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Being Agile When It Really Matters: How ICT can Facilitate Rapid Response to Cardiac Emergencies

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Abstract

Sudden cardiac death is a serious public health issue in Ireland, especially within rural communities that cannot be quickly reached by emergency ambulance services. When a person suffers a cardiac arrest, it is vital to invoke the "chain of survival" process, involving early access to the emergency services hotline, early CPR, early defibrillation, and early advanced paramedic support. It is vital that this process be executed quickly and efficiently. This paper proposes ideas on how the early stages of the "chain of survival" may potentially be enhanced and made more agile and responsive through the application of innovative ICT solutions designed in accordance with principles of interactive systems design and based on the new generation of mobile applications such as location-aware devices and social networking software.

Keywords: Emergency response; cardiac first response; location-aware mobile ICT; agile teams.

1 Introduction

Amongst the EU member states, Ireland has one of the highest rates of coronary heart disease [1]. There are approximately 5000 deaths resulting from cardiac arrest every year in Ireland, about 80% of which occur at home. At present, victims of cardiac arrest in out-of-hospital settings have a 1% chance of survival. The role of information systems in facilitating rapid emergency response has become topical as a research subject in recent years. However, most of the articles published in this area are concerned with homeland security, natural disasters or epidemics (e.g. [2,3,4]). No explicit consideration has as yet been given to how information systems can mobilise cardiac first responders (CFRs) to deal with life-threatening emergencies, the closest related work being that of Kyng et al [5].

There has been a lot of debate in the past decade around the general notion of "agility" and how organisations can adapt and re-design their work practices to flexibly respond to changing situational demands. Alongside this trend towards becoming more agile and responsive, we have seen a prolific growth in the rate of adoption of mobile information devices, messaging and collaboration software, and semantically-rich Web 2.0 applications. This new generation of information and communication technologies (ICT), – which includes social networking systems, location-aware devices, radio frequency identification (RFID), 3G mobile communications, and iPhone™/Android™ applications – enables people to easily and inexpensively connect with each other, thereby forming virtual social communities which, because they are not encumbered by the traditional constraints of physical presence, are by their nature more flexible and *ad hoc*.

The motivation for this paper is therefore to explore how the flow of communications through the "chain of survival" for cardiac emergency response may potentially be made more agile through the application of this new generation of intelligent information systems and rapid alert technologies. This paper is of the nature of a viewpoint article in so far as it does not actually make a technical contribution but rather proposes possible ideas for future applied research.

2 Setting the Scene: The “Chain of Survival” Process

When a person suffers a cardiac arrest, it is vital that the stages of the “chain of survival” are initiated without delay. These stages are: immediately notify the emergency services and request an ambulance, commence cardiopulmonary resuscitation (CPR), apply an automated external defibrillator (AED) as soon as possible, and ensure that advanced life support arrives quickly [6]. It is imperative that the early linkages in this chain are very quickly put in place because otherwise the best efforts of the advanced paramedics are likely to be in vain given that brain death sets in 4 minutes after cardiac arrest and the target ambulance response time for rural communities in Ireland is 25 minutes [7]. According to a spatial analysis of ambulance services published in 2005, 4.3% of the population of Ireland reside in areas that cannot be reached within 25 minutes, but this varies significantly by region with 14.9% of people in the West, 12.8% in the Midlands, and 10.1% in the North-West out of reach within that time [7]. Performance data from these three areas shows that only about 60% of emergency calls are actually responded to within 25 minutes [8,9]. International best practice suggests that paramedics should aim to arrive within 8 minutes, although this can possibly be extended by the intervention of a cardiac first responder (CFR) [1,10]. However, by way of indication, just 11% of rural emergency calls were responded to within 8 minutes in the HSE North-West area in the period between July 2004 and June 2005 [8]. Thus the role of CFRs who are trained in CPR and the use of an AED is vital to sustain a patient’s chances of survival in rural Ireland. An important issue is therefore how to mobilise CFRs residing within rural communities so that they can reach the patient within the critical time of 4 minutes, and also to ensure that where an AED is available in the community it is delivered within 10 minutes.

