Handy Navigation in Ever-Changing Spaces—an Ethnographic Study of Firefighting Practices

Sebastian Denef, Leonardo Ramirez, Tobias Dyrks, Gunnar Stevens
Fraunhofer Institute FIT
Schloss Birlinghoven
53754 Sankt Augustin,
Germany
+49 2241 142702
{firstname.lastname}@fit.fraunhofer.de

ABSTRACT
This paper presents an ethnographic study, conducted to gain an insight of the practices around navigation of firefighters on the first line of intervention.

We argue that the common approach of looking only at the technical aspects is incomplete. We show instead, that navigation of firefighters in ever-changing spaces is a collective craft or art, where technology is only one of the relevant pieces, but not the only one. Therefore design should take a deep look at existing navigation practices of firefighters.

In order to identify relevant work practices, we conducted our ethnographic study to find out patterns of navigation work and based on our findings, we provide an outline of how the navigation practices can be supported by ubiquitous computing.

Categories and Subject Descriptors
H.5.1 [**Information interfaces and presentation (e.g., HCI)**]: Multimedia Information Systems – *Evaluation/methodology*

H.5.3 [**Information interfaces and presentation (e.g., HCI)**]: Group and Organization Interfaces – *Evaluation/methodology, Computer-supported cooperative work*

General Terms
Design, Human Factors

Keywords
Ubiquitous Computing, Emergency Response, Ethnography, Empathic Design, Firefighting

1. INTRODUCTION
In December of 2005 two firefighters died in a fire of a 3-story house in the city of Tübingen in Germany. Their retreat path was blocked by a burning wall, and they were not able to find a new way out before the air of their respiration apparatuses was gone. Their bodies were found 3 meters away from a window connecting to the outside part of the building [33].

Navigation in ever-changing spaces with very few supporting infrastructure is a common situation for firefighters. They usually need to get into buildings full of smoke or without lights and, in such low-visibility conditions, explore the environment to build a shared knowledge of the situation, and to define the tasks of the intervention.

The WearIT@Work project at the Fraunhofer Institute FIT is working closely with the Paris Fire Brigade (Brigade de Sapeurs-Pompiers de Paris) on conducting a participatory design approach to bring wearable technologies to firefighters working on the first line of intervention. Firefighting constitutes a highly situated activity that heavily resorts to the implicit knowledge constructed through training and experience. The role of firefighters change dynamically during an intervention, and decisions must deal with highly unpredictable situations. Information resources are scarce at different levels. On one side the available information could be incomplete due to the complexities of an intervention, and on the other side, processing time for this information could be limited, as the attention of the firefighters must be focused on many different tasks during an intervention.

For firefighters, ubiquitous computing has the ability to instrument the reality [29]. The availability of sensors embedded in the environment or attached to garments provides an increasingly large amount of information to be processed. Moving, however, from the simple availability of information to a set of navigation tools requires, more than a set of technical resources, an appropriation [28] process driven by the interactions between the evolution of the technology and the uses and practices that users build around these technologies.

In ubiquitous computing, indoor navigation support has been mostly addressed as the technical problem of obtaining more or less precise location information [13, 24]. Navigation is however more than just a technical artefact. Navigation is an art or craft, a human practice constructed around technical possibilities such as indoor positioning or orientation tools, but also around cognitive capabilities of the navigators. Hence providing good, supportive navigation tools requires a deep understanding of the context in which the users require such support.

With this idea in mind, we setup our research to answer the questions that poses the construction of navigation tools for firefighters, overcoming, and moreover, making use of the uncertainties of the positioning and orientation technology available today.

In this paper we present a detailed report of the field studies that we conducted with the firefighters as well as an account of the methodological approach that guided our work.

2. RELATED WORK

Taken broadly, there are several relevant studies related to the main foci of this paper—designing mobile interactive systems for collaboration support in time-critical work and navigation and human orientation in unknown spaces.

Challenges in designing interactive systems for time-critical work are described in [22]. [4] presents an ethnographically informed system design for air traffic control in the UK. The paper provides an account of experiences of a project where an ethnographic study of air traffic controllers is being used to support the design of the controllers' interface to the flight data base. The authors claim that ethnographic studies are helpful in systems' design processes and may produce insights which contradict conventional thinking in system design. [14] reflects more generally on the experiences of using ethnography across different projects and in a variety of domains. On the side of designing mobile and ubiquitous computing systems, the palpable computing project [27] introduces a very interesting concept for framing the design of pervasive systems and making them graspable for its users.

