Design and evaluation of an electronic triage system for prehospital monitoring of patients

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Abstract: Prehospital emergency triage involves prioritising patients and deciding who are in the most urgent need of treatment and medical intervention. Currently used triage methods do not support simple sharing of patient-related information, making it challenging for emergency personnel to monitor the number, location and medical status of patients involved in an incident. We present the design and evaluation of an electronic system that facilitates patient tracking and monitoring of vital parameters from the incident scene to place of treatment. The system comprises a patient electronic triage bracelet, which communicates with software applications for patient monitoring. We tested the system in two situations: real-life, daily operations involving real patients over 1 month and in a 1-day, large-scale, mass casualty exercises. Results are presented, along with lessons learned and suggestions for future research.

Keywords: emergency management; prehospital triage; electronic triage; patient monitoring; GPS tracking; common operational picture.

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1 Introduction

Emergency medical services consist of a wide range of geographically dispersed human actors, including paramedics, ambulance personnel, dispatchers and hospital personnel. When an emergency occurs, vital tasks of the emergency medical services are to quickly establish an overview of the patients involved and ensure that they receive needed medical attention. The latter might involve medical treatment on-site, or require transportation to and medical intervention at another location, such as a hospital.

To obtain an overview of patients, paramedics at the incident site conduct prehospital emergency triage, which involves determining the priority of patients based on the need for medical intervention. To date, triage is most commonly done by attaching a paper triage tag to the patient, which contains the paramedic's initial medical evaluation (Jentsch et al., 2013).

This triage method poses several challenges to emergency medical services, by failing to provide valuable information about the number of patients involved in an incident, patients locations and changes in patients' medical status (Holzman, 1999). The paper tags are also fragile and can easily fall apart during harsh weather conditions. Furthermore, they do not support easy sharing of patient-related information between dispersed medical personnel. Patient-related information is exchanged between on- and off-site medical personnel mainly through radio and phone communication, face-to-face interaction and handwritten notes (Eide et al., 2013). Albeit they can be extremely useful, these means of communication can be both time-consuming and prone to misunderstandings, especially in the dynamic, harsh and time-critical context of emergency management (Eide et al., 2012).

Emergency medical services have raised the need for technology to support the triage process and the monitoring and easy sharing of patient-related information. Such technology would support real-time situation awareness and the establishment of a common operational picture among the different actors involved in the response (Eide et al., 2012). Over the past 10–15 years, several technologies for electronic triage and patient monitoring have been developed (Jentsch et al., 2013). Although existing solutions incorporate reasonable functionality and design, they can be revised further to better accommodate the needs and work methods of emergency medical services. On the basis of existing solutions and research on user needs, the first objective of our study was the following:

Objective 1: To develop a prehospital monitoring system that supports triage, monitoring and easy sharing of patient information between dispersed emergency medical services.

Technology for emergency management is generally tested in controlled environments, often as part of a 1-day training exercise resembling a large-scale incident (Killeen et al., 2006; Martín-Campillo et al., 2011). Few tests have been conducted in real-life, normal operation or over longer time spans. Even though current evaluation methods can provide valuable knowledge, their limitations could significantly influence the reliability and validity of the results (Haugstveit et al., 2015). We argue that there is a need for new approaches that include longer test durations, and testing in both large-scale incident scenarios, and real-world environments. To our knowledge, no other study in the field has applied this approach. The second objective of our study was therefore the following:

Objective 2: To test the prehospital monitoring system through (a) long-term, real-life normal operations and (b) a large-scale, mass casualty exercise.

Our research contributes to the development of systems for electronic triage and patient monitoring and sheds light on how such systems support the sharing of essential patient-related information. This can aid dispersed emergency medical services in to establishing a common operational picture and in decision-making. The study also contributes a new approach for evaluating technology within the emergency domain, including testing in large-scale incident scenarios and long-term testing in real-world environments. This approach can provide valuable findings concerning the design and usefulness of electronic triage and patient monitoring systems.

First, in this paper, we summarise earlier research within the domain, including a review of existing solutions for electronic triage and patient monitoring, and a discussion on testing and evaluation of such systems (Section 2). Next, we present a prehospital monitoring system that facilitates tracking and monitoring of patients from the scene of incident to the place of treatment (Section 3). We then describe the approach used to test the technology, which involved testing in real-life daily operations and testing during a mass casualty exercise (Section 4). We report and discuss the results from the tests (Section 5), followed by a conclusion (Section 6).

2 Earlier research on electronic triage and patient monitoring

The word triage comes from the French verb trier, meaning ‘to sort’. It originates from the Napoleonic wars, when triage was used to categorise wounded soldiers by the severity of their injuries (Hauswald, 2005). Triage is today a standard procedure within the military and in disaster situations and hospital emergency departments (Göransson et al., 2005).

In emergency response, triage refers to determining the priority of injured people based on their need for medical intervention. Standardised triage algorithms, such as the simple treatment and rapid transport (START) and the Triage Sieve, are often used (Jenkins et al., 2008), although systems vary between countries (Jentsch et al., 2013). Most include four triage levels, each with a dedicated colour. Minor (green) refers to patients with no life-threatening injuries. Delayed (yellow) includes patients with serious injuries and in need of treatment but who will survive without medical attention for the next hour. Immediate (red) includes patients in need of immediate medical attention and resuscitation to survive. Patients who are dead or not likely to survive even with medical attention are triaged as lifeless (black). A fifth triage level, urgent (orange), is sometimes used as an intermediate level between yellow and red (Mackway-Jones et al., 2014).

