Participatory Design in Emergency Medical Service: Designing for Future Practice

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ABSTRACT
We describe our research—its approach, results and products—on Danish emergency medical service (EMS) field or "pre-hospital" work in minor and major incidents. We discuss how commitments to participatory design and attention to the qualitative differences between minor and major incidents address challenges identified by disaster sociologists when designing for major incidents. Through qualitative research and participatory design, we have examined the features of EMS work and technology use in different emergency situations from the perspective of multiple actors. We conceptualize victims in incidents—and particularly in major incidents, where on-site medical assessments is highly incomplete—as boundary objects over which the complex and imperfect work of coordination is done. As an outcome of our participatory design approach, we describe a set of designs in support of future EMS work.

Author Keywords
Emergency medical service (EMS), major incidents, minor incidents, disasters, pre-hospital medicine, emergency response, participatory design, design by doing, Future Lab.

ACM Classification Keywords
H5 Information interfaces and presentation (e.g., HCI): H.5.0 General, H.5.1 Multimedia Information Systems, H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6), H.5.3 Group and Organization Interfaces, H.5.m Miscellaneous.

INTRODUCTION
This paper presents the findings from multiple qualitative studies of emergency medical service delivery, and our subsequent development of ideas for technology innovation. The research is grounded in participatory design (PD) [5, 10, 18], relying on the expertise and direct involvement of practitioners from multiple disciplines of emergency response to fully and richly articulate empirical findings and plans for innovation.

The paper presents the method and select findings from the overall arc of research: from *scientific inquiry to interpretation to design.* To that end, and with a focus on medical work, we examine the nature of emergency response services—"pre-hospital" work done at the scene of an incident—and its use of existing technologies. We direct these observations into participatory design-by-doing workshops that help imagine and explore future practice. This leads to design ideas for new interactive technology systems intended to support multi-disciplinary work in emergency medical response for minor as well as major incidents. Our investigative and participatory approach is meant to scale to ever-larger disasters, as the next section explains. However, for the purposes of our design work and applicability to Danish problems that this project addresses for now, we do not envision the designs reported here to be immediately suitable to catastrophic incidents like Hurricane Katrina or the 9/11 attacks. Major incidents assume some degree of functional infrastructure, e.g. networks and power supply.

As an outcome of our field studies, we have conceptualized that victims are themselves boundary objects in the work of emergency response. It is this observation that guides our designs. Many of the challenges in EMS are tied to this idea, given that there are few opportunities and means to explicitly identify and share information and decisions about victims with the multiple professional disciplines that descend on a site, each with distinct duties.

Emergency Response
Emergency situations demand fast and effective collaboration across an array of participants: different professional disciplines from different agencies are dispatched and come together at the incident site with emergency vehicles and equipment. Coordination and communication are critical throughout the emergency response engagement, from the point of initial assessment and dispatch, at the incident site, and then beyond, as the injured are dispersed to area hospitals. When caring for victims, response workers do what they can to assess individual needs and then coordinate to make decisions about follow-on care. The larger the incident, the less complete those assessments tend to be.

Emergency responders must make local decisions in the absence of a global assessment of a dynamic situation. Smaller-scale events are naturally easier to manage, though even there, response work is still improvised and adapted to the situation at hand. In these situations, workers are well-practiced at working together with incomplete knowledge. Overhearing, or 'listening in' on the 'partyline' as other researchers have documented [21, 22], plays an important awareness role in coordinating activities across multiple professions working different aspects of the incident.

However, organisational complexity and chaos scales exponentially with the size of incidents, often reaching a point where standard procedures break down [24]. Major incidents are, for our work, those that involve multi-agency response to incidents on the order of train, subway and bus accidents, large chemical spills and industrial fires, where many people might be injured or at risk, and damage to equipment, buildings and/or infrastructure is significant. They are characterized by having too few resources for the amount of response and relief work. Workers and victims are distributed over larger areas, even when the incident is relatively localized to a single area, like a train accident. More workers come from more agencies, perhaps even from other cities, meaning that they are not as familiar with the location of and routes to hospitals, and so on. Multiple hospitals in the region might prepare to accept victims, who usually arrive with incomplete medical information because field workers are spread too thin to do more than immediate life-saving assessments [14]. Many hospitals are underutilized in major incidents because evenly distributing victims to hospitals requires up-to-date, global knowledge of an always-changing situation [24].

Information and communication technology (ICT) support for field or 'pre-hospital' medical work, the focus of our research, tends not to be 'cutting-edge' and sometimes not well-suited for the job, especially in major incident situations. An objective of our work is to appreciate the roles of emergency medical workers in the field who need to make decisions and coordinate with others from other practice disciplines. Their work moves rapidly between global and local assessments that ultimately need to be resolved, however imperfectly. Broadly speaking, emergency workers need to make assessments about the distribution of immediate on-site care and efficient use of vehicles to transport personnel to area hospitals, who themselves need to prepare upon alert. Naturally, these kinds of assessments and decisions are themselves distributed across multiple personnel and revisited over time. How might EMS work for major incidents be supported with ICT so that global and local assessments—and their interdependencies—are supported?