Research on interactive systems for emergency response can be found in [19]. The study is concerned with the design of an innovative system for patient identification and monitoring. The authors present and analyze a set of design challenges that was derived from fieldwork and literature studies. They formulate design principles and visions that address these challenges and present a number of prototypes used to explore the visions and act as a basis for implementing real systems. The use of low-fidelity prototypes for the evolutionary design of a large electronic display for supporting collaboration tasks among incident commanders and operative firefighters is presented in [16]. Specific for the firefighting domain, [20] shows the importance of verbal communication as one of the key elements for coordination and discusses how verbal communication can be made persistent and accountable. A further study [21] identifies interaction patterns and gives an insight into information technology mediated intra- and inter-organizational. [8] analyses the hierarchical organization of verbal communication among firefighters and suggests a system design to enhance and improve these communication practices. In [7] a participatory design process based on ethnographic studies and prototyping is presented, focused on the construction of technologies to support emergency response teamwork.

There is an extensive amount of literature addressing the technical challenges of indoor positioning. A taxonomy of location technologies is presented in [13]. Inertial sensors such as accelerometers and gyroscopes can be combined with non-inertial sensors like magnetometers and barometers to obtain the position of firefighters in motion. [24] presents a feasibility study of inertial sensor based location systems for firefighters. [12] presents an RFID based indoor localization system called LANDMARC that uses the concept of "reference tags", firmly attached active tags used to improve location calibration. [1] describes a hybrid navigation system that combines different in- and outdoor positioning technologies to determine location.

Navigation is, however, more than just the technical availability of location information. Several studies have approached navigation from a cognitive perspective. [5] presents an ethnomethodological investigation about the different practices of way finding and navigation when people travel with a car. There is also many work on the subject of pedestrian navigation [11, 25, 30], assessing the relevance of landmark information. Ross proves that the addition of landmarks to pedestrian navigation instructions increases user confidence and improves navigation performance (reduction in errors). [31] investigates the role of global and local landmarks in a navigation experiment in a virtual environment. Distant landmarks such as towers or mountain peaks are visible from a large area and can serve as global landmarks. They define world-centered directions or a global reference frame that does not change when the observer moves a small distance. In contrast, local landmarks are visible only from a small distance (e.g. buildings, mailbox). Navigation by local landmarks relies on a sequence of intermediate goals defined by these local landmarks. They are therefore linked to route navigation. Results show that participants use different strategies during way finding decisions (preferring global or local landmarks).

If we take a deeper look at the process of human orientation in unknown environments, the terms "cognitive map" and "cognitive mapping" are broadly used in the literature [18]. The metaphor of a "cognitive map" has attracted wide interest since it was first proposed in the late 1940s. Researchers from fields as diverse as psychology, geography and urban planning have explored how humans process and use spatial information, often with the perspective of explaining why people make way finding errors or what makes certain persons better navigators than others. Cognitive psychologists have broken navigation down into its component steps and as interplay of neuro-cognitive functions, such as "spatial updating" and "reference frames" or "perception-action couplings". [15] illustrates the process of cognitive mapping of people with visual impairments and blindness. The study describes how blind people are able to use language, audition, haptics, smell and taste as well as awareness of flow and motion to gain a direct or indirect awareness of their geographic environment.

3. METHODOLOGY

The objective of our study was to get an insight of the knowledge, practices and experience of firefighters on the first line of intervention to look for opportunities for mediating or facilitating the work by using technology. For us, the role of the user in the design process is a delicate question of ethics to be answered by building a bridge of empathy [32] between designer and user. Motivated by this idea, we followed a participative oriented ethnographic approach by observing our users in their natural environment [17]. We took part and closely observed their practices in several field studies with an abductive attitude [26], looking for surprising facts and the emergence of observable patterns in the analysis of our results. In a next step we build up a categorization grounded on our ethnographic experience [17].

