Learning From Non-Acceptance: Design Dimensions for User Acceptance of E-Triage Systems

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ABSTRACT

As of 26 December 2016, seventeen electronic triage systems for disaster triage have been proposed in the ACM, IEEE, and ISCRAM publication databases. Most of these systems have remained inside the laboratory; the rest have disappeared entirely. Responders still prefer to do triage with paper tags from the 1960's, while no research has been presented on why the proposed e-triage systems have not found acceptance and use in the field. Based on exhaustive literature research and on the findings from the four-year long, EU research project BRIDGE , this paper presents e-triage acceptance dimensions, analyzes the main reasons why proposed systems have been rejected, and guides designers towards upcoming, well-accepted e-triage systems.

Keywords

Triage, E-Triage, Survey on existing approaches, Acceptance of ICT, Design guidelines

INTRODUCTION

Triage is the process of deciding which victims should be treated first in an emergency or disaster, given that there are not enough resources to treat all at the same time (WHO 2008). For the purpose of this research, a concise, generalised summary of triage is presented below. More detailed descriptions can be found in the works cited in the "State of the Art" section.

Seen separately from other, parallel-running response activities, triage consists of the following steps:

1. Estimate the victim's injuries and measure his or her vital values. This is usually carried out by direct inspection.
2. Mentally run a categorisation algorithm to determine priority of treatment. The input consists of the measured vital values, the output is a triage priority category. This priority gets further adjusted by the triager, depending on various, possibly ad-hoc, considerations.
3. Label the victim with a visible marker signifying the priority category. This helps other responders a) recognize that the victim has been triaged and b) recognize the victim's priority from afar. Any visible marker with an agreed-upon meaning may be used, but colored paper tags, clips, or plastic bracelets are the most common (Brownlee 2014).
4. Trigger the further handling of that victim. This usually means reporting the victim to the command post or to the treatment and transportation unit.

The measurement, categorisation, and marking must be completed within 15-45 seconds, depending on the legal framework (Wingerter 2013). There is no time to report each victim separately, so reporting is done after several or all victims have been triaged. This may delay transportation up to 20 minutes and medical treatment by 30-40 minutes (Donner et al. 2012; The BRIDGE Project 2011) .

The tools currently used for triage present various problems and limitations: the tags may be lost or damaged, information is handwritten, smeared, and unreadable, it takes too long for the data to reach the appropriate responders, location data is not captured, the needs of several responder groups are not fulfilled, etc. Such problems are extensively described in the research from the "State of the Art" section. This paper instead aims to critically analyse the proposed, IT-supported *solutions* to these problems, and to uncover why those solutions have not been accepted by first responders. After a categorized overview of proposed e-triage systems, the paper describes the methodology for assessing them. The subsequent section presents a set of e-triage acceptance dimensions, which influence whether responders adopt a proposed system. These dimensions are then used as basis for reviewing state of the art systems and approaches, so that it becomes clear why they have not been accepted in the field. Examples of typical problems are also provided for system designers to avoid design traps.

STATE OF THE ART ON ELECTRONIC TRIAGE SYSTEMS

A full-text search of "triage" in the ACM, IEEE, and ISCRAM publication databases shows 111 papers related to emergency and disaster triage[1]. 35 papers use IT to tackle singular problems. 39 papers present algorithms and systems for diagnostics, patient management, and hospital triage. 24 papers present 17 disaster e-triage systems (presented below in detail). Six papers mention triage as an example only. Five papers analyse the suitability of certain technologies for triage. Only two papers (of which one by this author) offer suggestions on how IT may impact the triage process itself. No papers analyse why electronic triage systems may fail.

The 17 e-triage systems proposed so far are listed below, grouped by common technology and interaction style.

WIMP or Touch-based mobile interfaces

Responders interact with these systems through a GUI on a mobile device they carry. The triage marker tag itself may or may not have computing capabilities.

Infrastructure-dependent systems

These systems require special infrastructures to exist or be created before triage can start.

WIISARD (Killeen et al. 2006) requires a WiFi mesh network to be deployed on the field before triage can start; this deployment, according to (Chipara et al. 2012), takes one hour or more. Triage tags are still made of paper, but they have a barcode that connects the tag to data entered on a PDA. By the authors' own testing, triage took on average 40 seconds per victim, with a range of up to 4 minutes.

The CrowdHelp system (Besaleva and Weaver 2013a; Besaleva and Weaver 2013b; Besaleva and Weaver 2013c) consists of a smartphone app for victims and a server-side backend for responders. After victims submit their symptoms, injury locations, and other relevant information through the app, they get informed about their possible diagnosis and what to do next. The triage category is assigned automatically, based on the self-reported symptoms. Machine-learning software offers responders a number of filters and visualizations, among which a clustering of the victims according to position and severity. The clusters are colored with the median triage category of the respective victims.

(Chandra-Sekaran et al. 2008) proposed a "Disaster Aid Network" composed of PDAs for the responders to monitor and record data, and ZigBee tags with temperature sensors for the victims. The system uses signal strength and temperature to calculate the victims' locations and the hot, warm, and cold zones respectively[2]. The authors report that calculation takes about 8 minutes and that localization reaches up to 2 meters accuracy, but that it needs a large number of position reference stations to be installed.