Bridging Design between Minor and Major Incidents: Two Commitments

We see the problems of coordination in emergency response to major incidents as, in part, opportunities for ICT innovation. However, designing for major incidents is a challenge because they do not happen often, nor are these the times to test out fledgling technology, nor carry on lengthy discussions with response workers. Yet, relying solely on 'lessons learned' for smaller events is misguided, since, as disaster sociologists Quarantelli and Tierney explain, the difference between small and large-scale incidents are also a matter of *kind*, not only *degree* [23, 26]. However, the need for a practical approach to innovation for major incident medical work remains. In Tierney and Quarantelli's discussion of concerns about approaches to future innovation for disaster, they write:

> *There is a need to be innovative in making use of technological advances and to work out better institutional and organizational arrangements in preparing for delivering disaster EMS. Persons in the medical area need to be involved, but they must understand that new technologies represent the means, not the end. Social and behavioral scientists who recognize the reality, rather than the ideal, of disaster situations must also be involved [26, p.75].*

In response to such a challenging call, we have strived to leverage the benefits of empirically accessible events through the participatory inclusion of practitioners, researchers and developers over a long trajectory of study, design and innovation that remains guided by accurate depictions of the complexities and messiness of the work involved in major incident response.

To that end, we are committed to *a participatory design approach* that includes use of source data from a variety of real-time, simulated (current and future) and video-documented events to richly articulate features of work and coordination in emergency work and guide innovation for future practice. The involvement of practitioners—i.e. medical, police, fire, call coordinators, and other emergency personnel—is central to the PD approach.

We couple with this another commitment to perspective when designing for major incidents. In keeping with Tierney and Quarantelli's warning, we design with the idea in mind that technology needs to cascade *down* to minor incidents (rather than the other way around). This has two important outcomes: *first it re-identifies the target of design to the more complex end of the spectrum*, rather than falling into the scaling up trap—the misguided idea that response to major incidents is simply a larger order response to a car accident, for example [23,26]. It also means that response workers, when working with new technologies, are able to get enough practice in the field, in anticipation of the major events that inevitably come. We call this the *familiarity principle.* With this approach, we see the delivery of medical treatment in minor incidents as an opportunity to set a standard for the kind of ICT-assisted care that we envision for major incidents. Marrying an understanding of how EMS is delivered under the best circumstances of minor incidents (relatively speaking, of course) with an appreciation of the complexities and difficulties of EMS in major incidents helps focus design and research objectives.

Related Work

Cooperation and information sharing is crucial in emergency response and several studies have looked into these issues in relation to emergency call centers (ECC), e.g. [9, 21]. Also much of the work on control rooms e. g. [13, 15] provides insights relevant to ECC. The focus of these studies has been on use of ICT for co-located workers with varying needs for cooperation. From Hughes et al [15] we learn that no single factor guaranteed the observed mutual awareness. Heath and Luff [13] show the importance of overhearing and seeing for maintaining the awareness necessary for coordination. Pettersson et al [21] introduce the notion of active 'listening-in' as an alternative to overhearing, and Artman and Waern [1] show how 'talking to the room' is used to get attention. Several studies have noticed problems in going from use of large shared paper maps on walls, to use of computerized maps on individualized pc's, e.g. Bowers and Martin [3].

When we move out of the call centers, and in to the field, fewer studies have been reported. Holzman [14] describes computer-human interface design and sketches a high-level software architecture for an emergency medical information system, including on-site biosensor data collection and communication. Holzman emphasizes the importance of making sure that those who work on-site have their hands free of gadgetry and are visually free of obstructions. To that end, he advocates a design based on speech recognition and synthesis. He does not focus on issues of on-site cooperation. Jiang et al [16] and Camp et al [7] focus on collaboration practices in the field, but both concentrate on fire emergency response work. Interesting work by Johnson [17] stresses the importance of collaboration between the CHI community and simulation research, with a focus on evacuation simulation systems, triggered by the differences between how evacuation of the World Trade Center was planned and how it was actually done.

OUR APPROACH: FROM STUDY TO DESIGN WITH PD

Our approach is firmly rooted in participatory design (PD) [6, 10, 18], in particular the design-by-doing approach originally developed in the Utopia project [8] and the ethnographically inspired development of the approach described in [10]. The purpose is to create a process that will support researchers/designers and practitioners in producing innovative, high quality results. An important aspect of this is to achieve, maintain and continuously develop a common understanding across the disciplines. Together, the researchers work to deeply understand the domain while domain professionals take an active part in designing their future ICT-supported work practice. The concrete research activities were (and continue to be) carried out as an iterative, parallel process and include field studies, collaborative data analysis and design sessions, prototype development and experimental workshops. For the latter, we use Future Labs [5], a recent addition to the PD toolbox. An objective of Future Labs is to move the PD 'design-workshop' meetings into realistic settings.

We divide the remainder of this paper into three sections that mirror the PD process. First, we present the methods for engaging with the domain, and the descriptive and conceptual findings of the initial qualitative research. One major conceptual finding from this work is the idea of 'victims as boundary objects,' which encapsulates much of the EMS work we observed. Second, we outline the steps in the PD process from observation to more explicit design activity. Third, we discuss the design implications that came out of the 'victims as boundary objects' observation, and present the particular designs that evolved.

FIELD & QUALITATIVE STUDIES

Methods for Engaging with the Domain

We employed five techniques for qualitatively studying and engaging with the domain which stretched over five months and included 14 researchers: ethnographers, architects, industrial designers, computer scientists, engineers, and nursing-trained IT researchers. Field studies are an important aspect of PD. Early on it is the most important activity in building up common, shared knowledge with all participants. It is a basis for building researchers' knowledge of the domain, for helping response personnel to become more explicitly reflective of their own work practices, and for the initial generation of design ideas [18].