Today’s paper triage tags pose several challenges. Relevant research suggests several needs that new technology for triage and patient monitoring should address (Jentsch et al., 2013). First, a triage system needs to support the task of keeping count of the number of patients involved in an incident. This is especially important, and is currently a large challenge, during incidents where the number of patients is high. Secondly, the system needs to provide an overview of the location of patients. Emergency responders need to know both the geographical location of a patient and whether patients are at the incident site, under transport or delivered at a hospital. Thirdly, there is a need for continuous monitoring of patients’ medical status, with the ability to provide notification of changes. Fourthly, the system needs to support easy sharing of patient-related data between dispersed on- and off-site emergency medical personnel. Finally, the system needs to be robust and capable of operating in harsh weather conditions.

2.1 Existing solutions for electronic triage and patient monitoring

Over the last two decades, several technological solutions have been developed to support the triage process and monitoring and sharing of patient-related information. In general, these solutions involve supplementing or replacing paper triage tags with digital units. The triage solutions proposed by, for example, Chao et al. (2007) and Inoue et al. (2006, 2008) use passive radio-frequency identification (RFID) tags, while Chaves et al. (2011) have utilised barcodes attached to paper tags or on separate wristbands. A handheld RFID reader or scanner can then be used to store and access the patient’s geolocation, triage level and medical information. However, attaching RFID or barcode tags to the original paper tags does not ensure robustness in rough weather. Further enhancements in electronic triage solutions include the use of electronic units that can track vital and physiological data and patient location and send global positioning system

(GPS) coordinates (Adler et al., 2011; Gao and White, 2006; Jentsch et al., 2013). Coloured LEDs have been used to display triage level in solutions proposed by Gao and White (2006), Lenert et al. (2005) and Massey et al. (2006).

Systems for providing situation overview and a common operational picture are designed mainly for resource tracking and allocation and do not display patient data directly (e.g., Büscher and Mogensen, 2007; Jiang et al., 2004). Information systems that have been developed for display of patient data usually include a list of triaged patients with ID, triage level, physiological sensor data and location (Gao et al., 2005; Killeen et al., 2006). A drawback, however, is that systems using RFID or barcodes are designed as scannable tags, and the information is only available to personnel with access to a scanner device. In addition, such tags only track and register the last time emergency medical personnel were in contact with the patient (Lenert et al., 2005) and thus do not support continuous, real-time monitoring. Lenert et al. (2005) suggest that the data stored in the tags should be easily retrievable by dispersed actors, and that systems for display of patient information should be integrated with already existing systems used by emergency medical personnel both in the field and elsewhere. Further developments (e.g., Gao et al., 2007) include systems that collect and disseminate patient data from the incident site to key members of the distributed emergency medical services.

2.2 Testing and evaluation of systems for emergency response

Evaluating new technology for the emergency response domain has most commonly been carried out in controlled environments involving pre-defined scenarios of a 1-day, large-scale emergency training exercise (Killeen et al., 2006; Martín-Campillo et al., 2011). Less often is technology tested in real-world environments or over longer periods. Even though current evaluation methods can provide valuable knowledge, their limitations could significantly influence the reliability and validity of the results (Haugstveit et al., 2015). We therefore find the methods used to test such systems somewhat limited. We argue that to obtain more reliable and valid knowledge and results, there is a need for technology to be tested in large-scale scenarios as well as in normal situations, and preferably over longer periods.

Testing technology in large-scale incident scenarios is important due to the specific characteristics such events entail. Maintaining a sufficient overview of patients is particularly challenging in incidents involving large numbers of response personnel working under complex, cross-agency collaboration structures. Such large events can rapidly overwhelm on-scene emergency medical personnel (Mistovich et al., 2013) and surpass their capacity to efficiently handle and treat patients. Moreover, the magnitude of such events makes it difficult to get a full overview of the situation, thus complicating the planning process, which is intended to ensure optimal treatment of patients (Adler et al., 2011).

Testing technology in more typical real-world situations is equally important. In accordance with other researchers (Adler et al., 2011), we believe that for technology to serve its intended purpose during extreme situations, it must also be used in daily work on a regular basis. Daily use supports user familiarity and skill in using the technology efficiently in different scenarios and environments. In addition, testing technology during daily use will generate knowledge of how the technology is adapted in the users' normal work settings.

3 The prehospital monitoring system

Existing solutions for electronic triage and patient monitoring incorporate central functionalities and elements of design that address the needs of emergency medical services. By revising existing solutions further, and with a particular focus on user needs, we developed a prehospital monitoring system that supports the triage process as well as monitoring and sharing patient-related information among dispersed emergency personnel.

The main aim when selecting the methodology for development of the prehospital monitoring system was to evaluate the ecological validity of the system. Ecological validity is concerned with the extent of findings' relevance in the real world (Soegaard and Dam, 2016). The methodology we used for development of the prehospital monitoring system adhered closely to the standard for human-centred design of interactive systems (International Organization for Standardization, 2009), which draws upon the early work of Norman and Draper (1986) on user-centred system design. The rationale was to ensure that the development of the system would take the actual needs, desires and challenges of its intended users into account. A prehospital monitoring system has, as far as we can tell, never been implemented in the Norwegian emergency management services. We therefore found it necessary to involve end-users from this specific context throughout the development process to ensure that the prototype would meet their requirements. Emergency medical services procedures differ from country to country, and we could not assume that the needs in Norway would be the same as those in other contexts reported on in previous research.