(Adler et al. 2011) present a concept based on handheld devices, satellite communications, and distributed databases. A tablet with special software is used for data input; network base stations need to be installed for connectivity. There is no automatic triaging. The system is intended for daily use as well as in disasters, but its interface differs between the two modes.

[1] These databases were chosen as the largest research collections on computing and electronics. We also consulted the "related work" cited by those papers that propose an e-triage system and we used general-purpose search engines as well, but the results lead back to the same databases.

[2] The hot, warm, and cold zones in a disaster area refer respectively to the dangerous, relatively dangerous, and safe areas.

Infrastructure-free systems with data-free triage tags

These systems do not require special communications infrastructure, but the tags they use typically serve only as an index into some database. No data is saved on the tag.

(Martín-Campillo et al. 2010; Martín-Campillo et al. 2011) proposed using a GPS/RFID-enabled smartphone and RFID chips embedded in paper tags. The triager must scan the RFID chip, use a GUI to run through the triage algorithm, and finally put the paper tag on the victim. The data are forwarded to the command post via opportunistic Wi-Fi links between the smartphones. Since each triager is supposed to return to base by a certain time, the data is selectively forwarded to the smartphone of the triager with the least time left before returning.

(Chang 2011) proposed an e-triage system with colored, active RFID tags, which can be read from a distance. Data is entered and saved in a PDA, then transmited over a Wifi or Cellular network to a central server and to the hospitals that will treat the victims. No data is saved on the tags. Colored LEDs show the triage category of the victim, with three blinking LED's showing a deceased victim.

(Raytheon 2007) presented an emergency patient tracking system based on barcodes, PDAs and WiFi communications. The data reside in a central, web-enabled database and are accessible to the command center, hospitals, and other agencies. The system was meant to be offered commercially, but as of 2016 its only remaining trace is the cited press release.

Infrastructure-free systems with data-containing triage tags

These systems also don't need special communications infrastructure, but the tags they use have sensing and/or computing capabilities and can communicate independently of the triager's handheld device.

AID-N (Gao et al. 2007) presented electronic tags with non-invasive sensors for continuous monitoring of victims' vital values. Triagers set the priority by inserting a specific card into the tag; an LED lights up to display the assigned color. Data is transmitted via a ZigBee network among the tags to gateway computers and from there to a central server. Data input is done through a PDA, while medics at the holding area can monitor multiple victims at once on a WIMP GUI. The system offers automatic monitoring of victims.

WIISARD v2 (Chipara et al. 2012) presented a fundamentally new communication architecture based on a ZigBee mesh network, "gossip"-protocols, and message broadcasting. The interaction with the system remained the same as WIISARD v1, i.e. PDAs were used. For cases when responders have to wear protective suits and can't use PDAs, a hardware tag with an RFID chip, display, and input buttons was provided (Lenert et al. 2011). Realistic testing of WIISARD showed an improved amount and quality of patient documentation, but the authors could not exclude a Hawthorne-effect (Lenert et al. 2011). Average triage time remained the same as with paper tags; it even increased for the "immediate" priority victims (i.e. the critically injured).

(Gillis et al. 2015) proposed a system based on Google Glass, while (Rocío Fuentes Fernández et al. 2014) used the Glass similarly, but with a voice-driven interface, since responders' hands are often busy. The triage category is determined automatically by asking questions about the victim to the triager. Even so, a third of the tested users (2 out of 6) told the app the triage category directly instead of answering the questions. (Berndt et al. 2015) report that head-mounted displays are suboptimal for emergency applications.

CodeBlue, a software infrastructure for sensor networks (Lorincz et al. 2004), used triage as a testbed application, similar to the above-mentioned PDA + WIMP GUI approaches. The authors took into account how the CodeBlue infrastructure could impact usability and designed the system accordingly. For example, they offer "best-effort" instead of "strong" security, since the necessary logins and PKI for strong security are incompatible with field work. Whereas CodeBlue was only a testbed, its architecture was reused in several of the e-triage systems listed here.

The triage device first proposed by (Sakanushi et al. 2011) (see "Dedicated Hardware Interfaces" below) was used by (Takahashi et al. 2011) for secondary triage (re-triage, the re-classification of the priority at the holding area, based on changes to the victim's vital values). The authors propose a touch-screen UI where a doctor can choose or draw the injury location and type. Together with sensor values, this input is used to automatically re-triage the victim. The authors report very positive evaluation results, but the system was only tested with students, in a tabletop exercise, and with victim information read from printed notes.

(Lawatschek et al. 2012) present ALARM, an emergency management system that also supports triage. Data are mirrored not only on an ad-hoc Wi-Fi network, but also on a passive, programmable RFID tag on the victim. A GPRS/UMTS/Satellite gateway makes the data available remotely. To provide visibility of triage status, the triager must stick colored labels on the tags after programming them. The system offers different devices to different roles, depending on their context: glove-tolerant smartphones for triagers, tablets for treatment area medics. Process efficiency measures are also taken and movements are logged.