To begin, 13 researchers participated in three day courses designed to train new personnel on minor and major incident procedures, equipment, communications and so on. The courses included practical simulated exercises that included a shooting, a car accident, a fire and a major train accident.

Second, four researchers participated as observers in more specialized trauma team training courses. The full day courses are based on highly realistic trauma incidents.

Third, we shadowed these personnel in incident response:

1. Police alarm centre personnel
2. Ambulance dispatch centre personnel
3. Fire fighter dispatch centre personnel
4. Ambulance personnel
5. Trauma emergency doctors
6. Fire fighter managers
7. Anaesthesiologists in in-hospital work

We observed the work in 8-hour shifts for the police, ambulance and fire brigade centres and ambulance personnel. We shadowed the trauma emergency doctor, the fire fighter manager and the anaesthesiologists in in-hospital work in 24 hour shifts. Ten researchers total participated over nine shadowing sessions.

Fourth, we observed videos of two real major incidents with the response personnel who were involved. The first was the January 2001 Knippelsbro bus accident, a major bus incident that resulted two fatalities and 16 serious casualties after the top of a double-decker was sheared off as it attempted to pass under a bridge. The second was the November 2004 Seest fireworks factory incident, a fire that took place at a fireworks factory situated in a mostly residential area. The incident required a response of over 70 emergency vehicles and required that approximately 400 families be evacuated and sheltered. Hundreds of houses were destroyed and a fire fighter was killed.

Fifth and finally, four researchers observed the pre-hospital activities of a city-sponsored exercise that simulated a collision of a school bus with a train carrying dangerous chemicals. The exercise lasted for six hours with school children acting as victims, and doctors, nurses, paramedics, fire fighters and policemen all responding to the incident.

Descriptive Findings: Danish Emergency Response

We describe how prototypical incidents are handled across fire, police, paramedic and medical personnel. We first present an overview of incident response, and then discuss in greater detail the emergency medical service work.

Overview of Danish Incident Response

The call alarm system—*Team 112 Danmark*—was developed by the Danish police and is a protocol used throughout Denmark. It includes a nationwide online system that is integrated with several support systems (digital maps, first aid systems, reporting systems) at the police stations. *Team 112 Danmark* is integrated with the communication systems and protocols used at the dispatch centres and fire stations in Denmark, known as *EVA2000*.

Witnesses to an incident place an alarm (emergency) call by dialing 112. Calls are routed to the police station closest to the place the calls originate from or (if this station is overloaded with work) to the second nearest[1]. If the call is placed from a stationary phone, the physical address and number data are automatically displayed. If the call comes from a mobile phone, the policeman has to determine where the caller is. After getting an initial description of the incident, the 112 representative contacts the emergency dispatch centre, the fire brigade and/or his colleagues at the police station. For minor incidents, the 112 representative continues to manage the call alone. As she gleans more information, she iteratively updates dispatch requests. When help arrives, she hands off the incident management to those on site.

The ambulance and fire brigade dispatch centres have immediate access to the information originating at the police alarm centre. Requests and confirmations move back and forth to coordinate the activities between the call and dispatch centres. The ambulance dispatch centre can follow all ambulances and mobile medical units via GPS. In addition the paramedics in an ambulance send status updates by pushing dedicated buttons on a radio. These communications inform decisions about vehicle dispatch.

For major incidents, a special coordination centre, called KSN, is established in a room reserved for this purpose. The police officers and liaison officers from the fire brigade and ambulance service that staff this room generally have more experience than the managers at the incident site. Specialists, like environmental or bomb experts, might also be on hand here. This group architects the plans and decisions in close cooperation with the on-site managers. Co-location facilitates the construction of a common, global view. At the KSN, several technologies are used, including a video-projector to display map information.

Personnel from multiple specialities coordinate at the incident site: police, ambulance staff, the fire brigade, nurses and doctors. The larger the incident, the more important a commonly accepted and understood personnel infrastructure becomes. The incident response system is used for all incidents—big and small—throughout Denmark; all professions are trained in the system, though the system itself is, interestingly, unnamed in the way that other national systems are (like ICS and the more recent NIMS in the US).

Current organisational structures favour cooperation vertically within each organisation. However, deliberate actions are taken to support horizontal cooperation as well. We know from recent examples of significant disasters in other countries, including the September 11 attacks [20] that horizontal communication can be seriously tested. Furthermore, the nature of incidents is such that each is unique, and responders must be prepared to flexibly adapt their work and communications needs to each, even given the overarching organisation of the incident response structure. Recent, painful lessons from Hurricane Katrina illustrate the need for such ‘organisational improvisation’ [27].

Primary job functions are established spatially in physical locations at the incident site. *The fire brigade manager* is responsible for dealing with fire and other hazardous conditions (like a chemical spill) and for rescuing people from the primary incident site, also called the ‘risk area’ or ‘the technical rescue zone’ (e.g. a wrecked bus, or a burning house). An inner cordon is mounted around the rescue zone where only specially equipped and trained professionals are allowed to enter and work.

