Towards Computer Support of Paper Workflows in Emergency Management

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ABSTRACT

A crucial aspect for large-scale disaster management is an efficient technology support for communication and decision-making processes in command and control centers. Yet, experiences with the introduction of novel technologies in this setting show that field professionals tend to remain attached to traditional workflows and artifacts, such as pen and paper. We contribute the results of a comprehensive field study which analyzes how the information flow is currently performed within different units and persons in the command and control center. These findings provide insights into key aspects of current workflows which should be preserved by novel technological solutions. As our second contribution, by using a participatory design approach and based on our findings, we present a novel approach for computer support in command and control centers. This relies on digital pens and paper and smoothly integrates traditional paper-based workflows with computing, thereby combining the advantages of paper and those of computers.

Keywords

User study, Emergency Management, Human-Computer Interaction

INTRODUCTION

Command and control tasks in a large-scale disaster response are highly complex, safety-time-critical activities. Professionals who are in charge of this stressful job in command and control centres (CACCs) should regularly make rapid and appropriate decisions in constantly changing conditions. During the last few decades many information technology (IT) systems and approaches have been proposed to facilitate the decision-making process from different aspects. However, despite the recent advances in technological support for CACC, the professionals still remained attached to their well-established and successful work practices with ordinary every-day artifacts such pen and papers.

One of the reasons which make professionals still reluctant to digital solutions might be the fact that computing hardware and user interfaces do not fit the current work practices which have developed over many years (Cohen et al., 2004). In addition, simply replacing the current work practices with novel digital systems will increase unknown risks due to the significant changes in the every-day routines and workflows. It is a significant challenge to integrate the offered digital solutions to the every-day practices of professionals in a way to minimize incompatible changes. In this fashion, the advantages of both the physical and the digital realms can be combined and people can leverage the IT solutions in CACC more effectively and safely.

In order to fundamentally and precisely understand the work practices of individuals who are working together in CACCs, we opened connection with the firefighting school of the Hesse state (HLFS) and the Agency for Technical Relief (THW) in Germany. In order to deal with the complexity of CACC systems we participated in a series of seminars which took place in HLFS. Moreover, we conducted a comprehensive literature survey as

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well as interviews with first responders and training supervisors from the firefighter's academia, to follow up a participatory design approach.

The contribution of this paper is two-fold. First, we present the results of the field studies with respect to the current workflow. On this basis, we establish requirements of CACC for large-scale incidents. Second, we present how to combine the traditional paper-based workflow in CACC with digitally enhanced solution in order to take advantage of both physical and digital worlds at the same time.

The remainder of the paper is as follows: first, we give a short overview on previous works and similar ongoing projects. Then we present our field study and the methodology, follows by findings and discussion. We derived some important design implications according to our findings and finally propose our solution to that.

RELATED WORK

MacKay in (MacKay, 1999) conducted a comprehensive user study to gain an in-depth understanding of the use of paper flight strips in safety-critical air traffic control activity. Her study showed that the traditional paper flight strips support safe and effective work practices in flight control. She suggested incorporating the paper flight strips itself as user interface to computer systems. In this fashion augmented papers are familiar to users and still provide the benefits of computers.

In (Cohen et al., 2004), Cohen and McGree suggested that safety-critical applications should let the users to employ the physical objects and languages of their workplace through the use of tangible multimodal (TMM) system. In this fashion digital systems based on TMM can take advantage from many physical world characteristic and affordances such as those of paper. They developed three systems Rasa, NISMap and NISChart which showed the capabilities of TMMs.

In table 1, a short overview on command and control systems currently employed by German first responders is given. Most of them are monolithic systems with limited possibilities of integrating information from external sources or allowing access from external systems. The European Union (EU) as well as the German Federal Ministry of Education and Research (BMBF) support a large range of research projects that are dedicated to emergency management and the support of collaborative structures in this context. Under the 7th Framework Program, the EU currently funds 54 projects[1] dealing with security research. The BMBF is currently sponsoring 17 projects[2] in the context of emergency management.