We arranged several meetings with experts and end-user representatives to gather feedback about specific aspects of the system. This work included identification of user needs, design creation, prototyping and evaluation. Through this process, the system evolved incrementally from low-fidelity paper models to a fully functional, high-fidelity prototype. As with earlier systems, the user needs analysis found that the system needed to support continuous monitoring of patients and efficient sharing of information across emergency medical personnel; make use of robust, standalone devices that travel with patients; and utilise state-of-the-art sensors to register vital parameters and geographical location. Moreover, the system should support monitoring of patients by emergency medical personnel in various locations.

The newly developed prehospital monitoring system consists of three main components: the eTriage bracelet, a location forwarder device and the patient monitoring tool, see Figure 1. The system shares several of the same features found in other similar systems (e.g., GPS for patient tracking, LEDs for marking triage level and wireless transfer of patient information). Additionally, it introduces new features, such as GSM-based transfer of data from bracelet to patient database storage, Bluetooth-enabled communication between bracelet and ambulance, and new user interfaces for the electronic triage bracelets and patient monitoring at the medical emergency dispatch centre.

3.1 eTriage bracelets

The main target end-users of the eTriage bracelets are paramedics in charge of conducting triage at the scene of an incident and transporting patients to the hospital or other treatment facility. Patients wear the bracelets, but they are not supposed to interact with the device in any sense and are thus viewed as passive users.

The eTriage bracelet is strapped to the patient during the triage process at the scene of an incident. It contains functionality that allows paramedics to set a triage level, a GPS receiver for sending geographical location, an infrared (IR) sensor for measuring temperature at the wrist, and an inertial measurement unit to measure movement. The two sensors were chosen partly due to feasibility. The idea behind the inclusion of these sensors was to gain experience with physiological monitoring via such a device in time-critical situations. When turned on, the bracelet communicates with a database by using SMS to send updates about the patient every minute.

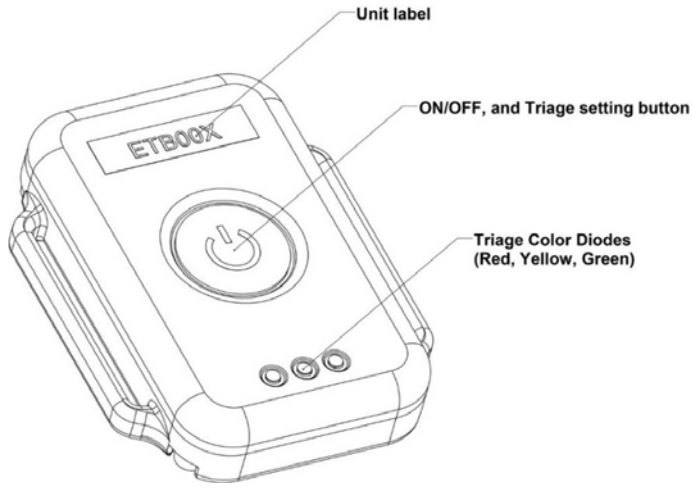
Figure 2 shows a technical illustration of the eTriage bracelet. Three coloured LEDs indicate the patient's current triage level, set by the paramedic. When possible, the device is to be fitted on the patient's left wrist with the LED lights towards the hand. However, other placements might be necessary in certain situations. The contactless IR temperature sensor is located on the back of the device, and the device must therefore be positioned so that the sensor can 'see' the patient's skin. The bracelet is fastened with hook-and-loop strap and is easily changeable.

Figure 1 Overview of the prehospital monitoring system (see online version for colours)

A single button is used for all operations. If the bracelet is off, a long press on the button will switch it on. If it is already on, a long press will unlock the current triage level, allowing the user to select a new triage level using short presses on the button. To avoid leaks, and make the bracelet more robust and easier to handle, charging is inductive and no wires are needed.

A number of laboratory tests were conducted, including functional tests, evaluation of LED visibility and environmental tests such as drop and humidity tests. Some of the tests were repeated multiple times to ensure that they would survive rough handling and harsh environments.

Figure 2 Technical illustration of the eTriage device (size: 9.5 × 7.5 cm)



3.2 Location forwarder application

The location forwarder consists of a GPS receiver and a short-range radio transceiver. When the patient is indoors and the GPS signals may be too are weak, the location forwarder communicates GPS coordinates and type of location to the bracelet. This also enables check-in and checkout of patients in ambulances and emergency rooms. The application requires no interaction from users and will not be discussed in detail in this paper. The location forwarder application was mainly a means of sending location data, and it was implemented on a standard smartphone.

3.3 Patient monitoring tool

The patient monitoring tool is a software application for obtaining a common operational picture and supporting monitoring of patient-centric data collected by the eTriage bracelets. By providing vital information to the emergency medical services, the tool supports decision-making about, for example, prioritisation and treatment of patients. Other features, such as communication of instructions to paramedics and coordination of vehicles, were not incorporated into the tool because the medical emergency dispatch centre already had several other systems to support this work. However, information provided by the patient monitoring tool has the potential to reduce the need to exchange patient-related information by radio, phone, or other means.