Outside the inner cordon, up to three different kinds of areas are organised, depending on the character and size of the incident. They are: 1) An area for casualties; 2) an area for placing fatalities; 3) and an area for gathering and registering the uninjured that were part of the incident. *The medical coordinator and the ambulance manager* work in close cooperation and are responsible for the casualty and fatality areas. The medical coordinator plans the treatment of the injured and prioritizes the order of their treatment and subsequent transport to the hospital in coordination with the ambulance manager. The often complex task of coordination with the hospitals is handled by the acute medical co-

[1] Currently location information on cell phones is rather imprecise, but a new system, which will give the exact location of the cell, is under development.

ordination centre, the AMK. This task requires close contact with hospital staff to ensure that the emergency medical staff is prepared to receive victims. *The police* are responsible for managing the third area, where uninjured victims are accounted for. Finally, the *police manager* is responsible for the overall management of the incident. She mounts the outer cordon that rings all the areas to prevent unauthorized people from getting access to the incident area. She also manages the public communication function.

For major incidents, the remote command centre at the police station, KSN, and the remote medical command centre, AMK are often supplemented with an on-site command centre, called KST, staffed with the police and fire brigade managers. This is practiced to ensure and support the horizontal communication at the incident site. The main communication is then between KSN and KST on the one hand and the medical coordinator and AMK on the other.

As described above, there is a high degree of division of work: four different managers are on site, managing central parts of the emergency response, with additional managers in the two command centres. What was clear in the field studies was that management personnel strive to cooperate. However there remains a disciplinary hierarchy: The fire brigade and police managers are responsible for the overall response effort while the medical coordinator is 'only' responsible for treatment of the injured and the ambulance manager 'only' their transportation. Between the fire and police management, we also see a clear division of work – the fire manager dominates the technical rescue zone, the police dominates the rest, though the two coordinate their efforts by physically staying together in KST. There are many potential points for conflict, with the most obvious being between the fire brigade manager and the medical coordinator when, for example, seriously injured people cannot easily be moved from the unsafe accident area to the safe treatment area. In an incident like a train accident, this might mean that those who are most seriously injured—because they are in the most inaccessible spots—are rescued last. This is difficult for medical personnel to accept.

Establishing and maintaining effective communication both within and across agencies and distance—even short distances—is one of the greatest challenges in emergency response, and was a core problem in the 9-11 response [20]. Radios and mobile phones are used with in-person communications, which itself depends on the benefits of overhearing [13, 21] others talk around them. Today each professional group (police, ambulance staff, medical staff and fire-fighters) uses radios with their own specific radio frequency. This means that the different professional groups cannot communicate unless they change frequencies. This is usually not practiced, usually because then communications within one's own professional group cannot be received. Thus to communicate across professions, the managers usually find each other physically and try to stay together. This, on the other hand, can cause other problems: with the managers centralized but not as mobile, they need to rely on radios to communicate with their staff. This burdens bandwidth; turning to mobile phones is a problem, too, even though personnel might attempt it, because those networks are highly taxed in incident areas. So, communication across even short distances is difficult.

Emergency Medical Service Response

Here we focus on the emergency medical service response work in incident response. We describe some critical aspects of EMS work—the management of victims, their injuries, and their care. Even under the best of circumstances, this work requires a series of handoffs from one responder to the next. In incidents with multiple victims, this work becomes exponentially difficult. As these descriptions reveal, the victims are the production function of the temporary organisation of the site-particular emergency response. They become the means by which the responders—from multiple agencies, arriving at different times—coordinate their work. Responders coordinate over them, sometimes together, but more often serially over time and then eventually over space. Because of the nature of the situation, persistent textual information that could be associated with each patient does not generally exist in major incidents. Instead, the victims themselves literally embody that information, requiring multiple assessments and reassessments over time by practitioners from different response disciplines. In this sense, the victims become the *boundary objects* by which EMS work is organized [4, 19, 25]. We will revisit this discussion in more depth following this description of EMS work.

Person id and registration of data. An *accident card* is supposed to be filled out for each victim. The main purpose of the card is to provide different professionals with a tool for registering of injuries, symptoms and on-site and ambulance care. The card contains a predefined unique person id number that is meant to track the person from the accident to the hospital. To ensure this, it has to be literally tied to the patient. In practice, however, we found the accident cards were not used—there was simply no time to complete them. If correct registration with names and id number was impossible, the only registration that occurred was an indication of to what hospital the victim was brought. Furthermore, id's were descriptive and not unique: "Woman, around 40 years, blonde short hair, chest injury." Observation of this practice again leads up to our discussion of the victim as boundary object.

When victims arrive at the hospital with or without accident cards, they receive additional specific trauma-id's. Meanwhile, hospital personnel try to determine real identity. Depending on when the final identification is done, victims might get temporary person-id-numbers, until their national id numbers are verified[2]. In this way, data belonging to the

[2] In Denmark, everyone is given a unique id-number at birth or when granted non-tourist permission to stay.

same person can be connected with up to four different numbers. This is a difficult administrative process and there is a risk for making mistakes.

The use of several person id's during the response effort complicates communication and coordination; it is often unclear what victim is in focus. This very problem limits the benefits of 'listening-in' over the 'partyline' [21, 22].

Categorization of Victims. The human damages in incidents can range from trivial to life-threatening or can cause death. To handle this situation with limited resources, victims in major incidents undergo triage. During triage they are categorized by a doctor according to the severity of their injuries and treated according to these categories: 1) Needs treatment immediately, 2) Needs treatment as soon as possible, 3) Treatment can wait, 4) Deceased/beyond treatment. Again, according to protocol, every victim is supposed to be marked with a colored, numbered card. The status of an injured person might easily change, and therefore needs to be monitored in the waiting area. However, from observations of real major incidents, we know that victims are not explicitly marked with triage cards; instead, this is communicated verbally through public demonstration of some action taken, and/or by the physical placement of victims in different areas at the incident site.

