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Bridging Resources and Agencies in Large-Scale Emergency Management

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Title:

Domain analysis II: User Interfaces and Interaction Design

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Abstract / Executive summary:

This deliverable presents key concepts and lessons learnt from domain analysis with a view to interface and interaction design within the BRIDGE project. Its purpose is to inform ongoing design efforts. The report begins with a review of current interface and interaction paradigms experienced by emergency responders. A focus on the situation in Norway provides concrete detail before the discussion briefly broadens out into the European context. A series of three chapters follows, exploring interface and interaction design issues along three key topic areas of design in BRIDGE – designing for situation awareness, ambient intelligence for supporting emergent collaboration, and supporting agile response and collaborative agile workflows. These chapters capture and develop the core interface and interaction design concepts employed in the BRIDGE project. A discussion of the e-triage system as part of BRIDGE system of systems then provides a synthesis, designed to illustrate how attention to these dimensions and concepts can enhance large scale multi-agency response through BRIDGE. The conclusion summarises key themes and lessons learnt. The deliverable closes with an appendix detailing the role of the BRIDGE Design Pattern Library for our interdisciplinary and collaborative design efforts.

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Table of Contents

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List of Figures

1 Introduction

The belief that more data or information automatically leads to better decisions is probably one of the most unfortunate mistakes of the information society.
(Woods & Hollnagel 2006)

The overall goal of the BRIDGE project is to increase the safety of citizens by developing technical and organisational solutions that significantly improve crisis and emergency management. One key aim is the development of advanced human-computer interaction techniques for more effective utilization of high-quality information. This complements the focus on supporting emergent interoperability between heterogeneous agencies and their information systems through a system of systems approach (see *D2.2 Interoperability and Integration*). Innovation is facilitated through a collaborative and experimental design process with strong user engagement. WP2 functions as the 'engine room' where insights from domain analysis undertaken by different partners and in relation to different tasks are brought together. Providing those insights to the technical WPs drives technical designers to translate those into their design (see Figure 1).

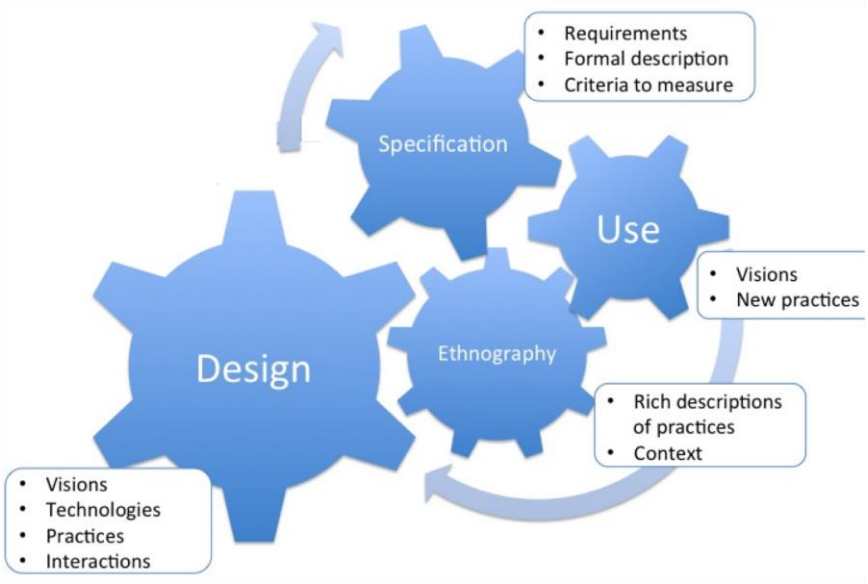


Figure 1. BRIDGE Domain Analysis and Collaborative Design.

The primary addressees of this deliverable are designers and technologists and in particular WP6 *Interaction design* who are developing the user interface components in BRIDGE. Figure 2 shows an overview of how the five WP2 deliverables interrelate to each other.

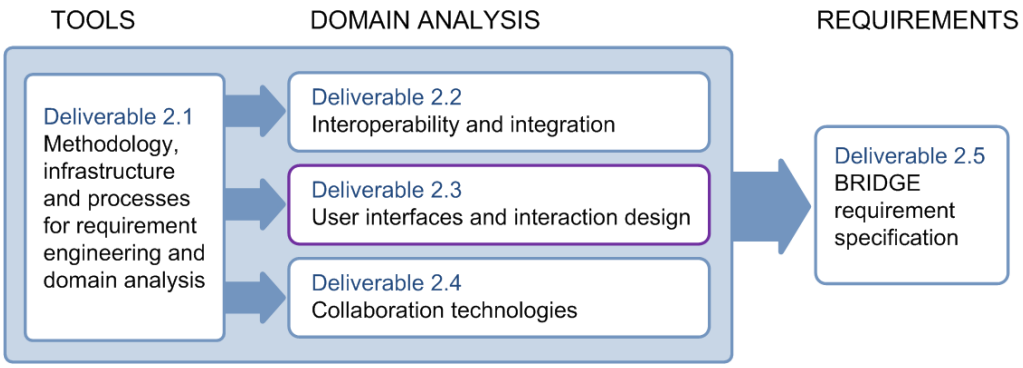


Figure 2. The Role of D2.3.

1.1 User Interfaces and Interaction Design in Multi-Agency Response

The BRIDGE project's focus on supporting large scale multi-agency emergency response with a system of systems approach poses particular challenges to interface and interaction design. Carver and Turoff (2007) emphasize the following aspects for implementing successful systems. There is a need for:

- Exchange of information including information from in the field
- Just-in-time decision support
- Focus user's attention on most important facts without the feeling of interruption
- Places for creativity to find a solution by the user
- Trust building between team members
- Facilitate workflow dependent communication; gain additional information over time

It is important that the systems under development support users in performing their tasks. A diversity of roles, perspectives and forms of expertise needs to come together in emergency management. The precise details of performing tasks, roles, perspectives and expertise may change with the introduction of new technologies, and this implies that the detail of evolving work practices and workflows must be considered when creating and evaluating the systems' user interfaces (UI) and interaction designs (IxD). Flentge et al. (2008) summarize key aspects based on the following points:

- Reduce complexity by supporting an overview of the situation
- Focus on tasks and devices in the UI design depending on the roles and needs
- Manageable system by novice and experts
- Flexible design depending on the environment and devices
- Security and privacy issues (depending on roles and needs)

These are generally relevant design principles for many applications, but they are very important to consider in safety-critical systems such as emergency management systems, because usefulness hinges on people's ability to integrate such systems into highly pressured, distributed and complex work practices. In addition, based on our studies with users and literature reviews around interoperability and integration (described in D2.2), we have identified needs for:

- Support for practicing emergent interoperability
- Support for assembly of systems to facilitate a system of systems

This can enable more efficient provision of information, which is critical for enhancing crisis management. However, it is ultimately the sense-making, i.e. the interpretation of information by the crisis response personnel in the context of the current situation and within their practices that must be supported, not merely the acquisition and processing of more and more data (Woods and Hollnagel 2006). With a view to supporting more effective sense-making with high-quality information, particular attention also needs to be paid to the specific characteristics crisis situations have. Therefore, Turoff et al. (2004) describe a framework with very specific design guidelines for emergency response systems (see also Lukowicz et al. 2010):

- Hierarchical overview of data to browse information easily
- Consider source and time aspects of information gained from the field
- Multi-directional communication between all parties
- Delivery of data based on the content
- Up-to-date information visualization

- Link between interrelated data
- Visibility of information to the right person (responsibility and accountability)
- Consider social needs in the design to build trust
- Prevent users from information overload

BRIDGE systems of systems innovation has to consider not only the different tasks, roles, perspectives and forms of expertise and requirements of crisis situations, but also the support of distributed sense-making and collaboration, for example to reduce information overload and support overview & understandability in crisis situations.

In this deliverable, we will present findings from the BRIDGE project with regard to designing interfaces and forms of interaction that fit the needs of practitioners in crisis situations. In doing so, we will particularly focus on three key topics which domain analysis and literature review have identified as important in the context of interface and interaction design for emergency response systems and the systems of systems approach of BRIDGE:

- Designing for Situation Awareness
- Ambient Intelligence for Supporting Emergent Collaboration
- Supporting Agile Response and Collaborative Agile Workflows

Some key insights and ideas are being collected in the BRIDGE Design Pattern Library[1] (DPL). This library was developed as a framework for *collaborative* development, discussion, sharing and evaluation of design patterns in the context of the project and with interested external parties (see also Reiners et al. 2012, Reiners et al. 2013). The DPL is described in a separate BRIDGE Deliverable (D06.1) and a summary of the library key concepts is provided in Appendix 1.

1.2 Overview of the deliverable

This deliverable is organized as follows: Chapter 2 presents an operational example as a context case study for showing what kind of interfaces are currently used by emergency agencies in Norway, and what challenges are related to their use. The study focuses on Norway for concrete insight, but broadens to review the European experience, based on interviews and engagement with the BRIDGE EUAB.

In a series of three chapters, we then discuss key dimensions of interface and interaction design in BRIDGE: designing to support situation awareness (Chapter 3), possibilities of making use of automation and ambient intelligence for supporting emergent collaboration (Chapter 4), and how to support collaborative agile emergency response with collaborative agile workflows (Chapter 5). These chapters capture and define core interface and interaction design concepts employed in the BRIDGE project.

Chapter 6 discusses the BRIDGE e-triage prototype system as a case study. As part of BRIDGE systems of systems approach, e-triage requires synthesis of support for situation awareness, ambient intelligence, and agile response, and we have developed and employed some of the core concepts here. The chapter illustrates how attention to these dimensions and concepts can enhance large-scale multi-agency response.

Chapter 7 concludes the deliverable with a summary of lessons learned.

[1] BRIDGE Design Pattern Library: http://bridge-pattern-library.fit.fraunhofer.de/

2 Operational examples – existing user interfaces and challenges

Emergency management involves a great variety of different personnel, ranging from tactic personnel working in the field, to operative and strategic personnel working from emergency centrals. All the individuals involved have different requirements and needs according to their role, tasks and the equipment they use. First responders need mobile equipment that supports hands-free communication, as their hands are busy with other tasks, such as driving to the incident site. Operative personnel in an emergency central, however, are better off with larger displays, enabling them to get a complete overview of the situation. Thus, for emergency response systems specific characteristics must be considered, both for the mobile devices interaction in the field, and the more fixed interaction taking place in the control post.

In that regard, user interfaces for local leaders (typically at a local control post) and field workers (emergency responders) in an emergency response must fulfill a set of specific requirements. Even though a local leader has a very attention requiring primary task, an application with a well-designed user interface may relieve the leader from some of the demands for attention. Doing the same for a field worker is more challenging, so for this user group it is more important to have non-intrusive ICT support, possibly offering non-visual modalities as an alternative to or in combination with visual presentation and interaction. For local leaders, supporting user interfaces on equipment with different screen sizes is important to give optimal solution both when the leader is at a local control post and when the leader is moving around. Local leaders have special needs regarding awareness of changes in the information presented, while field workers have special needs for knowing their own connection state (Nilsson and Stølen 2010).

In the next section, we will discuss existing user interfaces currently used by the Norwegian emergency agencies for the purpose of crisis management as an indicative case study. In the subsections we present the status and use of ICT in Norwegian emergency management, existing and currently used interfaces, and challenges in connection to their use. We conclude with a brief review of how this resonates with the situation more broadly in Europe.

2.1 Use of ICT in Norwegian emergency management

The use of ICT in Norwegian emergency management has been an important issue, especially in the lights of the terror attack in Oslo and at Utøya the 22nd of July 2011. The concluding report from the July 22nd commission states that the police's ICT systems are poorly developed, and that a regular police vehicle is rarely supported with communication possibilities other than radio (Gjørv 2012). Studies conducted in connection to BRIDGE have also shown similar trends (Eide et al. 2013). The police do not have access to proper geographical maps in the vehicles, unless commercial GPS systems have been installed, and they lack the possibility of maintaining an overview of other resources. Furthermore, tactical personnel do not have access to mobile devices to use the police's operative systems (e.g. registered vehicles, intelligence registers, etc.), nor do they have the possibility of sending and receiving text-based or multi-media messages (Gjørv 2012).

2.2 Existing interfaces

Interviews conducted with Norwegian emergency response personnel at a tactical and operational level has revealed the use of mainly 2 ICT systems in Norwegian crisis management: 1) CIM used by the police, and 2) LOCUS used by the fire and rescue service, and the health service.

CIM (see CIM 2013) is a software program for crisis management support, produced by One Voice AS, a company delivering crisis management solutions for a variety of organizations. The

CIM system supports aspects of crisis management such as quality assurance, risk and vulnerability analyses, emergency planning, training, and evaluation.

In April 2013, the police implemented CIM as a part of their tools for emergency management. The police will initially use CIM for the purpose of notifying police personnel when major incidents occur. The CIM system supports notification and alerting of personnel through distribution lists for sending messages by email, SMS, and phone. The system provides the receiver with several response alternatives which are logged, so that the sender of a message can keep track on the status of each alerted individual.

CIM is currently used by many organizations that the police collaborate closely with, among others, the Directorate for Civil Protection and Emergency Planning (DSB), The Norwegian Civil Defence, and all Norwegian municipalities and county governors.

LOCUS (see LOCUS 2013) is a company delivering mission-critical solutions and products to the fire and rescue service as well as to the health service, among others (e.g. transport and logistics, security service companies). The solutions are designed to reduce time constraints through being a tool for the emergency agencies to make the right decisions in relation to resource allocation.

LOCUS' solutions are directed towards use by the 110 and 113 emergency call centrals (TransFire for the fire and rescue service and TransMed for the health service) and mobile devices installed in vehicles for the tactical personnel (TransMobile 7) (Figure 3).

TransFire and TransMed are systems for resource allocation, used by many 110 and 113 emergency centrals. The system supports the 110/113 operators in managing and allocating the respective unit's resources, through detailed maps showing coordinates from the GPS trackers installed in the different vehicles. For TransMed, the map also displays an overview of other resources, such as boats, helicopters, and emergency wards. All who call the emergency centrals are positioned in the map, and the position and other information about the operation is being sent to TransMobile 7, installed in the vehicles. All data communication between the emergency centrals and the vehicles are continuously synchronized.

TransMobile 7 is a system installed in fire and rescue vehicles and in ambulances, providing tactical personnel with a map displaying the GPS coordinates of resources, coordinates for operations, and updated information from the emergency centrals. The system also includes information about roadblocks, and specific objects. The fire and rescue service also use TransPos Navigate, a GPS system showing the best route for a vehicle to get to the location of an operation. It is also possible to send and receive text messages through the system.

Figure 3. Locus TransMobile PC installed in a Norwegian ambulance vehicle.

(Older version of TransMobile 7, October 2011).

Some challenges exist in regard to the currently used interfaces and ICT systems used in Norwegian emergency management. The challenges relate to the use of different systems, display of information within and between units, and more organizational challenges connected to the monitoring and update of such systems.

Use of different systems

As seen in this section, the police make use of the CIM solution for crisis management, while the fire and rescue service and the health service use Locus. This use of different solutions for crisis management might be a barrier for establishing common situational awareness within and between agencies (Eide et al. 2012).

Display of information within and between units

A challenge raised by the agencies using Locus is that the system is only set up to display resources from within the districts one is assigned to operate in. For example, tactical fire and rescue personnel from Oslo cannot see resources from surrounding areas even if they are located within the borders of the district of Oslo. This can be problematic in situations that require additional resources from other districts and coordination of efforts beyond and between the districts.

Problems of Radio Communication - Lack of Visual Communication

Another major challenge in current emergency management is the high dependency of emergency agencies on radio communication. The problem is highlighted in a paper based on a workshop with emergency personnel (Eide et al. 2012), where not being able to use text-based technologies or send pictures to tactical personnel due to technological limitations of the used equipment is identified as a main barrier for efficient communication during large-scale emergency situations. More evidence for this shortcoming can also be found in the concluding

report from the July 22nd commission stating that the presence of text based or visual communications systems could likely have contributed to more efficient and effective actions being taken by the police (Gjorv 2012:14).

Organizational challenges

For ICT systems to be efficient for use in crisis management, it is crucial that the information exchanged and displayed is up to date. Ideally, this should not generate extra workload for responders, but data quality measures and updates should be part of normal organizational processes. Furthermore, crisis management technologies should be, as far as this is possible, part of everyday practices, to enable training and familiarity.