Name	Authority	Outstanding Feature
IGNIS	Fire Department	Replicated Database, scheduling of teams (Leitstelle Perspektiven, 2006)
InPol-neu	Police	Lookup of persons, car plates, automatic reasoning (INPOL-neu, 2003)
LUPUS	Police	Digital map, updates in real time, detailed logfiles
Microsoft Outlook / Exchange	Most public authorities	Email and calendar management. Users are accustomed to Outlook from day to day work. Some organizations run adopted versions using preprints.
ServicePlus	Fire Departments	Dispatcher system for daily business [3]
SHARE	Prototype	Ontologies improve communication, digital maps [4]
STABOS	Fire Department	Basic support for operational headquarter

[1] http://cordis.europa.eu/fetch?CALLER=FP7_SECURITY_PROJ_EN&DOC=41&QUERY= 012544ff9fe3:cb3c:560c6d79

2 http://www.bmbf.de/pub/research_for_civil_security_rescue_protection_people.pdf

[3] Product developed by LIS-GmbH, Oldendorf, Germany

[4] Software was developed in the EC FP6 funded project SHARE.

TecBos	Fire Department	Digital map, training and replay mode, logging of all events [5]
TUIS	Fire Department	Consortium of volunteers from chemical industry, TUIS offers consulting, transportation and specialists for all kind of chemical incident. Offers database for potentially dangerous chemicals.

Table 1: Overview on command and control system currently employed by German first responders.

The *SoKNOS* project (http://www.soknos.de/index.php?id=197&L=0) has also a strong focus on the command and control activities. However, none of the currently ongoing projects puts the focus on approaches that introduce IT technology while leaving central and established workflows untouched.

FIELD STUDY

Methodology

Disaster management and particularly teamwork in command and control centres is a sophisticated operation. We distinguish three approaches how to observe and analyze the workflows in CACC:

- Studying literatures and reports on previous disasters
- Observing training sessions and analyzing video recordings
- Observing the response operation in reality and analyzing video recordings

The first approach is mandatory for understanding basic challenges and workflows found in relevant CACCs. The second and especially third approach provide the most in-depth information about fieldwork and daily challenges the CACC teams have to face. However, observing disaster response operation in real situations is hardly possible due to inaccessibility and hazardous environments in disasters. Hence, one of the most feasible ways to study the disaster response operation is performing live action role-playings which normally take place in simulated environments (Dyrks et al., 2009).

The HLFS is the central place for education and practical training of volunteer fire companies (VFC), professional fire brigades, policemen, militaries and voluntaries of the German federal state of Hesse. It is also the actual place of the state command and control centre in case of state-wide disasters. The HLFS offers various command and control seminars for people that are or going to be in charge of any positions in CACC team work. Usually, seminars are comprised of theoretical parts which are followed by practical sessions. This cooperation gave us the possibility to attend a series of seminars and get a unique inside into the work of CACCs in Germany.

The seminars comprised of a short theoretical and a longer practical part. Introduction to the teamwork and essential functioning materials as well as the map materials and leading task were the most important content of theoretical parts and helped us to understand the current way of functioning in the CACC.

In the practical sessions live action role-playings were performed and allowed us to silently observe the participants. We participated in two disaster scenarios taking place in HLFS, namely an airplane crash and a gas leak with explosions in a swimming pool close to an urban area. Each of these scenarios lasted about four days. The CACC and the "Technische Einsatzleitungen (TEL)", i.e. mobile units in the field (see the findings section for detail), were located in prepared installations in HLFS. Communication between CACC and TEL was established per radio-handset, fax and phone. These communication devices are a common choice in real missions as well. After assigning responsibilities to each section and a short pre-practice the operation started and lasted 7 hours. There were no interruptions besides a short lunch break.

The observations were documented as field notes and transcribed after the session. In order to provide rich materials for the after-action analysis, we partially recorded the practical sessions on video and took pictures of artifacts and common workflows. Moreover, we conducted semi-structured interviews with professionals of the HLFS. Additionally, we participated in a one-day THW exercises and merge the findings with our main user study in the next section.

[5] Product developed by MSA Auer GmbH, Berlin, Germany

Findings

While it is relatively easy to envision enhancements for such complex operations, designing practicable solutions is always a challenging task. In order to enhance any process of CACCs, it needs first to be completely understood. Crisis response teams all over the world work full-time on managing disasters of all kind from small fires to earthquakes or industrial accidents. Smaller incidents usually do not require a dedicated CACC, therefore we focus on larger accidents, e.g. earthquakes, floods and gas leaks in the chemical industry.

