks whose significant impact results of high incidence rates.

Sudden cardiac arrest (SCA) is among the three most prominent causes of death after cancer and other cardiovascular diseases in industrialized nations (see Van Aken and Böttiger, 2015). Consistent with Labaka's definition of mitigation, 'actions to reduce possible negative effects on human life' are required, in particular because attempts of cardiopulmonary resuscitation are very often unsuccessful in those SCA incidents that take place out of hospital.

Helbing (2015) propagates a paradigm shift from power to societal empowerment in disaster risk mitigation. In this context, Neubauer, Nowak, Jager, Kloyber, Flachberger, Foitik and Schimak (2013), identified new processes called 'crowdtasking', 'dedicated to the improvement of volunteer management applying new media'.

German researchers are developing the app-based Early Warning and Alerting System (EWAS) ENSURE to mobilize registered volunteers. ENSURE aims to help reduce the effects of large-scale events, but also of ad-hoc incidents such as SCAs. Although these positive effects are unquestioned, implementing such a system, as well as EWAS in general, requires a justification of the costs (see e.g. Klafft and Meissen, 2011). This paper provides a holistic approach to assess EWAS-based SCA risk mitigation activities. It also gives an estimation of the increase in the survival rates in Germany, if volunteers are mobilized by such a service. [1]

NEED FOR WARNING APPS TO SAVE LIVES IN CASES OF SUDDEN CARDIAC ARREST

In Europe and the U.S., at least 1.4 million people die each year following SCA with unsuccessful out-of-hospital cardiopulmonary resuscitation (see Van Aken and Böttiger, 2015 and Weber, Bein, Möllenberg, Geldner, Andresen, Bohn, Braun, Ruppert, Scholz, Strauss, Beckers, Frey and Böttiger, 2014). The tragedy of this statistic is increased by the fact that the potential of successful mitigation measures is not fully exploited yet, while the potential benefits of appropriate reaction strategies are overwhelming. Besides saving lives, the probability that successfully treated patients (i.e., long-term survivors) return to work is high. 52.7% of the 530 patients in the study of Smith, Andrew, Lijovic, Nehme and Bernard (2014) worked prior to the cardiac arrest. 76.6% returned to work and 65.2% returned to the same role. However, only a small fraction of patients are currently long-term survivors, mostly due to the fact that resuscitation is initiated too late.

In Germany, approximately 75,000 people suffer an out-of-hospital SCA every year. Although the cardiovascular function may be initially restored in many cases, the majority of these patients nevertheless die within 30 days after being admitted to hospital. Only about 5,000 patients survive this scenario with an acceptable neurological outcome, i.e., without suffering from severe brain injuries and impairments (see Stroop, Strickmann and Kerner, 2015). A key factor for this unsatisfactory outcome is that resuscitation efforts begin too late, which is why researchers estimate that there is potential to save 10,000-15,000 additional people annually if reanimation measures are initiated immediately (see Perkins, Handley, Koster, Castrén, Smyth, Olasveengen, Monsieurs, Raffay, Gräsner, Wenzel, Ristagno and Soar, 2015).

Germany has very well-structured emergency services with a dense network of rescue stations. However, elapse after receiving the emergency call at the control centers can be up to 8 minutes before the arrival of the first responders. In rural areas, the response time increases to 12 minutes. The chance of survival in a cardiovascular arrest decreases by 10% per minute. After three to five minutes without oxygen, irreparable brain damage occurs (see Gontek, 2015). With an average layman resuscitation rate of only 27%, Germany is one of the lowest ranking countries in Europe where some countries report resuscitation of up to 70% (see Stroop et al., 2015).

The mobilization of volunteers can reduce the number of casualties. According to Grontek (2015), professional volunteers, a key target group for this measure, includes 2-3% of Germany's population. This demographic includes, but is not limited to, nurses, doctors, paramedics and firefighters.

Experts highlighted that 70,000 deaths after unsuccessful resuscitation are unacceptable and formulated the specific claim to shorten the 'resuscitation free' interval for patients. The introduction of smartphone-based systems is regarded as an important task in this regard (see Bohn, Van Aken, Müller, Böttinger, Wnent, Röhrenbeck, Möllenberg, Kehrberger, Gaupp, Kreimeier, Gräsner and Beckers, 2014 and BDA and GAI, 2015).