2.3 Interfaces and Interaction Design in Europe

Our reviews of existing technologies for organizational, legal, and semantic interoperability in other European countries and for cross-border crisis management resonate with these findings. Emergency responders from other European countries engaged in BRIDGE through domain analysis, co-design workshops and the end user advisory board (EUAB) highlight that technology has the potential to address critical coordination and interoperability issues, as '*problems of communication regularly occur between the tactical and strategic level'* (Heiko, German THW, Mobilizing Emergency Response, Lancaster, September 2012). At the same time, there are challenges that obstruct service providers from leveraging this potential. Most importantly, this refers to the diversity of different systems, work processes, and organizational models even within one country, but also to the lack of shared overview tools, concerns over data protection rules and privacy and social and organizational challenges to the implementation of new technologies. This assessment coincides with recent studies of information sharing and interoperability in Europe that find that '*the technology is way in advance of procedural [innovation]'* (Allen et al 2013), indicating that there is also a need of social innovation in order to apply the possibilities of the existing technology to the practice. During a major communications stocktaking exercise, the European Network and Information Security Agency found that:

- Terrestrial Trunked Radio (TETRA) is widely used (but is not ubiquitous) across Europe by emergency services
- Some emergency services do use data services, often on commercial networks, but data is not used between the emergency services and the public
- Some civil defence organisations have a military background and are subject to national security restrictions, limiting inter-agency working
- Standards and policies for emergency communications are often developed in vertical silos, making inter-agency communication (e.g. between police and ambulance organisations) difficult
- Technology failure is often an issue identified in post-crisis reviews of major incidents, and having broader technical back-up capabilities that anticipate and mitigate such failures is useful; data services (especially from the public) fit into this model

(ENISA 2012:1)

Interface and interaction design plays a major role in the mismatch between technological potential and its creative and responsible appropriation, as illustrated by this excerpt from a conversation between emergency responders and BRIDGE MESH network designers during a BRIDGE EUAB meeting:

> *Christian Van De Voorde (Firechief Ghent, Belgium): You cannot send mission critical info over the net. Our experience is that too many people are using this interface and it is crashing.*

Amro Al Akkad: We interviewed a specialist from THW regarding this issue, You have to see what [part of the network] is working and what is possible.

Heiko Werner (Civil Protection, Germany): The network goes down in a major emergency very quickly. How can you guarantee that it will work all the time, because if you cannot, they will not use it.

Erion Ellmaslari: The whole idea of the MESH is to cover the scene with connectivity, but not necessarily with interconnectivity. How MESH connects outside, it will use whatever is available, with an adaptor device and that is it.

Barbra Campbell (Police Bronze Commander, UK): How do you deal with data quality issues? How do you provide for the security?

(EUAB meeting, Flums, September 2012)[2]

In summary, our reviews of ICT use by emergency response agencies in Norway and Europe highlight three key challenges for interface and interaction design:

- **Designing for Situation awareness** – it is no longer a lack of data that constrains emergency responders' capability to develop and maintain timely situation awareness amongst large, diverse and distributed groups of actors. The challenge is to support people in finding and integrating relevant information from heterogeneous sources and to make the integrated information available and intelligible for other agencies – visually and in other multi-modal modes of representation.
- **Ambient Intelligence for Supporting Emergent Collaboration** – the inevitable uncertainty over the specifics of a crisis in the planning and preparation phase requires both trained discipline and flexibility when a crisis occurs. It must be possible to quickly identify and assemble appropriate emergency response teams, resources and technologies which can be supported by providing ambient intelligence.
- **Supporting Agile Response and Collaborate Agile Workflows** – responders and communities must be able to collaboratively solve problems by preparing plans, providing situation reports, managing resources, assigning orders and documenting progress.

Across Europe diverse social and cultural contexts and practices work to different logics and people find it difficult to mobilise technological potential with existing interfaces and interaction paradigms. Semantic interoperability is an obstacle (for example, a H on a map may mean hospital to paramedics, while it may mean fire hydrant to fire fighters) (Allen et al 2013), experiences of information overload hamper appropriation when emergency situations require responders to identify *relevant* information (Rake and Njå 2009), there are concerns of privacy and security, and the different agencies involved have different priorities, information models and approaches (Allen et al 2013). While network enabled and network centric organizational models and forms of 'agile response' are emergent in the US (Walker et al. 2007, Harrald 2006) and the Netherlands (Boersma et al. 2010), much of Europe finds it difficult to introduce new approaches to crisis management and technologies for greater interoperability and collaboration, because there is a lack of attention to the social, material and organizational practices of making services interoperable and a lack of support for the translation of these practices into more interoperable contextures at all levels of design, particularly interface and interaction design.

[2] See also *D5.4 Graphical User Interface of the Network Infrastructure*, where we describe how such discussions have informed the design of network visualization and inspection tools in BRIDGE.

3 Designing for Situation Awareness

In the following chapters, we turn to three key topics of designing interface and interaction design for BRIDGE systems of systems in detail: designing interfaces and forms of interaction to support situational awareness (Chapter 3), possibilities of making use of ambient intelligence for supporting emergent collaboration (Chapter 4), and how to support collaborative agile workflows for emergency response (Chapter 5).

Operations during an emergency response are usually led from a local command post close to the scene of the incident, often in a car, caravan, or tent (Nilsson 2009). The post serves as an information and communications hub that gives field commanders the best possible access to critical information. As information and communications technology advances, however, so does the amount of data flowing into that hub: Data from social media, new types of sensors, RFID-tagged resources, GPS signals, real-time digital mapping tools, and other sources pour into the command post. The challenge of 'access' is thus changing from one of gathering enough data about the environment for effective decision making, to one of making sense of all the data that are available.

Put another way, thanks to ICT, lack of situation data is becoming less of a problem in emergency response. Rather, the growing problem these days is to turn all of those data into meaningful information that actually helps emergency personnel to understand a situation, including how that situation came to be and how it might develop. With Hollnagel and Woods (2005) we stress that the 'belief that more data or information automatically leads to better decisions is probably one of the most unfortunate mistakes of the information society.' Innovation is needed to help those in the command post manage and interact with all of the available information in a way that fosters better awareness of the situation.

Situation awareness (SA) refers to how well individuals and teams know and understand what is going on around them (Endsley 2000). In effect, good SA provides a better foundation (though not a guarantee) for effective decision making. The following subsections describe one of the more popular SA models, outline some of the design principles from that model for supporting SA, and provide some examples of SA-supporting systems.

3.1 What is situation awareness?

Endsley (1995) defines SA as 'the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future'. That definition is perhaps one of the most popular and commonly used in the field, and Endsley's corresponding three-level model forms the basis of much of the Human Machine Interaction design work in BRIDGE. Several variations and alternatives to that model exist, but when it comes to UI design for complex systems, Endsley's is both abstract enough to use in different domains, but specific enough to highlight a set of activities (e.g., perception, comprehension, and projection) that a complex system should support.

Endsley's definition can be broken into three components, each forming one of three levels of SA in her model. Higher levels provide a better basis – though not a guarantee – for effective decision-making, as follows:

- *Level 1: Perception of the elements in the environment*. This level involves awareness of the 'status, attributes, and dynamics of relevant elements' in the environment of the given situation. Endsley (1995) provides an example of a battlefield commander knowing details of enemy and friendly forces – e.g., location, type, number, capabilities, and dynamics.
- *Level 2: Comprehension of the current situation*. This is a level of awareness based on

synthesizing and integrating the otherwise disjointed Level 1 elements. One understands those elements in terms of their significance to one's goals, sees patterns in them, and achieves a holistic view of the situation. Again in terms of the battlefield, Endsley describes how a group of enemy aircraft within a certain range of each other and in a certain location may highlight certain enemy objectives to an experienced commander. Novices may have a hard time reaching this level of awareness.

- *Level 3: Projection of future status*. This level of awareness means having the ability to anticipate the future behaviour (actions or values) of relevant situation elements in at least the near-term, and is it generally achievable only by experts. So, anticipating that enemy aircraft in a certain pattern and on a certain approach will likely attack in a certain manner, the commander can prepare accordingly.

Strater, Reynolds, Faulkner, Birch, Hyatt, Swetnam, and Endsley (2004), working within a military context, describe the three levels more simply in terms of three questions about a given situation: 'What?', 'So what?', and 'Now what?'

In BRIDGE, we would have to add a fourth dimension we could describe as "with whom?", since the project deals with developing for *shared* situation awareness of distributed actors. This adds to the complexity of design as providing coherence of different communication channels of different teams and organizations becomes important for building a common, shared picture of the current situation.

There are significant differences between situation awareness practices in military contexts and in disasters and these differences have significant implications for design (Harrald and Jefferson 2007). The context 'changes from one where decision makers are operating on a level playing field, with shared backgrounds, organizational culture, goals, and training to one where the decision makers have very diverse backgrounds, training, goals, etc.' and in a disaster, 'information needs change … the emphasis on quality, timeliness, and accuracy will also change at various points along the disaster timeline' (ibid: 7). This leads to design challenges specifically related to supporting SA in disaster response, focusing on support for negotiation between different semantic systems, awareness of data quality (completeness, timeliness), negotiation of different (and dynamically changing) criteria for information integration and filtering, configuration of consistency in perception and consistency in judgement over what (diverse) actions need to be taken and coordinated.

3.2 SA-oriented design

Endsley and Jones (2003) devoted a book to the challenges of incorporating SA considerations in the design of complex systems. For the BRIDGE team's reading of this contribution, the goal is to produce systems and interface and interaction principles that support each aspect of Endsley's definition of SA and its adaptation in disaster contexts – something that supports organization, presentation, and interaction with information in a way that lets users find what they need when they need it, while at the same time maintaining the big picture of the situation. To that end, Endsley and Jones describe an SA-oriented design process that can fit into high-level system design.

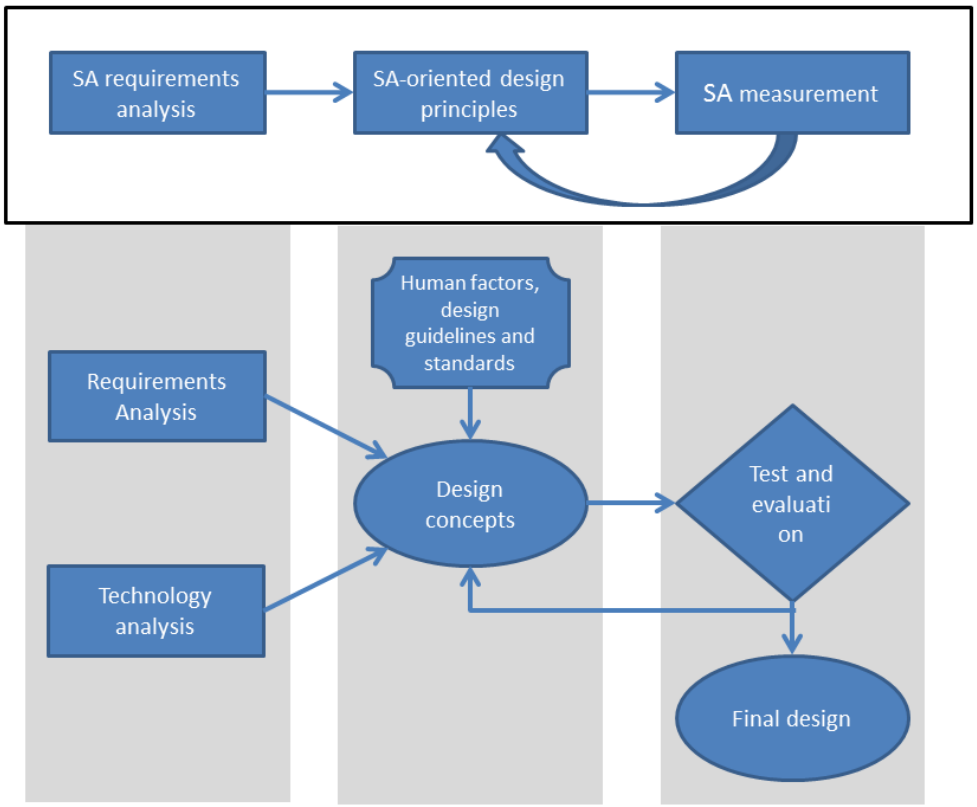


Figure 4. SA-oriented design as a part of the overall system design process.

(Adapted from Endsley & Jones, 2003:286).

In support of that design process, Endsley and Jones (2003) provide 50 design principles for assisting operator SA. They categorize those principles into seven groups: general, certainty, complexity, alarms, automation, multioperator, and training. Table 1 provides a summary of the either general principles, which are relevant to most any complex system.

1	Organize information around goals	Information should be grouped and presented in a way that best supports user goals, rather than broken down according to technological features (e.g., sensors) of the system.
2	Directly support Level 2 SA (comprehension)	Reduce demands on user working memory and attention by providing synthesized and prioritized situation information directly to users, rather than simply low-level or raw data. For example, present differences between expected and actual values rather than requiring users to make such calculations themselves.
3	Support Level 3 SA (projection)	Help users to anticipate possible outcomes and project future system states. A simple example is a trend display that shows changes in some

		parameter over time.
4	Support global SA	Provide users with a view of the overall situation while they are focused on details.
5	Support trade-offs between goal-driven and data-driven processing	Ensure that data salience complements rather than distracts from the user‘s goal-directed behavior – for example, by directing user attention toward critical events.
6	Highlight critical cues for situation recognition	Mental models and schemata theoretically play a key role in higher levels of SA, so highlight the main situational features likely to trigger those models.
7	Take advantage of parallel processing capabilities	To a certain degree, humans can process information from different sensory modalities in parallel. To the extent possible, then, instead of presenting all incoming information visually – and thus potentially overwhelming a user – offload some of that information (e.g., alerts, feedback) onto auditory or haptic channels.
8	Filter information carefully	Presenting automatically filtered data can deprive users of information they need to build and maintain global SA, as well as to anticipate future system states. Rather than designing information-filtering mechanisms, then, effort is better spent on developing ways for users to control what they see and when, and for presenting information in an easily processed format (see principles 1 and 2).

Table 1. Summary of general SA-oriented design principles (from Endsley & Jones, 2003).

In this context, it has to be noted that providing situation awareness is an important factor for understanding the situation, and helpful for supporting sense-making in crisis situations. Nevertheless, for making good decisions based on what you know, the design of further information management tools might be needed.

3.3 Examples of SA-supporting systems

Systems like the Master are an increasingly common focus of research and development in emergency response and multi-agency collaboration, particularly in regard to assembling a Common Operational Picture (COP). The Palcom project, for example, used ethnographical studies and participatory design techniques to design a prototype for a common operational picture to be shared by multiple agencies (Büscher and Mogensen 2007). That prototype provides a realistic (2.5D) presentation of the terrain at the scene of an incident, displays available resources, and provides a means for drawing the operational area, travel routes, and other zones. Figure 5 and Figure 6 show their prototype of a COP application. Figure 5 shows a railway station in which an accident has happened, showing the terrain at the scene with the first emergency vehicles arriving. Figure 6 shows a detail of the organization of the scenario incident

site drawn by the fire and police commanders, with inner and outer barrier. The waiting area (VP) is marked by a cross and transport routes are indicated.

Figure 5. Common operational picture with tracked vehicles shown.

(Reproduced with permission from Büscher and Mogensen, 2007)

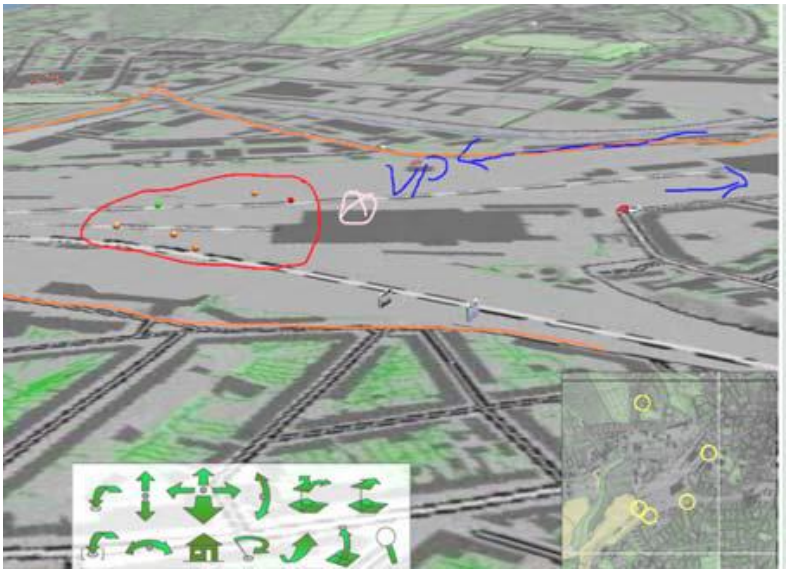


Figure 6. Common operational picture with manual annotations.