The triage categorization is determined by a quick evaluation of the victim. However, classification does not only depend on the specifics of an individual victim; in practice it also takes into account the condition of the *other* victims. The people performing triage need access to as much updated information as possible about the state of affairs.

Medical Assessment of Victims. Assessment of the state of a victim at the incident site follows the ABC protocol (airways, breathing, circulation), meaning first to ensure respiratory passage, then breathing and then finally blood circulation [12]. The pre-hospital doctor and the paramedics evaluate the condition of patients by observing injuries, skin color, respiration and other signs. They do not receive any information about earlier or present illnesses – they have to act upon what they can recognize from the on-site examination of the patient. When availability and time allows, they may also measure pulse, oxygen saturation and ECG. All Danish ambulances are equipped with this monitoring technology, and it is used every day in small incidents.

The biomonitors are wired and their use is severely hampered by the fact that data can only be seen by those who are immediately next to the display, which again has to be next to the patient. In this sense, the displays on the biomonitors are only as accessible and as mobile as the patient. An immobile patient cannot move without help. Moving people happens many times throughout an incident starting from the moment an incident happens through to treatment in the hospital (e.g.: From the ground -> temporary triage stretcher -> ambulance stretcher -> emergency room bed -> hospital bed -> scanner -> hospital bed….). Thus biomonitoring—with all the required wires and displays in place—can unfortunately hamper examination, treatment, as well as relocation of the patient.

In major incidents, biomonitors are rarely used. There is simply not enough biomedical equipment for these situations, and even then, it is often too difficult to transport. Furthermore there is a limited amount of time to place the biomonitors on victims. Lastly we have observed that even with limited use of biomonitors, there are not enough professionals at the incident site to keep an eye on all the collected biomedical data – because the displays can only be located right beside the victims. Thus in major incidents, monitors are only used for a few of the severely injured victims.

Communication about Victims. Particularly in major incidents, only the most basic information about patients is written down. Communications about victims are mostly verbal. This results in severe problems for the hospital trauma teams who find that it is almost impossible to get information from the incident site. Crucial information is reported by ambulance staff to the receiving trauma team, though this happens usually only once during transport because the ambulance workload is usually too high. Also, the infrastructure does not support automatic updates. In the hospital emergency room, a publicly viewable board is used to build an overview of the available information. Once the victim arrives, new evaluations by the trauma team are performed. Information about the victim is gathered over time and from multiple sources. This constructed view then itself is made explicit at the hospital. It is localized to the places where victims have been distributed. Given the nature of the work and the available technologies and infrastructure data gathering and communications, a 'situational overview' of the state of all incident victims is impossible to achieve.

CONCEPTUAL FINDING & DESIGN FOCUS: VICTIM AS BOUNDARY OBJECT

These descriptions of emergency medical service work illustrate a similar point—that coordination of medical work happens around the victim as one would expect, but also *through* the victim, so to speak. Over and over again, the victim is assessed by practitioners from the same and different disciplines for different purposes, but without the assistance of medical records. Medical records themselves work as objects that coordinate multiple disciplines in a hospital. As Berg and Bowker [2] explain, medical records serve as *boundary objects*—informational objects that belong to multiple groups for different purposes, and serve to translate the work across these different groups [4, 19, 25]. For Berg and Bowker, the medical records 'produce' the patient to be something that different medical workers and other professionals can respond to with respect to their own job functions. By 'produce' we mean create or depict a representation of the patient that supports the tasks at hand.

However, in the case of EMS, there are no medical records. In fact, documentation is rarely associated with each victim until after arriving at the hospital, when documentation is made though still incomplete. Instead, victims are produced and reproduced over time through verbal exchanges at each informal and formal handoff. Documentation of assessments and treatments is incomplete, and therefore the physical presence of the victim is necessary because the medical work to be done is assessed directly. Furthermore, victims often spend time alone without direct assistance at a major incident. Their very presence in the space of the incident is an indicator of the collective work-to-be-done.

Because there is little recorded information about victims following incidents, the victims themselves, then, can be viewed as boundary objects that serve to coordinate the work and work trajectories of EMS personnel. It is this insight that helped inspire some of the technology designs that arose from this work. The need to *attach* information to the patient in physical, virtual and proximal ways became one of our design objectives.

MOVING INTO DESIGN

Participatory design is an iterative and inclusive process—researchers and practitioners work together throughout to discover, explain, teach, reflect, and integrate knowledge with the goal of collaborating in design and evaluation. This kind of interactivity is productive and successful, but is difficult to relay in the serial form that papers tend to require. What we have done up to this point in the paper is present the descriptive findings and the conceptual, organizing finding of victims as boundary objects that arose out of our engagement with the field. However, throughout this observation process, our large team of researchers and practitioners also began the process of design, especially as we converged on the particular problem of ascribing information to the patient in a production where care for the patient is the organizing feature of the work. Working on design in turn helped us understand what we were seeing in the field. The dialectic of the processes of observation and design mutually assisted in the construction of shared knowledge.

Workshops and Future Labs

We now clarify matters by presenting the activities that had a design emphasis, and how our observations fed into these activities. The team engaged in two forms of design 'workshops:' the more traditional participatory design workshops that take place in a lab and the 'Future Labs' which take place in highly realistic settings.