Table 1. The “Chain of Survival”

Stage	**Early Access** →	**Early CPR** →	**Early Defibrillation** →	**Early Advanced Life Support**
Time limit	Immediately	Within 4 minutes of cardiac arrest	Within 10-12 minutes of cardiac arrest (ideally within 5-6 minutes)	25 minute target response time in Ireland (UK target 19 minutes)
Principal task	Make emergency telephone call to Ambulance Control	Ensure that a CFR arrives quickly at scene of incident	Ensure that an AED device is quickly brought to scene	Paramedics assume control, CFR passes information
Information required	• Telephone number • Location of incident • Chief complaint • No. of patients • Approximate age ↳ If > 35, Chest pain (Y/N) ? • Gender • Conscious (Y/N)? • Breathing normally (Y/N)?	• Location of incident • Contact details of CFRs in the immediate vicinity • If emergency caller is not trained in CPR, provide guidance on basic technique pending arrival of CFR/paramedics	• Location of incident • Location of AEDs in the immediate vicinity • Contact details of persons who can deliver AED to scene	• Location of most convenient ambulance • Contact details of advanced paramedics in the immediate vicinity • Information passed by Ambulance Control • Information passed by CFR (CFR Report) • Patient’s medical history i.e. conditions, medication, allergies etc.

It is clear from the overview provided in Table 1 that the essential challenge here is to design a mechanism which enables vital information and messages to be smoothly and quickly passed between the various actors involved in the process. Within the discipline of interactive systems design, there exists a number of useful techniques which can assist in this regard, including “personas”, “user stories”, and “scenarios”. These techniques permit user needs to be explored in depth, thereby helping to clarify assumptions by providing a better understanding of actors and their “real-world” environments. By way of example, the following scenario, which is a fictitionalised account based on actual events, describes the chaotic and hectic nature of a realistic cardiac arrest situation, in marked contrast to the artificially controlled simulations typically portrayed in CFR training videos:

> **Location:** The home of John O’Dowd in a small town in the West of Ireland.
>
> **Description of events:** The telephone rings at 8:40am. John recognises the caller ID as his brother Francis, who is spending his Christmas holidays in a rural holiday home 12 miles away. John was expecting a visit from

> Francis today but when he answers the telephone he realises that something is wrong. “John! I can’t wake Francis up! I don’t think he’s breathing!” cries the voice on the opposite end, that of Francis’ wife, “I don’t know what to do!!”. “What?” exclaims John, “You can’t wake him up? I’ll call an ambulance!”. He hangs up and immediately calls the regional hospital. “I need an ambulance to go to my brother’s house!” he says. “This is the main hospital switchboard, you’ll need to call 999” apologises the receptionist. He again hangs up and this time dials 999. “What service do you require?”. “I need an ambulance!” “OK, you’re straight through to Ambulance Control”. John quickly explains the situation and is told that an ambulance is on its way. “Can you please spell that address for me?” asks the controller, “And give me directions to the house?” Despite his panic, John provides clear instructions on how to reach his brother’s house, referring to various landmarks along the approaching roads and country lanes. Meanwhile, John’s eldest son, who was woken by the initial call, rummages through the telephone directory looking for the number of the police station nearest to his uncle’s house, wanting to find out where the closest AED is located and if somebody can quickly get to it. Having located the number, he makes a call on his mobile phone but it rings out. He then tries the next nearest police station, but again receives no answer. “We need a defibrillator!” he shouts to his mother, “where can we get one?”. “I don’t know!” she replies, as she tries to call the local GP on her mobile phone. “OK, slow down” answers the doctor, who lives 4 miles from Francis’ house, “Please explain the situation and give me those directions again”. Another son, despite the icy driving conditions, jumps into his car and immediately rushes to the scene. The ambulance overtakes him just before he arrives at his uncle’s house, shortly before 9:10am. By the time the ambulance arrived, it was probably 30 minutes after the initial cardiac arrest. Despite the best efforts of the paramedic crew to revive Francis, he passed away.

The above scenario shows that the weakest links in the “chain of survival” are often the early stages, as also asserted by Wellens et al [11]. Kyng et al [5] make the point that collaboration between multiple actors in emergency situations is complicated by the fact that the situation can change dynamically. Most ordinary civilians are unaccustomed to having to react to emergency situations and may not know what to do or might be flustered due to panic, especially where the victim is a family member. The metaphors of “agile”, “lean” and “extreme” are used within the literature on information systems development to refer to high-speed highly-efficient processes, and those same principles can be applied here to design a potentially life-saving communication workflow. Indeed, this is a truly “extreme” design challenge where the deadline, in the most literal sense of that word, is of the order of a few minutes.