Two versions of the tool were built: a Windows version for laptops and stationary PCs and a mobile version for tablets and smart phones. The system continuously receives and displays live data from the eTriage bracelets and makes it possible to track patients from the scene of the incident all the way to the point of delivery. Target users of the tool are operators at the medical emergency dispatch centre, incident commanders, emergency response personnel at the scene of the incident, and hospital emergency room personnel.

In accordance with identified user requirements, the tool was designed to support display of patient-centric data in several different ways, including interactive maps, lists, strip views or a combination of these. A view providing summarised information (e.g., number of active patients, number of patients at different locations) is also available. The data shown by the tool is updated continuously. For each patient, the tool displays ID, textual description about patient (e.g., gender, age, injuries, etc.), triage level, geographic position, general location (e.g., name of transport vehicle or hospital emergency room) and changes in activity level and skin temperature over time. Information about the eTriage bracelets includes current standby status, battery status, timestamp for the last reception of data, GSM network strength, and current number of connected GPS satellites. Figures 3 and 4 show examples of the map view and the patient detail view, respectively.

Figure 3 Example screenshot from the patient monitoring tool showing map view (see online version for colours)

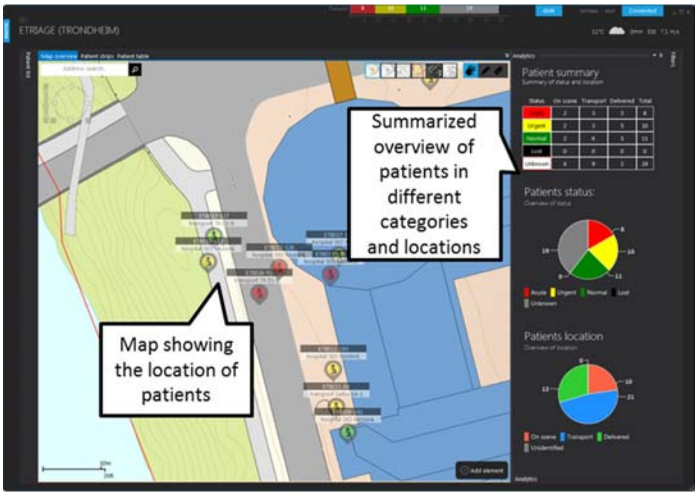
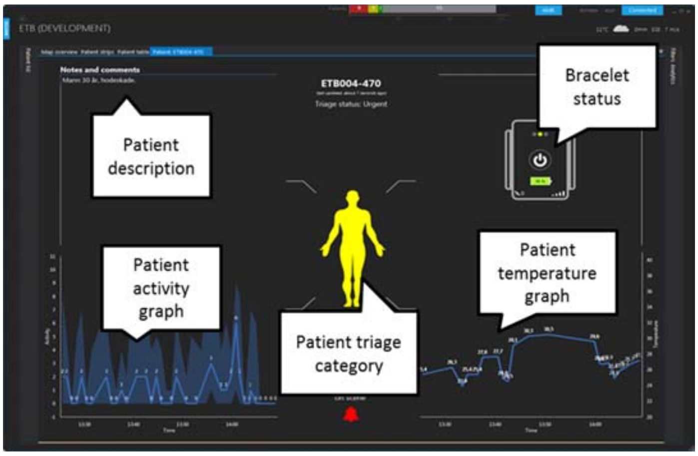


Figure 4 Example screenshot from the patient monitoring tool showing patient details view (see online version for colours)

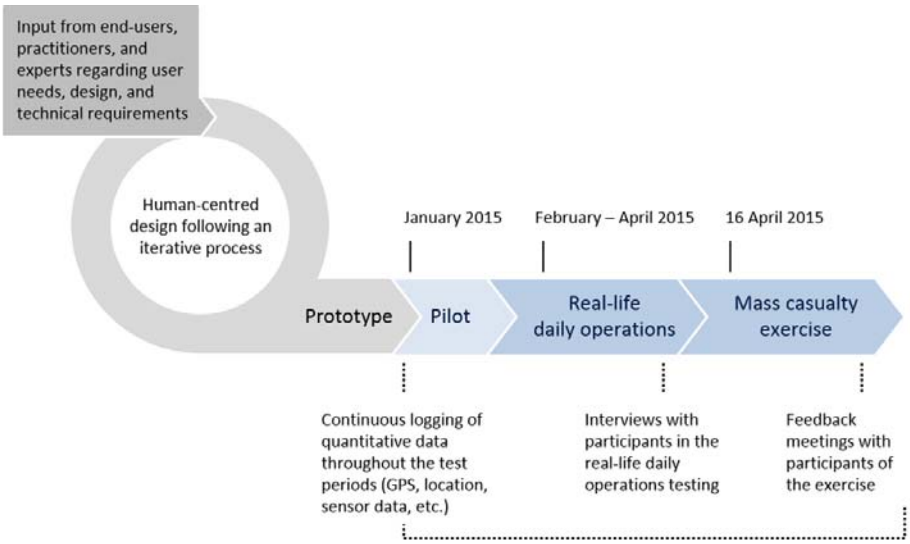


Users can interact with the tool by selecting different views, combine and customise views, filter visibility of patients (e.g., by general location or triage level), display detailed information about patients and bracelets, add patient descriptions and remove inactive patients from the system.