RISK MITIGATION AND EXISTING APPROACHES TO ASSESSING THE VALUE OF EWAS AND THEIR SUPPORT OF FIRST RESPONDER ACTIVITIES

Risk mitigation by using modern media and dynamic simulation is an up-to-date topic, see e.g. Oki & Hirokawa (2015). Examples for systems with a specific focus on mobilizing or enabling first responders, include the U.S. solution 'Pulsepoint', 'United Hatzalah' in Israel, and several European solutions presented by Stroop et al. (2015). Additional solutions which are in pilot use or under development include 'Mobile Retter' in Germany and the 'ENSURE' system which is designed to mobilize volunteers at large-scale and small-scale events to save lives and property. Another example, although not specifically focused on small single events such as SCA,

1 This research has been funded by the BMBF (project number 13N12813). We thank Dr. Ralf Stroop for his helpful advice.

is an Austrian approach which comprises the campaign 'Team Austria' and the system RE-ACTA (see Auferbauer, Ganhör and Tellioğlu, 2015).

Besides the existing *technical* approaches, analyses on the contribution of these systems to save lives are rare. While the economic benefits of EWAS are intensively investigated (see e.g. Wurster and Meissen, 2014 for an overview) and their contribution to save lives is unquestioned, their specific contribution to save lives in case of SCA is a research gap, which is addressed by this paper.

Interviews with fourteen experts were conducted to assess the benefit of ENSURE. The interviews with a medical expert and a disaster manager, as well as additional secondary sources (e.g. BDA and GAI, 2015 and Weber et al., 2014) highlight the potential of such a system to save lives in the SCA context. The formulas of the next section were developed to specify this potential contribution.

CONCEPT TO CALCULATE THE EFFECTIVENESS OF EWAS IN THE SCA CONTEXT

Inspired by Klafft and Meissen (2011), Wurster, Meissen and Klafft (2015) determined the benefit of EWAS to protect private property using formulas with five groups of factors: personal, prediction-related, dissemination-related, asset-specific, and disaster-specific.

This approach was used as a foundation for the calculation concept on the contribution of EWAS to save lives. It includes territorial and alerting-related factors, personal factors of the volunteers (first responders), situational factors as well as medical factors related to the affected persons and their treatment in hospital. Dissemination aspects, e.g. multiplier effects (see Wurster et al., 2015), were excluded because of specific location-based and time-specific constraints. The following list summarizes the relevant factors of the calculation concept:

i	: casualty i
vj	: volunteer
(x_i, y_i)	: coordinates of casualty i
(x_{vj}, y_{vj})	: coordinates of volunteer j
p	: factor for distance metrics
A	: planning area [km²]
d	: distance [km]
s_{vj}	: average speed of a specific volunteer j (related to age and speed)
Al_T	: probability that the alert is issued in time (i.e., within one minute)
N_v	: number of potential volunteers in the given area
$Lhood_{outage,i}$	: likelihood that the EWAS is inoperational
$Lhood_{subscr,vj}$	: likelihood that a member of the target group subscribes to the EWAS as a volunteer
$Lhood_{notice,vj}$	: likelihood that the volunteer notices an incoming warning message via the EWAS in time
$sLhood_{able,i,vj}$	: situational likelihood that the volunteer is able to perform resuscitation actions
$sLhood_{willing,\, i,vj}$	: situational likelihood that the volunteer is willing to perform relevant actions in case of an alert regarding incident i
$PROB_{vj}$	: probability that an immediately alerted volunteer reaches the victim in time (i.e., within three minutes) as a function of geo data and parameters of ordinary moving behavior (additional influences are separately considered in $PROB_{V,all,i}$)
CF	: correction factor for the probability that at a specific volunteer reaches the victim in time; considers mobility-related barriers, e.g. stopping at traffic lights etc.
$Lhood_{DISCOV\_IT,i.vj}$	: probability that the volunteer discovers the victim after arriving in the specified area in time
$PROB_{vm,i}$	: likelihood that victim i is reached by at least one volunteer if the alert is immediately triggered and no technology and personal factors are considered
$PROB_{V,all,i}$	: probability that at least one volunteer reaches victim i in time when technical and personal factors are also considered
$RESSUC_{V,i}$	: probability of resuscitation success for victim i
$CURpot_i$	: curability, yes =1, no = 0, this paper only considers curable persons in the given area
$C_{FIRSTRESP,i}$	: correctness of the reanimation measures of the volunteer
$C_{HOSTREAT,i}$	: correctness of hospital treatment, in our example yes = 1
SAVPLUSpot	: victims who might be saved in addition to current statistics
SAVSYS	: victims who can be saved by the system