In Germany the fire department is responsible for managing the operational part of a disaster response. This is done in close cooperation with other departments e.g. police, THW (German Federal Agency for Technical Relief) and Federal Ministry of the Interior.

The roots of the current workflow can be traced back to several regulations from 1975, since then it is constantly revised and improved. Finally all disaster related regulations were merged into a single document called “fire brigade service regulations 100” (FWDV100, 1999). All personnel are trained based on the FwDV100 which is a consistent directive composed and adapted from several nationwide regulatories of the last 35 years. The FwDV100 regulates all aspects of command and control work.

We focus on three main aspects, namely organization within a CACC, hierarchy of command and control units and most important information flow within a command and control centre.

The CACC is organized into different sections. Four major sections are defined by the tasks they fulfil in the CACC.

- Personnel/Internal Services (S1)
- Situation (S2)
- Operation (S3)
- Supply (S4)

Two optional sections are defined and might be used when needed.

- Public relations (S5)
- Information and Communication (S6)

The organizational structure scales with the size of the incident. At smaller incidents a consolidation of the four sections into two larger groups, usually S1/S4 and S2/S3 is quite common. All sections are subordinated to the officer-in-charge and can be filled with different number of assistants and specialists as demanded by the operation. Additional to this structure liaison officers are put in place to coordinate the work of different departments and specialized advisors can be used by all sections (as shown in figure 1).

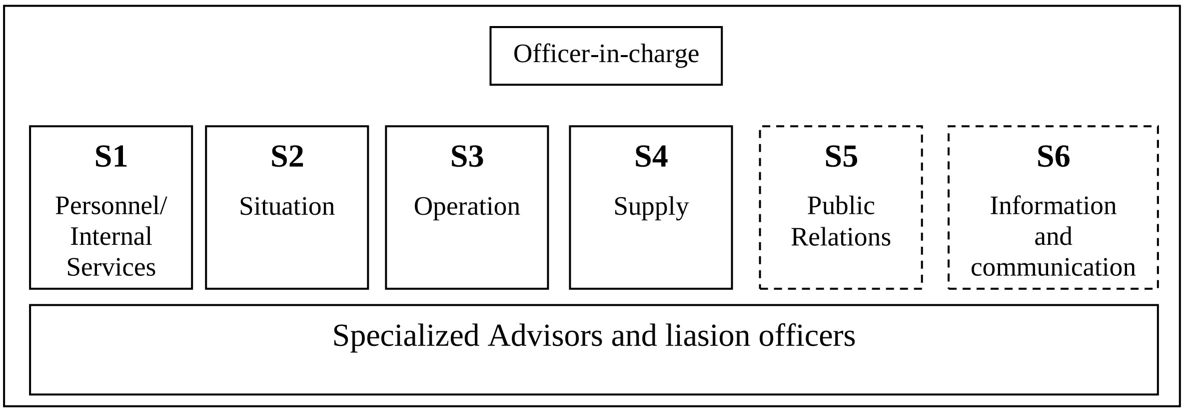
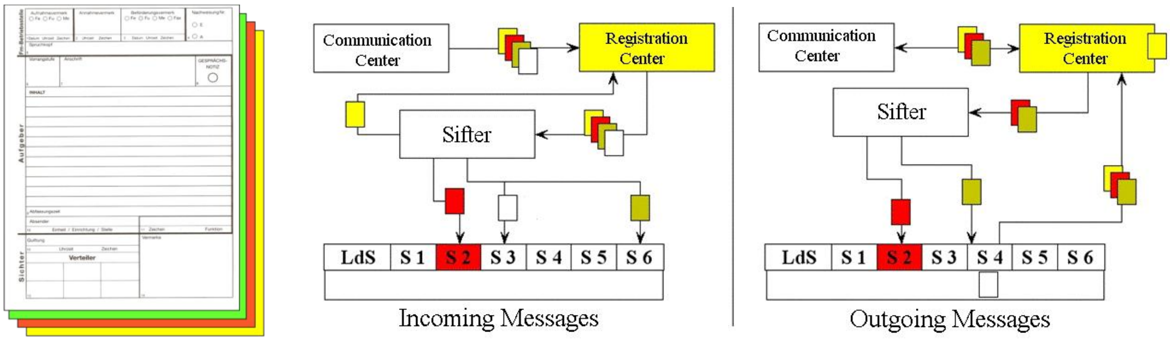