4 Evaluation of the prehospital monitoring system

The prehospital monitoring system was tested according to a test approach that involved two main situations: one month testing in real-life daily operations, and testing during a 1-day mass casualty exercise. A pilot study was conducted to eliminate issues that needed to be addressed. The approach and methods used are illustrated in Figure 5.

Figure 5 Illustration of the study's approach and methods (see online version for colours)



4.1 Pilot study and preparations

When an operational prototype was ready, a 1-week pilot test was conducted at the site where the testing during daily operations was to be carried out. Pilot studies are useful for trying out test approaches and procedures in advance of larger studies in order to reveal possible pitfalls (van Teijlingen and Hundley, 2001). The pilot study indicated technological errors that needed to be addressed before the actual testing started and provided input on how to instruct participants in the use of the technologies. Training is important for people to adapt new technology into their work processes and for the technology to produce enhanced productivity and satisfaction (Furnham, 2005). Participants received an introduction to the technology through lectures and informal conversations, while others practiced self-learning by reading manuals provided by the researchers. The manuals for the concepts were developed in close collaboration with end-users, and technical support was provided throughout the test period.

4.2 Testing in real-life daily operations

The rationale for applying the technology in real-life daily operations over a period of one month was to allow participants to get used to the technology and to increase the realism and thus the validity of the results. The overall purpose was to investigate how the prehospital monitoring system can support emergency medical personnel in performing triage and in establishing a common operational picture of situations during daily operations.

Two different groups within the emergency medical services participated in the testing. The first group consisted of ambulance paramedics. When an incident occurs, ambulance paramedics are the on-site personnel responsible for performing initial medical evaluations of patients, providing initial prehospital medical care and conducting triage. They also need to communicate information to the medical emergency dispatch centre. Patient-related information is currently communicated to dispatchers via radio and phone. In the testing during real-life daily operations, the ambulance paramedics had the task of attaching the eTriage bracelets to patients transported in the ambulance and setting the triage level. Patient data were then automatically transmitted to the patient monitoring tool.

The second participant group consisted of emergency medical dispatchers. The dispatchers, located at the medical emergency dispatch centre, were to use the patient monitoring tool to monitor patient data collected by the eTriage bracelet and to use the data appropriately to guide their work. Their tasks included dispatching emergency medical services resources to the incident scene; gathering and documenting patient-related and incident-related information; assisting and instructing on-site medical personnel (e.g., ambulance paramedics); and informing treatment facilities (e.g., hospitals) about the situation, arriving patients, and their conditions.

The testing was carried out in two Norwegian cities, Stavanger and Trondheim, between February and April 2015. In each city, two ambulances were each equipped with three eTriage bracelets. In the ambulances and at the entrance of the respective cities' hospital emergency rooms, location forwarder components were installed to send location data to the eTriage bracelets. The medical emergency dispatch centre of each city was equipped with a laptop running the patient monitoring tool.

4.3 Testing during mass casualty exercise

The purpose of testing the prehospital monitoring system during a mass casualty exercise was to evaluate the technology under a more hectic situation and with more than 20 eTriage bracelets being used simultaneously. The exercise took place on 16 April, 2015 in the Trondheim Fjord. The scenario was an explosion on a public ferry carrying ~100 passengers. The people acting as injured passengers were given descriptions of their initial injuries and how their conditions would evolve over time, and they were instructed in how to play their roles. About 300 emergency response personnel participated in the exercise. The central actors in the emergency medical services were ambulance paramedics, emergency medical dispatchers at the medical emergency dispatch centre, medical personnel at the emergency room at St. Olav's Hospital in Trondheim, and coordinators at the Joint Rescue and Coordination Centre. Other participating agencies were the police and fire departments, military civil defence and the municipality. During the exercise, researchers from the project group were located at the different locations where the emergency medical services performed their jobs, both on and off the exercise site.

Even though the overall prehospital monitoring system was used during the mass casualty exercise, the patient monitoring tool was the only concept tested directly by the end-users. Personnel at the medical emergency dispatch centre, the hospital emergency room, and the Joint Rescue and Coordination Centre accessed the tool on PCs and tablets. The eTriage bracelets were not operated by the end-users themselves during the exercise; rather, researchers from the project group attached the bracelets to patients and set the triage level based on medical assessments by paramedics. A standard, paper-based triage system was already being used by paramedics during the exercise, and we did not want to interrupt the triage training more than necessary. In addition, the participating paramedics had not been trained in how to use the eTriage bracelets. The bracelets were checked regularly by the researchers, and the triage level was changed in accordance with paramedics' ongoing evaluations of patients' status.

4.4 Data collection and analyses

Several types of data were collected from the two test activities. In order to gather knowledge about participants' experiences with the technology, semi-structured individual interviews were conducted after completion of the 1-month, daily operations test with seven paramedics who had used the eTriage bracelet. Questions addressed four main themes:

- the introduction to the technology
- usage of the eTriage (e.g., procedures for and experiences with attaching bracelet to patients, turning the eTriage on/off, and charging and cleaning bracelets)
- perceived usefulness of the eTriage
- suggestions for future development.