Based on the given factors and the structural principles of Klafft and Meissen (2011) and Wurster et al. (2015), a calculation approach consisting of two formulas was developed. The factors A and S_{vj} are used in separate calculations shown in the next chapter. They determine the probability that a specific volunteer reaches the victim in time ($PROB_{vj}$).

The following formula calculates the probability that at least one volunteer reaches the victim in time ($PROB_{V,all,i}$):

Formula 1:

$$PROB_{V,all,i} = (1-(1-PROB_{vj})^{(N_V \cdot Lhood_{subscr,vj} \cdot LHood_{notice,vj} \cdot sLHood_{willing,i,vj} \cdot sLHood_{able,i,vj})}) \cdot Al_T \cdot (1-Lhood_{outage,i}) \cdot sLhood_{DISCOV\_IT,i,vj} \cdot CF$$

The formula considers the probability that at least one volunteer reaches the victim in time. In particular, the equation includes factors like the subscription rate ($Lhood_{subscr,vj}$), the probability that the alert (A_T) is issued immediately after the incident, possible communication loss ($Lhood_{outage,i}$), attention ($Lhood_{notice,i,vj}$), as well as the situational willingness ($sLhood_{willing,i,vj}$) and ability ($Lhood_{able,i,vj}$) of the volunteers to conduct relevant actions in case of an SCA incident. Consequently, the benefit of the system in the SCA context can be calculated as:

Formula 2:

$$RESSUC_{V,i} = \sum_i \left[PROB_{V,all,i} \cdot CURpot_i \cdot C_{FIRSTRESP,i} \cdot C_{HOSTREAT,i}\right]$$

The equation above summarizes the resuscitation success ($RESSUC_v$) of reanimation actions by the volunteers who reach the victim in time ($PROB,_{V,all,i}$) after being alerted by the EWAS. It considers the curability of the victim ($CUR_{pot,i}$) as well as the variables $C_{FIRSTRESP}$ and $C_{HOSTREAT}$, which describe the quality of the reanimation measures and the treatment in hospital. According to Table 1, two of these three variables build on the medical RACA[2] score of Grassner, Meybohm, Lefering, Wnent, Bahr, Messelken, Jantzen, Franz, Scholz, Schleppers, Böttiger, Bein, Fischer and the German Resuscitation Registry Study Group (2011).

Variables of formula 2	Independent variables of the RACA score with a significant positive (+) or negative (-) impact on the probability of survival
$CUR_{pot,i}$	male gender (-); age ≥80 years (-); nursing home (-); time until professionals arrival (-); public place (+), asystole (-); intoxication (+), trauma (-), presumable aetiology of hypoxia (+)
$C_{FIRSTRESP}$	witnessing by lay people (+) and by professionals (+)
The variables location at doctor's office (+) and medical institution (+) were excluded in the context of out of hospital SCA	

Table 1. Variables of the RACA Score in this Concept (source: authors)

As highlighted earlier, Perkins et al. (2015) estimate that 10,000-15,000 additional SCA victims can be saved with an acceptable neurological outcome in Germany, if volunteers are mobilized appropriately. The realization requires that the victims are a) curable, b) receive appropriate reanimation and c) appropriate treatment in hospital. Only these victims were considered to formulate assumption 1:

Assumption 1: $CURpot_i \cdot C_{FIRSTRESP,i} \cdot C_{HOSTREAT,i} = 100\% = 1$

Consequently, assumption 2 describes an additional premise.

Assumption 2: $RESSUC_{V,i} = PROB_{V,all,i}$

The product of $PROB_{V,all,i}$ and SAVPLUSpot, the number of additional victims, which might be saved in a given period, shows the number of victims who can be saved by the system in the relevant period (SAVSYS). The following chapter demonstrates the possible benefit of EWAS in the Geman SCA context.