The first part our work explored the relationship of firefighters with existing and new technology. In a training facility of the Paris Firefighting Brigade we ran seven simulated reconnaissance missions to which we introduced the use of location information. The missions were run in a building specially designed for training with teams of up to eight firefighters equipped with the complete required equipment, including protective clothes and breathing apparatuses in a building specially designed for training. To simulate null visibility conditions, a sheet of sandwich paper was placed in the breathing masks, thus blocking sight, but allowing a rough recognition of light sources. The task in every case was a reconnaissance mission that consisted in walking through the building and in some cases finding bottles of water, which were previously hidden by members of the team. We asked the firefighters to conduct their work as close to the reality as possible, although some elements were strange to their common practices, such as the bottles and the use of maps and positioning information.

To obtain indoor positioning, we constructed a Wizard-of-Oz prototyping platform. One facilitator was assigned to each and every firefighter in the mission. He disclosed the actual position of the firefighter by clicking on a map of the building shown on a piece of software specifically designed for the task. This information was transmitted using a wireless network to a central computer mounted on a command post, where visualization software allowed following the position of the tracked firefighter in a Large Interactive Display.

After each missions we had immediate semi-structured interviews to gather impressions first-hand. We asked the firefighters about their overall experience, about the differences between real-world incidents and the simulated mission and why they acted the way they did. The breakdown situations were discussed in detail so that both the commander and the firefighters in action could give feedback.

Every intervention was videotaped in parallel from the perspective of firefighters, team leaders and the commander in the command post. We synchronized the videos afterwards to achieve a global perspective of every mission [Figure 1]. A custom transcription tool supported the analysis of the synchronized videos by comparing different viewpoints side-by-side and by allowing toggling between the audio channels. Even though the firefighters did not use our Wizard-of-Oz indoor positioning tool in every simulation, we kept using our tool as a way to keep track of their positions, to analyze the way that they took through the building.

In a second study, dressed up with the required equipment, we took active part of a set of normal training exercises with a group of 20 firefighters. The exercises ranged from basic techniques for handling the fire nozzle to a walk in a specially prepared tunnel full with smoke, using breathing support devices.

In the following sections we present a thick description of our experiences with the firefighters, and provide some insights of their context of work. We follow with an account of relevant findings concerning the problem of indoors navigation.

4. ON-SITE STUDIES

4.1 Simulated Reconnaissance Missions

Reconnaissance missions play a central role in firefighting practice, and their main goal is to gather information about the place in order to support strategic decisions. By entering an unknown building in poor visibility and potentially dangerous conditions, firefighters face a situation where orientation and navigation are key success factors.

4.1.1 Setup

We planned seven simulated mission with the help of an independent professional firefighter who had no further involvement in the project. Using floor plans of the training facility he provided us with scenarios matching real-world interventions, which we later used to design our missions. On-site we introduced the mission to a local captain who then instructed his team of firefighters.

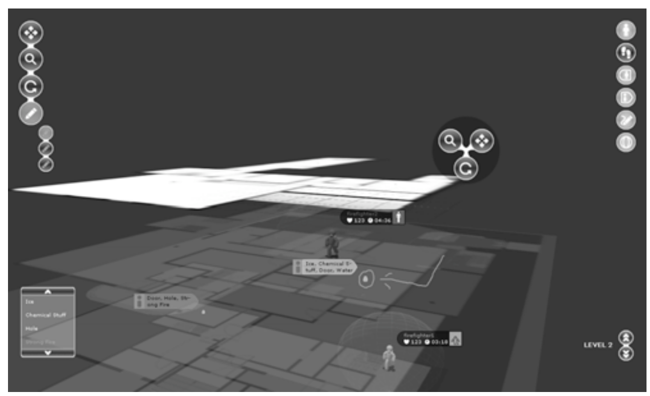

Figure 2. Command Post Application.

Some of the simulations were completely explorative, while others also included experimental elements [34]. The former allowed studying real-world practices while the latter purposely disturbed the system of practices [23] by introducing positioning information to the firefighters, information which is not available in real-world situations. In that way we got a glimpse on how the practices adopt to new technologies and how unforeseen breakdowns emerge out of the use of this technology. We also used this disturbance to spark a process of reflection and innovation around the practices [6].