Figure 1: Sections in Command & Control

Figure 2: An example of 4-fach Vordruck (quadruple carbon preprint) on left and the information flow resulted from



passing the 4FV within different centers in CACC (right)

As important as the organization inside the command and control center is the hierarchical organization between the command and control center and the field. The command and control center is not directly responsible for the responders in the field. The disaster area itself is separated into several smaller command and control stations called "Technische Einsatzleitung" (TEL). These intermediary mobile units act as data aggregators from the field to the CACC and as a multiplier for commands coming from the CACC.

The most important organizational matter is the information flow within the CACC and with the field. It is crucial for a successful first response mission and therefore highly structured. Due to this structure and the importance, information flow is also the point where information technology needs to be put in place to enhance established processes. In order to understand the potential improvement we will take an in-depth look at the current workflow.

The information flow at larger incidents is usually following the topology of a scale free network (Butts, 2007). The Communication center is the gate of information to/from CACC, which means almost of the information, is sent and received via the communication center. Regarding information processing, CACC can be divided into two sections, the center itself where information is processed and decisions are made and the actual information hub section, which archives, transfers, verifies and tags the messages. Between both sections the sifter, acts as a switching center, he is responsible for sighting, sifting and distribution of information.

Every piece of information gets written down on a carbon preprint, the so-called "4-fach Vordruck" (4FV) as shown in

Figure 2 left. It replicates any written message three times. Information written on the white sheet gets copied onto colored sheets. When messages arrive at the ICC (incoming information flow, Fig. 3), they are transferred onto 4FV by the communication section no matter which input channel (e.g. funk, phone, email, fax) was used. The upper part of the sheet is dedicated to the communication center and is used to write down two different timestamps: first the start time of dispatching the message from mobile units and second, the time of well receiving the message in communication center of CACC. The middle part is reserved for the message itself and the name of sender. The 4FV is then forwarded to the registration centre, which is responsible for registering (assigning a unique ID), keeping on file and passing the 4FVs to the sifter. His remarks are written down in the lower part of the form. He marks the recipients of a message, e.g. officer-in-charge or S1 to S6. The message is then forwarded to different recipients using the available copies. The yellow copy is held back for archiving purposes in the registration center.

When a message is composed inside the CACC (outgoing information flow, Fig. 2 right) the middle part of the sheet is used for the message content and the address of receiver. The 4FV is registered and the upper part is reserved for the communication centre with the corresponding timestamps and remarks. After transmitting the message to the desired mobile unit, a sheet is sent back to the sender via sifter as an acknowledgment.

Summing up, the acquisition and the flow of information are highly structured. A 4FV is used to transfer any kind of information. It appears that this process does not have the tendency to be changed easily since it is established for decades and the teams are well accustomed to it, hence are somewhat reluctant to abandon it. With respect to the information flow mentioned above, we discuss the advantages and drawbacks of the current approach in the next section.