A similar approach was undertaken in DIORAMA by (Ganz et al. 2013); triagers need to apply both an RFID tag *and* a paper tag to victims. Victim positions are shown overlaid on the commander's map. Active RFID tags are used to support RFID-based positioning. The tags transmit over Wi-Fi and the responder's helmet has a Wi-Fi receiver. To discern which tag is being manipulated, the tag should touch the reader device and a button should be pressed simultaneously. The system logs all information and can replay every movement on the scene.

Dedicated Hardware Interfaces

The triage interface in these devices is on the tag itself. The tag has, of necessity, computing capabilities. All the systems proposed so far that fall under this category also happen to be infrastructure-free.

(Sakanushi et al. 2011) proposed an electronic tag based on a blood oxygenation and pulse sensor. The tag is attached by inserting a finger from the victim in the appropriate sensor opening. The interface consists of eight LED-s to signal questions for the triager, and two buttons labeled "Yes" and "No" to input the answers. The system triages the victim automatically. Data are transmitted to a central server via a ZigBee network. The authors report halving the time it takes to triage a victim and lowering the death rate from 22.4% to 14%, but these are theoretical results, not empirical measurements.

(Carella and McGrath 2006) focused specifically on the military's requirements and proposed ARTEMIS, an e-triage system using embedded sensors to decide the triage category automatically. Data is transmitted via ad-hoc WiFi networking and a publish/subscribe middleware concept. The triage tags and monitoring sensors continue sending data all the way to the hospital, which provides continuous monitoring of the victim and a log of the data from the beginning.

(Noe 2010) used ZigBee sensors and microcontrollers to design the hardware for an electronic tag. Particular attention was paid to energy efficiency, scalability, and resiliency of the systems. The author's evaluation was focused not so much on actual use and acceptance as it was on the raw technical performance of the system, which was shown to handle hundreds of tagged victims at once.

Partial approaches to electronic triage

Various other papers and technology studies tackle only one aspect of e-triage, such as network routing, or only the suitability of certain IT technologies for e-triage. This research is listed here for completeness only, since it does not present a usable triage system.

(Kobayashi et al. 2010) propose a way to discover a walkable path from a doctor's location to a victim that needs attention.

(George et al. 2010) proposed DistressNet, an architecture for wireless networks made up of sensor nodes organized in a certain hierarchy. The proposed composition and protocols have since been superseded, but the basic architecture was used in several of the other e-triage systems.

(Lubrin et al. 2006) used the UTAUT model to judge the acceptance of sensor motes in medical institutions. The authors conclude that sensor motes are generally unknown to people, they present problems in how much effort they demand, they negatively affect privacy, and as a result they may not be well-accepted in a medical context.

(Garson and Adams 2008) tackle security and privacy in a hospital emergency context. They recognize that certain security solutions are incompatible with emergency work and propose ways to build usable security architectures for emergency situations.

(Togt et al. 2004) studied the added value from location-based services in disaster response. They also analyzed the types of information needed and found out that positioning and LBS need to be available indoors, not just outdoors.

Design frameworks for e-triage systems

(Turoff et al. 2004) proposed the DERMIS design model to generate a Management Information System for Emergency Response. While the outlined principles are sound, they are necessarily generic, driven by an MIS focus, and are not tailored to electronic triage. Some design principles for e-triage were also proposed by (Gao et al. 2007), but, as the authors themselves note, they are focused on re-triage and on the medics at a treatment area rather than on the complete triage process and on responders in general.

RESEARCH METHODOLOGY

This paper is based on research carried out over four years in seven countries as part of the BRIDGE project[3], an EU-funded FP7 research whose goal is to develop technical and organisational solutions for inter-agency, cross-border crisis and emergency management. An e-triage system was developed through a combination of participant-centered design, participatory design, and grounded theory methods (Slavin 2016; Greenbaum 1991; Glaser and Strauss 1967) as described in following. The research and development for this system led to the recognition of both the needs of first responders and their problems with the e-triage approaches proposed so far.

User Centered Design (UCD), (Norman and Draper 1986), which focuses on end users and their context to build fitting systems, has traditionally been recommended for designing emergency-related systems (South West Thames Regional Health Authority 1993). In the course of this research, however, a purely *user*-centered approach showed weaknesses. Triage is essentially an interaction between two responders, where one responder's understanding of the situation is transmitted to another responder, at a different place and time; an e-triage system is a machine that *mediates* this *human-human* interaction. UCD, in comparison, was meant for human-machine interaction. A second problem with UCD arises through its focus on "users". Few responders "use" a triage system directly (triagers, holding area medics), but the system impacts the work of many others (incident command, victims themselves, ambulance medics, doctors in a hospital, logistics managers[4], etc.). A participant-centered approach, focused on all the response participants impacted by triage, proved to be a better approach (Slavin 2016).

To take advantage of expert knowledge and to assure the acceptance of the final system among responders, participatory design techniques were used (Greenbaum 1991; Ehn 2008). An Advisory Board of responders worked with us to design the system and create prototypes. Testing and validation was carried out with other responders in multiple realistic emergency exercises with 20-400 participants.