The initial design work is done in workshops that occur in labs set up to suggest features of the domain to fuel imagination [10]. Such settings are theater-like, in the sense that props encourage people to 'fill in the blanks' and assume their professional response worker roles. We conducted 4 of these workshops which took place over 8 months. These workshops generated the initial observation-driven requirements and eventual designs that we then built or mocked up and tested.

With our first designs in place, we graduated into the field in what we call 'Future Labs' [5]. For this work, the Future Lab setting was a training site for response personnel that have areas where car accidents, building fires, and other incidents can be staged. The location is also sometimes used as film sets. 'Victims' can wear makeup to simulate injury and so on. We had one Future Lab workshop that took course over two days and included 14 researchers, 10 practitioners and 3 'victims.' We also had a real ambulance on hand. We acted through 11 incident situations using our designs and mockups of our designs, again enabling us to improve them, better understand and describe use scenarios. Personnel were situated in a simulated AMK center while responders were out at an incident site.

Specific Designs

We return to our observation that victims are, naturally, the production function of emergency medical response, and that because of the particular nature of incidents, particularly larger incidents, the victims themselves become the boundary objects by which response professionals organize themselves and their work. Three primary design implications emerged from this observation: 1) information needs to be better and persistently associated with patients over the course of an incident and over the course of personnel handoffs; and that 2) information about victim status can be gathered at a distance but still on site, so that a limited number of response personnel can simultaneously monitor multiple patients over an incident site. From these two stems a third implication, which is 3) enable multiple pieces of information to be associated together so that different personnel can see the entire picture and interpret the pieces of information that are relevant to them. In this way, we want to create technology that produces a record or picture of victims that support response coordination. This will reduce the burden on the system of victim-as-boundary-object, and move it instead to a representation that acts in proxy. This third implication also sets the stage for enabling a global, situational overview of the incident, including where people and resources are located, how and to where they are being evacuated, and so on.

Wireless Biomonitors and Remote Access Displays

As a result of the design implications above, a wireless biomonitoring system became our first innovative focus. The goal was to design a system that could be both useful and easy-to-use in major incidents and daily EMS.

This priority, made together with the end users, is caused by severe problems related with today's use of biosensors. There are three main objectives: 1) users will be able to remotely access information collected by different kinds of sensors and 2) several users can access data from the same monitor/injured person, and that 3) patients will be easier to relocate within an incident site area.

An example for a major incidents situation is that the users want to be able to do the following: If we have a train accident with many people trapped, it should be possible for the firefighters to mount biomonitors on all those trapped. The status of all the injured people could then be monitored by the medical coordinator, and he or she can help the firefighters prioritize the rescue order. So, use of wireless biomonitors —in addition to providing information about the victim's condition—could also support communication, cooperation and coordination of work across professional disciplines.

The system, which as our most mature innovation that we have prototyped and tested, collects biomedical signals from the victim via Bluetooth sent to a base station. The computer base station can collect and store signals from up to 20 monitors. From the base station, the signals can be shown on any number of displays in the surrounding area also via Bluetooth within a radius of 100 meters, which is within but at the edges of the current limits of the technology[3]. Thus, in principle and if desired, biomonitored data can be shown on different displays at the same time. Data can also be communicated to computers and displays at a distance—hospitals or in ambulances—via WIFI or GPRS.

The biomonitoring unit can handle up to 8 different data signals. Together with our practitioner participants, we have isolated the most critical information features, which are based on the basic triage measures for trauma patients and the ABC concept [12].

From here, we are developing small biomonitors with different form factors, some of them not smaller than can be handled *also* by firefighters with big gloves. We are experimenting with use of a microphone/accelerometer that can pick up respiration sound and frequency as well as electrodes to collect a *basic* ECG[4] signal and sensors for measuring pulse and oxygen saturation—as alternatives to the existing Oxymeters, which are not optimal in (cold) outdoor settings. Electrodes can be affixed using special plaster and rubber adhesive and some can be realized as nano fibers woven into neck collars.

When the monitoring devices are placed on victims, it is automatically activated and begins to send data over the network to the base station. Data can be displayed on connected monitors as required. The biomonitor can also communicates directly with other Bluetooth enabled units, e.g. a mobile phone or a PDA. This ability to use alternative communication and display devices is important for providing robust service. It is also a feature not found in similar systems such as the one described in [14].

The most obvious challenges to address with the wireless biomonitor concept are 1) to ensure that the user can clearly associate the data with the correct patient; 2) to provide ways to manage information overload; 3) to support the user in recognizing changes in the patient's condition, without necessarily being next to the patient; and 4) to support the user in recognizing and handling equipment failures.

Capturing and Displaying Triage Classification

Another useful data feature to build into the biomonitor device is the ability to display, assign and change a victims' triage category. This is intended to support responders by always having an updated overview of all victims' status to support the decisions about treatment and transportation to hospital. The triage category should be immediately visible both at the site of the victim and on remotely located displays. Such a configuration would support both global and local action. The development is still at an analysis and early design stage, but the plan is to keep the colors and numbers consistent with the format of today's triage cards.

Resource and Victim Identification & Location

As mentioned earlier, a victim can have up to three different id numbers before his real person id number is determined. By assigning an id tag to the person as soon as he is spotted means that only one additional person id will be in use. This will reduce the risk for making mistakes, and will be the basis for resolving the collection and display of remotely gathered biomonitor data. Moreover it might facilitate communication about the victim or at least ease the necessity of written documentation. But since the information is almost exclusively shared by word-of-mouth, a number might not be the best identification label, because it won't help individual responders remember who is who, distinguish victims or easily communicated about them. This is a central issue that has to be further investigated.