The historical evolution of “lean” and “agile” work practices can be traced from the “scientific management” movement of the 1910s, through to Toyota’s production processes in the 1950s which in turn led to “Just-in-Time” (JIT), Total Quality Management (TQM), and Business Process Re-engineering (BPR). The principles of “lean” production include teamwork, communication and the efficient use of resources. The objective of work practices such as JIT is to redesign workflows so as to reduce setup time and eliminate redundancy; using this approach, Toyota famously managed to re-engineer tasks so that cycle times were reduced from hours down to a few minutes [12]. The initial stage of JIT Implementation Design is the Design Flow Process, the key objective of which is to speed up turnaround by reconfiguring the flow of work to maximise efficiencies. Applying that principle to a cardiac arrest situation, it is vital that anything in the flow of communications or logistics which is likely to unnecessarily waste valuable seconds must be eliminated.

“Response time” is defined by the Pre-Hospital Emergency Care Council (PHECC) as the “time from receipt of the call to arrival at the scene” [7]. This paper is not concerned with this particular aspect because the logistics of ambulance control is already well-researched (e.g. [7,8,13,14]). Indeed, the London Ambulance Service’s Computer-Aided Dispatch system (LASCAD) is one of the best-known cases of information systems “failure” within the academic literature [15]. Nor shall the paper deal with the use of in-ambulance electronic patient care records (ePCR) by paramedics, which again is the subject of other research (e.g. [16]) and indeed has also been known to give rise to problems in practice [17]. Instead, the paper shall concentrate on the first three links in the chain of survival and will propose ideas on how these critical early stages can be better supported through time-efficient ICT solutions.

3 Supporting the "Chain of Survival" Using ICT

3.1 Early Access

"Alert time" is defined as the "time from the moment of the accident to the call to emergency services" [7]. When the call is answered, there is a further short delay as the controller processes the basic information required to dispatch an ambulance. In principle, it should be possible to reduce the time required to execute this stage to less than 5 seconds using quite simple technology.

The "information required" as shown in Table 1 under the Early Access column is as stipulated on the Request Emergency Dispatch (RED) card which the PHECC issues to CFRs [6]. The most essential information which needs to be communicated is that a person has suffered a cardiac arrest at a particular location, as well as the telephone number and name of the person making the call. All of these facts can very easily be sent using a telephone, either mobile or fixed landline, which automatically sends the GPS co-ordinates from which the call is being made and the full caller line identity (CLI) to a dedicated emergency number (i.e. other than 999 or 112) set aside for cardiac emergencies. This idea of a separate number is also suggested by Wellens et al [11], meaning that there is no unnecessary delay in ascertaining the nature of the emergency before dispatching an ambulance to a precise location. Given that most cardiac arrests occur at home, it is theoretically possible to simplify the interaction by just having to press a cardiac panic button on a telephone handset. Clearly, a single button has benefits in terms of ease and speed of use, especially for elderly users, but it would have to be designed to prevent the possibility of accidental activation. Additional controls would need to be built to ensure that the location of the telephone is actually beside the location of the incident (unlike the scenario case described in Section 2), and to confirm that the travel directions suggested by the GPS sat-nav are accurate. The information automatically sent to Cardiac Ambulance Control could further be extended by linking the telephone number to a unique house ID (with precise GPS location), perhaps linked to the electoral register (i.e. the names of the usual adult residents) and the personal electronic healthcare records (EHR) of those residents. As it stands, policies regarding CLI traceback on calls to emergency services differ across the European Union [1], and privacy issues come into play when attempting to consolidate personal data across different sources. There are also issues with the accuracy of locations derived from mast triangulation in rural areas: this method is not sufficiently precise, and although new initiatives in Ireland such as the installation of roadside signage with route numbers for all by-roads and the proposed introduction of unique postal house numbers both help to aid navigation, it is preferable if the emergency caller can use a device which sends exact GPS co-ordinates of the incident.

The above suggestion assumes that the cardiac arrest has been witnessed, but in actuality about 40% of arrests are unwitnessed. Indeed, even if witnessed by a bystander trained in CPR it may take up to a minute to confirm arrest and alert emergency services [11]. The only way that delay can be avoided in the event of an unwitnessed arrest is if the victim is fitted with a biosensory apparatus. Wellens et al call for the design of a wearable device which can monitor vital signs, alert bystanders in the event of a cardiac arrest, record the time of collapse, automatically notify emergency services of the location of the victim, and transmit a signal to the nearest community-based AED [11]. Such technology can potentially be supported using telecommunication standards such as GSM/CDMA, WiFi, RFID, and GPS/location-aware devices. An example of how it might be implemented is provided in [18], which describes a low-cost personal electrocardiogram (ECG) monitor that can send GPS co-ordinates, ECG data, and the EHR of a cardiac arrest victim to the nearest emergency service centre, which in turn notifies the closest GP via SMS. However, such devices are not yet available on the consumer market, though GPS-enabled "fall detection" products which automatically raise an alarm are available. Within the field of biomedical engineering, a number of research projects are currently ongoing which are looking at the use of nanotechnology sensors to monitor heart rhythms. Although much of the leading-edge research in the area of remote biosensors has been conducted on NASA astronauts, it is anticipated that such technologies will become available for domestic use within the near future [19].

