Is the Frontier Shifting into the Right Direction? A Qualitative Analysis of Acceptance Factors for Novel Firefighter Information Technologies

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Abstract The use of innovative information technologies such as unmanned aerial vehicles, intelligent protective clothing, or digital plans is frequently pursued to improve the effectiveness of emergency response processes. So far, however, little effort has been made to study the acceptance of such innovative information technologies by firefighters, who are supposed to use them in their daily practice. In this paper, we present the results of a qualitative study, in which we interviewed 21 members of German fire departments to gain insights into the perceived potential of seven emerging technologies from a Diffusion of Innovations perspective. The results suggest that firefighters find emerging technologies to deliver potential advantages. Factors characterizing disadvantages, the perceived compatibility, and complexity of emerging technologies were viewed as potentially substantial acceptance barriers, however. These factors ought to be taken into consideration when designing new technologies to ensure that they indeed meet the practical needs of the users.

Keywords Firefighter information technologies, acceptance factors, qualitative study, Diffusion of Innovations Theory

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1 Introduction

As a consequence of significant human-made and natural disasters such as terrorist attacks, earthquakes, hurricane strikes, or wildland fires, improving the efficacy of emergency first responders is receiving increasing attention in academia and practice. In recent times, substantial efforts have been made to enhance the organization of fire and rescue departments and to optimize their emergency response processes. As part of these efforts, the use of several new and emerging information technologies has been proposed in scientific literature as well as in practice. Innovative information technologies like drones, ground robots, intelligent protective clothing, and others are supposed to help gathering, sharing, and presenting real-time information, allowing emergency responders to better comprehend the situation at hand and the capabilities of the available resources (Barrado et al. 2010; Carton and Dunne 2013; Juhnke 2011; Kozlovszky and Pavlinic 2014). In theory, they should hence provide a better, more informed basis for firefighters and rescuers to make critical context-dependent decisions on site that are inevitably required to successfully respond to an emergency.

Typically, the use of novel information technologies in emergency response processes is pursued because of their innovative features and the presumed functional potential resulting from these features. Such essentially technology-driven strategies, however, tend to neglect the aspect that information technologies simultaneously are delicate artifacts for emergency responders, for which several additional requirements and constraints exist (Schlauderer et al. 2016). In particular, they have to be easily and efficiently usable during the response to an emergency. During an emergency response process, information technologies are usually only used parsimoniously, that is to the minimum extent necessary to provide a certain required functionality. Consequently, any gain in functionality will likely have to be weighed against the additional overload and/or restrictions that arise for the end users. Yet, literature hardly even discusses the specific factors that positively or negatively influence the adoption of information technologies by emergency responders. Therefore, it remains difficult to assess if and under which conditions a new information technology might indeed be viewed as beneficial and be adopted in practice. If adoption and usage-related requirements are not systematically taken into consideration from the beginning, however, newly designed information technologies run a risk of missing the practical needs of the users. In the domain of emergency response information systems, such concerns are of particular importance since “an emergency system that is not used on a regular basis before an emergency will never be of use in an actual emergency” (Turoff et al. 2004).

With the study presented in the paper at hand, we intend to contribute to the closure of this literature gap by systematically exploring the perceived potential of emerging technologies to support emergency response processes and deriving factors that determine their acceptance in practice. To narrow the scope of the study, we decided to concentrate on examining the acceptance of information technologies that have been suggested to support the emergency response processes of fire departments (FDs). Taking the Diffusion of Innovations (DOI) theory as a lens of analysis, we particularly address the following research questions: "*To what extent do firefighters perceive emerging technologies as suitable to support their emergency response processes? Which factors affect the acceptance of emerging firefighter information technologies?*" To examine these research questions, we decided to adopt a qualitative, interview-based research approach that allows us to obtain rich insights into the context and to interpret the obtained results. Following this goal, we interviewed 21 members of German FDs and asked them about their perception of several emerging technologies, which are currently being suggested in academia and practice. In particular, we wanted to know, which factors positively or negatively influence the acceptance of these technologies. We decided to gather our data from German FDs because we managed to get the support of the national firefighter association. Similar to countries as the United States, Australia, Canada, and France, the firefighter service in Germany is maintained both by voluntary and professional departments. The chosen setting hence allowed us to study the perceptions of members of both groups in depth.