(Reproduced with permission from Büscher and Mogensen, 2007)

Jiang, Hong, Takayama, and Landay (2004) also address the common operational picture, including incident details, resource management as well as monitoring firefighters and automatic reasoning based on monitored values, but they focus more on developing prototypes that enhance existing solutions for firefighters. In a prototype called Firewall, for example, a wall-sized display shows field commanders sensor feeds indicating the fire area and the location of firefighters, overlaid on a floor plan. Although they address only firefighters in their empirical studies and suggested solutions, the authors argue that similarities between agencies (like common procedures and training) make their results applicable for other agencies. Figure 7 shows their prototype of a COP application for local leaders in the fire services.

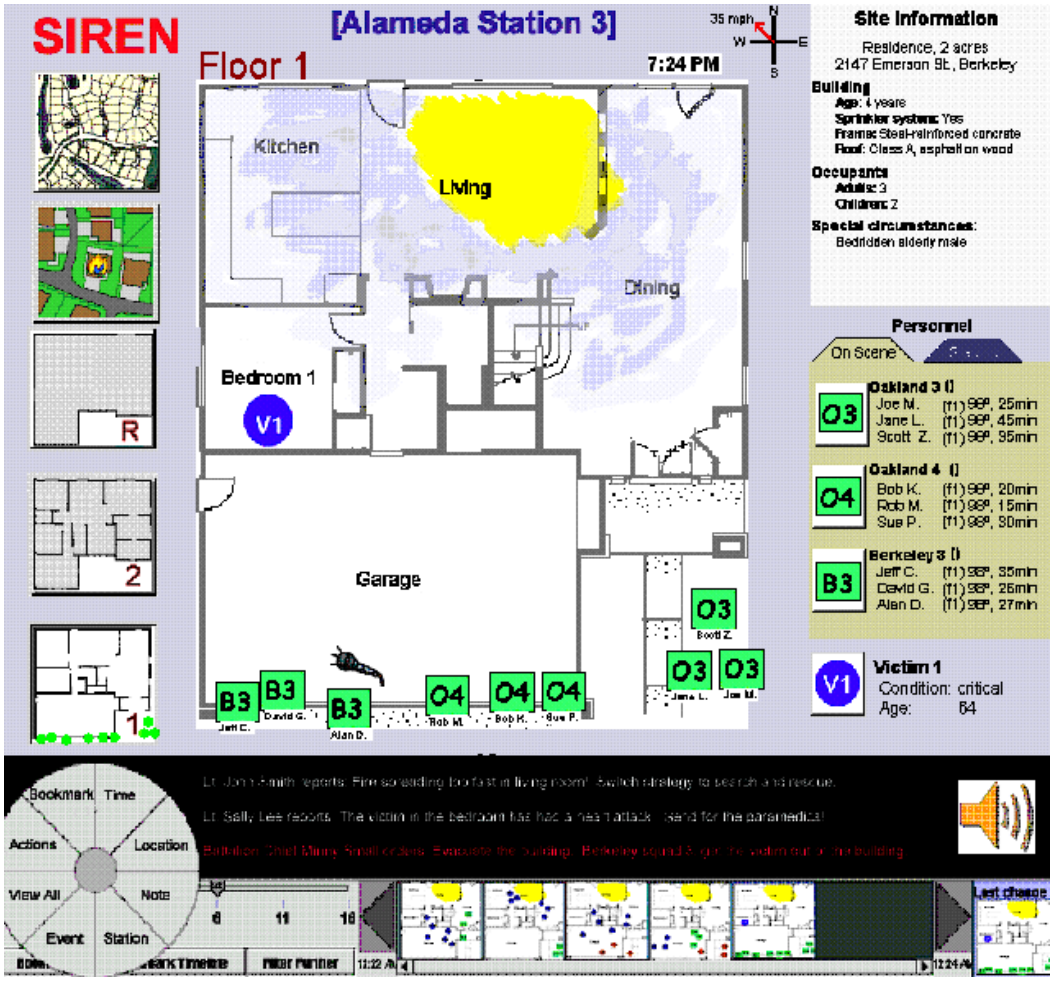


Figure 7. Firewall, showing an operational picture for local leaders in fire services.

(From Jiang et al, 2004b)

Other notable work in this area includes the @aGlance project (www.aglance.dk), which has prototyped a COP that combines 2.5D maps, 3D models of buildings, resource tracking, and integrated pictures and videos from surveillance cameras. Figure 8 shows their prototype of a COP application.

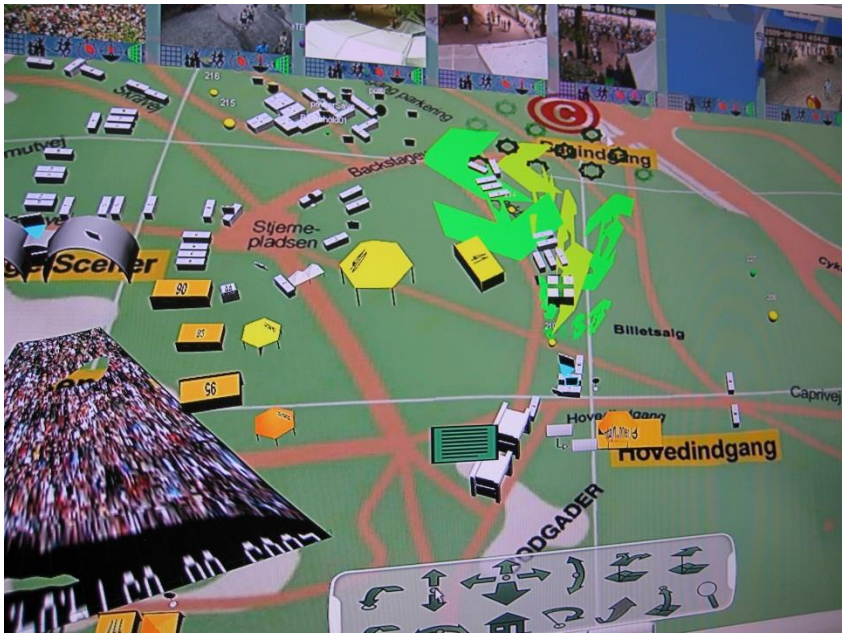


Figure 8. Common operational picture with rich content.

(From http://www.aglance.dk/wp-content/IMG_1251.JPG)

In addition to these examples, Kristensen, Kyng, and Palen (2006) and Kyng, Nielsen, and Kristensen (2006) investigate systems that provide a COP that shows incident details and allows monitoring and resource management.

Turoff et al (2004) apply a broad perspective on information systems support for emergency response, outlining among other central information requirements. Their focus is on design principles for such information systems, emphasizing the need for a single, dynamic and integrated system. Streefkerk et al (2006) address both design principles and methods for designing user interfaces supporting emergency response. They focus on adapting solutions to the user‘s context, as well as the special needs when users are solving attention requiring tasks, but do not address concrete user interface functionality.

More recently, ‘Precision Information Environment’ or PIEs have been proposed as a new concept for SA support technology. PIEs seek to provide ‘visual analytic capabilities through novel interactions that transform the way emergency professionals - from first responders to policy makers - engage with each other and with information’ (Boulos et al. 2011: 21, Figure 9). This is an ambitious goal, all built around the idea of ‘precision’:

> *At the centre of the Precision Information Environment is a profile for each user that defines the user’s information interests and needs. One’s role in an emergency event is a core part of this profile, and the PIE system uses roles defined by the National Incident Management System of the US Federal Emergency Management Agency to provide an initial template for information interest. Role-driven tailored information services and adaptive data triage bring ‘Precision’ into a Precision Information Environment. They allow an emergency manager to get exactly the right information at the right time and avoid information overload by filtering data to only those which are likely to be most relevant to a given user. In this way, the user can stay focused on the tasks and activities that matter. (Boulos et al. 2011: 22)*

From left: Remote collaboration, interaction with wearable device and in-car display, desktop interaction with remote experts, planning on table, modelling of alternatives, all involving mapping, information aggregation and visualization, linking, communications, routing, resource allocation, interaction with remote experts, …

Figure 9. Precision Information Environments.

(Screenshots from website http://precisioninformation.org)

We are sceptical about the rigid role driven personalization of information filtering and aggregation tools in a context where role improvisation is inevitable (Webb 2004), but the support for collaboration within a common information space is inspiring.

3.4 Configuring Awareness: Designing for SA in BRIDGE

Systems like the ones described above all have the same general goal of making an abundance of data available. Some also develop ideas for supporting people in making information meaningful and configuring awareness in diverse and distributed teams. This is a critical issue, since situation awareness in such teams needs to be produced and negotiated. Sense-making, not just 'access' to 'more' information is critical, and the collaborative practices that are necessary for sense-making need to be supported.

Heath and colleagues (Heath et al. 2002) developed the concept of configuring awareness through analysis of collaborative work practices in 'centres of coordination', including police operation rooms and traffic control centres, with a view to informing the design of computational support for distributed collaboration. They show that situation awareness is not just a 'state' of shared understanding of a particular situation dependent on availability of accurate information, but a continuous social process that relies on people being able to – often very subtly – highlight different aspects of a situation for themselves, but also for others who need to know. The sensitivities, practices and skills involved in knowing who needs to know what, gaining and paying attention when it matters, and assembling information to make meaning can be impoverished and undermined by new technologies.

The BRIDGE Master seeks to support responders in 'mastering information'. It allows them to dynamically draw information together from a wide array of diverse sources within a system of system assembled for the specific crisis at hand (see Figure 13). By documenting unfolding events as richly as this is possible and by supporting visual aggregation and abstraction of information as well as 'drill down', the BRIDGE Master supports collaborative distributed sense-making and configuring awareness.

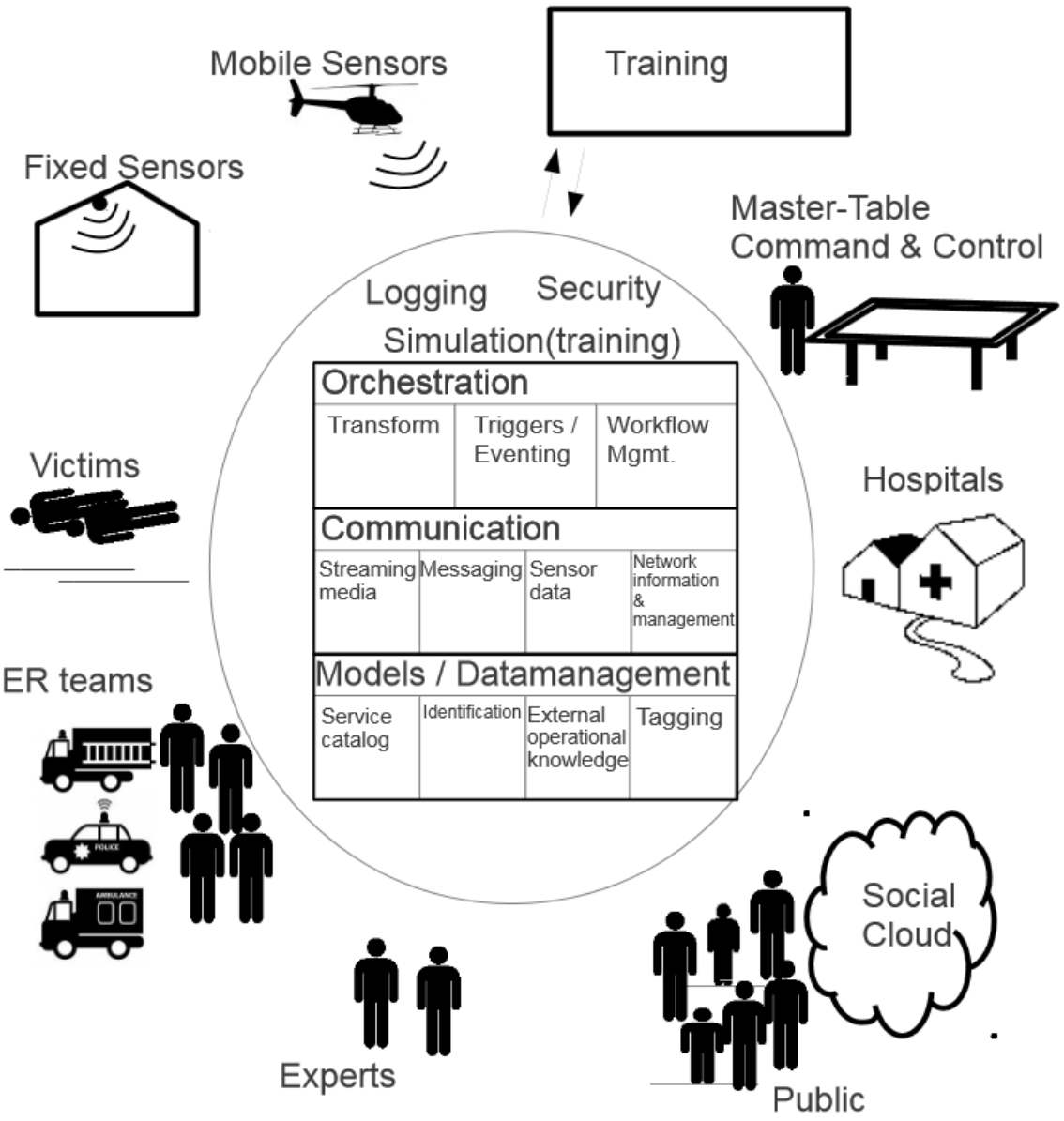


Figure 10. The BRIDGE Master.

4 Ambient Intelligence for Supporting Emergent Collaboration

... the development of networking technologies must also take account of the social processes that form an important component of command and control and inter- agency cooperation. (McMaster et al.: 79)

Almost without exception, whilst highlighting exemplary successes, reviews and reflections after disasters express concerns over the different emergency agencies' abilities to work together. Lack of or suboptimal utilization of technologies – from disrupted network connectivity to inappropriate communications tools – are important (albeit not the main) reasons (e.g. Gjorv 2012). Recent research in Ambient Intelligence (AmI) develops new support for coordination in emergency response through ad-hoc networking (Jones et al. 2005), agent-based workflow support (Van Veelen et al. 2006), self-management and self-healing of emergent systems of systems (Ayala et al. 2012), activity recognition (Choudhury et al. 2008), and risk analysis (Aziz et al 2009). These technologies have great potential for BRIDGE, but a deeper understanding of such factors and practices is needed to design useful support for real world practice.

This section explores AmI interface and interaction design issues based on a (constructive) critique of the potential of ambient intelligence technologies in emergency response. We explore how AmI tools may feature in a sociotechnical arrangement or 'system of systems' which supports inter-agency collaboration during emergency response, and describe three challenges with reference to literature and our own fieldwork in Emergency Management Information Systems (EMIS) design: data transparency, information overload, and interpretation/intuition. We posit that ambient intelligence has a great deal to offer in the creation of EMIS and that these offerings can be enhanced through attention to interface and interaction design.

4.1 Background: Emergence in Emergency Response

BRIDGE develops architectural support for the assembly of systems of systems for emergency response. Emergency management encompasses a variety of activities such as risk assessment, planning, training, response and recovery. Emergency response involves an exchange of data between different agencies and institutions, movement of people from service to service and cooperation from other actors (such as utilities companies, insurance providers, and telecoms opera- tors). The emergence of appropriate assemblies of responders and resources depends on coordinated improvisation in a time critical, often dangerous and unpredictable environment. Collaboration is paramount and 'effective' collaboration may save lives. Ambient Intelligence or AmI has great potential in this context, as it can contribute in coordinating and orchestrating emergent interoperability, and help people identify actors and services relevant for the situation at hand. Innovation in this area, however, must be grounded in an understanding of the difficulties emergency responders experience, and their often multi-dimensional causes, as well as an appreciation of the often highly sophisticated and delicate practices of collaboration that make coordination possible. Undermining and failing to appreciate the local, lived and often successful collaboration efforts of those operating 'on the ground' can lead to costly failures with the potential to damage relations between organizations (Shapiro 2005). It is important for design to focus its efforts on supporting collaboration where it is needed without disrupting the social practices which enable these disparate yet cooperating entities to work together (Van de Walle et al. 2010). Attention to interface and interaction design can make a pivotal difference in this context.

To inform our discussion, the next section explores some difficulties in, and successful practices of, inter-agency collaboration in emergency response, revealed in ethnographic field studies and collaborative design workshops with first responders undertaken in the BRIDGE project.