Our positioning system supported the commander by showing him the positions of his teams on a large interactive display with

Figure 1. Capturing video in parallel from three different perspectives.

multi-touch input control. This custom made command post application included floor plans for the four-story training facility aligned in a 3D view and provided simple input methods to zoom, pan and rotate the virtual building. The prototype also allowed switching the floor perspective so that a defined floor level is in focus and other levels become semi-transparent [Figure 2]. Using a virtual pen the commander could mark certain points and draw paths and hints in the map in 3D fashion so that marks stay at defined points in the map, even when the map is rotated.

With the Wizard-of-Oz tablet PC for generating positioning information [Figure 3], this system was not designed to be a complete application for real-world scenarios. We were instead interested in seeing how positioning information could influence the practices of firefighting in reaching their goals.

Figure 3. A tablet PC was used to track the path of firemen.

4.1.2 Reference Missions

On the first day we ran two missions, each with two teams of firefighters who were sent on a reconnaissance mission to the third and fourth floor of the training building. These two floors feature a complete apartment with bedrooms, bathrooms and a large living room with a staircase to the fourth floor with an exit to the balcony and a large deck on the rooftop of the building. All rooms were equipped with furniture to simulate a realistic setting. The apartment setting provides entryways on both floors.

As explained before for these two missions we did not introduce the command post system to the firefighters in order to have baseline scenarios close to reality.

A team consists of two firefighters who enter the building and a team lead who stays in a safe place outside. They are connected through the so-called 'lifeline', a rope latched at the belt of one of the firefighters and hold on the other end by the team lead. Using that rope firefighters can find a way back outside. The commander of the mission gives directions to the team-leads who then talk to their respective teams. The commander stays in a dedicated mission control room located in a building next to the actual training facility.

The teams entered the building and checked the apartment room by room. To protect from the potential heat that grows higher close to the roof, firefighters were crawling on the floor and felt their way through the apartment. They stayed close to the walls first and continued to the next room only when they had thoroughly scanned the room for potential victims. In the large living room the firefighters pushed chairs and furniture to the middle of the room while passing the walls. This way they also got some auditive feedback about the contents of the middle of the room.

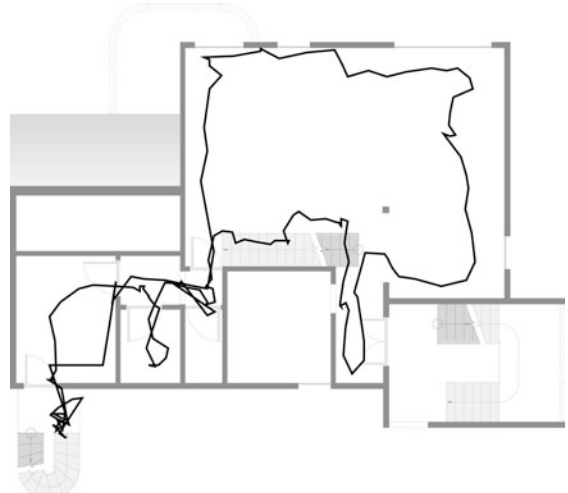

Figure 4. Path of a reconnaissance mission on third floor.

In these missions the teams were given directions by a commander via radio communication. The firefighters had a button integrated in their clothes that they could push to talk and used a bone-microphone inside their helmets that transmit the vibrations of their skullcap as they talking. The firefighters also carried a signal-horn that they use when the mission is completed and they want the team lead to pull back the lifeline, or when a victim is found.

After scanning all rooms firefighters returned, making use of their lifeline as a path finder. They faced some difficulties using the lifeline as it got tangled up in the furniture. After freeing the lifeline they returned and exited the floor on their entrance point [Figure 4].

At the end of the reconnaissance mission, firefighters reported to the commander, drawing a sketch of the building on the floor using pieces of chalk that they carry as part of their standard equipment. Based on their recalls of the mission, they draw the path that they followed and with any other detail that could be relevant to the intervention [Figure 5].

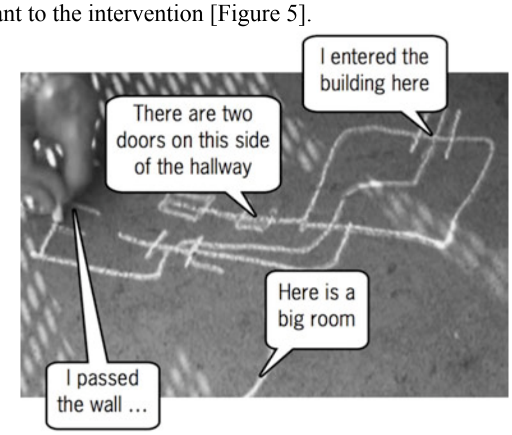

Figure 5. Drawing a map for debrief.