We also interviewed three operators of the medical emergency dispatch centre who had access to the patient monitoring tool during the test period. However, due to lack of use of the tool during the test period, these latter interviews were redirected towards introducing the tool to the informants and collecting their initial views of the technology rather than gathering their informed opinions after use. All interviews lasted about 30–45 min.

For the mass casualty exercise, user perspectives on the patient monitoring tool were obtained through the researchers' observations and feedback from participants during the exercise, as well as through meetings with participants after the exercise had finished. Observation notes and notes containing participants' reflections and feedback on the technology were collected. Even though the eTriage bracelets were not used directly by the medical emergency end-users during the exercise, we were able to collect feedback on their impressions about the bracelets.

For both test activities, quantitative data were continuously collected from the bracelets and logged in an encrypted database. The logging of data covered all parameters monitored by the bracelets, including patient ID, locations, vital parameters and bracelet status. All quantitative data collected from the bracelets was analysed to identify errors that might have occurred during the testing of the system and to verify the number of patients triaged and the overall operation of the system from a technical perspective. Explorative data analysis was used to structure the qualitative information obtained during interviews and meetings. This included researchers going through participants' answers and extracting their views on and experiences with the technology.

4.5 Ethical considerations

Approval was granted from national and local bodies for privacy and research ethics to carry out our study. Since our testing involved real patients of actual emergency events, participants were instructed not to use the eTriage bracelets or patient monitoring tool in cases where this could hinder the efficiency of their work. Patients wearing the eTriage bracelet received an explanation of its purpose and technical functioning. According to the participating paramedics, none of the patients reacted negatively to wearing the bracelet. It should be emphasised that the logged data did not contain any personal information that could be linked to specific individuals.

5 Findings and discussion

Altogether, over 100 patients were triaged and monitored, including more than 60 patients during the testing in daily operations and over 40 actors playing patients in the mass casualty exercise. From a technical perspective, the system worked as intended, and the few errors that occurred were fixed during the test period.

We first report and discuss findings and feedback from use of the eTriage bracelets. We then describe findings from use of the patient monitoring tool. Reflections and lessons learned concerning the test approach and methods are presented throughout, with a summary in the final section.

5.1 Using eTriage bracelets during emergency situations

In general, the eTriage bracelets were viewed positively by most of the paramedics involved in the testing. Paramedics consistently reported that the eTriage bracelets were easy to operate and did not hinder them in carrying out their work efficiently. The logged data seem to support this finding as bracelets were used on all types of patients regardless of the severity of their conditions and despite the fact that the paramedics were instructed not to use the bracelets in cases where this could hamper the efficiency of their work. Moreover, participants reported the eTriage bracelet to have the potential to save time and support ease communication between paramedics and personnel at medical emergency dispatch centres and hospital emergency rooms. Information from the bracelets was sent much faster to the medical emergency dispatch centre compared with current methods for reporting patient status, showing the potential for time savings because reporting by radio would no longer be required. In addition, a shared system where dispersed emergency medical personnel can jointly document patient-related information has the potential to eliminate the work of separately documenting information that is later merged.

The bracelets were perceived as being a more robust alternative to the paper-based triage tags, especially in harsh weather conditions. When tested in real-life daily operations, the eTriage bracelets were used in all types of weather. During the mass casualty exercise, the weather was rainy and windy. However, this also meant that the persons acting as patients were for the most part moved inside by emergency medical personnel.

Participants' emphasised the advantage of having patient locations available throughout the chain of patient-related events and not losing track of patients at any time. The eTriage was perceived to be most beneficial during large-scale events where the need for rapid organisation and fast assistance is most apparent. All seven interviewed paramedics preferred the eTriage over triage methods currently used during mass casualty incidents, as the following quotes show:

> "The paper tags did not work satisfactorily during the exercise. It took time to prepare the tags, and for some [patients] the paper tags became wet and were ruined. It is hard to maintain information if [the patient is] re-triaged. The eTriage works as a supplement to manual measurements and eases communication with the dispatch centre."

> "The eTriage would be better [to use] than current paper tags since it would ease the information flow to the management."

For daily operations and smaller incidents involving one or a few patients, the paramedics found less value in the bracelets. Despite this, the seven paramedics interviewed viewed the eTriage as a tool that could become a standardised part of future emergency medical services, particularly highlighting that the information provided by bracelets could simplify work at hospital emergency rooms.

Participants offered some suggestions for future development of the eTriage. For instance, some found the bracelet a bit too large, making it hard to attach to some patients. The hook-and-loop strap was part of this problem, and it was suggested that the strap should be narrower and have some sort of locking mechanism. This could make is easier to attach the bracelet to other parts of the body in cases where it could not be fitted to an arm. The following quote exemplifies this:

> "The device was a little too large and became hard to tighten, especially on elderly women with skinny arms. I cut the hook-and-loop strap myself, tried different lengths, but it became cumbersome and was too stiff for small arms. The method for fastening [the eTriage bracelet] needs a tightening mechanism similar to a wristwatch."

Moreover, there were some concerns regarding usage procedures. For example, several of the participants forgot to use the eTriage because it was stored in an inconvenient place in the ambulance. Having the eTriage visible and easy to grab was pointed out as an important factor for use. In addition, some participants thought the routine for sanitising the bracelets was unclear. It was also suggested that it should be possible to charge the eTriage in the ambulance, as the following quote states:

> "The routine was that all [nine ambulance paramedics] should take care of charging. This was not always done. There should have been a charger for the bracelets in the ambulance. Then it [the bracelet] is always ready [for use]."