Finally, as the resulting e-triage system was willingly accepted and successfully used by responders, with no training necessary, we used a grounded theory approach (Glaser and Strauss 1967) to understand its success factors[5]. A grounded theory approach was made necessary by the lack of acceptance models for e-triage systems in particular, and scarcity of models for emergency systems in general. The existing acceptance models (Turoff et al. 2004; Venkatesh et al. 2003; Dishaw et al. 2002; Ammenwerth et al. 2006; Goodhue and Thompson 1995) link an individual's past experience with IT to their present attitude towards IT and to their future decision to use IT for a given task. These are unfortunately too generic for the restricted, niche context of e-triage. Only (Turoff et al. 2004) takes into account some trade-offs of disaster management and offers some emergency-domain factors that impact experience. None of the models offer actionable advice on how to design an e-triage system for acceptance.

The empirical research for this paper involved firefighters, paramedics, doctors, police, disaster relief workers, logistics support managers, incident commanders, and hospital doctors from Norway, UK, Netherlands, Ireland, Switzerland, Austria, and Germany. At least two different methods of investigation were used for each question to reveal latent and tacit needs, as recommended by (Sanders 1992). As part of the user research, several e-triage systems from the state of the art were discussed with end users. Table 2 in the Appendix presents the detailed research activities. More than 300 hours of user research work and 30 hours of user testing with our prototype implementation were carried out with emergency responders and other domain experts, under realistic conditions, and in large-scale exercises:

- A train accident and a mass car crash in a tunnel in Switzerland, both accompanied by fire. Three Swiss and one Irish fire brigades were involved, each with 20-30 members, as well as paramedic teams.
- A chemical accident accompanied by flood and heavy weather in a populated area in Germany. Paramedics, Army, Police, and Logistics were involved.
- A terrorist attack at a petrol terminal port in Norway. 400 national responders were involved: firefighters, medics, triagers, and police.

The events' distribution supports the international applicability of the findings such that results are not bound to national regulations.

[3]http://www.bridgeproject.eu/en

[4]As an example, logistics support organizations do not do triage, yet they have to provide the infrastructure, power, and other technical resources needed by it.

[5]Responder organisations expressed interest in purchasing the developed system as soon as the development work finishes.

STAKEHOLDER NEEDS TOWARDS A TRIAGE SYSTEM

When analysing why an e-triage solution succeeds or fails with responders, it is necessary to know what responders deem an improvement over the current, paper-based triage and what do they wish an e-triage system could do. Two key observations are in order here:

- Throughout the rest of this paper, the term "responders" is preferred instead of "triagers", because a triage system touches upon many responder groups (see section "Research Methodology").
- Even though the same responder may perform multiple roles (e.g firefighting and triage), these roles never overlap in time. Each responder performs only one role at any given moment. The separation of roles is so strong that a) the role must be considered as a separate, orthogonal dimension when describing users and groups, and b) user needs can best be summarised by role instead of by other dimensions like demographics, task experience, or attitude to IT. This is how user needs have been grouped and presented below.

Triagers need a fast and reliable way to mark the victim's category and to leave notes for other responders who handle each victim. The triage tools should continue to be extremely lightweight. A way of knowing where there might be other, not-yet triaged victims, is also desirable. The system should grant triagers ultimate authority in what priority a victim gets, and should avoid the possibility for triagers to be penalized for their good-faith actions and decisions.

Victims need a system that does not cause them pain or further injury (e.g. by requiring them to move or expose skin for sensor contact). They also need the system to assure fairness, i.e. not allow low-priority victims to steal triage tags from high-priority ones[6].

Firefighters need the triage system to not cause them any more work than they already have to do. If they must do something related to triage, then a) they would accept to put a mark or label on the victims b) the tools for marking should be extremely lightweight, fast, easy to use, and reliable, c) the mark must not be interpreted as a triage priority (Elmasllari 2017) .

Paramedics need the system to tell them ASAP where triaged victims are and what is their priority[7]. If the triager has left notes related to the victim, the paramedics should be able to access those notes. An improved triage system should also help paramedics detect which victims have exchanged their markers.

Treatment area (TA) medics need the system to allow easy re-triage, both to a lower and to a higher priority. Since many medics are also triagers, re-triage should be done using the same tools as primary triage, in order to avoid confusion. Also, in order to fulfill the hospital doctors' need for a history of the victim's vital values, the TA medics want the system to help them monitor the victims, make notes, and log vital values (Elmasllari 2017) . Ideally, the system would also raise an alarm when these values change so much that a re-triage is warranted.

Incident commanders need to know how many victims there are from each category and how are they spread on the incident area. They need this information ASAP.

Hospital doctors need the victims to be transported to hospital as soon as possible, which requires triage to not be a bottleneck and quickly allow victims to be transported. The doctors also need a detailed history of the vital values as well as the notes about each victim.

The hospital administration needs the victim's generalia; if possible these should come automatically into the hospital's systems. The same generalia are also of interest for the **police** in order to investigate or notify families.

