

Assessing the Impact of Crowd Tasking Apps on Resuscitation Success: The Case of Sudden Cardiac Arrests in Germany

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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 IT-systems to mobilize volunteers. SCA emergencies require immediate action and advanced first aid skills. As of today, emergency services are often unable to arrive at the victim in time, and laypeople on the scene frequently fail to conduct resuscitation properly. One approach to solve this problem is to rely on skilled volunteers, who are alerted by smartphone apps. Among others, German researchers are currently 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 based upon data from Germany. Its concept was analyzed by experts and benefited from their feedback.

KEYWORDS

Benefit Analysis, Crisis Communication, ENSURE Project, Rescue, Resuscitation, Volunteers, Warning App

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 & Turoff, 2008). According to Labaka, Hernantes, Laugé & Sarriegi (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’ (p. 132). Van de Walle & Turoff (2008) consider specific large-scale events with a significant impact on life and property. Labaka et al.’s (2013) definition also allows for referring to large numbers of small risks whose significant impact results from 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 & Böttiger, 2015). Consistent with Labaka et al.’s definition of mitigation, ‘actions to ... reduce possible negative effects on human life’ are required, in particular because attempts of cardiopulmonary resuscitation are 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 & Schimak

(2013), identified new processes called ‘crowd tasking,’ ‘dedicated to the improvement of volunteer management applying new media’ (p. 345).

German researchers are developing app-based Early Warning and Alerting System (EWAS) to mobilize registered volunteers. The first such system was “Mobile Retter” (mobile rescuers), which was specifically designed to save lives in case of SCAs, and has been used in practice since 2013 (Stroop, Strickmann, Horstkötter, Kuhlbusch, Hartweg, & Kerner 2015). A similar system which has been designed for a broader range of scenarios beyond SCA, including large-scale incidents and disasters is the ENSURE system which is currently being tested in the city of Berlin (Jendreck, Meissen, Rösler et al., 2016).

Although the positive effects of systems like “Mobile Retter” and ENSURE are unquestioned, implementing such a system, as well as EWAS in general, requires a justification of the costs (see e.g. Klafft & 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 The paper is organized as follows: the next section discusses the need for warning apps to alert volunteers in case of sudden cardiac arrests. Thereafter, existing approaches for assessing alerting systems are discussed. These approaches lack a discussion of legal and ethical aspects, which is why specific attention is given to these aspects in a separate section. After having completed the discussion of key success factors, an assessment model is developed, and subsequently applied to the case of Germany. The impact assessment of crowdtasking apps for Germany is based on two scenarios: a conservative one based on what has already been achieved in areas where the “Mobile Retter” system is operational, and an optimistic scenario with increased volunteer participation due to potential changes in the legal framework. Finally, the paper concludes with an evaluation, a summary and outlook.

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 & Böttiger, 2015 and Weber, Bein, Möllenberg, Geldner, Andresen, Bohn, Braun, Ruppert, Scholz, Strauss, Beckers, Frey & 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 et al. (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 (Stroop, Strickmann, & 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 et al., 2015).

Germany has very well-structured emergency services with a dense network of rescue stations. However, the delay between receiving the emergency call at the control centers and the arrival of professional first responders can still be up to 8 minutes in cities. In rural areas, the response time is considerably higher and reaches 12 minutes on average. 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% (Stroop et al., 2015).

The mobilization of volunteers can reduce the number of casualties. According to Gontek (2015), professional volunteers, a key target group for this measure, include 2-3% of Germany's population. This figure 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, et al., 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 Niwa, Osaragi, Oki & Hirokawa (2015) for an example), and advanced IT systems can help to effectively integrate volunteers for different tasks. Based on Web 2.0, participation concepts as crowdtasking facilitated the commitment of volunteers, mobilized them and have been successfully applied in emergency management (Schimak, Havlik & Pielorz, 2015). In addition, the widespread use of mobile devices throughout the population has a huge potential to facilitate the participation of citizens as active helpers (Reuter, Heger & Pipek, 2012). With the help of mobile crowdtasking applications, information can be provided and disseminated in real-time and activities of local helpers can be organised and coordinated.

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, Strickmann & Kerner (2015). As discussed above, solutions in Germany include "Mobile Retter," and the ENSURE system, which is designed to mobilize volunteers at large-scale and small-scale events to save lives and property. Figures 1 and 2 give an impression of specific components of this system. Figure 1 shows the software for control centres and Figure 2 gives an example for a message sent to volunteers to provide first aid measures. As Figure 1 shows, the system allows an effective alerting of the volunteers based on specific geo information. The task manager can, for example, see the specific place of the incident, receive information on the number of volunteers in the relevant area and can determine which volunteer is next to the victim.