During the testing, charging was done at the ambulance garage, which at times caused participants to forget to charge the bracelets. Good routines regarding storage in the ambulance, cleaning of bracelets and charging was emphasised as crucial if such technology were to be implemented.

The data collected during the mass casualty exercise show that triage levels were changed often when the bracelets were active. In many cases, a change in triage level was observed when the patient entered a new location (e.g., hospital), indicating that the patient was re-triaged by medical personnel. However, changes in triage levels may also have occurred because active bracelets were moved to new patients without restarting the devices. Because of this, future versions of the electronic patient bracelets should have built-in functionality for resetting the bracelet without requiring a restart. This could increase efficiency when using bracelets in mass casualty situations where availability of bracelets is limited.

5.2 Monitoring patients at emergency dispatch centres

In general, use of the patient monitoring tool at the two participating medical dispatch centres was less successful than use of the eTriage bracelets. The most prominent challenge was getting participants to incorporate the tool into their daily work routines. The workplaces of the operators were already filled with screens and systems requiring their attention. Thus, the natural work environment at the dispatch centres provided little physical and mental room for yet another system. Consequently, the placement of the PCs running the patient monitoring tool was not optimal. As one participant stated:

> "It's about capacity, really. It is very hectic at the centre during the day. It would definitely be good to have it [the tool], but I had to leave my working position to look at it and therefore it became a bit cumbersome."

Participants did not feel they received enough training in using the patient monitoring tool, which resulted in the system sometimes being ignored. Despite these difficulties, interviews with participants, along with feedback from the mass casualty exercise, still provided highly valuable information regarding the usefulness of the patient monitoring tool.

Overall, participants were positive about the idea of accessing real-time patient data. The tool particularly attracted attention and interest during the mass casualty exercise. At the Joint Rescue and Coordination Centre, operators expressed excitement about the tool's potential to provide a quick overview of an incident site and concrete understanding of a situation. Interest in the tool was also high at the hospital emergency rooms participating in the exercise.

Participants from the dispatch centres reported that the tool has the potential to simplify communication with paramedics during daily operations. The following quote explains how access to patient data can affect work during daily operating conditions:

> "This system will make it [our work] easier, I think. Currently, the ambulance [personnel] needs to contact us and provide information, which we then need to write down."

This seems to indicate that the operators at the dispatch centres also see value in using the tool in daily operations, which differs somewhat from the views of the paramedics. The explanation for this discrepancy is, perhaps, that the dispatch centre operators often need to coordinate multiple patients and ambulances, while the paramedics typically only handle one or two patients at a time.

In similarity with paramedics, the operators at the dispatcher centres also seemed to find the system most useful during mass casualty situations. This finding was expected, as mass casualty situations make it increasingly difficult to maintain an overview of the affected individuals. A participant highlighted that the tool could reduce the load on the radio network, which is often a problem during such large events involving complex cross-agency collaboration structures (Eide et al., 2012). A quote from this participant is given below:

> "[The tool is] very applicable in mass casualty situations, or when more [actors] are involved. It can probably not replace normal communication, but perhaps one would not need as much normal communication when using this [tool]. One would not have to overload the [radio] network with this type of information when using this system."

Another interesting finding is that the patient monitoring tool perhaps would be just as useful for hospital emergency rooms as it is at dispatch centres. The following quotation explains how access to patient data can affect work in hospital emergency rooms:

> "One will become better prepared before the patients arrive at the hospitals. The sorting of patients can be conducted before they arrive at the hospital. We will be able to plan our work better."

More detailed information about patient condition and time of arrival would allow hospital personnel to plan ahead for more efficient treatment. Currently, dispatchers communicate this information to the hospitals by radio or phone. It was stated that having the patient monitoring tool available at the hospital emergency room could support dispatchers in sharing, and hospital personnel in getting, this information. Feedback from the mass casualty exercise suggests that presentation of information in hospital emergency rooms should also include an indication of when patients are estimated to arrive.

The patient monitoring tool allows several different alternative views, including map-based, list, table and strip views. Participants were asked to explain which of the views they felt provided the best overview. Two dispatch centre operators preferred the strip view because this view made it easy to get an overview of the general location of patients, their current status, and the most important physiological information. One operator stated:

> "The strip view is the best alternative for me. It gives a very good overview. I can see which [patients] are on-scene, which ones are under transport, and how many have been delivered [to the hospital]."

Another operator felt the table view would probably be the best as it was most similar to the other systems they use, but this operator said the strip view was also a good alternative. Figure 6 shows the strip view.