4.2 Emergent Collaboration

Some of the concerns expressed in official reports over how a lack of collaboration following emergency response efforts sit uncomfortably with empirical studies of emergency responders' work practices. Such studies, including our own, show, how first responders work well together, how their practices fold into each other's and how they address incidents effectively through collaborative working and engagement on a day on day, week on week basis. Empirical accounts of practices highlight an economical yet sophisticated process of emergent collaboration with practices of configuring awareness (Petterson et al. 2007, Heath and Luff 1992), the emergence of 'adhocracies' of emergency response actors (e.g. in the aftermath of the 9/11 attacks, (Mendonça et al. 2007, Kendra and Wachtendorf 2006)), and the ability to 'stretch' communicative capabilities with new technologies (Büscher et al. 2008), creatively avoiding a 'fracturing' of perceptual ecologies (Luff et al. 2003).

Post-disasters reports and inquiries often underestimate the difficulties of interoperability in emergency response both at a human and at a technical level. A technocratic belief in the feasibility of better interoperability often motivates attempts to eliminate differences among participating agencies, for example through centralization. This has not proven to be effective (Shapiro 2005, Wise 2006, Boin et al. 2009, Committee of Public Accounts 2011). Overeager centralization, cumbersome legislation, and conflicting business rationales negatively impact on responders' capabilities to coordinate their contributions and collaborate. Yet, such measures often furnish a powerful background to technological innovation. Particularly pertinent to interface and interaction design is that when work is augmented by technologies, important, but often taken for granted aspects of collaborative practices can become undermined. Problems between agencies can emerge – they may, for example, be unable to share information embedded within technologies or act on information obtained through communication or observation. What works on a person to person level, for example in 'motorhood' collaboration around physical surfaces in co-present situations, should not be disrupted by systems which cannot interoperate or logging systems which can only be viewed by one agency. New systems need to be designed with greater sensitivity to realities of collaborative work practices between agencies, moving between perspectives gracefully, without undermining important unnoticed practices. Technological innovation must focus not only on overcoming 'failures' or 'problems' in collaboration, but also on supporting and 'stretching' existing, effective ways of working together.

4.3 AmI for emergency response

Many authors have formulated visions for emergency response where AmI could improve collaboration and coordination of response efforts. In this section, we discuss key challenges and opportunities under a series of headings ranging from 'abstraction' to 'network awareness'.

Abstracting social and material practices – Emergency AmI is often envisioned or designed to recognize the needs of people through analysis of abstractions of behaviour, predicting needs and actions (Ingold 2010). In a scenario proposed by Jones et al. (Jones et al. 2005), for instance, a world is imagined where, as off duty paramedics approach a scene of an incident '...body-worn AmI devices register them with the ambulance control centre <ad hoc networking, identification and authentication> and they are directed to the place they can be of most use' [Jones et al.: 119). The benefits of such interactions – faster deployment and effortless registration and logging – are highly prized by practitioners when discussing the potential of AmI systems in the context of emergency response. Such use of AmI raises, however, a number of concerns about the way in which the 'social' is removed or made invisible from these envisaged interactions. Critiques of AmI interface and interaction design in health care and telemedicine, for example, highlight the ways in which creating intelligent environments can disrupt social connectedness. For example, remote monitoring of vital signs removes the

personal connections and the feeling of being cared for [21]. AmI tools can inadvertently undermine practices of inter-agency collaboration by removing negotiations or the need for interaction between participants. Furthermore, they can create dependencies of the users on the provided technologies which need to be avoided when designing for crisis situations.

Against this background, it is a deep challenge for AmI interaction design paradigms to balance engagement and automation. Büscher et al. (2008) have suggested that people need support in making ambient intelligence systems 'palpable', enabling visibility, de-construction, understandability, coherence, stability, user control and deference. Rogers (2006) has stated that promoting 'engaged' living, where it is possible to control interactions with the world as an alternate possibility for steering the field. Aiming at these qualities presents a plethora of opportunities for technological innovation yet also raises a number of serious challenges at different levels in the design of AmI systems. In our work, we identified several of these challenges. In the following we describe three of them with reference to literature and our own fieldwork in BRIDGE design.

Logging social and material practices – Ambient intelligent environments often make extensive use of instrumented environments via omnipresent sensors and actuators such as CCTV, RFIDs tags, etc. (Hert et al. 2008), which imply a growing potential for increased surveillance possibilities. In a co-design workshop, we discussed anxieties about breaching the data protection act when sharing data in multi-agency collaboration. A dilemma was presented where a policeman needs to do something with a person and that person is known to be HIV positive. The ambulance representative stated, 'We tell them discreetly 'use your gloves''. Jim, a Norwegian police officer, described inter-organizational collaboration on the scene of an incident during the workshop,

> *If there's a known violent criminal who might be armed injured on the scene, you'd tell the medics 'be careful with him'*

This is not in breach of data protection regulations and highly effective for the safety of emergency response personnel. It is an ethical requirement for information systems to (at least) respect existing health and safety practices. The above exchanges are likely to happen in 'fleeting moments', in direct face-to-face interaction or, less likely, via the radio system. The information would be ephemeral and it is relatively easy to understand who is within reach of this information spatially, organizationally, and temporally. However, in future, such communications may be logged automatically, opening them up for retrospective scrutiny. Moreover, it may be possible to triangulate the personal information implied in the communication with ID information and location. This change of context might make professionals less inclined to divulge what they know to protect their colleagues, for fear of breaching data protection regulations. This raises the question of balancing between the benefits of seamlessly connected system and the privacy concerns that the profiling and monitoring capabilities of AmI systems create. Within BRIDGE interaction design paradigms of reflective, accountable and palpable computing and 'seamful' design (Chalmers 2003 can be leveraged to support transparency.

Making sense of and using information – Harrald and Jefferson (2007) show that a 'common operational picture' does not lead to 'situation awareness'. The assumption 'that data is the only barrier to appropriate [understanding and] action' is deeply flawed. This was highlighted in our fieldwork where it was felt that information should be appropriately available at the different levels of an emergency command structure, that a common operational picture was not reliant on data intensive practices, and that providing excess information could 'blur the lines of command' and lead to problems of micro-management (Peter, Advanced Paramedic, co-design workshop, Lancaster, April 2012):

> *As a commander remote [incident commander on site], I don't think you would be interested in that particular information [the status of individual victims]. I think you'd want the headline; the numbers (John, Senior Fire Fighter, Co-design Workshop Lancaster, April 2012).*

Yet increasingly, systems are developed that aim to generate more and more 'data' for emergency responders in order to 'improve' situation awareness, creating the potential to mask what is of importance. There is a delicate balance to be struck between information overload and information simplification where digitally extended and augmented environments change interaction and involvement possibilities. Ambient intelligence interaction design for presenting information should provide interfaces that enhance people's ability to 'dig deep' enough into the system to inspect information and modulate mechanisms of information generation, aggregation and visualization.

Asymmetries between human and machine intelligence – It is not possible for an intelligent environment to be intelligent enough to automatically support situated human sense-making. In human communication and collaboration, interpretation, social, cultural and material practices are used to understand intent and negotiate interaction. It is impossible to design systems that can act appropriately due to their incapacity to 'understand' context and intentions (pace Turing, see Suchman 2007). This does not mean that computational ambient 'intelligence' is not useful, as the example of resource allocation support below highlights.

Resource allocation – During a co-design workshop, in a discussion regarding the allocation of resources, responders talked, for example, about how the allocation or movement of personnel from one location to another is not simply the movement of people from one place to another. Ex-police officer and resilience manager, David, states:

> *One little thing that we questioned slightly is... automatic deployment... We felt that wasn't really taking account of the dialogue that goes on between control rooms and the units that they are deploying: officers or paramedics are feeding back local knowledge and things like this and we felt that that's something, an area that really needs looking at. It's never a one way process, deploying resources.*

Resource allocation implies a process of negotiation that defines the task itself, its parameters and how it should be accomplished. There needs to be support for dialog and closed loop communication even in visual and automated contexts. The work that is 'done' during the allocation of resources cannot necessarily be broken down into matching an individual's skills with a situation and location where assistance is required. As the example shows, asking someone to do something may involve trust in their professional capabilities, and delegation of responsibility or collaboration and negotiation: to determine whether the person being moved is fit for duty and indeed the best resource to move in the circumstances. Further to this, the accuracy to which such systems can 'abstract' human conduct underlying collaborative practices is limited. A police officer might move from one side of the building to another, for example. What does such movement mean? That one area is now safe? That the area where they were standing is now dangerous? That there is more need for them in the new location or that they are due to go home? AmI has no capacity to 'read' scenes in a way that could answer such questions. It can, however, make digital representations of some of the elements of the situation, available to support people in reading a scene and collaboratively construct awareness and situated sense-making. Interface and interaction design paradigms that explicitly pay attention to asymmetries between machine intelligence and human sense-making practices (rather than foregrounding machine intelligence) may find expression by embedding or 'punching' support for direct communication through the abstract 'resource' visualizations in the interface (rather than just 'representing' 'a resource' 'objectively'. This supports visibility, but also collaborative negotiation of the suitability of that resource for the task at hand.

Network awareness – It has been shown in a number of different domains, including emergency response, that making computing literally 'invisible' can be counterproductive to creative and effective appropriation, and not at all in the spirit of Mark Weiser's seminal call for ubiquitous and calm computing. Examples can be found in literature on GPS and networking infrastructures, emergency response, nomadic and mobile work, pervasive displays (Chalmers 2003, Buscher and Mogensen 2009, Mark and Su 2010, Davies and Langheinrich 2012). In the context of emergency response, it is critical that people can make themselves aware of what kind of connectivity is available. BRIDGE network and sensor visualizations are discussed separately in *D5.4 Graphical User Interface of the Network Infrastructure*, but the general principle is illustrated in Figure 11.

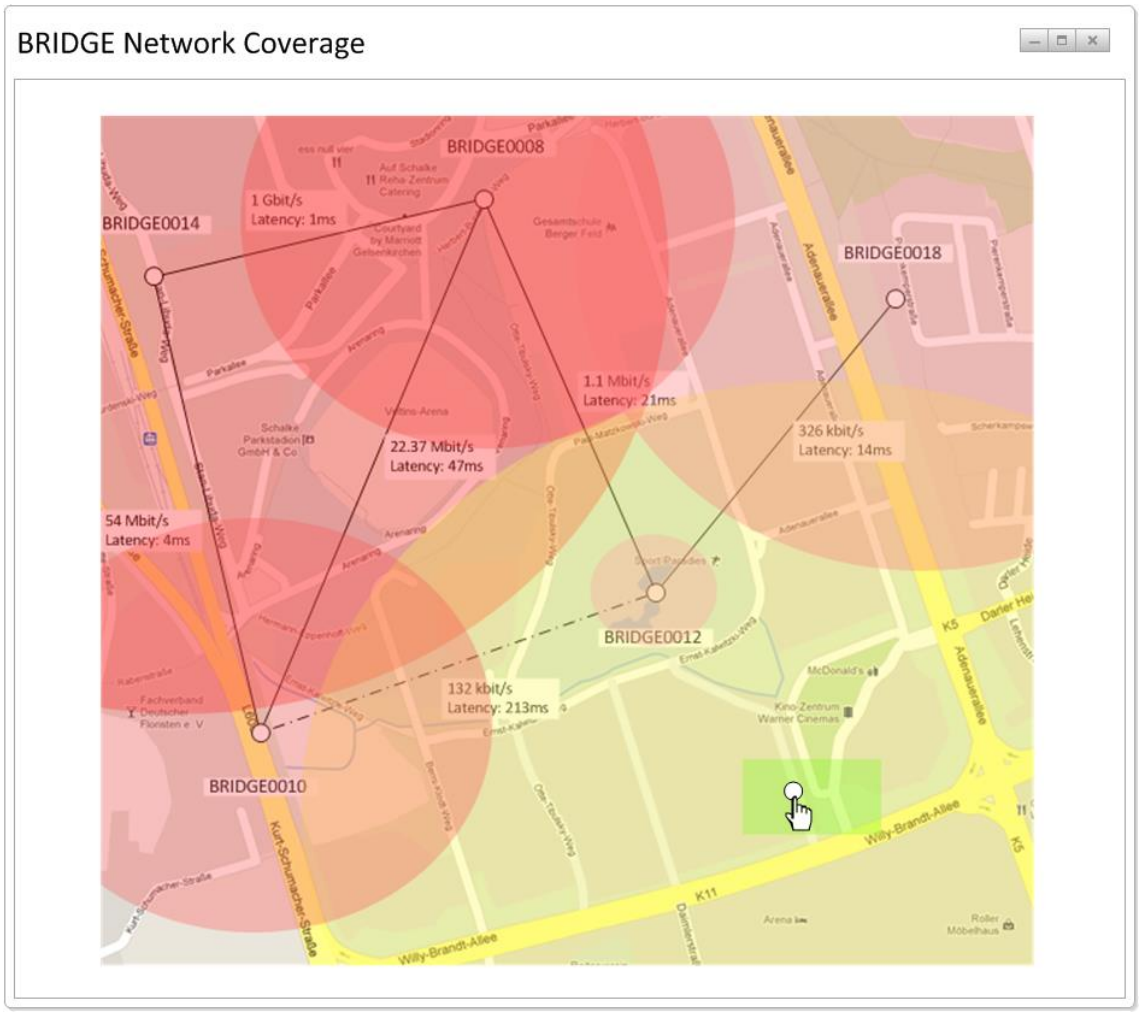


Figure 11. Possible visualization of BRIDGE network coverage.

The visualization affords inspection of the degree of network destruction or disruption, the potential to patch networking from 'leftover resources'. In addition, visualizations like these are being designed to enable users to reason about privacy and security concerns. This aspect is developed in D4.2 Functional View on the BRIDGE System Architecture.

4.4 Interface and interaction design for AmI and automation in BRIDGE

Disasters and emergency situations pose great challenges for inter-agency collaboration. Technological innovation must focus not only on overcoming 'failures' or 'problems' in collaboration, but also on supporting and 'stretching' existing, effective ways of working together.

One of the BRIDGE project's means to reach this aim is inspired by Douglas Engelbart and based on Rogers 'New Agenda' for ubiquitous computing, aiming to 'augment human intellect ..., extending [people's] ability to learn, make decisions, reason, create, solve complex problems and generate innovative ideas' (Rogers 2006: 411). Rogers states that UbiComp should move from 'a mind-set that wants to make the environment smart and proactive to one that enables people, themselves, to be smarter and proactive in their everyday and working practices.' (Rogers 2006: 418).

In this section we have presented a constructive critique of AmI for emergency response based on longitudinal socio-technical design collaborations with emergency service responders. The discussion of interfaces and forms of interaction that support inter-agency emergency response, aiming at supporting people in balancing automation and user control has highlighted opportunities and challenges. Overall, we argue that ambient intelligence has a great deal to offer in the creation of emergency management information systems but that 'modesty' and an on-going engagement with emergency practitioners to tailor and fine-tune automated 'intelligent' support is critical (see also Anderson et al. 2003 on the need for participatory design in making autonomic computer systems accountable).

5 Agile Response/Collaborative Agile Workflows

This section explores interface and interaction design issues in relation to the vision of IT supported 'agile response' and particularly the potential and challenges for 'collaborative agile workflows' in this context.

Augmented with the right kinds of technologies, human ability to communicate, collaborate and coordinate emergency response can be improved. Augmented capabilities can enable new forms of 'agile response' (Harrald, 2006, Harrald, 2009). Our notion of agile response contrasts with the 'revolution in military affairs' through new 'agile' surveillance, communication and targeting technologies (Cockburn, 2012). It is not based on 'surveillance' but on concepts of broader, deeper, and more information enriched closed loop communications between multiple interdependent actors. This is more resonant with agile software design methods than military metaphors, and key features include adaptive planning, rapid and flexible coordination, sensitive to context. Agility as we use it here describes enhanced abilities to combine knowledge, skills, resources from diverse human and non-human actors (colleagues, the public, sensors, software agents) on the fly. It suggests that distributed, but closely coupled, diagnostic and remedial work can be supported, that support for 'emergent interoperability' is needed amongst changing 'adhocracies' of actors (Mendonça et al. 2007), and support for improvisation within clearly structured response management, combining agility and discipline (Harrald, 2006).

This ideal of agile response is hard to realise. Both military and civic attempts to leverage the potential of IT have led to spectacular, costly failures (Shapiro 2005, see also Whalen 1995) (National Audit Office 2011). In the following, we construct an overview of important challenges for collaborative workflows in rapidly changing, dynamic emergency response contexts. This is followed by an exploration of three particularly important challenges: awareness, trust and accountability. With a view to interaction design for collaboration between professional responders, we delve more concretely into the detail of collaborative practices from a socio-technical perspective. Focusing on 'collaborative agile workflows' as a candidate design response, we then open up a discussion of interface and interaction design principles and the role of collaborative agile workflows for 'agile response'.