ASSESSING THE BENEFITS OF EWAS TO INCREASE THE SCA SURVIVAL RATE IN GERMANY

In an interview on the benefits of EWAS in Germany, an expert formulated the goal to motivate all persons with professional medical expertise to subscribe to an EWAS. Table 2 analyzes a scenario in which at least 50% of these more than 2 million persons subscribe to the service.

A key foundation of the successful app-based mobilization of volunteers is the timely transmission of the alert $Al_{T.}$ This is influenced by the probability that the precursory emergency call is issued immediately after the incident or that the emergency is indicated by vital parameter monitoring (VPM). Based on the urgent need for

[2] The foundation of this index is the Return of spontaneous circulation (ROSC) score. RACA prepresents ROSC after cardiac arrest.

action, the probability Al_T that the alert is transmitted within the first minute after the occurrence of the SCA is focused in the example calculation of Table 2.

The current survival rate can be interpreted as a result of help within five minutes. The number of additional SCA incidents which can be noticed within one minute (1/5 of the time) is less than 1/5 of the 15,000 additional curable victims (SAVPLUSpot). The reason is the situation-specific time-lag. The relevant share was estimated to be 5 percent including cases indicated by VPM.

Based on this assumption, the app-based SCA response process was divided into five stages: 1. Noticing the incident and emergency call (1 minute), 2. Mobilization of the volunteers including reaction time and decision making (1 minute, based on experience with the app 'Mobile Retter', see below), 3. Moving to the victim (3 minutes), 4. Treatment by emergency medical services and 5. Treatment in hospital. As described in the previous chapter, our focus is on the first three stages which belong to formula 1 and do not last more than 5 minutes in total. Due to assumption 1 and 2, the remaining stages are not considered separately.

Statistics of the app 'Mobile Retter' kindly shared with the authors were an important source for this calculation. Their data refers to the administrative district Guetersloh. It has a territory of approximately 1,000 km^2 with approximately 360,000 inhabitants. 'Mobile Retter' has 550 registered volunteers. Two volunteers are alarmed per incident. The faster volunteer reaches the victim after 4:18 minutes and passing a distance d of 1.05km on average. Statistics of Mobile Retter between September 2013 and December 2015 include remarkable data showing that the volunteers notice an alert in 24 seconds on average (see Mobile Retter, 2016). The pragmatic estimation in Table 2 builds on a value of $Lhood_{notice,i,vj}$ of 85%. As such, better results are possible in reality.

Previously, the coordinators of 'Mobile Retter' considered two different moving speeds for the response processes. The walking speed of 5km/h was chosen if the emergency was located within 0.3km of the next volunteer and an average speed of 40km/h was used for longer distances - assuming the volunteers would take a car. Based on internal statistics of 'Mobile Retter', the walking speed was reduced. It was found that even for distances under 0.3km, the volunteers were likely to go by car.

The choice of the speed of 40km/h builds on several framework conditions. Guetersloh is a rural area where cars are parked in close distance and in which the probability of traffic jams is low. This shows that the 40km/h car speed on average cannot be transferred to Germany as a whole. An average moving speed of 15km/h was used instead. This value comprises the values for pedestrians, cars and bicycles. Pedestrians are assumed to be slower, cars faster and the average speed of bicyclists is around 17km/h) (see Schleinitz, Petzoldt, Franke-Bartholdt, Krems and Gehlert, in press). Therefore, the maximum average distance volunteers can move within a three minute interval can be calculated as d = 0.75km. Since this distance is based on the road network the calculation of the actual covered geographic area requires the use of an adequate metrics. Shahid, Bertazzon, Knudtson and Ghali (2009) suggest the use of the Minkowski metrics described in formula 3 as an approximation, where [1 <=p <= 2].

Formula 3: $$d = [(x_i - x_{vj})^p + (y_i - y_{vj})^p]^{1/p}$$

Values for p can be estimated based on the actual network of the planning area, where p=1 and p=2 lead to the Euclidian and the Manhattan metric. For the purpose of this study it is assumed that p=1.43. This value is based on an analysis by the authors for a planning region in Germany. Shahid et al. (2009) calculated comparable values for the City of Calgary.