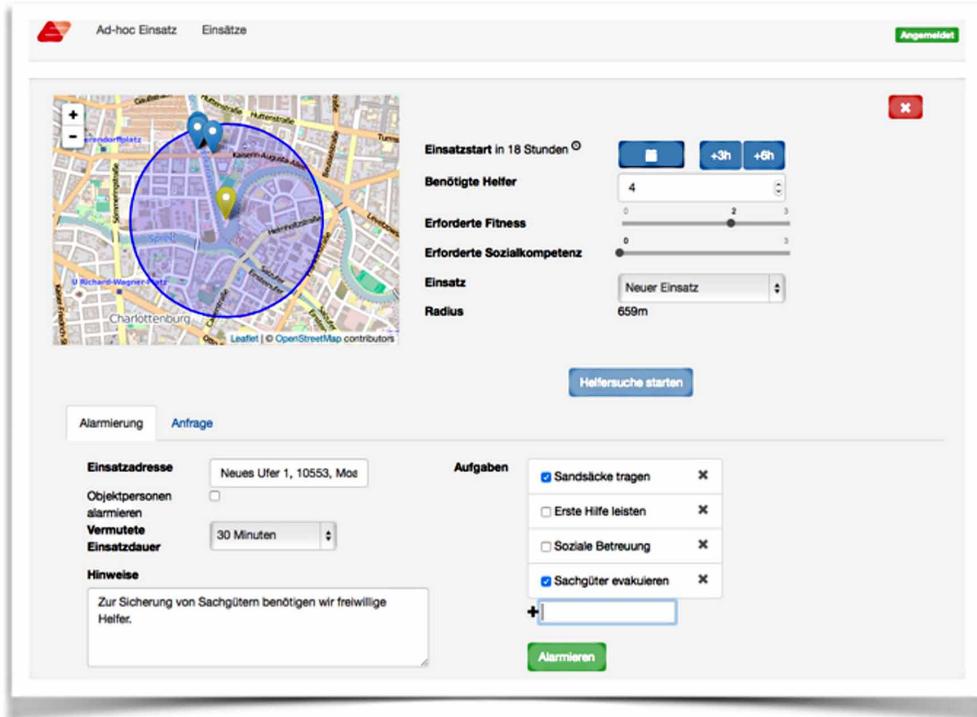
The alert message, shown in Figure 2, provides, for example, a summary of the incident, specific geo information of the incident as well as a description of the specific task requested from the volunteer. Due to the need for immediate reaction, the app triggers a specific sound to draw the attention of the attention of the relevant volunteer to the alert message. The volunteer is asked to respond immediately whether he/she can complete the task.

Another example, although not specifically focused on small single events such as SCA, is an Austrian approach which comprises the campaign 'Team Austria' and the system RE-ACTA (see Auferbauer, Ganhör & Tellioglu, 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 & 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. Based on the framework conditions described in the last chapter, the research question is summarized in Figure 3.

Interviews with five experts were conducted to assess the benefit of systems like "Mobile Retter" or ENSURE. The interviews with a medical expert and a disaster manager, as well as additional secondary sources (e.g. BDA & GAI, 2015 and Weber et al., 2014) highlight the potential of such a system to save lives in the SCA context. However, in order to be successful, and to achieve the desired