During the disaster, **response organisations** need to know at what point in the workflow each triaged victim is. They want a system that does not require workflow or organisational changes; ideally no training is necessary to use it, because such training is expensive and must be repeated often. The system should also be usable in daily emergencies (heart attacks, car crashes etc.) so that the doctors and paramedics who do triage have a fresh memory of how to use it (Elmasllari 2017; *The BRIDGE Project*) . Triage tools should allow responders to override them, use them in unforeseen ways, replace them ad-hoc, or combine them with other tools and systems, all without losing the capability to perform triage. The system should also allow to analyse and learn from past response interventions.

Logistics support organisations need the triage system to be cheap and ready at a moment's notice and be low- or no-maintenance. It should not require particular infrastructures, especially power or communication. Ideally, the triage system's components should be in a single grab-and-go bag, ready to use.

[6]It has happened that low-priority victims steal a high-priority tag from an unconscious victim (*The BRIDGE Project*) .

[7]It is not necessary to know where a particular victim is, as a victim's personal characteristics do not play a role in getting that victim out before other victims of the same priority.

For all roles the system should be usable in all kinds of weather and incidents (including chemical/radioactive, underground or in altitude, etc.), be usable even in a degraded state (Elmasllari 2017) , and should not increase the risk to responders (e.g. the system should not create sparks or intense radiation). Also, since "It is impossible to predict who will undertake what role in a crisis situation." (Turoff et al. 2004), no aspect of the system should depend on knowing the users' roles and intentions in advance.

LESSONS LEARNED FOR E-TRIAGE SYSTEM DESIGN

E-triage acceptance dimensions

By categorising the findings from our user research, six e-triage acceptance dimensions were identified to have impact on the adoption of a system. For each acceptance dimension, typical problems and examples are presented. We have not yet identified the order of importance for the dimensions, but this remains an open topic for future work.

Dimension 1: Completeness and appropriateness for triage

An e-triage system is inappropriate for triage when, due to the system's design or features, it is not possible to complete triage correctly, or when it is only possible to do so with disproportionate effort and/or discomfort. The system is incomplete when it only supports a part of the triage-related processes, or only a part of the users. Inappropriateness for triage may signify incomplete understanding of the emergency response context.

Typical problems and examples include:

- Basing the triage decision on incomplete or unreliable data about the victim, for example when victims self-report their status and symptoms. Victims cannot be expected to correctly judge and honestly report their own symptoms. Victims who can coherently communicate are also not the ones that need immediate treatment.
- Forcing either a certain triage algorithm, or automated triage. Algorithms change in two occasions: at committee meetings, and during the disaster response. The former can be programmed, but the latter are decided on the spot and depend on the victim (a crime witness may get priority treatment), on the available resources (with no available beds, an immediate-priority victim may be tagged as "intermediate"), and on other socially-acceptable but legally-dubious criteria (children may be given higher priorities than the elderly). Systems that do not give the triager control over the triage decision will be deemed inappropriate for triage.
- Requiring too much information, inputs, or other work. Triage relies on two information elements: the presence of a triage tag, and its color (priority). Systems that require triagers to fill in victim details, connect sensors, etc. may hinder triagers for the benefit of other responders (see also Dimension 2 below).
- Not supporting improvisation and "mixing and matching" of triage tools and markers. When triage tags are in short supply or unavailable, triagers are trained to use anything colored as a triage tag: clothespins, spray paint, colored rope, etc. Restricting them the ability to use the e-triage system alongside such ad-hoc solutions will put the e-triage system at a disadvantage.
- Not providing for reliability and *useful* degradation to a *well-known, minimum-functioning state*. This is related to the above-mentioned mixing and matching. Responders expect their tools to be very robust and reliable, but they also know how exactly the tool may fail and what a failed tool can still be used for. An e-triage system that is not reliable, fails too often, or fails to a "black box" or "useless" state does not offer the kind of "useful degradation" that responders expect of their tools.
- Not keeping in mind the physical context. Triagers go into a disaster field with a pack of triage tags (36 in our case), carry up to 20 kg of personal protection, gloves, and tools, and walk over unstable, slippery ground. A 100 gram tag translates to an undesired 3.6 extra kilograms of weight at the very least.

Dimension 2: Impact on workflows

Disaster response is a highly choreographed effort that is undertaken in an unfamiliar, ever-changing, overloaded, and chaotic situation. Response workflows and processes are patterns of behavior that have proven successful time and again over decades, maybe centuries. Changing them introduces inefficiencies at two levels:

1. Since their conscious mind is overloaded, responders can do their job only if their behavior is an automated "skill" independent of conscious thought (Rasmussen 1983). Process and workflow changes make behavior knowledge-driven, which resides at the inefficient, slow, and error-prone conscious level of processing.

2. Most new requirements to the e-triage system come not from triagers, but from responders with less time-sensitive requirements. Changing the triage workflow may introduce inefficiencies into this time-critical step, for the benefit of less time-sensitive tasks.