4.1.3 Breakdowns with the Positioning System

On the second day we introduced the command post application to the teams and placed plastic water bottles in the apartment as targets for the reconnaissance missions. We marked the positions of the bottles in the floor plans of the command post application and showed them to the commander only. He used the radio to direct his team to find the bottles and then marked in the command post application the bottles that were already found. The system only showed the position of the firefighters, and not the direction they were heading. This made it initially difficult for the commander to give clear relative directions to his team. After a while he asked his team to move back and forth so that he could identify the direction by the observing the movement of the representation of the firefighter on the command post application. This way the team quickly overcame the problem of missing heading information.

In the middle of the mission the positions coming from the tablet PCs were not always transmitted due to problems in the wireless network. The commander now saw the positions of his firefighters only updated very sparsely [Figure 6]. The virtual characters on the command post application froze for long periods and then suddenly jumped to new positions. After experiencing this behavior for some time the commander started using the pen-tool of the command post application to draw a path following the descriptions the firefighters gave via radio and thus to track their position.

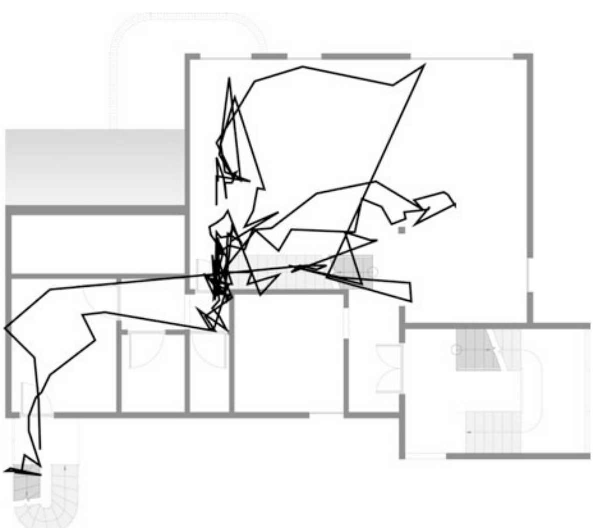

Figure 6. Sparsely updated positioning information.

For our next mission we improved the wireless setup and sent a new team of firefighters to perform the same task that the previous team performed. The positions were now updated continuously so the commander was able to easily track his team. However due to an accidental mistake, a tablet PC facilitator forgot to switch the floor level and thus at a certain point the firefighters were displayed to be on third floor while they were actually on the fourth floor.

This way the description that the firefighters sent via radio did not match the floor plan the commander saw on the command post application. Moreover, after a while the firefighters reported about the end of the room while the captain saw them in the middle of a room as the dotted path in [Figure 7] shows.

Figure 7. Cancelled mission on fourth floor.

The commander tried to solve the problem with his team and as he was not able to find a solution, decided then to cancel the mission and bring his people out of the building.

While the commander believed that his team was still on third floor, they were actually only 2 meters away from the target on the fourth floor when he ordered the team to come back [Figure 7].

In a second attempt he used the command post application to find an alternative path. Through a staircase the firefighters entered the deck and from there on the apartment on fourth floor. Finding all the bottles in the two attempts took more than an hour and thus twice the time of the previous mission. The firefighters were crawling almost all the time during these missions and bore a highly intense physical work.

4.1.4 Hand-Over Situations

In our third mission on day two we wanted to learn more about a typical hand-over situation.

Figure 8. Fixing the lifeline at a door handle.

We chose to send two pairs of firefighters on a reconnaissance mission in the basement of the building. The basement had a more complex structure with many small rooms filled with simulated technical machinery for different kind of exercises. The first team entered, stepped down the stairs, passed a hallway and scanned a room with a large heating installation. Before leaving the building back, they fixed their lifeline to one of the door handles [Figure 8], marked certain positions on their way back with knots in the lifeline and left the building.