3.2 Early CPR

The most common category of victims of cardiac arrest is males over the age of 50. Accordingly, the most common category of witnesses of cardiac arrest is those mens' partners, usually middle-aged to elderly women, who unfortunately often do not know how to perform CPR, are no longer physically strong enough to perform CPR, or become so taken over with panic as to not know what to do. Early CPR is the second link in the chain of survival and must be initiated by a CFR within 4 minutes of cardiac arrest. Realistically, in a rural community this means that the CFR must be within a radius of 1 mile of the incident in order to be able to get there on time, assuming private motorised transport is available. What this means is that, whenever a person collapses because of a cardiac arrest, it is vital to be able to immediately alert all qualified CFRs within close proximity of the incident.

There are a number of dimensions to this process design challenge. Firstly, it is necessary to be able to provide precise information on the location of the victim, including telephone contact number. This information is already gathered during the Early Access stage by the emergency services call operator, so it must be passed on to CFRs in order to enable them to respond. Thus arises the second consideration: how to contact CFRs within the vicinity of the victim. This requires that a contact database including mobile telephone details must be kept for all certified CFRs. It is possible to undertake CFR training in Ireland through a variety of channels, including voluntary bodies (e.g. Red Cross), cardiac foundations (e.g. CROÍ, Irish Heart Foundation), sporting bodies (e.g. GAA, FAI), workplace health & safety training, and on-the-job training (e.g. police, fire brigade, teachers, doctors, nurses). The Irish Heart Foundation aspires to a situation where 10% of the adult population in Ireland are trained in CPR and is calling for the introduction of CPR training on to the secondary school curriculum, a move supported by the Sudden Cardiac Death Task Group [20]. What all of this means is that an increasing number of people in Ireland are now CFR trained. Many but not all of these qualifications are certified by PHECC and the personal details of CFRs are held on file, though often just in paper-based format within the records of the training body. It is therefore necessary to systematically maintain these PHECC certifications, and indeed other qualification paths if feasible to do so (e.g. some CFRs in Ireland are certified by the American Heart Foundation). Having thus built a database of CFRs, the final piece is to be able to identify who is in the immediate vicinity of the reported cardiac arrest. A crude way of doing this is to ask each CFR to specify his/her normal location at different times of the day e.g. during normal working hours, in the evenings, at weekends etc. There currently exists a number of group calendaring software products, some of which are actually dedicated to the co-ordination of rescue teams (e.g. Decisions For Heroes – D4H), which allow a volunteer community group to share details of personal whereabouts and hours of availability. If a shared calender were deployed, CFR volunteers could then be sent an alert to their mobile phone or pager device if an incident were to be reported within the area they are expected to be within. However, given the constraint of being within an approximate radius of 1 mile, this crude "expected location" technique is unreliable. It would be much more accurate, although also much more intrusive, if "on-call" CFR volunteers consented to their precise whereabouts being tracked using mobile GPS "pings". Although there are potential privacy and security issues with such an approach, technologies such as Google Latitude already enable social communities to share location details in a similar manner.

3.3 Early Defibrillation

In order to facilitate early defibrillation, it is essential to know where the nearest AED device is located and how to get it delivered to the scene of the incident as quickly as possible. In their study of how long it took people to find AEDs in two international airports, Kaneko et al [21] found that while the theoretically expected discovery time should have been of the order of 30-40 seconds, the actual discovery time was about 3 minutes. They conclude that the presence of clear directions is an important factor for rapid retrieval of an AED device.