Typical problems and examples include:

- Haphazardly mixing marking and monitoring aspects of the system into the same tool, artefact, or process. It is crucial to understand that triage does *not* include the "further handling" of the victim (transportation, monitoring, medical treatment, etc.). Triage is a marking process where the mark represents a) the victim's state at one point in time (Jentsch et al. 2013), b) the belief that this victim is saveable. Monitoring is instead a continuous or periodic observation *after* it has been decided that the victim is saveable. "At the end of the day, [triagers] need a very simple tool that says that a patient is a priority." (Brownlee 2014). Triagers need the system to optimally support marking. It is the other responders that need monitoring.[8]
- Redistributing or assigning new tasks to a role without a comparable benefit to that role. As an example: if the system requires triagers to enter vital values into a GUI, it forces a time-consuming workflow change without direct benefits to triagers: they still have to measure those values. But if the system requires triagers to clip wireless sensors on the victim, the additional effort might be justified by the time savings, since the triager could use the sensor values and would not need to measure them.
- Requiring responders to attend to IT instead of doing response. Typical examples are setting up IT and network infrastructure, configuring PDA and terminal network settings, and even inputting a username and password "for security reasons". In the words of a triager: "If you communicate on the radio [during triage], you're not caring about the victim." (*The BRIDGE Project*) . By the same token, if you are attending to IT, you are not caring about the victim either.

Dimension 3: Consideration for organisational needs

E-triage systems are used by individual users, but are provided, purchased, and maintained by response *organisations*. Failing to account for organisational needs and workflows is a common barrier to acceptance of e-triage systems. In the words of a response organisation manager:

> They come to us and offer us [emergency management systems]. Then we say "Great! How do we power them where the power lines have been destroyed?" They answer: "No problem, here's a generator." And we ask "OK, now where do we find the petrol for the generator when no oil truck can reach us over the piles of rubble on the road?" And then they go away. (Source: Personal interview)

Typical problems and examples include:

- The logistics of deploying the system are impossible to satisfy, or take too much time and effort. This is the case where the e-triage system needs some kind of power or communication infrastructure to be laid out before it can be used for triage.
- System maintenance is required, needs special training, is complicated, or is otherwise cumbersome. This is the case with software and operating system updates, especially if they come up during the response.
- Some kind of configuration is required periodically, for each activation of the system, or during the response. Examples include inputting wireless network names, passwords, encryption keys, destination addresses for the data streams, data formats, etc.
- The system artefacts have special storage requirements. This is the case with electronics that need to be stored at particular temperature and humidity levels, batteries that self-discharge in storage, etc. Such storage requirements may be acceptable compared to the benefits from the system, but they still represent a disadvantage that system designers should keep in mind.
- The system is not usable for handling daily emergencies. This forces agencies to train responders explicitly, since the option of daily experience is not available. As training with an e-triage system will likely cost more than training with paper-tags, the e-triage system would face a considerable disadvantage.

[8] It is possible to mix marking and monitoring in the same process or artefact, but this must be done without harming the workflows. As an example, paper tags, an artefact for triage, provide form fields for notes and vital values monitoring. Those fields, however, are meant to be filled by medics at the holding area, which is a time-insensitive context, not by triagers in their time-critical context.

- Triage and monitoring data are only readable over the system, or data are not easy to import in the hospital's own patient management system. This includes using proprietary data formats, using proprietary interfaces, as well as not providing redundant access to the data when the system breaks or has not yet been fully installed.
- The system can only be introduced in an "all or nothing" fashion, or requires several organisations or roles to adopt the system at the same time[9]. Coordination among agencies with different ownership, budgets, priorities, and time plans is unlikely. The inability to introduce the system slowly by purchasing only small parts at a time means that organisations would have to either blindly trust the system or simply reject it. Given the limited agency budgets, rejection would be far more likely.
- The cost of the system may simply be too high for the response agencies[10].

Dimension 4: Appropriateness of interaction

A key characteristic of a triage system artefact is its ability to enable interaction among users and groups across time and space[11]. Since e-triage systems enable machine-mediated human-human interaction, they may introduce problems at both the human-machine and the human-human interaction level.

Typical problems and examples include:

- Generic usability problems according to ISO9241 (ISO9241). These may hint at insufficient analysis of the context of use.
- Interactions take too much time and/or resources. We have personally witnessed a proposed e-triage system where responders had to long-press a button for 8 seconds to turn the tag on, then 3 seconds for each color until the desired one, then another 8 seconds to activate the tag. This interaction takes, by itself, longer than the triage time allowed in some countries.
- Using explicit interactions where an implicit alternative is available. An example is the explicit scanning an RFID tag before putting it on the victim, whereas an implicit method is available and has been used successfully with first responders by (Zúñiga 2012).
- A closely related problem arises when interaction with the system replaces interaction with the victim. This is typical of systems where the responder needs to input data on a GUI: both visual focus and the locus of attention are moved away from the victim. Loss of eye contact also makes it impossible to observe, comfort, or reassure the victim, thus breaking a critical human-human interaction.

Dimension 5: Consideration for responders' attitude to IT

First responders, even when they are early adopters in private life, tend to distrust IT on the disaster field[12]. (Adler et al. 2012) report that handling of electronic devices is the biggest stressor in disaster response. E-triage systems need to be explicitly designed to work despite this attitude, and change it. Such design must also be clearly communicated to the responders.