In the following debriefing session they draw a map and told their colleagues about the marks and where they had fixed the lifeline. This way the second team could engage into the building, finding their path using the already deployed lifeline. Following the instructions their mission was to further explore the basement by scanning the following two rooms. After doing that and leaving the building the team extended the map initially drawn by the first team and reported other details of their mission to the commander.

4.1.5 Getting Directions
On the third day of our study we asked a team of firefighters to perform a similar mission than the day before, scanning rooms and finding water bottles hidden in rooms in third and fourth floor of the building. In a first mission we handed a map on a sheet of paper to the commander that showed the position of the bottles. Via radio he asked his team questions about their current situation and gave them directions about which way to follow, based on the map. After half an hour the team had found all the bottles and reported back to the commander.

Following, we gave the exact same mission to a different team of firefighters this using our command post application and position information instead of a paper map. This way he could see the position of the bottles and the current position of the firefighters at the same time. With no breakdowns the commander seamlessly directed his team to the bottles. With the experiences of the previous day the team started to change their practice of walking along the walls and directly followed the directions of the commander. This way the team managed to find all bottles in just 15 minutes. While reporting back, however, the team showed problems in drawing a map of the mission findings.

4.2 Joining a Training Exercise
In debriefing sessions after the reconnaissance missions we discussed the possibility of joining routine training exercises ourselves. A commander of the Fire Brigade actively supported this idea and suggested us to be part of a one day training session for firefighters. From his previous experiences in other research projects he was convinced that feeling the weight of the equipment and the heat of fire will change our view of the work of firefighters and could thus be very beneficial for our approach.

Equipped with fire-protective clothes, helmets and breathing apparatuses we took part in four different exercises at the training premises of the Paris Fire Brigade. The exercises were set-up for 20 firefighters showing different levels of experience. Some of them were novices while others had followed the same training many times before and also had a lot of practical experience in real-world incidents. Due to these different levels of expertise, the captains thoroughly described every procedure to ensure that everybody was on track and able to follow the instructions.

For the first activity, a container was used to show how fire propagates, how to effectively extinguish fire and how to deal with smoke in closed spaces. The container was set on fire and we were able to observe the different states of a fire. Afterwards a captain presented different techniques for using the fire nozzle. We could experience extremely high temperature conditions and we learned to crawl on the floor in order to protect ourselves from the raising hot air when getting close to the container. In this exercise the captain made us aware of the importance of air as an insulation medium between skin and clothes. Especially when kneeing on the ground it is important to ensure that the trousers don't get pressed to the skin, and that some air remains in between the different layers of clothing to prevent burnings [Figure 9].

Figure 9. Training with a container set on fire.

In teams we were trained how to use the fire nozzle and to resist the recoil of spouting water. The fire nozzle features very rough ways of interaction with big handles that allow switching it on and off, control the amount and diffusion of water. Using these three control mechanisms, it was possible to change between modes to support different techniques ranging from extinguishing fire in far distances to building protective water shields.

With this preparation, we started the next exercise. In it, we fumbled our way through a tunnel in complete darkness. The tunnel was about 30 meters long and 1.5 meters wide. A fire was then lighted up in the middle of the tunnel. With the breathing apparatus working, we entered the tunnel in teams of two, one researcher and one firefighter. A rope around 2 meters long connected us with the firefighter. In complete darkness one could only see the fire ahead and fumble the nearby wall. This exercise created a highly stressful setting that was physically and mentally demanding.

Walking and crawling we passed through the tunnel following commands of the firefighters who told us how to correctly use the walls as guides to crawl around. A firefighter always uses the outside of his hand to touch doors and walls to protects his life in case of accidentally touching an uncovered electric cable, as the contraction of his muscles will move his hands away from the wall, and prevent him from grabbing the wire.

For the final exercise we entered a fire simulator designed especially to be set on fire in a controlled way from a control console. The exercise was similar to the first one but in a controlled environment. In a kitchen first the oven then the overall ceiling was set on fire. The experience was useful to learn about the distribution of temperature in a burning environment, and the dynamics of heat in a burning environment.

5. PATTERNS AND FINDINGS

5.1 Navigation Practices of Firefighters are Very Sensitive to Changes

We found that the current navigation practices are very sensitive to change and present extremely complex structures of behavior. They are developed out of direct experience over long periods of time and feature multiple implicit attributes that have to be taken into account.