Figure 1. Example for a crowd tasking system – software at the control center



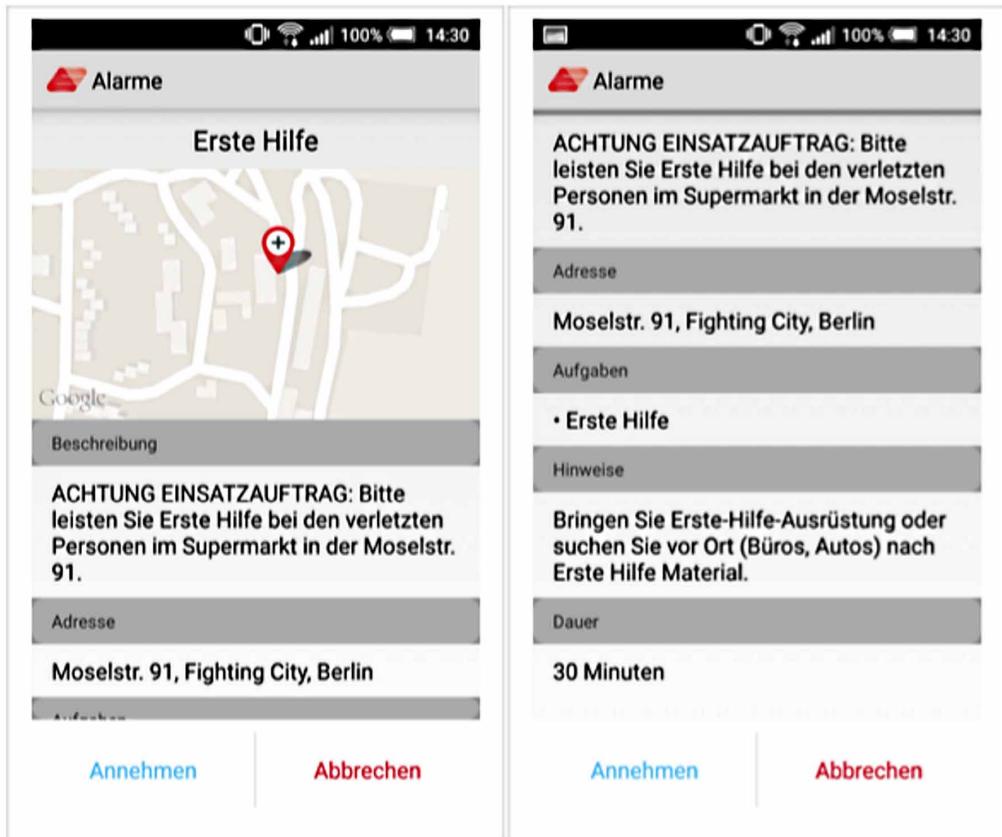
impact, crowdtasking systems require a large number of volunteers to participate. In some countries, including Germany, there are still some legal obstacles which prevent a stronger participation of volunteers, which is why these impediments for success need to be discussed in more detail in the next section.

Legal and Ethical Issues

The success of a crowdtasking app that assigns resuscitation tasks to trained volunteers will depend to a large extent on the legal and ethical framework under which such an app is operated. Current approaches insist that participation in the program is entirely voluntary, and once registered with the service, volunteers are under no obligation to answer or follow a resuscitation request. These assurances are given in order to increase the number of volunteers who otherwise might be reluctant to join the service.

Given the fact that operators typically alert several volunteers instantaneously in case of an SCA, they are confident that enough helpers can be activated even if some of them decline the task assignment, and are in no way trying to punish non-respondents. However, from a legal perspective, the situation is not as easy as it may seem on the first glance. Several countries, including Germany which we will consider in the case presented, have laws in place that require anybody to help to their best ability once he or she becomes aware of an emergency or common danger. Failing to do so can result in fines or even prison sentences of up to one year according to §323c of the German penal code. The only reasons stipulated for not following this legal requirement are if the person asked for help endangers himself (which will rarely be the case when helping in a sudden cardiac arrest), or if the potential volunteer has to neglect "other important duties" by following the help request issued by

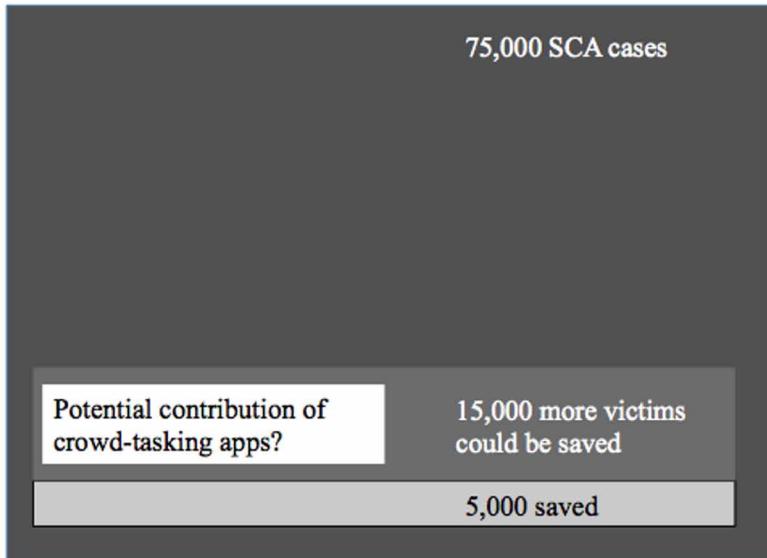
Figure 2. Example for a crowd tasking system – message for a volunteer