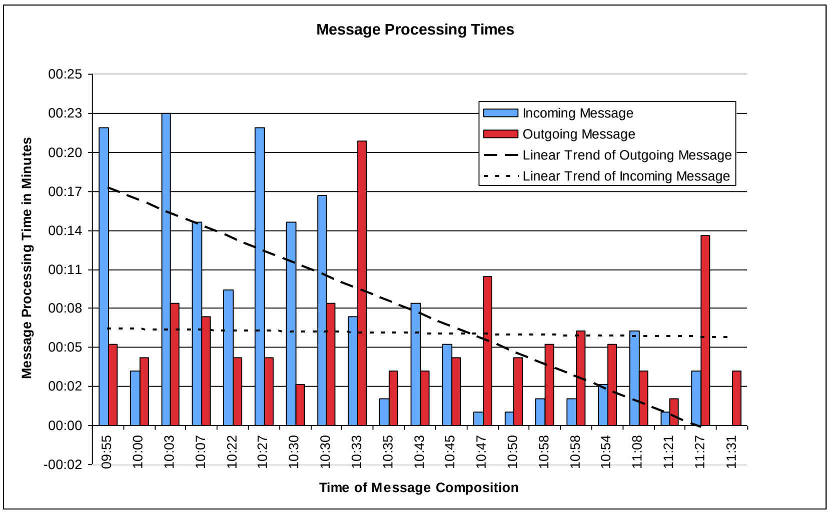


Figure 3: Message Passing Processing Time on 4VF

We have summarized the main findings from practical part of the field study as follows:

- Paper (particularly predefined forms like 4FV, Fig. 4), pen, table, and wall (whiteboards and flipcharts) were used regularly for information exchange and for logging purposes in all over the process.
- All the personnel (S1 – S4) were flooded in 4FV. We observed that searching, browsing and archiving the 4VF sheets were frequently carried out by officers. Later on in our interviews we figured out that browsing and particularly searching in a pile of 4FV was a tedious task.
- If the CACC sends an order to one of TEL (outgoing information flow Fig.2 right), it was hardly possible to further follow up the consequences of the message. A blue send acknowledgement is always kept, but advancements or delays during the process were not reported to the CACC.
- We found that the sifter was the bottleneck in the information flow. He is the switching centre between the communication office and the officers in CAC centre. Particularly in peak times the sifter was overloaded by too much information to distribute.
- We especially observed cases in which sifter has received messages on 4VF with high priority and later overlooked the messages which were held on.
- Figure 3 shows the message processing time seen in the observed disaster scenarios. On the x-axis the first 2 hours of the incident are plotted, from the message processing point-of-view, the processing delays of the incoming messages for CACC (blue bars) show a typical pattern. In the first hours after the incident, the CACC does only have a vague understanding of the situation in the field. The level of uncertainty is high, which leads to a high delay in data gathering, sorting and in the decision-making-process. After about 50 minutes, the crewmembers had a basic overview of the situation in the field. The confidence in their message processing approach is higher which leads to faster processing times. Outgoing messages did not show a clear pattern, the receiver of the message is already filled in at composition time; uncertainty is not the main challenge in this part of the message flow. This does depend mainly on the workload of the communication centre. This chart also shows that due to the sifter bottleneck, incoming messages have more delay on processing till been received on the desired person.
- We often observed other paper artifacts such as faxes or email printouts were attached to the 4FV which made the paper workflow more sophisticated to the officers.

After each practical part we conducted semi-structured interviews with experienced participants and trainers in HLFS and THW. Especially the trainers and professionals do believe on the current approach with the better part being paper work. Moreover, they talked about their experiences in centers which were equipped with desktop computers to digitize the information flow and particularly, in terms of message passing with 4FV. Although information and communication technology aims at digitizing the information and allows the officers to manipulate digital information, there are still challenges, which are not covered by currently available technological solutions. In interviews, experienced officers and trainers explained that there are many reasons for their reluctance to use computer systems. Lightweight, flexible, readily available, and supportive in

Figure 4: Left and center show CACC flooded with traditional paper –Right, shows 4FV registration section

collaboration as well as safe-to-fail characteristics of paper (in any form like map, flipchart etc.) and pens were mentioned most frequently.

In addition, interviews revealed that in CACCs which are equipped with computer systems, officers communicate and discuss much less with each other (which is crucial for decision making in CACC). However, the team in the CACC should communicate frequently, the spoken word, gestures, mimics and even longer discussions are a critical success factor.

Design Implication

In general, the user study showed that despite the advances in technology, paper is still playing an important role in CACC. Moreover, the large workspace of whiteboard and tables also offered important benefits for co-located activities while commanding and controlling operation. Large workspaces allow users to represent large amount and complex information spaces without loss of contextual information. Fig. 4 (center) shows a large table and whiteboard (consists of three whiteboards: in the middle map of the operation was located and two surroundings were used as place of the map complementary information) were widely used during the operation for different purposes. For example tables provided easy sharing, manipulating and organizing tangibles like papers. There is considerable amount of research, which investigate on digital surfaces to facilitate such collaborative activities (Steimle et al., 2008).