Today few technologies are used for recognizing where, who and what is happening at a given time in major incidents situations. To be able to obtain and maintain positions of victims, professionals and equipment, we are investigating id tagging of people as well as equipment. If and when everyone and everything involved is tagged and when the location of every tag can be determined, this can be used for e.g. creating situational overviews and to support continuity by coupling and communicating different kinds of data across different localities. The primary issues to address here are 1) what technology should be used for tagging; 2) should tags be built into the biomonitor; and 3) to what level should equipment be tagged? These are issues still under debate. Moreover, issues about the location of id tags need additional investigation.

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[3] See *www.bluegiga.com/default.asp?file=201* to see the specification details of Bluetooth

[4] We are aware of existing use of 12 points ECG measurements, wirelessly transmitted to displays over far distances. This technology has been thoroughly tested and is well described in the medical research literature. The 12 points ECG however is not our focus. Measurement of the basic ECG signal, we are working with, cannot be used for diagnosis of heart diseases/strokes, but can be used to indicate the "C" (circulation) of the ABC concept.

Coupling and Communicating Different Types of Data

It should be possible at the incident site for those involved to register and obtain different kinds of information about a specific victim. These data should be coupled to the person's id, together with e.g. biomonitor data, triage status, and location information. The purpose is to ensure continuity in the observations, examinations and treatment pre- and in-hospital. Prototypes for this are still on the drawing table, but the main idea we are working with is to link time- and location-stamps with speech or written annotations and pictures, and associate these to the appropriate victim.

DISCUSSION

In summary, we have found that there is a predefined, well-understood division of labour between Danish emergency response professions. This is combined with deliberate—but, in major incidents, often ineffective—efforts to coordinate and communicate across professions. We have found that assignment and use of person-id's, registration of different kinds of data, and categorization and medical assessment of victims, together with communication about victims, are difficult to handle and create recurrent problems. We have conceptualized the victim as a boundary object. This informs our design work, where we focus on development of wireless biomonitoring with remote access via displays and indication of triage category. Moreover we have worked on resource and victim identification and victim location, as well as the coupling and communication of different types of data.

This extended participatory design research effort has been designed to reveal opportunities for innovation that can support coordination across multiple people, disciplines and places. We have targeted emergency medical response, knowing that, in most cases, technology is used for minor incidents. However, it is the larger and major incidents that are the most complex, and can therefore benefit the most from such innovations. But to this end, the technologies need to be familiar and well-practiced by responders. Therefore, technology to be used in major incident situations should also be used in minor everyday incident situations on a daily basis. This is not to say that designing for minor incidents scales up to major incidents. We understand that they are qualitatively different, and that major incidents themselves have degrees of complexity that put different demands on response.

By heeding the advice of sociologists who study disaster, we have designed for the more (but perhaps not most) complex crisis situations. Designing for future Hurricane Katrinas, while terribly important for our community to address, does not necessarily solve the crises that occur more regularly and also need our attention, like large train and mass collision accidents. By conceptually scaling down from major to minor incidents, rather than the other way around, we have better addressed how response work is done—and how technology might be integrated—in the more complex matters of coordination that occur there.

FUTURE WORK

During the next phase of the project, we will continue development and testing of our prototypes. They will be evaluated iteratively in increasingly more realistic settings, including field exercises for pre-hospital activities. One of the major directions for the future is to make the development of *situational overviews* technically feasible as well as useful. By bringing multiple forms of data together, we envision a future where all types of data and decisions by personnel throughout an incident response can be depicted spatially on maps, remotely at hospitals or in KSN, and in a form that allows different specialities to coordinate their work together. Being able to obtain and contribute to a continuously updated situational overview on site and in the command centres could be tailored to the different professionals as well as sharable collaboratively across them.

In addition, visibility of wireless connections is crucial and a major challenge. The users need to be sure that they are looking at exactly what they think they are. For example, if they want to see data from injured people A and B, they need to be sure that it is that data they see, and not data from the victims C and D close by.

Further investigation has to be done regarding the id problem. Although we have seen that though unique id numbers, such as the national id numbers, are perceived as valuable in theory, numbered ids are difficult to easily and quickly distinguish. New ways to identify victims to better support communication about them need to be considered.

To ensure that technologies are used, they have to be useful as well as easy-to-use. This relates to the fact that emergencies happen fast and demand immediate rescue efforts. There is no time for fumbling with technology. In addition they should be robust and stable in the rapidly changing context of an incident. Finally, because we know that technologies will still fail, they need to keep responders informed up to the point of failure. It is important that the responders are not lost in the automation and can easily assume manual control of the situation.

On a more general level, we have found that in EMS for major incidents, there is a great deal of interaction and cooperation across different professions. Future technology should focus on both aspects of cooperation and interaction.

CONCLUSION

Carrying out field studies as a part of the PD process has been an indispensable activity of the research project. Together with the workshops we have had with the professionals acting within the major incidents field, field studies have contributed to the possibilities of uncovering needs for and getting design ideas to new technologies to support professionals in major incident situations. We have developed mock-ups and early prototypes as solutions for several of the needs we have uncovered, and these have been tested in semi-realistic settings. Despite the distance yet to traverse in turning them into products, once available, as

Holzman points out [14], simultaneous installation of comprehensive, cross-organisational systems may be more straightforward in publicly owned health care systems (like in the Scandinavian countries) than in American civilian settings.