Typical problems and examples include:

- Reliability problems. The most degraded state of an e-triage system must be at least as useful as paper tags. The system designers must also communicate this clearly, providing proof as appropriate.
- Trust problems. The ability of IT-based tools to log every action causes mistrust and worries responders. They fear that the logs may be abused, especially by victims' lawyers suing for profit (The Associated Press 2015). The e-triage system must therefore provide for (some) anonymity.
- Seamless, black-box design of the system or its artefacts. Responders know that, below a certain level, any tool is composed of black boxes. What they perceive as problematic are systems or artefacts that do not allow inspection, recombination, repair on the field, or appropriation of the parts for other purposes (mixing and matching). The design of the system should make it clear how the parts work together and where "the seams" are, making seamful-design (Chalmers 2003) a preferred paradigm.

[9] As an example, e-triage tags that are visible only through AR glasses would force triagers and paramedics to adopt AR glasses simultaneously.

[10] We only report cost as a problem for the sake of completeness, because it is neither applicable nor fair to consider it for research prototypes.

[11] As an example, a paper tag enables communication between triagers and paramedics who come to the same victim (place) later. It also enables communication between treatment area medics and hospital doctors at both a later time and different place

[12] Various sources imply that responders trust and widely use communication technologies (radio, phones, satellites, fax, etc.), but IT is restricted to high-level and remote command posts (Starčević 2015; ITU-D Study Group 2 2014).

Dimension 6: Sound design methodology

Design methodology weaknesses cannot be judged directly by first responders, but they may be the root cause of errors in the other dimensions. We have encountered the following weaknesses in published work:

- Not having defined an explicit risk model during e-triage system design. Triage systems are used in inherently hostile environments. Without a risk model it is not possible to prioritize actual, probable risks from mere theoretical and neglectable ones. Lack of a risk model is the reason why some e-triage systems prevent responders from accessing victim data (in the name of privacy), yet leave their network infrastructure open to DoS attacks by anybody with a portable Wi-Fi router.
- Testing the system in the wrong context, or with the wrong users. Several authors report testing e-triage systems in a lab or hall, using students and other unexperienced civilians in the role of triager, and using printed descriptions of how a victim should be triaged. This testing environment is neither comparable nor generalisable to real disaster response.
- Not accounting for all stakeholders of a triage system. Triagers, medics, and hospital doctors are most often taken into account, but the needs of other responders (firefighters, police, ambulance drivers, etc.) and those of response organisations as separate stakeholders are rarely considered.

Review of state of the art e-triage systems

The above e-triage acceptance dimensions were used by the authors to review the e-triage systems from the state of the art and identify barriers to acceptance. The results are anonymously[13] summarised in Table 1 below. The following general findings apply:

- All of the proposed systems present methodology weaknesses in that they lack a risk model. We did not mark this, so that we could draw attention to the second most common methodology problem: inappropriate testing, using students or other people with no experience in triage, in ideal lab conditions, and on tabletop exercises where victims are represented by printed descriptions.
- Systems using a PDA and/or WIMP GUI do not argue why this is the most usable approach for the intended users, especially given the physical environment, the reported suboptimality of PDAs in emergency use (Turoff et al. 2004), and the cognitive load of the disaster field. In the words of a triager: "When dozens of people are screaming for help all around you, even tearing strips off of a tag might be too much for you to do reliably, let alone fill out a complicated form." (Brownlee 2014).
- Several proposed systems can be used both in disasters *and* in daily emergencies, but they offer a different interface for each case. Considering that "the interface *is* the system" (Monson-Haefel 2009), and that using the same methods and tools in both everyday life and disaster management has a positive impact on the quality of triage (Nagata et al. 2006; The BRIDGE Project 2011) , we wonder why the proposed approaches forego these benefits willfully.

[13]It is not our intention to point fingers but rather to highlight common problems so that system designers can learn from them.

Table 1. Review of proposed systems. The symbol × represents problems in the respective dimension.

System	*Problematic dimension:* 1. Complete/appropriate	2. Workflow impact	3. Org. needs	4. Interactions	5. IT attitude	6. Methodology	*Notes*
System 1		×	×	×			Requires infrastructure and additional work attaching sensors, all-or-nothing deployment, mixes marking/monitoring, logistics not addressed
System 2	×	×					Takes longer than paper-based triage, requires infrastructure deployment before triage
System 3	×		×				Takes longer than paper, Different interfaces for same role, specifically discourages learning through daily usage
System 4		×		×		×	Requires infrastructure to be installed, mixes marking and monitoring, focuses attention on device, unrealistic testing
System 5	×	×	×		×	×	Unreliable triage data and misleading visualisations, requires pre-existing infrastructure, completely changes the triage workflow, cannot be used in all kinds of events, no risk model
System 6	×	×		×			No victim tracking, no monitoring possible, network reliability depends on attending to IT and prior planning, explicit interaction required
System 7	×		×	×		×	Does not account for unexpected input, not tested in actual conditions, diverts attention from victim, focused on hospital triage, problematic logistics in cross-border events
System 8	×	×			×	×	Automated triage, no influence on algorithm, attending to IT, reported results are theoretical, never tested in real conditions, no role separation, modifies triage algorithm because the technology could not measure certain required inputs
System 9	×		×	×		×	Automated triage with no override, unrealistic testing, holding device influences medic's capability to work, specifically discourages learning through daily usage
System 10	×	×	×		×		No useful degradation possible, requires infrastructure deployment, black-box design, data available only through system
System 11	×	†				†	† No testing reported, no usability details reported, not clear if infrastructure is needed or when it is deployed. Automated triage requested by the client, but not usable for the general case
System 12		×	×	×			Needs infrastructure installation, specifically discourages learning through daily usage, moves attention from victim, unclear usability and reliability in disaster environment

Continued on next page

Table 1. Review of proposed systems (continued).