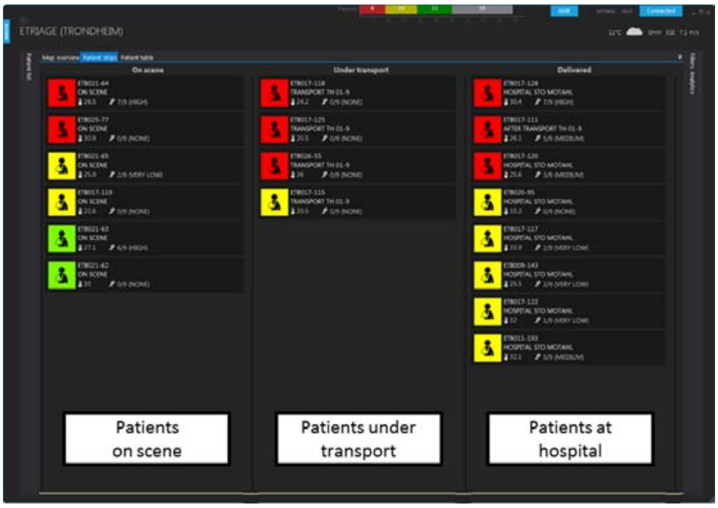
The participants also had strong opinions regarding how the tool should be incorporated into their current working environment. Several strongly expressed that the information should be integrated into systems already used in the dispatch centre. The lack of such integration is probably one of the main reasons why operators ignored the system in the first place, and this was a main drawback that should be improved upon in future versions of the tool. Development of future versions should also consider another suggestion given by two participants, which is to display the patient information on large displays that anyone in the dispatch centre or hospital emergency room can look at without leaving their working position.

Operators from the dispatch centres said they would like to see additional vital parameter patient information, such as pulse, blood pressure, heart rate and respiration. Display of such parameters could easily be added to the patient monitoring tool.

However, it will be a challenge to incorporate additional sensors into the eTriage bracelets that are reliable enough to be used in such life-critical contexts.

Suggestions were also put forward during evaluation meetings following the mass casualty exercise. First, it was suggested that the tool should provide support for geo-fencing in the map view, allowing users to supervise when patients enter certain areas that have been marked by users of the tool. This could be highly useful in mass casualty situations where the incident commanders set up ad hoc areas for gathering patients. Secondly, it was suggested that support be added for showing the destination of the patient after the ambulance has left the incident scene. This could be useful for resource management at the dispatch centres and for hospital emergency rooms, especially when patients from one incident are being delivered to several different hospitals. Thirdly, it was suggested that the icons used in the map view should be improved to avoid the chance of misinterpretation.

Figure 6 Example screenshot from the patient monitoring tool showing the strip view (see online version for colours)



5.3 Reflections and lessons learned concerning the test approach

Some feedback also addressed the method used for testing the prehospital monitoring system. The training provided to the participants prior to the testing varied; some attended a presentation about the purpose and use of the technology while others performed self-learning using manuals. Especially for participants performing self-learning, the purpose of the technology was easily missed as the manuals mainly provided information about how to use the technology rather than explaining why it should be used. The purpose of and need for the technology should be highlighted more clearly in future studies.

Introduction of new technology in time-critical domains such as emergency management is a highly challenging task. A main lesson from our study is that procedures for use of new technology within this domain must be developed and that these new procedures should be aligned with existing procedures and tested frequently. It is important to clarify how and when the technology should be used and how to handle system failure. We also experienced challenges in being able to monitor the system sufficiently during the testing period. In light of this, we recommend that technical support personnel in close proximity to the testing environment should monitor future testing in daily operations.

Further, because it was a first functional prototype, the tested system was not integrated with existing decision-support systems already used by the operators at the dispatch centre. Consequently, the operators had to use a separate PC to access the information provided by the patient monitoring tool. In hindsight, we believe that efforts should be made to integrate information into existing systems instead of building a new information tool. We highly recommend that future research in this area consider this alternative.

6 Conclusion and future work

We have presented the design and evaluation of a prehospital monitoring system that facilitates triage and monitoring of patients from the scene of an incident to the place of treatment.

Our research contributes to the development of technologies for prehospital electronic triage and patient monitoring that have the potential to improve efficiency in emergency medical services. Specifically, the research provides insights into how long-term, real-world testing can be approached in this domain and offers details concerning the design and usefulness of electronic triage systems.

To test the system, we developed and applied an approach that included testing during daily operations as well as during a large-scale, mass casualty exercise. This approach provided highly valuable insight into the design, use, and usefulness of the system in varied situations and events. We argue that this approach might also prove valuable when evaluating similar or other systems within the domain. Meanwhile, we recommend the lessons learned from this study be taken into account when designing similar studies in the future.

Our findings indicate that the prehospital monitoring system has the potential to ease communication and information flow between emergency medical personnel, located both on and off the scene of an incident. The eTriage bracelet was perceived as easy to operate, and it was seen as a better solution than the current method for performing triage. The patient monitoring tool was able to provide operators at the dispatch centres with an overview of triaged patients, including their location and medical data. It was stated that the tool would also be valuable for other actors in the management of emergency events, such as hospital emergency rooms and the Joint Rescue and Coordination Centre.

The study also brought forward possibilities for future research and improvements of the prehospital monitoring system. For example, it may be helpful to include additional physiological sensors in a future version of the eTriage bracelet. In the sports and fitness market, optical sensors for measuring heart rate at the arm have become common. Also, wearable oxygen saturation and blood pressure devices are available. It is possible for this kind of sensor to be integrated in an eTriage bracelet, but care must be taken to ensure that sensors give valid results in various environments. Further research is needed to identify relevant and feasible physiological data to be measured by the eTriage bracelet. For the patient monitoring tool, there is a need to investigate how to present data in the best possible way to support the work of emergency medical personnel. How such a system can be integrated into existing systems used by emergency medical personnel should also be investigated.

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