a crowdtasking app. Messerschmidt & Wester (2016) analyzed the legal implications of this law and summarized that in the case of an SCA, the legal bars to refuse aid are particularly high because an SCA situation is per se life threatening for the victim. As a consequence, the only acceptable reason to decline a help request in the case of SCA is if the life of somebody were threatened while trying to help the SCA victim. Examples given by Messerschmidt & Wester (2016) include, for example, parents who are in the process of bathing a baby (and would endanger the life of their baby while leaving it in the bathtub when rushing out of home). As a consequence, while joining a crowdtasking app is entirely voluntary, helping becomes an obligation once the app has been installed. In case that this fact becomes widely known, there is a substantial danger that skilled volunteers will be reluctant to join the program. Possible solutions to this problem are to include an “Opt-in / Opt-out” mechanism in the app that allows volunteers to declare themselves unavailable (and making it technically impossible to contact them by doing so).

However, even joining the app program may de facto not be voluntary. As we are targeting skilled professionals in the scenario discussed, there might be substantial social pressure to join the crowdtasking effort and to install the SCA alert app. This aspect is highlighted by Venkatesh, Thong & Xu (2012), who identified social influence as a key factor affecting app uptake. Peer pressure in the community of healthcare and rescue professionals may therefore actually be a driver of app uptake. However, being reluctantly obliged to install the app may be a cause of reactance. Once

Figure 3. Visualization of the research questions



again, including an “unavailability mode” into the app could be a possible solution to the problem. A different solution would be to alter the penal code so that it does not punish registered volunteers.

However, an ethical assessment could also come to a completely different conclusion: that life of the victim is more important than privacy concerns and that all competent professionals should be required by law to join a crowdtasking program. While this may simply provoke unwilling participants to switch off their mobile phones as often as possible, it would still lead to a substantial increase in participation and success rates.

As a consequence of the considerations above, we will discuss two different scenarios. The first scenario is very conservative and will be based upon already observed participation rates in the different areas where such crowdtasking apps are currently being deployed. A best case scenario will assume that participating in SCA apps has become a legal obligation for relevant professionals and that 50% of these are actually joining the program. In reality, the true effect of the app will be in between the two scenarios presented.

CONCEPT TO CALCULATE THE EFFECTIVENESS OF EWAS IN THE SCA CONTEXT

Inspired by Klafft & Meissen (2011), Wurster, Meissen & 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:

; casualty i

- v_j: volunteer
 (x_i, y_i): coordinates of casualty i
 (x_{v_j}, y_{v_j}): coordinates of volunteer j
 p: factor for distance metrics
 A: planning area [km²]
 d: distance [km]
 s_{v_j}: 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,v_j}: likelihood that a member of the target group subscribes to the EWAS as a volunteer
 Lhood_{notice,v_j}: likelihood that the volunteer notices an incoming warning message via the EWAS in time
 sLhood_{able,i,v_j}: situational likelihood that the volunteer is able to perform resuscitation actions
 sLhood_{willing,i,v_j}: situational likelihood that the volunteer is willing to perform relevant actions in case of an alert regarding incident i
 PROB_{v_j}: 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,v_j}: 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
 CUR_{pot,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
 SAVPLUS_{spot}: 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 & Meissen (2011) and Wurster et al. (2015), a calculation approach consisting of two formulas was developed. The territorial factors *moving speed* and the *number of volunteers in a given area* are used in separate calculations shown in the next chapter. They determine the probability that a specific volunteer reaches the victim in time based on data of ordinary moving behaviour (PROB_{v_j}).

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

Formula 1:

$$PROB_{V,all,i} = \left(1 - \left(1 - PROB_{v_j} \right)^{N_v \cdot Lhood_{subscr,v_j} \cdot Lhood_{notice,v_j} \cdot sLhood_{willing,i,v_j} \cdot sLhood_{able,i,v_j}} \right) \cdot Al_T \left(1 - Lhood_{outage,i} \right) \cdot sLhood_{DISCOV_IT,i,v_j} \cdot CF$$

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 RACA² score of Gräsner, Meybohm, Lefering, Wnent, Bahr, Messelken, Jantzen, Franz, Scholz, Schleppers, Böttiger, Bein, Fischer & the German Resuscitation Registry Study Group (2011).

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: $CUR_{pot,i} \cdot C_{FIRSTRESP,i} \cdot C_{HOSTREAT,i} = 100\% = 1$

Consequently, assumption 2 describes an additional premise.