System	*1. Complete/appropriate*	*2. Workflow impact*	*3. Org. needs*	*4. Interactions*	*5. IT attitude*	*6. Methodology*	*Notes*
System 13	×			×			A good approach, but unfortunately incomplete. Device usage may divert attention from victim
System 14	✳	✳	×	×	✳	✳	✳ Almost no details available. Data may not be accessed outside the system. The type of device and network used may divert attention from victim
System 15	×						System explicitly tackled reliability and logistics issues, but is unfortunately incomplete
System 16	×	×			×		Asks unnecessary questions, doubles the amount of work needed for marking, gives impression of detailed logging
System 17		×		×	×	×	Doubles amount of work for marking, requires attending to IT & explicit interaction, commander is assigned out-of-scope tasks, extremely detailed logging, questionable testing

CONCLUSION AND OUTLOOK

This paper presented the results of a detailed study of emergency response and triage in particular, which aimed at understanding both (i) what responders need from an e-triage system, and (ii) why already proposed, IT-supported e-triage systems have not been adopted in real life. By categorising the problems expressed by responders, the paper presented six "e-triage acceptance dimensions" impacting e-triage systems and illustrated each dimension with typical design mistakes and examples. A review was presented, where state-of-the art e-triage systems were analysed for problems along these dimensions.

The e-triage acceptance dimensions are best thought of as a summarised and categorised knowledge collection of "lessons learned". They can already serve as an aid for e-triage system designers to avoid design pitfalls. For future work, the identified dimensions will serve as basis for a design space in which new approaches can be categorized and evaluated, and where various design aspects can be weighed against each other by importance. The design space may also hint at new system architectures that may have escaped attention so far.

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APPENDIX

The table below lists the dates, places, and kinds of empirical user research carried out for this work.

Table 2. Schedule of user research activities

Meeting	*Date/Place*	*Observation*	*Contextual Enquiry*	*Interviews*	*Focus Groups*	*Sandbox Sessions*	*Blue Sky sessions*	*Prototype Workstations*	*Scenario Walkthrough*	*Expert Reviews*	*User testing*
EUAB Meeting	*27.6.2011, Austria*			✓	✓				✓		
Expert Workshop I	*28-30.9.2011, UK*			✓	✓	✓	✓				
Architecture Workshop	*7-9.11.2011, Germany*				✓			✓	✓		
EUAB Meeting	*28-29.11.2011, Austria*			✓	✓				✓	✓	
Expert Workshop III	*5-7.12.2011, UK*			✓	✓	✓	✓				
Ethics Requirements Workshop	*5.3.2012, UK*								✓	✓	
THW Interview	*12.3.2012, Germany*			✓					✓	✓	
Co-Design Workshop	*15-16.4.2012, UK*				✓	✓	✓	✓			
EUAB Meeting	*3.5.2012, Switzerland*				✓				✓	✓	
Firefighter Interview	*4.5.2012, Switzerland*	✓	✓	✓							✓
NIMBUS Exercise	*11.5.2012, Germany*	✓									
Interoperability Discussions	*25.12.2012, Germany*								✓	✓	
System Demonstration	*22-23.8.2012, Switzerland*	✓	✓	✓	✓					✓	✓
Integration test	*31.8.2012, Switzerland*	✓	✓								✓
System Demonstration	*17-19.9.2012, Switzerland*	✓	✓							✓	✓
EUAB Meeting	*20-21.9.2012, Switzerland*				✓				✓	✓	
Technical Meeting	*25-26.2.2013, Netherlands*									✓	
Firefighter Training	*03.2013, Switzerland*	✓	✓	✓							✓
System Demonstration	*23-24.4.2013, Norway*	✓		✓	✓					✓	✓
Civil Protection Forum	*15-16.5.2013, Belgium*							✓			✓
EUAB Meeting	*28-29.5.2013, Belgium*				✓			✓	✓	✓	
Validation Meeting	*6.8.2013, Germany*							✓	✓	✓	
System Demonstration	*23-24.9.2013, Norway*	✓	✓	✓						✓	✓
EUAB Meeting	*24-25.9.2013, Norway*				✓				✓	✓	
EMS Conference	*25.9.2013, Norway*									✓	
EUAB Commentary	*11.3.2014, Distributed*								✓	✓	
Ethics Workshop	*14.3.2014, Distributed*			✓	✓				✓	✓	
Project Meeting	*7-8.5.2014, Spain*				✓				✓	✓	
Validation	*19.11.2014, Norway*							✓		✓	
Exploitation Workshop	*12-13.3.2015, Netherlands*				✓			✓			
UAV Integration	*29.4.2015, Austria*		✓					✓	✓		✓

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