5.1 Five interaction design principles for Agility

We begin by exploring five interaction design paradigms, using our own research and examples from literature to discuss the issues at stake in socio-technical collaborative practices, motivating the development of 'collaborative agile workflows'.

*5.1.1 Flexibility **and** intelligibility – Autonomy **and** accountability*

Far from being merely subservient to human instruction, systems have become smart, and pro-active, with software agents interpreting human inputs and constructing networks of actors and task flows. Jennings and his colleagues introduce the term Human-Agent-Collectives (HACs) to capture how human and technological reasoning and action can be brought together, developing enhanced human-machine interdependence (Jennings and Rodden, 2010).

With a view to disaster response, Jennings et al. envisage sensors, unmanned vehicles, CCTV, crowdsourced intelligence and software agents to come together with 'flexible autonomy', able to '*visualise the provenance of large numbers of decisions and vast amounts of data, … cope with incomplete and delayed data, coming from multiple, correlated, unverifiable and unreliable sources'* (ibid). It is, as yet, unclear how flexible autonomy and 'relevant' visualizations of data can be achieved technically and – perhaps even more importantly – in ways that enable learning, creative appropriation, trust and management of breakdowns. These are hard to support because competence, creativity and trust require 'accountability' and mutual intelligibility – between people and between people and technologies, and flexibility and

autonomy in system interaction paradigms make accountability and intelligibility difficult. There is a need for reconciling contradictory design aims of flexibility and intelligibility and autonomy and accountability through interface and interaction design. We will elaborate this high level design principle with concrete ideas in section 5.1.5 on *Transparency* below.

5.1.2 Decision making in crises: Rich, context aware communication

During crisis situations, high uncertainty affects the space for diagnosis, deliberation and action. The more complex and ill-understood a crisis situation is, the more time responders need to collect and process intelligence to gain 'situation awareness', that is, a dynamic understanding of the situation based on both detailed information and overview, including anticipation of likely future developments. At the same time, the more complex and ill-understood a problem is, the more likely it is to escalate along unforeseen dimensions, and the less time there is to synthesize information. Furthermore, crises can develop in multiple locations and require coordination among various agencies. These conditions pose challenges to practices of sense-making, developing and sharing situation awareness, and acting in a coordinated manner, which have crucial bearing on interface and interaction design.

As we have noted above, it is not the case that solutions need to 'simply' gather, process and visualize more information in order to support a shared understanding of a context. Indeed, echoing Hollnagel and Woods (2005), Michael Gladwell discusses how more information can be 'more than useless', because deliberation may paralyze practitioners (Gladwell 2006). It is critical to enable people to modulate the amount of information and communication they engage with, to employ different perspectives, to exercise intuition and rapid decision-making as well as to analyse and deliberate as, when and how it is appropriate. "Cognitive tunnelling" should be avoided at all costs and safety measures could be taken into account in the design process. Decisions in crises are likely to be developed in response to partial information from the field, and they will be incremental (in need of adaptation, extension), and informed and constrained by past decisions. Decision-making under these conditions depends on rich, context aware communication supported by a structured approach for command and reporting.

5.1.3 Expert Systems: Systems for Experts

Echoing our discussion around ambient intelligence and the need to recognise asymmetries between human practices of perception and reasoning and computational processes, research shows that decision support and expert systems must be designed as systems for experts to be functional. That is, they must seek to augment rather than 'replace' human judgement and control. This can be done highly effectively, but to do so:

> *System design must recognize the real limitations of machine expertise, and must build an interface that allows the human practitioner to fully review, assess, and, most important, understand the machine's actions and recommendations, which means being able to comprehend why the machine made those recommendations or took those actions.*
>
> *(Whalen 1995:23)*

Yet, of equal importance is the understanding of users' static and dynamic cognitive limitations/capabilities. In some areas, such as medical imaging and radiology such an approach has been successful. For example, Slack et al (2009) describe how Computer Aided Cancer Detection systems were seen as useful tools by radiologists trying to identify the risk of breast cancer for large numbers of patients: 'The main strengths of the CADe machine in supporting diagnostic work seemed to lie in picking up subtle signs – signs that some readers felt they might easily have missed – and thereby stimulating interaction between reader and the technology by prompting them to re-examine' the mammogram'. Translating transparency of computational processes into the design of expert systems and the way they can be assembled into systems of systems for large scale multi-agency response requires innovation in interface

and interaction design to focus on making it possible for people to inspect the technologies' working processes.

5.1.4 Plans and Emergent interoperability

Collaboration in emergency response is, only seemingly paradoxically, simultaneously emergent and driven by strict formal structures. Disasters strike and unfold in ways that are impossible to predict, necessitating improvisation. Emergency and resilience plans, unified command structures and coordinating procedures such as the Incident Command System (ICS), as well as frequent training prepare the diverse agencies involved for such intense situations. But rules, structures and rehearsals are not the antithesis of improvisation; on the contrary, they can provide strong scaffolding for creativity. In terms of intra-organizational interoperability, for example, a subsidiarity principle creates hierarchical structures that place commanders 'in command but not in control' (Gladwell 2006), empowering response workers on the ground to mobilise resources, and act flexibly on their individually situated local knowledge. In terms of inter-organisational interoperability, ICS-based interfaces and interaction protocols can create trading zones of shared understanding within a discourse where multiple ontologies prevail.

System design paradigms of minimal interaction, based on self-repair and flexible autonomy can create coherence amongst heterogeneous assemblies of technologies, and between diverse cooperating organizational systems, while run-time adaptation and extension can support flexible assembly of systems of systems that are adapted to the circumstances at hand. These are building blocks of interaction design solutions for supporting 'emergent interoperability', that is, '*a disciplined approach to achieving flexibility and improvisation*' (Mendonça et al. 2007). However, people must be able to notice, make sense of, and trust (changing) functionalities of individual components and assemblies of technologies. To develop these ideas, it is important to appreciate how the 'smartness', 'context awareness' and 'agency' of machines are categorically different from their human counterparts.

5.1.5 Transparency

Consequential asymmetries of 'understanding' can arise in human-machine interaction (Suchman 2007). For example, impoverished interpretations of human intent or need can cause technologies to fail their purpose, while human failure to understand computational processes can lead into failure to notice and use potentially powerful support. Human-technology interdependence can become problematic here, but it is also an area where innovative approaches might leverage significant advances.

Interaction between people is characterized by accountability and awareness of others' actions and intentions. People are able to verbally 'account for' their actions, retrospectively, and in situ. However, such explicit accounting is usually only required in exceptional circumstances, for example, when one does something that could be construed as inappropriate. This is the case, because the embodied and contextual nature of human action documents motivations, intentions, and likely next moves. Even if collaboration is non-verbal, uniforms, embodied conduct and movement, and facial expressions richly 'account' for (trajectories of) action.

Similarly, the visibility of cause and effect relationships in analogue technologies (hammers and nails, for example) also 'accounts' or provides intelligible histories of action like the non-verbal accounts of human actors. Using the hammer and nail example, there is visible action (the hammer swings up and down, makes audible contact with the nail and the nail moves) and there is a visible outcome (a nail embedded in a piece of wood provides a history of the action). Computing technologies, in contrast, can seem immaterial, 'magic', and can neither easily sense a need for an account nor provide appropriate accounts. Invisibility of cause and effect, complexity or multi-causality can obscure the explanation of computational processes from the human actors. This is beneficial when things work and the purpose is clear. It underpins

adaptivity, self-repair, and flexible autonomy. However, when things break down or people need to be creative with their technologies, invisibility excludes and hinders. Computational processes can often only be 'held to account' by skilled engineers. This is problematic, because accountability is needed to enable people to notice, use and trust system functionality, to fix breakdowns and to be creative.

But accountability can be designed for. We say 'designed for', because accountability is an effect of interaction in context, not a property that could be designed 'into' systems. This makes design difficult, but it is precisely the kind design that seems needed. Anderson et al. (2003) compare for example, how human accounts are 'recipient designed', that is, tailored to the situation and recipients' situated and idiosyncratic capabilities of attention and understanding. In contrast, all designed for accounts of technological agency must be pre-prepared, and '*are limited in their capacity to answer … the user's canonical interaction question 'why that now?"* However, by working with users in collaborative and ethnographically informed design processes, such as that practiced in the BRIDGE project, 'satisficing' accounts may be embedded into technologies, that is, pre-prepared accounts that are 'as good as they can be', given the difficulty. Developing a careful understanding of potential users and the situations and concerns they may bring when inspecting technological capabilities should enhance the intelligibility of technologies. This should augment users' ability to creatively and confidently 'collaborate' with technologies, working towards making technologies 'part of the team' (Carver and Turoff, 2007).

5.2 Collaborative Agile Workflows

To support collaborative work in emergency response HACs, an on-going understanding of actions of both humans and automated agents is required. Modelling workflows has been shown to be useful in situations which are 'predictable and production like' (Brahe and Schmidt, 2007). Here, human and non-human agency can effectively be 'black-boxed', that is, inputs and outputs can be defined and the exact processes of their situated production are, for all practical purposes, irrelevant for the success of the human-agent collaboration. However, how do workflows translate into unpredictable crisis situations? The use of workflows in this area exacerbates the tensions highlighted in the previous section; there is a requirement to ensure that the changing context of the sociotechnical world informs flexible assembly and adaptation of technologies in order to facilitate collaboration; and, at the same time, there is a need for intelligible technological causalities, publicly documented. This puts a strain on workflows as previously reported in other situations (Brahe and Schmidt, 2007). Within crisis response, where the field and information domain are rapidly and unpredictably changing, blackboxing workflows could hinder response efforts. A system that fails to document its function or that fails to 'keep up' with the dynamics of the situation could increase the risk within that environment compared to not having a system present at all.

We now explore workflows, annotations, agreements and self-management as candidate interaction design responses for workflow support; to document and 'keep up' with the dynamic circumstances of emergency response.

5.2.1 Workflows

A workflow describes a process as a composition of steps (van der Aalst and van Hee, 2004). Each step prescribes an activity. An activity can be performed by both human and agent actors (and by groups, e.g. a crew of fire fighters or a set of sensors). The steps are chained, which means that every step operates on the output of the previous step(s). A workflow can be used to formalize actions in collaborative work. Workflows are useful tools for: 1) analysing performance and bottlenecks in (production) processes, 2) identifying desired functionality at design time, 3) specifying interfaces between activities i.e. the formal interaction through inputs

and outputs, 4) representing planning and intent in the communication between (human) actors and 5) monitoring performance and adjusting for disturbances and failure in collaborative processes at run-time.

Hence, a workflow is a means of communication at design time, as well as at run-time. To interpret a workflow, the producers and consumers need to share a common understanding of the terms used to describe the activities and the artefacts. The semantics of activities and artefacts as well as the relations between each activity and its associated input- and output artefacts can be stored in a system's knowledge base, e.g., formalised in an ontology.

Workflows can support static interaction between parties (van Veelen et al., 2008). Static in this context assumes definitions of activities are accurately abstracted from dynamic environments and actors. Two limitations of workflows need to be understood. First, when large numbers of activities are involved, workflows become large and complex. Using the concept of compositional activities, which hide sub-workflows, offers relief by providing a clearer overview of a complex workflow, at the price of hiding potentially vital details. Second, a workflow describing just activities and information does not represent the qualitative aspects of the activities and information. Activities describe the job that needs to get done, qualitative aspects of activities describe how well the job needs to be done. This limitation can be addressed with annotations (Figure 12).

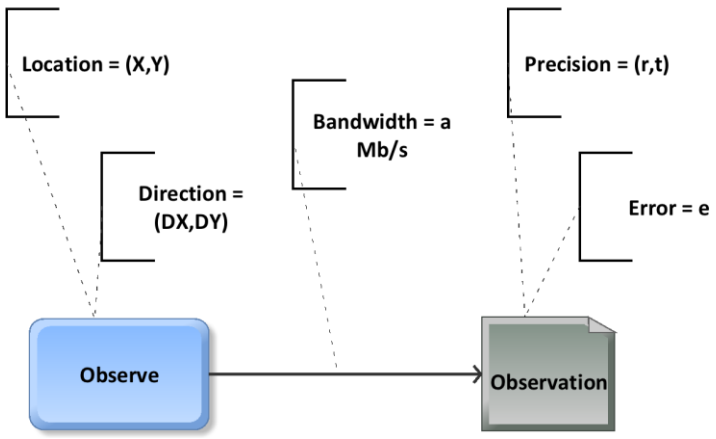


Figure 12. A simple annotated workflow.

5.2.2 Annotated Workflows

We annotate workflows to include additional information and interdependencies. The main components of a workflow, the activities, the artefacts and the arrows, possess (required) properties not easily included in the graphical depiction of the workflow. These (required) properties pertain to the (non-) functional aspects of execution, execution results and communication of results, described as annotations. Fig. 1 depicts annotations as 'boxes attached to components'. In general, annotations take the form of a name-value pair, where the name identifies the property uniquely (i.e. there is only one definition of, for example 'oxygen level') and implicitly defines a range of allowable values (e.g. 'above/below threshold'). Values may have complex structures.

We require agent systems to adapt dynamically, making it more difficult to keep track of what the agents are doing. To resolve this issue, we use agreements. Agreements explicate expected interactions of involved parties and define the sanctions if the agreed interactions are not met. Within the boundaries of the constraints, each agent is free to adapt its planning or service-level.

In automated systems, service level agreements (SLAs) are commonly used to specify such contracts. SLAs help human machine collaboration, as agreements bring more flexibility between autonomous entities. Agreements can be included and inspected as annotations to activities. A single workflow may contain multiple SLAs, each SLA covering one or more activities.

5.2.3 Self-management and workflows

To create and use collaborative agile workflows effectively requires self-management capabilities. Agile collaborative workflows depend on dynamic composition, negotiation, monitoring and adaptation. Collaborative composition creates workflows in response to current functionality requirements. Negotiation determines the boundaries of autonomy and the quality of service of activities. Monitoring tracks the progress and quality of workflow execution and identifies the need for adaptation. Adaptation is needed when changes occur in the environment or in resource availability. Adaptations either respect the boundaries defined in the agreements, or require renegotiation of agreements. In BRIDGE a self-management architecture is used allowing local self-management of distributed agile workflows (van Veelen et al., 2008).

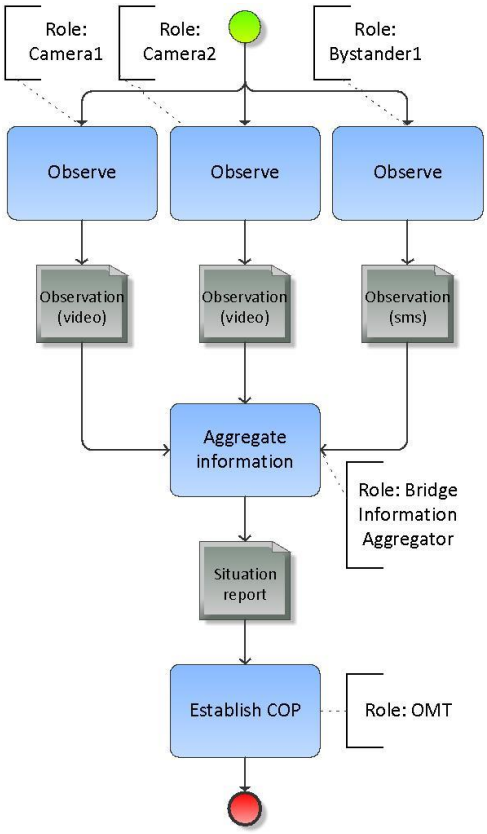


Figure 13. A simple agile collaborative workflow.

Figure 13 depicts an example of an agile collaborative workflow for data collection, where observations are made by two surveillance cameras and one bystander. The observations from the cameras and the bystander are transferred to an Information Aggregator. The Information Aggregator aggregates the information, producing a situation report, which is presented to the Operational Management Team (OMT). Agreements in this workflow, for example, can specify the frequency at which the situation report is generated. Agreements between cameras and Information Aggregator can specify the quality of the video (maybe requiring lower-level agreements to ensure availability of bandwidth).

5.3 Designing for Agility with Workflows

In the section 'Transparency' we raised the idea that accountability can be designed for. The autonomous technological components need to be able to explain and justify decisions and selections they made on a level that is comprehensible to their human collaborators. Basically, we need to provide the autonomous system parts with the capability to answer the user's canonical question 'why that now?'