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

The following chapter demonstrates the possible benefit of EWAS in the German SCA context.

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

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

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 – which includes about two million people according to the national statistics office.

Besides participation rates, 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) or by an eyewitness. According to Wnent, Bohn, Seewald, Fischer, Messelken, Jantzen, Gräsner & Gräsner (2013), 46.9% of SCAs in Germany are witnessed by other persons present. In most cases, these people are able to trigger an alert. Based on the urgent need for action, the probability Al_T that the alert is actually transmitted within the first minute after the occurrence of the SCA is a key factor in the impact calculation. We assume this figure to be close to the observations by Wnent et al. (2013) and set Al_T to (40%). 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, is then 40% of the 15,000 additional curable victims. 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. We then calculate the potential lives being saved by the app using (a) a conservative scenario, and (b) an optimistic scenario under ideal conditions.

Conservative Scenario

The conservative scenario builds upon observations of a crowdtasking app project for SCA which is already operational in some parts of Germany. The app project, also mentioned in previous sections is called ‘Mobile Retter.’ It kindly shared important data with the authors for the calculations in Tables 2 and 3. Their data refer to the administrative district of Gütersloh. It has a territory of approximately 1,000 km² with approximately 360,000 inhabitants. ‘Mobile Retter’ has 550 registered volunteers, which is about 0.15% of the population. 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). Empirical data from ‘Mobile Retter’ indicate that in 62.5% of cases, a volunteer picks up the alert and rushes to the victim (which is a combination of the likelihoods to notice the alert, the willingness to participate, and the ability to help). 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 shorter than 0.3km, the volunteers were likely to go by car. However, in line with the conservative scenario, the authors believe that the average speed of the volunteers will be below 40 km/h if the whole of the country is concerned. The observed average speed of 40km/h builds on several framework conditions. Gütersloh is a rural area where cars are parked in close distance and in which the probability of traffic jams is low. In order to remain cautious and to estimate data for the whole country, 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 & Gehlert, 2015). Therefore, the maximum average distance volunteers can move within a three minute interval can be calculated as $d = 0.75\text{km}$. 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 & Ghali (2009) suggest the use of the Minkowski metrics described in formula 3 as an approximation, where $[1 \leq p \leq 2]$.

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

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} .

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

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 $A'=1.51 \text{ km}^2$. Assuming an equal distribution of volunteers in the planning area, the probability that a specific volunteer v_j is located within the planning area, can be approximated by $\text{PROB}_{vj} = \min(1, A'/A)$. For the case of Germany with an area $A=357,168\text{km}^2$ the probability that an available volunteer is actually located within the maximum radius of the victim is therefore shown in formula 5.

$$\text{Formula 5: } \text{PROB}_{vj} = 1.51 / 357,168 = 0.0000042277$$

Based on this result, Table 2 shows all data of the calculation. Note that we conservatively assume that the number of volunteers cannot be augmented beyond the observed participation rate of 'Mobile Retter', which stands at 0.15% of the overall population, or 6% of the population which is trained in resuscitation.

Based on Table 2, approximately 1,219 SCA victims can be saved by EWAS in Germany annually if 6% of the potential volunteers subscribe to the service (as observed in practice). Note that this number is higher than in a previous estimation by the authors (Wurster, Fiedrich, Klafft, & Bohn 2016), because the literature (Wnent et al., 2013) shows that many more SCAs are actually witnessed by bystanders than initially estimated. This is a dominant factor, which outweighs the lower subscription rates observed in practice.

Optimistic Scenario

In this scenario, the authors assume that the government has decided to require skilled healthcare professionals by law to subscribe to the crowdtasking app, and that the subscription rate therefore reaches 50%. Willingness to react will decline in this scenario, but only slightly to 85% due to social pressure and the legal obligations discussed in the legal and ethical section above. In this optimistic scenario, the app would even be able to save more lives (see Table 3), however, at the expense of the freedom and privacy of healthcare professionals. Whether the impact of the app justifies such a heavy intrusion into health workers' private life is a political decision to be taken under legal, and ethical considerations. Additionally, for the optimistic scenario, we assume that 45% of SCA cases are reported to emergency services immediately (meaning that 19 of 20 observers do immediately call for help).