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REFERENCES

1. Artman, H., Waern, Y. Distributed cognition in an emergency Co-ordination Center. *H. Artman (Ed). Fördelade kunskapsprocesser i ledningscentraler vid nödsituationer: koordination och situationsmedvetenhet*. Linköping, Tema Kommunikation, Linköping, Sweden, (1999), 183-199.
2. Berg, M. & Bowker, G. The Multiple Bodies of the Medical Record, *Sociological Quarterly, 38(3),* (1997), 513-537.
3. Bowers J. M. & Martin, D. Informing collaborative Information Visualization Through an ethnography of ambulance control. *Proc ECSCW,* (1999), 309-330.
4. Bowker, G. & Star, S. L. *Sorting Things Out,* Cambridge, MA: MIT Press, (1999).
5. Büscher, M., Eriksen, M., Kristensen, J., & Mogensen, P. Ways of grounding imagination. *Proc. PDC*, (2004), 193-203.
6. Bødker, S, Grønbæk, K, Kyng, M. Cooperative Design: Techniques and experiences from the Scandinavian Scene. *A. Namioka & D. Schuler (Eds.), Participatory Design*, Lawrence Erlbaum Associates (1993), 157-175.
7. Camp, P.J., Hudson, J.M., Keldorph, R.B., Lewis, S., Mynatt, E.D. Supporting Communication and Collaboration Practices in Safety-Critical Situations. *Proc. of CHI,* (2000), 249-250.
8. Ehn, P., Kyng, M. Cardboard Computers: Mocking-it-up or Hands-on the Future, *J. Greenbaum & M. Kyng (Eds.). Design at Work: Cooperative Design of Computer Systems*, Lawrence Erlbaum, Hillsdale, NJ, (1991), 169-195.
9. Flowers, S. *Software failure: management failure – amazing stories and cautionary tales,* John Wiley & Sons Ltd, (1996).
10. Greenbaum, J. Kyng, M. Situated Design. *J. Greenbaum & M. Kyng (Eds.), Design at Work: Cooperative Design of Computer Systems*, Lawrence Erlbaum, Hillsdale, NJ, (1991), 1-24.
11. Grønbæk, K. Kyng, M., Mogensen, P. Toward a Cooperative Experimental System Development Approach. *M. Kyng & L. Mathiassen (Eds), Computers and Design in Context*. The MIT Press, Cambridge, Masachusetts, (1997), 201-238
12. Guidelines 2000 for cardiopulmonary resuscitation and emergency cardiovascular care. *http: //circ.ahajournals.org/cgi/content/full/102/suppl_1/I-1*
13. Heath, C.C. & Luff, P. Collaborative Activity and Technological Design: Task Coordination in London Underground Control Rooms. *Proc. ECSCW*, (1991), 65-80.
14. Holzman, T. G. Computer-human interface solutions for emergency medical care.*Interactions 6(3),* (1999), 13-24.
15. Hughes, J.A, Randall, D., Shapiro, D. Faltering from ethnography to design, *Proc. CSCW,* (1992), 115-122.
16. Jiang, X., Hong, J.I., Takayama, L.A., Landay, J.A. Ubicoutous Computing for Firefighters: Field Studies and Prototypes of Large Displays for Incident Command. *CHI Letters, 6(1),* (2004), 679-686.
17. Johnson, C.W. Applying the Lessons of the Attack on the World Trade Center, 11th September 2001, to the Design and Use of Interactive Evacuation Simulations. *Proc. of ACM CHI,* (2005), 651-660.
18. Kyng. M. Scandinavian Design: Users in Product Development, *Proc. CHI,* (1994), 3-9.
19. Lutters, W. G. & Ackerman, M. S. 2002. Achieving safety: a field study of boundary objects in aircraft technical support, *Proc. of CSCW,* (2002), 266-275.
20. National Commission on Terrorist Attacks upon the United States. *The 9-11 Commission Report: Final Report of the National Commission on Terrorist Attacks Upon the United States*, Official Government Edition, Claitor's Law Books and Publishing Division, (2004).
21. Pettersson, M., Randall, D., & Helgeson, B. Ambiguities, awareness and economy: a study of emergency service work, *Proc. CSCW,* (2002), 286-295.
22. Pettersson, M. WaterCalls: An ambient call queue for cooperation between emergency service centres. *Personal Ubiquitous Comput. 8(3-4),* (2004), 192-199.
23. Quarantelli, E. L. *Delivery of Emergency Medical Services in Disasters: Assumption and Realities,* New York: Irvington Publishers, (1983).
24. Quarantelli, E. L. Non-Medical Difficulties During Emergency Medical Services at the Time of Disasters. *University of Delaware Disaster Research Center Publication,* No. 319, (1997).
25. Star, S. L. & Griesemer, J. Institutional Ecology, "Translations," and Boundary Objects, *Social Studies of Science*, *19(3),* (1989), 387-420.
26. Tierney, K., & Quarantelli, E. L. Needed Innovation in the Delivery of Emergency Medical Services in Disasters: Present and Future. *Disaster Management, 2:2* (1989), 70-76.
27. Wachtendorf, T. & Kendra, J.M. (2005). Improvising Disaster in the City of Jazz: Organizational Response to Hurricane Katrina. Understanding Katrina: Perspectives from the Social Sciences, *http://understandingkatrina.ssrc.org/Wachtendorf_Kendra/*
28. *www.ist-palcom.org/*