The design of workflows that span bridges between human and artificial actors, improving collaboration in emergency response, needs to address the aspects of trust, autonomy, reliability and human-system interaction. In this section we discuss how the annotated workflows and workflow management systems we are developing address these aspects.

5.3.1 Trust

Annotated workflows can support trust by communicating the organisation of work and the relation between tasks, thus supporting mutual understanding and enhancing social appropriation. Workflows provide an overview of actions and interactions in an automated system, enhancing transparency. During the workflow generation process it is rather easy to include annotations that explain why a task is required or why a particular resource is allocated to a task. Using annotations to document how a workflow gets created helps answering questions like 'Why that now?' and 'Why is a task allocated to this entity?'. However, increasing trust by explanation is just an initial step toward usefulness, as it only fulfils one of the very basic requirements; and further development on trust aspects is needed (e.g. Nevejan and Brazier 2011). Different means for representation of and reasoning about trust within workflows exist (Viriyasitavat and Martin 2012).

Using mechanisms to capture accreditation and feedback and including the captured values as personal preferences with the resource descriptions that are used during the workflow generation process, allows us to direct the workflow generation process by forcing it to select the most preferred candidates available during task allocation. Including the considerations during a selection as annotations will help to justify the selection to end-users, by showing that the allocated resources are indeed 'the right men for the job', given the user's preferences.

5.3.2 Autonomy

Autonomy is supported in annotated workflows by stating the boundaries of operational freedom in agreements. To keep workflows adaptable but at the same time transparent and understandable, we use compositionality in workflows. Combined with agreements, a system is allowed to autonomously implement or plan how to achieve the requested functionality. To merit this autonomy, a system requires self-management capabilities (Kephart and Chess 2003): the system needs to be able to manage its own (inter-) actions, requiring dynamic composition, negotiation, monitoring and adaptation capabilities. To maintain autonomy, transparency and understandability, adaptations should remain local, and affect the enveloping high-level workflows only in case of failure.

An autonomous system needs to be able to adapt by itself, when opportunities arise, or when there is an explicit need for adaptation. Handling such adaptations should not require human attention. However, how can such autonomy be supported while keeping the behaviour of the overall system transparent and understandable? Here annotated workflows can help by including the criteria that will trigger an adjustment or modification of the workflow. Users can be allowed to inspect or alter these modification criteria, increasing the transparency of the behaviour of the autonomous system's components.

5.3.3 Reliability

The reliability of a collaboration agreement depends on the awareness of mutual expectation, realistic tasking and ability to cope with failure. Workflows increase awareness by making the responsibility of each participant explicit; participants can prohibit being assigned tasks that exceed their capabilities or violate their operational constraints. This prevents the activation of workflows that cannot be completed due to lacking capabilities or restrictive operational constraints. However, an activity can fail, meaning it is not completed or not completed successfully. Workflow monitoring agents detect the failure, since agreements are not fulfilled (in time). The agents assess the consequences of the failure and decide on the need for reparative actions or adaptation of relevant branches of the workflow.

Like annotations describing the modification criteria, annotations in annotated workflows can include criteria to replace a (part of) an active workflow due to failure. We will call these criteria 'failure criteria'. The failure criteria can be linked to the SLA specifying the penalties. Failure criteria could also be linked to repair/adaptation actions i.e. activation of a failure criteria acts as a trigger to default repair actions, provided these repair actions are at all possible.

5.3.4 Human-System interaction

Regarding human-system interaction, the use of workflows to plan, modify and communicate a coordinated collaboration process must fit its purpose, that is, support the user in a task and not hamper him/her. The use of agile workflows must render an organization more flexible, not more rigid. This means that presenting a workflow to actors must increase their understanding of the responsibilities they are assigned and what is to be expected from their peers (here, peers are executors of flow dependent activities in a workflow). When the context forces an actor to improvise, it must be easy to modify the workflow to reflect this.

By displaying explanation and justification meta-data (annotations) on demand, annotated workflows can provide insight in why the workflow is composed as it is, increasing the trust of the end-users that the current proposition described by the workflow is indeed an adequate deployment of the available resources.

Providing mechanisms that allow the inspection and modification of the criteria that force the adjustment or replacement of an active workflow increases the transparency of the system's behaviour, and place the human in control over the triggers that cause potentially expensive or undesired system behaviours. To justify a workflow modification or replacement, a dynamic view comparing requirement values stated in annotations and the current observed values, allowing for better human interpretation.

5.4 Annotated Workflows for Accountable Computing

In the previous section we argued how the design principles of supporting trust, autonomy, reliability and human-system interaction for annotated workflows enable agile response systems. In this section we demonstrate how annotations in workflows can help support the trust of end-users in the current flow of activities as described in an active workflow. We will address the issues of supporting trust by explanation and justification and incorporating trust information obtained by accreditation and feedback mechanisms. We also address the issue of reliability by including the failure criteria in an annotated workflow.

5.4.1 Supporting Trust in Annotated Workflows

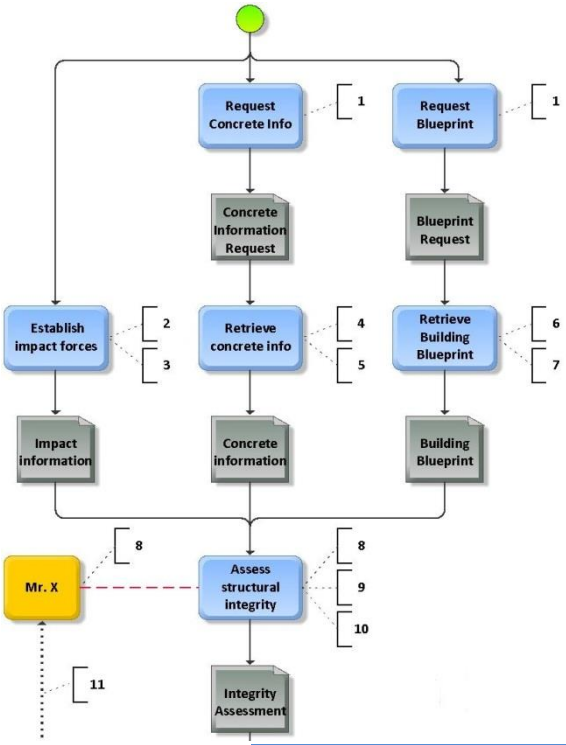
In order to provide trust support for end-users regarding the workflows that are generated by automated workflow generation mechanisms, we let the workflow generation mechanisms include annotations in the workflow that record how the workflow was generated. During generation, the generating process performs two tasks that are fit for explanation.

The first task is the selection of a resource (human or artificial) to execute an activity in a workflow. We call this 'task allocation'. Task allocation can be directed to select the most preferred resource to execute the task, instead of, for example the (financially) cheapest resource or (geographically) closest resource.

Earlier studies have shown how accreditation and feedback can be collected to establish a trust value for collaboration (e.g. Nevejan and Brazier 2011, and Viriyasitavat and Martin 2012). In this case we need previously collected feedback on past performances of a resource. It is important that this feedback is personalized, that is, it must be attributed to the person that gives the feedback, and it needs to be diversified to each task the resource has performed in the past. On the other hand, we need also aggregate trust values for each skill of a resource, in case the resource has not provided service to potential clients in the collaborative organisation.

A simple example would be an incident commander who wants to have an assessment of the structural integrity of a blast-impacted building before he sends personnel inside. In case the workflow generation mechanism finds several candidates that can provide this assessment, the resource that has been awarded the highest feedback on previous occasions will be selected.

The second action is to discover the requirements that need to be met before a specific task in the workflow can be executed. As an extension to the previous example, in order to assess the structural integrity of a building, an expert needs to have information regarding the building, like its blueprints and details on the concrete used in its construction, and secondly the expert needs information on the impacts that the building structure may have been exposed to. The workflow itself intuitively explains what inputs are required for a task and who provides these inputs. But the annotations on the assessment task can explain why the inputs are required, for example stating that that '`building blueprints provide structural outlay of building`', '`concrete used provides insight in strength of structural elements`' and '`blast impact data provides damage insight`'. The tasks that provide these requirements can be annotated with the reason why a task is allocated to a specific role, for example, '`municipality collects and stores building blueprints`'. These annotations can be used to explain how the tasks depend on each other.



1 `Role: Information officer`

2 `Role: Explosives expert`

3 `Explanation: explosive expert is qualified to calculate impact information`

4 `Role: Building company`

5 `Explanation: Building company records Concrete used in construction`

6 `Role: Clerk Municipality`

7 `Explanation: Municipality collects and stores building blueprints`

8 `Role: Integrity expert`

9 `Explanation:`
`-Building blueprints provide structural outlay of building`
`-Concrete used provides insight in strength of structural elements`
`- Blast impact data provides`

```
                damage insight

10  Provides: Integrity
    Assessment
11  Source: Mrs. Y
    Target: Mr. X
    Skill: Integrity Assessment
    Trust-value: 7
12  Role: Incident Commander
13  Requires: Integrity
    Assessment
    With: Trust-value >= 5
```

Figure 14. Integrity Assessment.

In Figure 14 we give a graphical representation of the annotated workflow for the assessment example. For the purpose of readability the annotations are listed next to the workflow. Please note that the particular graphical representation we use in this paper is intended to illustrate the examples; it is not the representation we propose for human-system interaction purposes.

The annotated workflow provides annotations for the requirements of the activities 'Decide on deployment' (annotation 13) and 'Assess structural integrity' (annotation 9). The activities that produce artefacts satisfying these requirements are annotated with the artefact they produce.

In the workflow we have included some of the resources that are allocated to the activities in the workflow. Mr. X is assigned the assessment activity in the role of integrity expert, whereas Mrs. Y is assigned the role of incident commander. Furthermore, we have indicated using a dotted arrow with an annotation, that Mrs. Y trusts Mr. X's integrity assessment competence with a trust-value 7. Annotation 13 denotes that the activity 'Decide on deployment' requires an assessment from a source with trust-value of at least 5, which is satisfied by Mr. X.

5.4.2 Reliability in Annotated Workflows

Like the explanation and justification annotations in the previous subsection, modification and failure criteria can be included in annotations in the workflow. The modification criteria describe the event or combination of events that will trigger a modification operation of the workflow. Once the modification criteria are met, the circumstances allow improvement of the current workflow.

The failure criteria, on the other hand, describe (combinations of) events that force the workflow management mechanisms to assume the current workflow will not complete or not complete successfully. In this case the workflow management mechanisms will try to find alternative solutions.

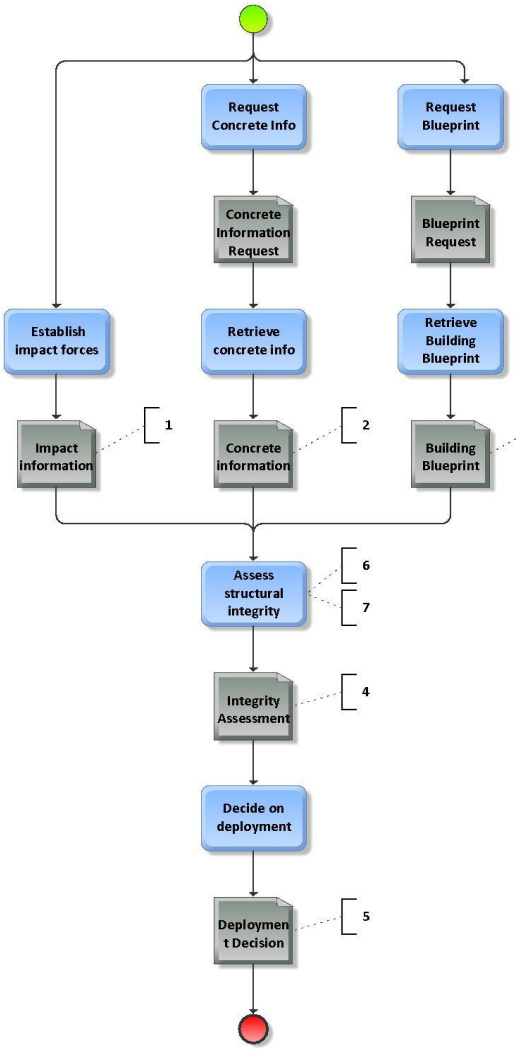
Modification of a workflow that is being executed can be an expensive operation, since it may imply current activities are ceased (total loss of effort) and new activities are initiated which may incur an additional configuration cost. Therefore, end-users may want to maintain control over when and how modifications are committed, or keep the decision of modification to themselves.

Both modification and failure criteria may include constraints and requirements on timing, performance qualities or the availability of specific resources. During the generation of the workflow the failure criteria are documented in the Service Level Agreements. The SLA's can be included in the form of annotations to activities or artefacts in the workflow. The modification criteria can likewise be included as annotations to the activities and artefacts. The

aim of including the modification and failure criteria as annotations in the workflow is to be able to explain the behaviour of the autonomous system to the end-users. The annotations can be inspected by the users and modified if they wish to do so. For example, and end-user can relax or tighten the constraints, or tell the system to leave the decision to modify to a human operator.

Returning to our example in the previous sub-section, it might prove difficult or time-consuming to provide the required inputs for the assessment. So, as an extension to the example, suppose the structure expert can also make a crude assessment of a buildings' structural integrity by examining photographic evidence of the impact. In that case, the architect that designed the building or the contractor that built it may provide a better informed assessment. (Please note that it would be possible to generate a workflow that includes a parallel execution of all three options, providing the incident commander with multiple assessments of different quality. But for the purpose of this example we assume there are reasons not to do so.)

During the generation of the assessment workflow, we can identify a modification criterion in case the architect or the building contractor becomes available as an assessment expert, and a failure criterion in case the collection of the information required by the assessment takes too long to acquire.



1 Due: 11:55
Failure:
If: not ready at due-time
Perform: inform incident commander

2 Due: 11:55
Failure:
If: not ready at due-time
Perform: inform incident commander

3 Due: 11:55
Failure:
If: not ready at due-time
Perform: inform incident commander

4 Due: 12:00
Failure:
If: not ready at due-time
Perform: inform incident commander

5 Due: 12:05
Failure:
If: not ready at due-time
Perform: inform second-in-command

6 Modify:
If: building architect becomes available
Perform: inside expert integrity assessment

7 Modify:
If: building contractor becomes available
Perform: inside expert integrity assessment

Figure 15. Integrity Assessment with failure criteria.

In Figure 15 we present the integrity assessment workflow with the modification and failure criteria included as annotations, with their contents listed next to the figure.

On inspection of the workflow, the incident commander may decide to fine-tune the failure requirement by allowing less time for the collection of the required information, and to change the modification requirement in the sense that the commander is informed when either the architect or the contractor become available.

5.5 BRIDGE Workflows: Interface and Interaction Design

We have discussed how workflows allow functionality to be designed for during technological development and how workflows, may be used to publicly document and account for processes and functionalities and to communicate with human actors in emergency response. This could become strong 'scaffolding' for effective collaboration and improvisation. Workflows have an established productive role in supporting static interaction between parties. However, workflows in adaptive and evolving human-agent collectives can become very complex and large, when all implicated actions need to be presented. Such size and complexity leads to a lack of transparency and hence a breakdown in the collaborative system. A further challenge in using workflows for collaborative systems is the difficulty in visually representing the qualitative aspects of inputs and outputs. Allowing compositionality (hiding subtasks) and adding annotations can help solve these difficulties.

Annotations increase the expressivity of workflows, allowing representation of qualitative aspects of a workflow. However, these representations will always be directed by assumptions about likely contexts embedded in the socio-technical system, such as the fields available for input in the technical artefact or the ability of the actor. However, as argued in this paper, it is not possible to achieve collaboration through simplistic information aggregation. To successfully design for collaborative work in emergency response, a more complex arrangement of knowledge sharing and shared understanding in a human-agent collective is needed.

At the root of the 'agile' design requirement is the need to support mutual intelligibility in human-agent collectives – where actors are able to shape, manage and adapt the varying levels and kinds of contextual information. The technology and the human, as well as the various extended entanglements or collectives they may form will have hidden complexities and processes which are categorically different. This causes asymmetries and difficulties in mutual understanding in human agent collaboration. What becomes 'useful' annotation, agreement, or workflow management is dependent on the actors involved being able to make sense to each other.

This does not necessarily demand that asymmetries are overcome (indeed, we would argue that this is impossible), or a genuine 'collective' and 'coming together' of human and machine has to be made possible. It may be quite productive to enable both kinds of actors to put the machine 'in-formation' with human actors and intentions. Collaborative agile workflows combine annotations, agreements and workflow management to generate computational services. These begin to enable such contributions to be put in formation with the contextual environment by allowing them to be shaped by actors. This process enables dynamic negotiation and creation of 'fit' within human-agent-collectives.