Table 2. Benefit calculation conservative scenario

(a) N_v	2,019,175
(b) $Lhood_{subscr,vj}$	6.0%
(c) $PROB_{vj}$	0.00042%
(d) $Lhood_{notice,i,vj}$	73.1%
(e) $sLhood_{able,i,vj}$	90.0%
(f) $sLhood_{willing,i,vj}$	95.0%
(g) $PROB_{vm,i}$	27.2%
(h) AI_T	40.0%
(i) $Lhood_{outage,i}$	1.0%
(j) $Lhood_{DISCOV_IT,i,vj}$	80.2%
(k) CF	93.0%
(l) $PROB_{V,all,i}$	8.1%
(m) SAVPLUSpot	15,000
(n) SAVSYS (l · m)	1,219

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

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

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 3. Benefit calculation optimistic scenario

(a) N_v	2,019,175
(b) $Lhood_{subscr,vj}$	50.0%
(c) $PROB_{vj}$	0.00042%
(d) $Lhood_{notice,i,vj}$	73.1%
(e) $sLhood_{able,i,vj}$	90.0%
(f) $sLhood_{willing,i,vj}$	85.0%
(g) $PROB_{vm,i}$	90.66%
(h) AI_T	40.0%
(i) $Lhood_{outage,i}$	1.0%
(j) $Lhood_{DISCOV_IT,i,vj}$	80.2%
(k) CF	93.0%
(l) $PROB_{V,all,i}$	27.0%
(m) SAVPLUSpot	15,000
(n) SAVSYS (l · m)	4,057

As can be seen, the number of people saved annually in Germany would increase to approximately 4,057 under the optimistic scenario.

Cost Benefit Analysis

According to experts, the costs of operating SCA crowdtasking apps like ‘Mobile Retter’ or ENSURE will be comparable to the costs of already established IT-based warning systems. Using a shared

infrastructure with other alerting and crowdtasking applications will enable emergency services to limit the operational costs of the app. In this case, costs for each county or major city are likely to be in a range of approx. 15,000 € upfront (for installation and initial training), and annual operating and maintenance costs of 3,000 €. This cost estimate is based on an analogy to existing alerting systems (for their costs, see NOZ 2013). Due to the analogy presented, this is a rough cost estimate which only applies to Germany, and it neither includes costs for energy and communication, nor possible payments / remunerations for the volunteers who try to help SCA victims.

Saving lives in the SCA context is only one goal of crowdtasking apps. In this context, the marginal annual cost per administrative district is worth the effort even if the system saves only a few lives per year (see next section). Furthermore, the potential life-saving is not limited to SCA incidents, 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, which have meanwhile become available through the experiences of the “Mobile Retter” app. This feedback was translated into the example calculation in Table 2. Expert 3 suggested focusing on some subgroups within healthcare professionals who have frequent practical experience with resuscitation, such as ambulance drivers who are off duty. The fourth expert highlighted the capability of EWAS to reach victims in less than five minutes, based upon his experiences from the ‘Mobile Retter’ project. 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 worldwide 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 ‘Mobile Retter’, ENSURE and comparable apps are for example accidents and crime. These contexts require further research.

Another issue that needs to be addressed in the future are situations where resuscitation has to be performed over an extended period of time due to a delay in ambulance arrival, which is often the case in rural areas. In such cases, the quality of resuscitation efforts of the first trained volunteer (i.e., first healthcare professional off duty who reached the victim) will begin to deteriorate after about 2 minutes due to exhaustion. This factor is not yet reflected in the formulae above due to the lack of knowledge on the exact impact of exhaustion, and the lack of practical experience on how to guide a second (or more) volunteers to the scene of the SCA. Empirical observations so far only focused on the likelihood that at least one trained volunteer was in fact able to reach the victim in time. Therefore, this aspect remains an issue for future research.

Another aspect for future research is how to incorporate the possible use of Automated External Defibrillators (AED) into the formulas presented. In densely populated areas, AEDs are becoming increasingly available and can enhance the chances of the victim’s survival substantially. If an AED is located close to the victim or on the volunteer’s way towards the victim, the best strategy might be to pick up the AED to apply it instantaneously upon arrival. However, since AEDs are only available in some places, and since there is no empirical data on the impact of using AEDs in combination with crowdtasking apps, we did not include this aspect in our model yet.

The model discussed in this paper is a two-dimensional approach which does not include height as an additional variable. In the mostly flat and rural counties where the “Mobile Retter” app is currently operated, height has not been an issue, and in most German cities it will be of limited relevance due to

the absence of skyscrapers. However, if skyscrapers are present, it may take volunteers considerable time to reach the ground floor before being able to drive / ride / run to the victim. Although this factor has not been taken into account yet, it can be added to the model once field data from large cities becomes available.

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ENDNOTES

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

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