Navigation tools have to be easy enough to be fully handled and to easily recognize causes for problems. Their introduction requires an in-depth training and they have to match existing navigational practices. Instead of replacing existing practices new navigation systems should improve and augment existing concepts or add tools only if they are capable of being integrated thoroughly within the socio-technical system. Furthermore they must be constructed in a way that facilitates their appropriation:

» After introducing positioning information to firefighters they started to change their common practice of moving along the walls by crawling straight through the rooms. This change helped them to finish the mission faster but also negatively influenced their ability to build a cognitive map of the facility and thus constrained them in drawing floor plans.

» Incorrect positioning information motivated breakdowns on the praxis and different reactions of the commanders in charge. Even though a better knowledge of the system might have prevented the captain to cancel the mission, the fact remains that unforeseen problems with technical infrastructure can lead to misinterpretations with potentially serious effects.

» Navigation on the first line of interventions is a very physical and instinctive activity. Firefighters are trained to feel their ways in unknown spaces and thus combine multiple sensory channels. They use their full body and objects to sense their surrounding. This multi-sensorial relationship to the environment is essential to their navigation practices.

5.2 Navigation of Firefighters is a Collaborative Activity

Teamwork is a central element in firefighting. It defines and highly affects every detail of the practices. The strong relationship and responsibility existing between firefighters can be exploited in future designs as a base for collaboration:

» Finding the way out of a potentially dangerous place is a crucial task in firefighters' practices especially when working with breathing apparatus that can provide support for a very limited amount of time only. Firefighters engage missions only in pairs. Each pair carries a lifeline. This rope connects the pair with a team leader waiting in a safe place, usually outside of the building. Firefighters are only able to fulfill their mission and return safe if the team is able to work together seamlessly.

Navigation is a task that involves more than one person, and that might consist of components distributed to multiple users such as shared in- and output mechanisms:

» Analyzing our videos we found a high level of division of labor. In the simulated condition of zero-visibility firefighters were scanning a room. Crawling on the floor they stayed close to the walls fumbling for furniture to get a sense of the room. In most cases they did not probe the same parts of the objects twice but instead talked to each other, sharing their impressions about the space, and building together an idea of the environment.

» Firefighters were crawling along walls to stay oriented. In order to further explore the room, often one of the two firefighters drops the lifeline and relies on his partner instead. They remain connected by grabbing each other or holding their hands. This way one firefighter is able to explore the room more freely while his companion remains safely connected with the lifeline.

It is essential for firefighters to learn from the actions that other firefighters previously performed and they use this knowledge to link information to places:

» A firefighting mission usually comprises more than a single pair of firefighters engaging a certain area. Additionally regulations require firefighters to work no longer than half an hour with a breathing apparatus. Communication thus becomes important to hand-over information. After each mission they debrief and share their experiences with the rest of the team. In these debriefing sessions firefighters use chalk to draw maps and diagrams of the rooms they engaged for reconnaissance. Such diagrams were used by the firefighters both as a communication tool as well as a memory support for building their account of the mission

A navigation system needs to ensure that the relevant navigation information flows between the different involved members of the team and should include ways of pushing information to higher and lower levels:

» A hierarchical work structure requires that relevant information gathered at a low hierarchy level get brought up to mission controllers and from there is transferred to other firefighters working on the first line of intervention.

5.3 Firefighters Improvise to Navigate

Firefighting is intrinsically a highly situated action that requires lots of improvisation and instinctive reactions. Some of the practices improvised emerge in debriefing sessions and then evolve slowly to standard practices. Highly hierarchical structures of command that define a strict set of action patterns provide the firefighters with the required confidence for taking very fast intuitive decisions.

During an intervention, firefighters creatively use tools that are open for different uses to develop ad-hoc solutions. This flexibility must be extended to the design of solutions for navigation [9, 10]:

» Firefighters used simple available tools in diverse ways and tried to make use of the current environment to their benefit. The lifeline was not only used as a retreat path but also as a way to connect team members. In addition they also used the lifeline to mark retreat paths. Once they reached their target they tied the rope at that location. On their way back they marked certain positions with knots. While debriefing and handing-over to the follow-up team they referred to the knots and to the path that they marked.

» Every firefighter carries some pieces of chalk used to draw maps on the floor but also as a tool to mark doors of rooms when the room has been checked or to leave annotations for other firefighters.