There already exists a number of software applications which provide area maps showing the locations of AEDs. For example, in the Netherlands the AED4EU project set up by the University of Nijmegen

Medical Centre uses Google Maps/Street View to show where AEDs are situated (http://www.aed4.eu); this application can be accessed using a Web browser and is also commercially available as an iPhone/Android application. In the United Kingdom, a similar project called AED Locator was recently established in partnership with the Arrythmia Alliance charity whereby local communities can submit details of AEDs in their area (http://www.aedlocator.org). More ambitiously, there is a freely available iPhone application named "AED Nearby" and a corresponding Android application named "ShowNearby AED" which aim to create a worldwide map of the locaton of AED devices (http://www.firstaidcorps.org/locate-aeds-near-you/). Clearly, the usefulness of such systems depends on the accuracy and completeness of the information they contain. For example, it is important to know when the AED was last tested or if it has been returned to its location after the previous use. This kind of information can be recorded using dynamic RFID, a technology that can also be used to sent out a "homing" signal so that an AED can more easily be found. As is clear from the previously mentioned findings of Kaneko et al [21], it is not sufficient to tell somebody that an AED is located within a building on a particular street because vital time can be wasted searching for the exact location within that building. Even GPS co-ordinates are not necessarily enough because a building with multiple floors will have a number of points on different floors with the same GPS co-ordinates (GPS does not provide sufficiently accurate altitude readings to be able to determine with certainty which floor you are on). It is therefore necessary to somehow provide information about how to navigate buildings, with details of the locations of elevators, stairs, and corridors. At a very basic level, this involves clearly marked signage within buildings. At a more advanced level, a building could be digitally mapped. A person seeking the AED could then be directed towards its precise location by means of a mobile application that dynamically guides the person using voice navigation. As yet, there is no application which shows the locations of AEDs in Ireland. The only information readily available on the Web is a list of the locations of defibrillators provided by CROÍ, the West of Ireland Cardiac Foundation (http://www.croi.ie/is-there-a-croi-defibrillator-near-me).

Wellens et al [11] make the point that "time between collapse and defibrillation can also be shortened by having a sufficient number of AEDs and a dense network of 'cardiac arrest watchers' in the community." There is a considerable body of research in the public health literature on the optimal placing of community-based AEDs using spatial analysis models and operations research algorithms. The reality in most rural communities in Ireland is that there is a low density of AED distribution, they being mainly located in sports clubs, public buildings, and GP clinics. Considering the imperative to commence early defibrillation within 10 minutes, and assuming that the victim is not in possession of a home-based AED or implanted AED, it is preferable if a person based near the site of the community AED could be sent an automatic alert to immediately bring it to the location of the incident, rather than somebody travelling from the incident to fetch the AED and double-back. This step could be enhanced by recording who collected the AED device, at what time they collected it, and the expected time of arrival (ETA) at the location of the incident. Again, this information could be made available for sharing with the volunteer network through the use of mobile applications based on technologies such as RFID, GPS and Web 2.0 social networking.

4 Conclusions and Future Directions

Speaking of the challenge of improving survival rates from out-of-hospital cardiac arrests in Northern Ireland, Moore et al recognise that "no one strategy is likely to constitute a single best approach … Systematic efforts to strengthen each link in the chain of survival would incrementally improve survival" [22]. Substantial progress has indeed been made in recent years on steps to reduce the incidence of sudden cardiac death in Ireland [20], but there is clearly no "silver bullet". This paper has set forth a number of ideas, inspired by concepts of agility and principles of interactive systems design, which suggest how innovative ICT applications can potentially help to achieve process efficiencies in the form of quicker reaction times, thereby strengthening the chain of survival, especially at the critical early stages. Notwithstanding this potential, the implementation of ICT solutions in practice is rarely clear-cut because of the socially and politically complex nature of organisations and stakeholder groups, especially where public health issues are involved. For example, Rialle et al [19], in discussing their concept of a "health smart home", outline five categories of constraints which impact the use of such technologies: ethical issues, economical cost-effectiveness, technological suitability and privacy, psychosocial issues (i.e. usability, acceptability), and public health considerations. Similarly, Varshney [23] acknowledges that there is a strong economic and public health incentive to advance the agenda of "pervasive healthcare", but makes the point that there are substantial roll-out hurdles to overcome as regards medical, management, and technology issues. In addition, legal issues are problematic, concerning not just security and privacy but also the thornier issue of litigation, there as yet being no "Good Samaritan" Act in force in Ireland [20]. The ongoing reform of the healthcare sector in Ireland is yet another consideration, because for example there is no integration between statutory ambulance services, private ambulance services, and the voluntary bodies (e.g. Red Cross, Order of Malta, Civil Defence, St. John Ambulance Brigade) [24]. To conclude on a positive note, there is a growing public awareness in Ireland of the need to address the serious problem of sudden cardiac death and there is a willingness to embrace new initiatives that further this agenda. Given this receptive mood amongst the general public, especially within local volunteer groups, it would be interesting to attempt to implement some of the ideas proposed in this paper as "proof-of-concept" pilot projects.

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