Using the Minkowski metrics with p=1.43 and d=0.75 and assuming the coordinates of the victim with (0.0) the resulting formula 4 can be used to calculate values for y_{vj} for variations of $x_{vj.}$

Formula 4: $$0.75 = [(-x_{vj})^{1.43} + (-y_{vj})^{1.43}]^{1/1.43}$$

The approximate size of the area where the volunteer v_j needs to be located to arrive within the three minute interval can therefore be estimated by A'=1.51 km². Assuming an equal distribution of volunteers in the planning area, the probability that a specific volunteer vj is located within the planning area, can be approximated by PROBvj = min (1, A'/A). For the case of Germany with an area A=357,168km² the probability that an available volunteer is actually located within the maximum radius of the victim is therefore shown in formula 5.

Formula 5: $$PROB_{vj} = 1.51 / 357{,}168 = 0.0000042277$$

Based on this result, Table 2 shows all data of the calculation.

(a) N_v	2,019,175
(b) $Lhood_{subscr,vj}$	50.0%
(c) $PROB_{Vj}$	0.000423%
(d) $Lhood_{notice,i,vj}$	85.0%
(e) $sLhood_{able,i,vj}$	90.0%
(f) $sLhood_{willing,i,vj}$	95.0%
(g) $PROB_{vm,i}$	95.51%
(h) AI_T	5.0%
(i) $Lhood_{outage,i}$	1.0%
(j) $Lhood_{DISCOV\_IT,i,vj}$	98.0%
(k) CF	93.0%
(l) $PROB_{V,all,i}$	4.3%
(m) SAVPLUSpot	15,000
(n) SAVSYS (l ˙ m)	**646**

$PROB_{vm,i}$ builds on probability law = 1 - (1 - c)^(a ˙ b ˙ d ˙ e ˙ f)

$PROB_{V,all,i}$ = (1 - (1 - c)^(a ˙ b ˙ d ˙ e ˙ f)) ˙ h ˙ (1-i) ˙ j ˙ k

= $PROB_{vm,i}$ ˙ h ˙ (1-i) ˙ j ˙ k

Estimations of $Lhood_{notice,i,vj}$ and $sLhood_{able,i,vj}$ refer to the first minute after the transmission of the alert and the nearest volunteers in total

Table 2. Benefit Calculation

Based on Table 2, approximately 646 SCA victims can be saved by EWAS in Germany annually if an appropriate number of skilled volunteers subscribe to the service.

COST-BENEFIT ANALYSIS

According to experts, ENSURE's costs will be comparable to the cost of the already established IT-based warning system KATWARN.

KATWARN's costs are shared between insurance companies and the administrative districts that use the system. The cost of the technical infrastructure, the operation of the system and additional R&D activities are borne by the insurance companies. Based on this, each administrative district has to pay an initial fee of €15,000 for installation, customization, initial training and marketing. Maintenance costs per year are €3,000. Energy consumption causes some minor additional costs.

Saving lives in the SCA context is only one goal of ENSURE. In this context, the marginal annual cost per administrative district is worth the effort even if the system saves only one life per year (see next section). Furthermore, the potential life-saving benefit of the system does not only include SCA but all cases in which first aid is needed.

EVALUATION

The presented formulas were reviewed by five experts from three countries with expertise in the fields of warning systems, first aid, emergency medicine and emergency management. Expert 1 stressed in particular the plausibility of the formulas. The second expert highlighted the importance of having appropriate data for the relevant calculations. This feedback was translated into the example calculation in Table 2. Expert 3 suggested focusing on alerting specific target groups, ambulances which are not on duty by the time of an alert.

The fourth expert provided the authors with attractive data of a comparable initiative. They stress the capability of EWAS to reach victims in less than five minutes. A key comment of the fifth expert referred to the importance of training resuscitation skills appropriately. Finally he stated that the app is successful - even if it can save one life only.

As mentioned, there are 1.4 million cases of SCA in the U.S. and Europe each year. Based on this, there is potential to save many more lives by apps for immediate resuscitation measures.

SUMMARY AND OUTLOOK

This paper demonstrated the potential contribution of advanced EWAS to save lives in cases of SCA. Additional areas that can be addressed by ENSURE and comparable apps are for example accidents and crime. Due to its functionalities to facilitate first-aid measures, it also helps to face the new man-made threats the Western world currently faces. These contexts require further research.

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