» When we marked targets using plastic water bottles the firefighters kept them and used them to feel around the floor as an extension of the arm.

Navigation systems should keep users in full control and allow them to make their own decisions. Furthermore, they should support users in making their decisions and give them rich feedback and full accountability of their inner workings [3].

» When introducing navigational support, barriers and breakdowns in the system forced the firefighters to reflect on the technology and to act in new ways. At the first breakdown situation the commander chose to use the digital pen to keep track of the positions of the firefighters following their descriptions via radio. In a similar situation misleading position information showed the commander his team working on an incorrect floor, but this time he decided to cancel the mission and get his men out to a safe place first.

Firefighters are open and interested in using new tools and in trying things out. We therefore see this environment as a great opportunity for a participatory design approach:

» As the system showed only the position of the firefighters but not the direction in which they were heading, they quickly developed a practice for overcoming this limitation. They started to shortly move back and forth by following the instructions of the team lead to show the heading of movement.

5.4 Firefighters Navigate Using Diverse and Dynamic Sets of Reference Points

A map of the incident site is usually not available for firefighters and even if it is, they cannot be certain about this information. It might be out-dated or the incident itself might have rendered no longer available some of the paths listed on the map. Firefighters resource to a complex set of practices to overcome this problem.

A system that provides navigation support to firefighters has to support the diversity of reference points. Over the course of the incident these reference points may change and a navigational system has to adjust dynamically to new conditions:

» In limited visibility conditions firefighters navigate using the existing infrastructure such as walls and doors. These reference points help them to create a mental model of the environment.

» Firefighters use the lifeline as a retreat path and as a way to define positions along the line using knots.

» During debrief their descriptions referred to existing infrastructure. Simple elements such as doors, corners and windows become reference points. These elements can dramatically change in the course of an intervention, due to the effects of fire.

» Chalk is used to mark places and to store information on-site.

» Outside of the incident site, fire trucks are used as reference points.

» All information gathered by firefighters is transferred to the team lead and then to the captain who works on creating a global picture of the overall scene. In large incidents the teams also include an especially trained firefighter that can draw ad-hoc maps and diagrams to support the strategic reasoning. These maps consist of a mixture of reference points from the existing site, fire and smoke, fire trucks and other equipment.

6. CONCLUSION

The central question was how firefighters of the Paris Fire Brigade navigate today and what we can learn from their practices and their reactions to disturbances to the socio-technical system that they form. In our prototypical positioning system we followed a basic concept where positioning information was displayed to a commander who becomes the central navigator of the overall mission.

When we were initially thinking of providing navigational directions to firefighters, our ideas were close to navigation systems used in cars. Our studies showed instead, that firefighting is a tremendously different environment. As a matter of example, while one has to update maps for navigation systems used in cars rarely, the maps required for firefighting need to stay up-to-date with the current, highly changing situation.

We learned that the central question lies on the implementation of systems for real-world use. Physical conditions, heavy equipment and stress are key factors to design. Assumptions about on-site conditions are almost impossible to be made, a fact that is missed in lab settings. That is why our goal is to create systems that can be feasible with the current technical possibilities [2] and that allow firefighters themselves to develop new ways of navigation. Providing visions for technological solutions is not really difficult. However, providing valuable support based on today available technology is the real challenge.

Today, the lifeline is one of the main tools for navigation in the firefighters' practice. Additionally basic reference points and written tags are used by firefighters when sharing navigation information. In our next design steps we will take these artifacts, which were shaped inside a long tradition, into account. We plan to augment the lifeline and allow firefighters to leave more meaningful information along their way. One of the design issues is to develop a system supporting firefighters on manually placing digital interactive landmarks, thus building an ad-hoc reference system. The design rational behind this concept is that local tags help firefighters to enhance their mental model of the environment and also help them to create reference points that they can share with their colleagues. Tags could be wirelessly connected and exchange information or be isolated entities that store information locally. Other design options include the possibility to display information on the tag itself or equip firefighters with an information in- and output device.

In this way we want to provide an open infrastructure to be used in manifold ways. This infrastructure should support firefighters in building a shared mental model of the environment, allow for creative use in an ever-changing space and share attributes of infrastructure [32]. Rather than telling firefighters where to go we want to support them in creating their own paths.

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