The findings from the user study provide valuable insights to propose an enhancement to the current workflow. With respect to the findings as well as previous work, we can summarize the main requirements which the perspective system should fulfil:

- Preserving the fundamental aspects of the professional's work practice
- Augmenting (not replacing) the manual work practices of the users with novel technologies
- Making user interfaces more natural and fairly invisible in order to increase the bandwidth of interaction between human and computer in time-critical work settings
- Supporting the system's fail and provide a graceful degradation to the ordinary setting
- Removing the human-interaction aspects which are performed by proxies like traditional mouse and keyboard and instead, permitting the users to interact with intuitive every-day objects like traditional paper and pen.

UBIQUITOUS PEN-BASED INTERACTION APPROACH

Inspired from the results of the previous section, our approach relies highly on augmenting physical objects (pen, paper and surfaces) and providing an ambient form of technology in CACC. Despite of many other approaches which focus on specific applications in CACC (http://www.soknos.de/index.php?id=197&L=0), our design enables users to seamlessly interact with augmented physical objects in the environment. In our design, we aim to support the existing workplace routines in CACCs, both physically and digitally.

In order to do so, we leverage digital pens as a highly flexible interaction device which allows interaction with different computing devices and physical paper artifacts. It enables officers in charge to physically interact with augmented objects and surfaces, while the digital version of information is simultaneously and automatically captured and updated. We employ Anoto[6] digital pen technology. These pens are widely used nowadays for capturing information which is written on traditional paper. The physical writings on paper are encoded with a two dimensional dot pattern, which can be printed with an ordinary laser printer on paper. Moreover, the dot

[6] http://www.anoto.com/

pattern can also be printed on various types of foils (Leitner et al., 2009) to be used on tabletops, and it enables pen interaction with the tabletop surface. The Anoto pen generally behaves like normal ballpoint pen and thus produces ink on paper. However, it also possesses an embedded, tiny infrared camera and a processing unit that scans the dot pattern and decodes the locations it has observed into electronic ink data, short *eInk*. It is capable of saving recorded eInk data (batch mode) and/or streaming data per Bluetooth. In addition to the ink recording feature, a digital pen can be used to perform digital commands using specific gestures or by tapping on specific printed button regions.

For example one can design an interaction technique specifically for the sifter in CACC that support the digital distribution of the 4FV to the desired officer's digital workplace. This reduces the workload of the sifter and decreases the delay time of message passing within CACC.

As a technological software foundation to develop novel application based on the concept of ubiquitous pen based interaction for CACCs, a framework was specifically designed and developed to meet the necessary needs. This framework is built on top of a well-established ubiquitous computing middleware called Mundocore (Aitenbichler et al., 2007). Mundocore enables the cooperation of objects, independent of devices, operating systems and programming languages, through a loosely coupled publish-subscribe middleware. The framework is formed out of a series of successive processing steps, each transforming the eInk data to process and relate the interaction to the specific artefact, screen or any other entity equipped with the dot pattern.

The framework supports multiple Anoto pens, which can be deployed on different computer nodes hosting the described processing steps. These nodes can be distributed in the CACC and can even run on mobile devices for in the field application, depending on the concrete setup required. In this fashion each officer possesses an Anoto pen to pervasively interact in the augmented environment. Since each pen in the system has a unique ID all the interactions are authenticated and easily be tracked later on, collaborative interaction on digitally augmented, physical objects and electronic devices in the CACC becomes possible.

CONCLUSION AND FUTURE WORK

In this paper we presented a comprehensive field study on information flows within CACC. Particularly, we observed and focused on the use of different physical media for transferring information and clearly defined their role in CACC. Moreover, based on our findings we derived a set of design implications and proposed the solution to augment physical paper in CACC in order to take advantage of both the physical and the digital worlds.

We believe that the proposed system (which is currently under implementation) will significantly improve the currently deployed paper-based system in CACC without requiring any radical change in the well-established work practices. Particularly, we will test the proposed system in terms of speed of message passing and information flow in one of the forthcoming practical sessions of HLFS in order to benchmark the system performance and user reactions and acceptance.

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