6 Case Study: eTriage

In the following case study, we will show the role of the three key topics that we have identified as central to interface and interaction design for sustainable socio-technical innovation in multi-agency emergency response. In doing so, we will focus on empirical observations in the context of triage processes, and show how they relate to the design implications. As part of BRIDGE systems of systems innovation and middleware development, e-triage requires synthesis of support for situation awareness, ambient intelligence, and agility, and we have developed and employed some of the core concepts here. The chapter illustrates how attention to these dimensions and concepts can enhance large scale multi-agency response.

6.1 Background: Triage Systems and Processes

Most of the electronic triage projects described in the literature aim at replacing paper tags with some form of electronic augmented nodes. The most basic form is the use of barcodes or other mechanisms to make tags readable with an electronic device. Research by Inoue et al. (2006), Gao and White (2006) and Lenert et al. (2005) focus on the construction of hardware to support tagging of patients. In Inoue et al. (2006) a rewritable RFID tag is attached to the paper tag. Data is read and updated through a set of mobile terminals. The e-triage project uses barcodes for classical outdoor triage as well (Chaves et al. 2011). The barcodes are added to normal paper tags and can be scanned by an introduced tablet PC. The use of simple identifiers places a strong focus in the logistic processes of tracking patients. In Bouman (2000), the authors describe a system that enhances the inner hospital triage process by attaching wristbands with barcodes to patients. The wristband is scanned every time data for the patient is requested or updated and information concerning the patients is managed using networked computers using a central database. The barcodes work as highly reliable methods for patient identification, providing better organized access to information that can help in dealing with overload created by mass casualty incidents.

A further proposed enhancement in electronic triage system is the addition of sensors to the nodes, used for tracking position, physiological data and other forms of information. The AID-N project uses wireless motes which indicate the triage category through four colored LEDs (Gao and White 2006). The motes are equipped with a GPS chip for outdoor tracking and MoteTrack, an indoor tracking system. Different vital sign sensors can be connected. All data is continuously broadcasted to a base station laptop and a PDA. The system in Lenert et al. (2005) uses wireless nodes to which additional sensors can be connected. Again a set of LEDs is used to indicate the triage category and also to signal medical alerts and patient management information.

The introduction of complex capabilities to triage systems creates a new set of interaction challenges and problems. Holzman (1999) reports several iterations of an electronic triage system. In the first iteration of the project, it was assumed that a hands-free and eye-free user interface would be necessary because ‘medics’ eyes and hands may be too occupied with patient assessment and treatment to allow them to carry a computer, look at its screen, and use a pen for making inputs.’ The developers of the system consequently used speech input and a head-mounted display. This design decision created problems with the acceptance of the system. A test user reported that ‘patients might be frightened by the appearance of a medic wearing a headband with a heads-up display over one of his eyes’. A user study of the AID-N project raised concern about the use of a necklace sensor ‘due to the fragility of the neck with spinal cord injuries’ (Massey et al. 2006).

A further HCI concern in electronic triage systems is the interaction with the collected triaged data. A system developed by Inampudi (2011) displays location and category of patients on a website. It uses triage data as input for an emergency resource allocation system, a patient

dispatch system and a resource planning tool. A prototype developed in the frame of the PalCom project (Büscher and Mogensen 2007) proposed a virtual 3D environment in which triage data is visualized. Responders at the emergency site could capture georeferenced images of the scene by operating a camera embedded in their helmets. These pictures were then automatically inserted and positioned in a virtual representation of the incident site. This helped remote teams to get a better picture of the emergency site.

In general, if we leave the implementation particularities of each system, we observe that most of the existing IT supported triage systems described in the literature are similar, and centre around a very concrete set of functionalities:

- Redesign of the interactive technology currently in use
- Deployment of wireless sensor network and other supporting infrastructure
- Monitoring and alerting on changes in condition
- Automatic reclassification of victims
- Logistic of tracking casualties

As discussed in reports of triage systems, these set of capabilities are important and seem to be a sensible selection. Consequently, in developing a probe to explore triage processes during large scale emergencies, an essential part for our work centred on revisiting these features. They are often taken for granted, and we were interested in (i) understanding what potential implications of introducing these features are and (ii) discovering issues and opportunities missed by the existing approaches before defining our own platform.

6.2 Observations during user workshops

6.2.1 Situation Awareness

The electronic augmentation of the triage processes is often seen as a premise for supporting a richer common operational picture. Harrald (2007), however, argue that a ‘common operational picture’ does not necessarily lead to ‘situation awareness’. The assumption that ‘data is the only barrier to appropriate [understanding and] action’ is deeply flawed. Our fieldwork with the eTriage prototype revealed that a common operational picture was not reliant on data intensive practices. As we have discussed in Chapter 5, providing excess information could ‘blur the lines of command’ and lead to problems of micro-management as well as to cognitive biases, for example of preferring one category of information over another without logical reasoning. The electronic transmission of patient statuses to others beyond the immediate vicinity of the patient, in a command centre for example, could create difficulties as well as shared situational awareness of distributed actors (which has its own implication with regard to the questions who should be aware of whose actions). Participants in our workshop told us that, traditionally, those who are not at the scene cannot interfere with the triage process, due to their detached location and their own duties that they need to attend to. A workshop participant explained that, with more data available, people are starting to make decisions out of the scope of their responsibilities, resulting in blurred lines of command:

> *If you provide more information to gold command, etc., [the] border might blur. For instance, gold can order cars somewhere else but the car was placed there by a bronze for a certain reason. So, it is good to have responsibilities distributed as they are. (Paramedic, Plenary Discussion, Co-Design Workshop Lancaster, April 2012, UK)*

Electronically augmented triage systems which aim at improving situation awareness by producing more and more data for emergency responders, also have the potential to mask what is of true importance. As such, there is a delicate balance to be made between information overload and information simplification.

The intention is that more data leads to additional knowledge about the events occurring at the emergency site, and that better knowledge might give a stronger, less uncertain, foundation to decisions. But new knowledge can also add new problems to the decision making processes. We refer to the common process that triagers shall not treat people who do not have life-threatening injuries. But those triagers are working under traumatic and stressful situations. As such, the knowledge about the critical status of a person makes it difficult for triage personnel to follow the intended process of continuing triage and not interrupting the process to deliver treatment. Collecting patient data, such as vital statistics, blood pressure, oxygen saturation level, has the potential to give the person conducting triage a greater knowledge and understanding of the severity of a person's injuries. This has the potential to further complicate the process of walking away from a casualty once they have been triaged.

The introduction of electronic sensors and the wireless distribution of live data allow any single responder to learn data that they would not have had without technology. Currently responders receive knowledge about the incident by their own embodied involvement in the event, through perception or communication with colleagues. BRIDGE has shown that making data which is currently only available to particular individuals or roles at the emergency site available to others can lead to unwanted consequences. An example for this is the following statement by a police officer in a co-design session:

> *The police wants information about patients in order to tell the medics: This is a drug dealer (Police officer, Co-Design Workshop, September 2011, Norway).*

Knowing about a criminal background may be useful information for medics for self-protection. On the other hand, if the drug dealer is a harmless victim in this situation, s/he would have been unnecessarily stigmatised. In traditional triage, all victims of the same category have the same priority of transport or treatment. In the new, integrated e-triage, the medic might prioritise the treatment of the drug dealer lower than s/he would have done without that knowledge. In the worst case, the medic could become afraid of the patient and refuse treatment.

But co-design discussions of technological potential also inspire interface and interaction design ideas of aggregation and abstraction, for example through clustering information on a map, to counteract temptations of micro-management:

> *In an ideal world you have such a system that aggregates data … from level to level so that you end up at the ministry -they're having the same data … no-one needs to touch the flow of information anymore. We have the biggest losses of accuracy in the transfer of data from one reporting system to the other … In an ideal world you have such a system that transfers the single volunteer's data into a reporting system and you end up with one dot for 10,000 [injured or affected] people in the ministry all without touching the information flow. That would be nice. (Heiko, Mobilizing Emergency Response Workshop, September 2012, Lancaster)*

Similar ideas are evolving alongside the realization of positive and negative unintended consequences of implementing electronic triage systems in relation to the impact of more information on carrying out triage and multi-agency collaboration.

6.2.2 Ambient Intelligence

Reconfiguring Accountability

The sensors and communication methods used in eTriage solutions supply a wealth of useful information, but they also imply a growing potential for surveillance. The fleeting nature of current practices discussed in Chapter 5 allows for precise, economic, but highly relevant and potentially consequential statements such as 'be careful with him' to warn a colleague

paramedic of the fact that he is about to approach a known violent criminal injured in a crash. This ad-hoc inter-organizational collaboration on the scene of an incident is likely to happen in face-to-face interaction or, less likely, via the radio system. The information is ephemeral and it is relatively easy to understand who is within reach of this information spatially, organizationally, and temporally.

New technologies have the potential to re-mediate this sort of information and alter its reach and persistence, potentially opening the data for retrospective scrutiny. This might make professionals less inclined to divulge what they know, for fear of breaching data protection regulations, even though the aim was only to protect a colleague. So, the benefits of seamlessly connected systems should be evaluated in the context of the ethical and privacy concerns that their monitoring capabilities introduce.

The possibility of logging can also influence the way of working of first responders. Agencies have well-defined processes for how triage should work. First responders are trained so that they know the process by rote. In practice though, processes need to be modified and adapted to the situation at hand. 'If health care workers [lose the ability to adjust these processes] to the on-going flow of contingencies that characterises medical work - then this will inevitably lead to a loss of efficiency and quality of care' (Berg 1997).

Our workshop participants confirmed this:

> *You are not supposed to change the triage process. Which does not mean that people don't. (Paramedic, Co-Design Workshop, April 2012, Lancaster).*

According to the process definition, triagers should not treat people during triaged, no matter how badly they may be injured (Bradley 2011). In practice, '*it is a different* [difficult] *thing to wait when people are screaming and have pain.* (Paramedic, Co-Design Workshop, April 2012, Lancaster). They may be unable to ignore someone in need (screaming for help) and deviate from intended processes.

With the introduction of electronic triage systems that log data such as vital values or locations of patients and responders, there is the potential to reconstruct or make retrospective assessment of decisions made by triagers and other first responders. In addition to triage, 'firefighting is also a highly situated action that requires lots of improvisation and instinctive reactions' (Denef et al. 2008). Not having to think about negative consequences of one's actions and improvisations is vital for being able to instinctively perform them in both professions. Re-assessing decisions opens the possibility of initiating legal consequences after every operation, which may be feared by some. This fear can negatively influence a responder's ability to quickly take intuitive decisions without being judged afterwards. Furthermore, the reconstruction of decisions can only be done on incomplete data, because it won't be possible to electronically capture aspects like stress or misinterpretations.

Supporting Trust

Information which responders receive can be unreliable (Holzman 1999). Bystanders may have misunderstood something, victims can have a wrong recollection of the events, technology may be faulty, or non-experts have to perform a task because no expert was available. In the face of the unreliability, rescue personnel try to confirm the information they receive. For example, we saw in the Hot Run session in Switzerland that radio messages are always affirmed by fire fighters. This 'closed loop' communication convention is an easy, fast and effective way to ensure that information is received and understood (Salas et al. 2009).

One reason why closed loop conventions are so effective is because, as highlighted above, the biggest losses of accuracy occur when information needs to be handed over between

practitioners. Our workshops revealed that triage data is often verbally handed over to other responders. Verbal handover includes the possibility of misunderstandings.

Closed loop communication can be multi-modal. In co-design workshops, responders and designers realize that movement (shown on the master map) or photos or video of the emergency site relayed to a command post have potential to function as a supplementary form of closed loop communication:

> *Remote photos or video can help us determine whether or not the person reporting the incident has a correct understanding of the situation. (Command Center Officer, Blue-Sky session, Co-Design workshop 2011, Oslo, Norway).*

This opens up novel opportunities for out how trust in triage results can be supported in relation to information from experts and non-experts.

A doctor in our 2011 Co-Design session in Norway stated that *'Triage [sometimes has to] be done by police or other non-medics'*, and went on to argue that the quality of triage data from non-medics is lower than the quality of triage data from medical personnel. The police officer and fire fighter who were present at the discussion agreed. Other working groups confirmed this as an important issue, and brought examples of bad experience with non-expert information. They were convinced that, where triage is done by police or other non-medics, an electronic triage system would improve the quality of triage data. In another session, a medic suggested to (re-)calculate the triage category automatically based on sensor values. Assuming the sensor measurements to be correct, this implies a trust in technology to calculate the correct triage category just as well as a human triager, and possibly faster.

A statement in the subsequent plenary compared the situation in emergency management to a decision which has been taken in aviation:

> *Pilots learn that they must listen to the computer instead of a human. We may have to do this step for emergency management, too. (Disaster Management Specialist, Plenary Discussion, April 2012, UK).*

Other participants showed more belief in experts and in situ examination rather than in technology based systems. On the discussion whether an electronic triage system should allow remote or automatic retriage, he stated:

> *The only one who should be allowed to do retriage is the one at the patient. (Paramedic, Plenary Discussion, April 2012, UK).*

Combining both approaches is possible, but requires support for trust in triage results, including triage carried out by non-experts, and recommendations made by technologies. What is needed is an interface that allows responders to review, assess, and, understand the technology's actions and recommendations, which means being able to comprehend why the machine made those recommendations or took those actions, providing answers to the question 'Why that now?'.

6.2.3 Agile Response

Supporting Appropriation and Assembly of Systems of Systems

Emergency processes are often very sensitive to change:

> *They are developed out of direct experience over long periods of time and feature multiple implicit attributes that have to be taken into account. Tools have to be easy enough to be fully handled and to easily recognize causes for problems' (Denef et al. 2008).*

This hampers agility in the appropriation of new technologies and assembly of systems of systems. Responders are considerably hindered by the introductions of new technology without training on how to handle it (Denef 2011). Training has to be repeated very often and over a long period, so that it will become part of a reflexive response. In order to minimize the amount of training needed, a reasonable approach is to augment already used tools and use familiar interfaces. Our participants confirmed the need for easy to understand technology and suggested to stick to well-known interfaces:

> *Use everyday technology so that the UI is clear. (Doctor, Co-Design Workshop, September 2011, Norway).*

During our design work, we found that sticking to well-known interfaces does not necessarily mean that the physical appearance of introduced technology must copy existing tools. As an example, for the Co-Design Session UK, we introduced an O2 saturation sensor which looks quite different from the sensors the medic was used to. However, he could immediately deploy the sensor and even teach us a better way to use it. He knew about the general way of functioning of O2 saturation sensors and taught us that we receive more reliable values if we put it to the nail bed and if we let the patient lay her hand on her knee.

Agility and Speed

A large amount of research in triage technologies aims to improve triage by reducing the time it takes. The argument is that if triage is speeded up, more patients can be treated faster:

> *120 people in a train with one person doing triage at 30 seconds each, that's an hour of triage. While if you had a 5 second system, that brings it down to 5 minutes. (Paramedic, Plenary Discussion, April 2012, UK).*

An expert with longstanding experience of disaster management, specifically the care of survivors, raised an issue relating to the negative implications of this speed-up:

> *If technology reduces time with the patients, some caretaking also gets lost. (Disaster Management Specialist, Plenary Discussion, April 2012, UK).*

Even if the people who are doing triage usually do not do treatment, victims feel safer when an expert is around and is doing 'something'. As an example from one of the author's own experiences of being a paramedic for one year, responders often connect patients to oxygen bottles although it is not medically indicated, only to calm them down. When a faster triage process reduces the time a responder is close to the patient, the feelings of safety and care can be reduced or get lost. Psychological health also has an influence on the physical wellbeing of patients and panic can be caused if patients are not cared for.

ICT Supported triage should support responders in balancing concerns of speed with quality of service. By supporting triage by non-experts, by utilising systems of systems support to locate and identify victims (e.g. through incorporating telecoms and GPS data into the system of systems assembled for response), and by providing richer data from individual patients, including sensor data about changes in condition, opportunities for a more agile triage process are created. Agility would make triage more responsive to the availability of resources and the condition of individual victims, and augment the capacity of triagers to flexibly address the situation.

6.3 Implications for Design

In this section, we will discuss key findings from triage-related domain analysis with regard to their implications for interface and interaction design.

Being Conscious of a Reconfiguration of Scope

Several of the issues we discussed above arise as part of an implicit transformation in the scope of triage. The traditional triage process is about sorting. The electronic monitoring of the victims' vital values and the availability of that data over a network can be helpful for emergency workers, but is not simply triage anymore. E-triage systems often merge the sorting process—triage—with a monitoring process. Designers of such systems should keep this reconfiguration of the process in mind and try to mitigate its unwanted side effects. In that context, it is also important to see if this additional functionality was requested by the users, or if it is a technological push towards changing existing practices.

A significant transformation of the triage process emerging from the development of electronic devices concerns logging. Logging is not part of a traditional triage system. Novel possibility to capture, combine, and post process sensed values and actions in e-triage systems can reconfigure the scope of the triage process to include live accounting as actions are taken by responders. Such logging can be extremely helpful for post-operation analysis. However, it should be assured that the detected behaviour of responders is only used for learning. Knowing about potential other consequences, such as dismissal or legal consequences, could negatively influence responders' work in the field. Triage systems should therefore either offer a 'forgetting' functionality to delete the tracked information after the emergency, or offer the possibility of disabling logging when the use of data for reprisal cannot be assured.

As we explained, emergency processes are subject to continuous analysis and improvement. Adding monitoring functionalities to the triage process can change the amount of knowledge available to any person involved, while automating certain tasks such as monitoring the health status of triaged victims could support the emergency worker to focus on other tasks such as treating injuries (for example if he or she has a dynamic role). This different knowledge can improve a responder's work, but it also requires more training and expertise from the emergency workers. Sometimes, though, providing more information might create new problems for particular responders, for example information overload, or derailing from the task flow. Controlling what part of the information pool is available to which person is not an issue in traditional triage, but is vital in etriage. It can be helpful to have an authority analyse the potential negative implications of providing particular knowledge to particular persons, and configure the system accordingly. An electronic triage system could support these changes by providing the possibility of defining roles and configuring which data is available for a particular role.

There are good arguments for storing a history of locations or vital values during the time of emergency. When patients have lost their tag and cannot be found anymore, analysing their last known location may provide useful information. Discovery of a victim's vital values deterioration was requested in the workshops. It can be detected when those values go outside some general range, but it can be detected even earlier by comparing measured values to stored values of the same victim.

> *Have an alarm when vital values deteriorate. (Doctor, Co-Design Workshop, September 2011, Norway)*

However, as we previously mentioned, the deterioration of triaged patients' status could be very distracting for those conducting triage and attempting to move forward with triaging other casualties. To negotiate this, measured vital values and triage category can be made unavailable to triagers as the knowledge about deteriorating vital values or triage category evokes the question whether to continue triage or interrupt triage for treatment. For the task of triagers to tag all patients at the emergency site, it suffices to know which patients have already been tagged. So, the location or a list of tagged patients is enough, information about their vital values or triage category is not necessary for the triage task.

A single person can incorporate different roles during an emergency. As soon as the triage task is finished, the same responder may take on the task of treatment, hence a new role and new needs for information. A transparent switching of roles in an electronic triage system can support this aspect.

Designing for trust and appropriation

In our workshops, few first responders expressed reservations against the introduction of technology in emergency response. This is remarkable since emergency processes are so sensitive to changes. For some responders, technology-derived (sensor) information even seems to be more trustworthy than non-experts' information. Information quality is thus an especially important aspect for an electronic triage system. The trust advantage can be confirmed when technology is working correctly. In the same way, bad experiences with failing technology would probably reduce the trust advantage. Having a reliable system reduces the chance that it is refused as a consequence of failure at the first test.

Critically, emergency support systems should also be intuitive to handle right from the start to facilitate appropriation and assembly into systems of systems (Kyng 2006). One way to achieve this is by utilizing everyday technology. For example, secure smartphones could be used for displaying triage data. They incorporate well-known touchscreen input methodologies like panning and zooming and use does not have to be trained. Another alternative is to leverage the tools which are used in the traditional triage process. These are familiar to first responders, whether due to their intuitiveness or due to continuous training. So, trying to integrate technology into existing tools is a reasonable approach for ensuring usability. When integrating technology into existing tools, it is not necessary to copy the physical appearance of the known tool. It might be more important that the basic functionality remains and is openly identifiable. For instance, an O2 saturation sensor might look different to a traditional one but must be put to the patient in the same way. If it is not possible to seamlessly integrate new technology, this does not mean that the system has to fail. The introduction to responders' work processes can still be achieved through training.

Support According to Expertise Levels

Electronic triage systems can focus on delivering information where none is available otherwise, or where only non-experts are available to gather information. First responders tend not to trust non-expert's information in relation to expert's information resulting in higher need for improvement. Technology is trusted to bolster confidence in information and support decision making in these situations. For example, sometimes police officers or fire fighters have to conduct triage. Since they are not medical experts, there is a higher chance of over- or under-triage compared to triage conducted by paramedics. Having the triage tag reliably calculate its category automatically from sensor values can help here.

Yet, the effect of technological self-categorization would be less when medical personnel are doing the triage. Furthermore, expert's skills and knowledge in assessing patients should not lose attention because of the electronic triage system. An electronic triage system could be designed as a recommender and let an expert validate information. This is also to be combined with the role(s) of the particular expert; for example, the triage system can recommend a retriage, but only a medic at the patient can carry out the retriage and reassignment of category. If the system knows this process, it could also provide alerts if someone other than a medic is trying to retriage.

Agility means improving quality *as well as* improving speed

Speeding up the process is one way how technology can improve triage. Yet, a careful examination of the triage process is needed, in order not to lose the micro-processes, often informal and implicit, that happen during each step of traditional triage. An accelerated process

may involve a loss of caretaking, or give victims the perception that 'nobody is taking real care of them'. Instead of speeding up triage, introduced technology can also aim at supporting a more agile triage approach that mobilises the maximum of resources in the most appropriate way with a keen awareness of individual victims needs and conditions. For example, the quality of gathered data can be improved. As explained in section 'Supporting trust', gathering data is currently error-prone. This can be target of improvement as well. For example, when paper tags are enhanced or replaced by electronic tags and triage data is displayed on a personal smartphone of the paramedic, readability can be improved compared to handwriting like it was proposed in (Inoue et al. 2006), and the information could be made more coherent as everyone would be using the same forms.

Besides its representation, also the actual data can be made more accurate. This is achieved when sensors measure vital values more accurate than paramedics do. Furthermore, electronic information transfer removes the factor of misunderstanding in human communication. Of course, misinterpretations of the electronic data representation need to be avoided as well, thus putting emphasis on interface and interaction design of the command systems.

6.4 Summary

In this chapter, we have presented a case study from the BRIDGE project that illustrates how the three dimensions situation awareness, ambient intelligence/emergent collaboration and agile response relate to the empirical findings of domain analysis and co-design. As part of BRIDGE systems of systems innovation and middleware development, e-triage requires synthesis of support for situation awareness, automation and ambient intelligence, and agile response, and we have developed and employed some of the core design principles here. The chapter illustrates how attention to these principles can enhance large scale multi-agency response. The design of interactions and interfaces for technologies that aim at supporting the triage process need to find a balance between information overload and oversimplifying the displayed information, and they need to fit into emergent future work practices of triagers in the context of multi-agency emergency response. Using interfaces and interaction from common devices such as smartphones provides interesting opportunities in this regard, as the practitioners were generally open towards adapting technology for their triage work. At the same time, the design needs to be sensitive that the triage process is not transformed in unwanted ways, for example if the system can be interpreted as a surveillance device. As we have shown, social aspects such as trust played an important role in that regard, requiring a detailed understanding of triage practices and technologies to avoid misunderstandings and mismatches between design and the context of practices.

7 Interface and Interaction Design in the BRIDGE Project: Some Conclusions

Technologies for supporting crisis and emergency management can increase the safety of citizens in dangerous situations. However, supporting collaboration across multiple agencies, professional responders and volunteers in complex and time-critical situations with diverse actors and limited resources is highly challenging. Designing adequate interfaces and interactions is a critical aspect for enabling actors to deal with this complexity.

In this deliverable, we have presented concepts and lessons learned that guide the development of interfaces and interaction design in the BRIDGE project. In the report, we have focused on three key topics which have been found to be important for designing emergency response systems in the context of the BRIDGE system of systems approach:

- **Designing for Situation Awareness:** Firstly, we have argued that lack of situation data is less of a problem nowadays as compared to the aggregation of existing information in ways that prevents information overload and allows actors to make sense of the situation and take informed and situation aware decisions in crisis response. We have discussed ways of presenting and interacting with such information for supporting dynamic production and sharing of situation awareness, as well as practices of configuring awareness in highly distributed and diverse multi-agency emergency response.
- **Ambient Intelligence for Supporting Emergent Collaboration:** Secondly, another important design issue that directly affects the ability of different agencies to collaborate is the development of new support systems that enable emergent forms of collaboration. We have discussed various interfaces and interaction design issues in the context of Ambient Intelligence technologies with a focus on three challenges: data transparency, information overload and data interpretation. In that regard, we have shown that AmI technologies have a great potential for emergency support systems, but that these offerings need to be guided by an ongoing engagement with practitioners, which yields specific and relevant design principles to make ambient intelligence useful and transparent.
- **Supporting Agile Response and Collaborate Agile Workflows:** Thirdly, we have discussed challenges and chances of supporting agile response, with specific reference to collaborative agile workflows. In doing so, we have shown that augmenting human capabilities can enable productive new forms of agility in emergency response. In the discussion, we have identified important challenges for addressing collaborative workflows in rapidly changing dynamic contexts, and have discussed interface and interaction design principles that are relevant in that regard such as annotations and visual representations.

The concepts and lessons learned that have been presented in this report guide the design of user interfaces and interactions of the BRIDGE system of systems. A key lesson from the project is that BRIDGE systems of systems innovation has to consider not only the different tasks, roles, perspectives and forms of expertise and requirements of crisis situations, but also the support of distributed sense-making practices of the involved parties, for example to reduce information overload and support overview and understandability in crisis situations.

In that context, successfully designing for collaborative work requires a more complex arrangement of knowledge sharing and shared understanding in human-agent collectives. The ‘grounded’ design approach of the BRIDGE project which aims for a close connection between empirical studies and design, documented, partially, in the Design Pattern Library and the eTriage case study, is a helpful tool in that regard as it allows to take informed design decisions and deal with the complexities of designing adequate technology having the potential to be supportive inside the domain of emergency response.

Appendix 1: The BRIDGE Design Pattern Library

Design patterns originated as an architectural concept introduced by Christopher Alexander (1977). Design patterns are used to describe best practices and effective design solutions, and for capturing and sharing design knowledge with other people faced with the same problem and context. The solution proposed by a design pattern should be generic rather than specific, so that it can be implemented in numerous different ways.

The BRIDGE DPL[3] builds on a less strict definition of design patterns by including *design concepts* that are under consideration and most probably not the 'optimal solution' to a problem. In this way we expand the scope of the DPL to include the insights gained from evaluating design solutions in workshops and case studies and demonstration activities with domain experts throughout the BRIDGE project. The main content of the library is thus a collection of design solutions and examples developed and validated within the BRIDGE project. Generally, the use and relevance of a pattern will vary depending on the context of use, the perspective of the user, and the mediating hardware and/or software system. A variety of patterns should be expected as relevant, and DPL users can submit any type of pattern to the library. However, to maintain integrity of the library all submitted patterns are subjected to a review process before publication. This review process enables us to ascertain that the content of the library is well grounded and presented in a consistent way.

The patterns in the BRIDGE DPL have certain required fields or attributes, carefully chosen to comply with standard forms of patterns, while serving developers both within BRIDGE and more generally in the field of crisis management. The *pattern name* should be short and instructive, perhaps reflecting an aspect of the solution to the problem being addressed. The *problem summary* should state the essence of the problem being addressed by the design pattern. The *pattern context/usage* field should describe the context in which the pattern is relevant. Whenever possible, it should also provide the necessary background and information about the user, the user's task(s), the technology and more general aspects that affect the design problem. The core element in a pattern is contained in the field *solution* – a statement of how to solve the problem in the given context. The solution should always be accompanied by a sketch, diagram, illustration or picture. *Pattern origin* denotes the source of the pattern, *and pattern state* is used to track the development of the pattern over time: just created, under consideration, pattern candidate and approved, the latter to designate validated patterns.

The pattern library in BRIDGE enables a preview mode of the design patterns by choosing the 'browse pattern' tab, see Figure 16. Here the patterns are shown in a hierarchical mode that highlights different categorical levels of patterns and their interdependencies.

[3] The new BRIDGE Design Pattern Library launched in June 2013 and is currently under evaluation: http://bridge-pattern-library.fit.fraunhofer.de/eval/. The prior version can be found here: http://bridge-pattern-library.fit.fraunhofer.de/ (until the evaluation is finished, then the new version will be moved to this link).

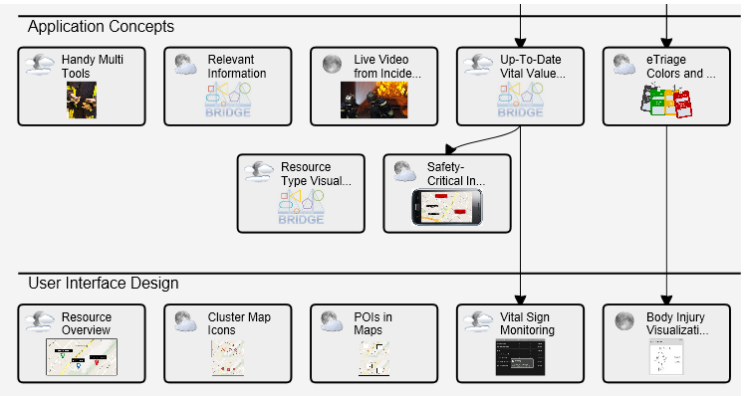


Figure 16. Screenshot from the BRIDGE design pattern library, showing the hierarchical browse mode.

When selecting a specific pattern element a full view of the pattern attributes is provided. An example pattern, **Clustering of map icons** is described here and the accompanying sketch is provided in Figure 17.

- Pattern name: Clustering of map icons
- Problem Summary: Map-based interfaces often get cluttered due to a high amount of icons/markers displayed simultaneously.
- Pattern Context / Usage: In emergency management systems, map-based interfaces might be used to show information about resources, patients, victims, or other points of interest. When these interfaces makes use of markers/icons to represent such points of interest, they will often get cluttered due to the large amounts of markers/icons that are displayed simultaneously, resulting in information overload for the user. Clustering of map-icons can be used to avoid cluttering the map-based interface, and to reduce information overload
- Solution: Represent similar points of interest that are located close to each other on the map (depending on the zoom level of the map) by one single cluster icon, instead of having one icon for each single point of interest. The clustering of icons should be relative to the current zoom level of the map.
- Pattern Origin: External
- Pattern State: Pattern Candidate
- Pattern Type: UI Design Pattern

Figure 17. Example pattern: clustering of map icons.

The Design Pattern Library is meant to offer assistance in developing collaboration between specialized workgroups in the BRIDGE project. Different workgroups tend to prefer different methods, tools and documentation formats. At the same time, knowledge exchange between different perspectives (professional practice, social science, ethical studies, computer science etc) and work packages is extremely important for successful system, application, technology and interaction design and sustainable socio-technical innovation in emergency services. Design patterns can sensitize analysts, designers and practice stakeholders to specific and generic constraints and possibilities inherent in work practices and technological potential (see also Reiners et al. 2012, Reiners et al. 2013).[4]

As extensive documentation, video and audio material as well as technical diagrams and specifications are created by each individual work package, identifying and understanding the important extracts of that information flood is a time-consuming task. The BRIDGE Design Pattern Library aims to support knowledge exchange by making use of the pattern format to document information in design patterns that describe a current context, a problem or opportunity and an innovative 'solution'. Design patterns are an established practice for leveraging knowledge exchange and guide design decision in software projects. As discussed above, good patterns should be generic enough that they fit into different domains in the shared context of a project, but so concrete that they can guide designers in taking informed design decisions. Instead of using patterns to document validated knowledge, the concept follows a grassroots approach in which knowledge can be formulated as open challenge that needs a designerly 'solution'. We place 'solution' in quotation marks to highlight that design is not narrowly focused on 'fixing' 'problems', but on defining desirable socio-technical futures – for example, a qualitative improvement in the way emergency response services can be provided or co-created – where the potential of new technologies can be utilised and integrated into new work practices.

[4] For more information on the role and design of the BRIDGE DPL, see Reiners, R.: Applying Evolutionary Patterns for Managing and Refining Project Knowledge. Univ. Diss. Aachen (in preparation).

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