The findings of our research contribute to the building of theories that explain the acceptance of information technologies in the context of emergency response processes. Emergency response processes have specific characteristics, for instance with respect to time, effort, and complexity, which result in specific factors that influence the acceptance of supporting information technologies (Schlauderer et al. 2016). It seems hence appropriate to develop specific theories that explain the adoption of information technologies in such contexts. Furthermore, we deliver a unique overview of emerging firefighter information technologies (FITs) and design requirements that ought to be fulfilled to facilitate the adoption of these technologies in practice. We proceed as follows: in section 2, we describe the background of our study and discuss related work in order to emphasize the existing research gap. In section 3, we describe our research approach in more detail. The results of our study are presented in section 4. In section 5, we discuss the results and elaborate on the implications for academia and practice. We also describe the limitations pertaining to our study. We conclude by summarizing key findings in section 6.

2 Background and Related Work

During the response to an emergency, firefighters have to make critical context-dependent decisions on site. The quality of such decisions depends on the ability of emergency responders to comprehend the situation at hand and the capabilities of available resources (Mehrotra et al. 2004). To a considerable extent, the efficacy of emergency responses is hence determined by the information that is available on the site of an emergency (Danielsson 1998; Yang et al. 2009). Typically, however, firefighters and other first responders only have limited access to real-time information about the emergency site such as, for example, the environmental conditions inside a building, the weather conditions, the status of available resources, casualties etc. For this reason, decisions today often have to be made with a high level of uncertainty and risk.

2.1 Innovative Technologies for Firefighters

To improve this situation, the adoption and use of several novel technologies to gather, share, and present real-time information in the appropriate format and to the right persons has recently been suggested in academia and practice. Multiple ideas have been described how such new and emerging technologies could be leveraged and integrated into emergency response information systems, which shall support emergency response activities such as information gathering, analysis, communication, management of responder resources, and on-site decision making in general (Yang 2007; Yang et al. 2009).

To obtain an overview of innovative FITs that have recently been suggested and to study in how far on-site emergency response systems for firefighters have been discussed in literature, we conducted a structured literature review following the recommendations of Webster and Watson (2002). We queried various databases, including Google Scholar, AIS Library, IEEE Xplore, and the ACM Digital Library, using keywords such as “firefighter”, “fire brigade”, “fire department”, “emergency”, or “disaster” in combination with “information system” or “information technology”. We inspected the titles and abstracts of the resulting articles to sort out irrelevant results. The remaining articles were then inspected in detail using a narrative review method (King and He 2005). In addition, we conducted backward and forward searches on the remaining articles. Based on the results of our literature review, we identified seven frequently discussed types of emerging FITs (T1-T7), which are assumed to support the emergency response process of firefighters (cf. Figures 1 to 3 for illustrations).

In order to facilitate the investigation of an emergency site and the necessary operations, literature particularly discusses the use of *digital plans and guides* (T1). This term is used to describe all sorts of maps and reference guides that are made available in digital form using information technology. They range from digital maps of affected buildings and the surrounding landscape to hydrant maps to technical bulletins and manuals, for instance, to cut open vehicles involved in an accident (Shahid and Elbanna 2015; Johnson 2005; Takahagi et al. 2015). Digital plans are supposed to deliver information that can efficiently be accessed, searched, updated, and presented using mobile devices, which are either specialized to certain types of plans or provide access to multiple sorts of plans in an integrated approach (Koch et al. 2007; Freßmann et al. 2007).

To better coordinate emergency responses, it is frequently proposed in literature to introduce *on-site emergency response information systems* (on-site ERISs, T2), which provide a shared platform to gather, present, and share relevant information on site (Prasanna et al. 2011; Ha 2012; Luyten et al. 2006; Majchrzak and More 2011). On-site ERISs range from simple platforms, which have to be filled with information by hand (Monares et al. 2009), to systems, which are fed with live data from sensors (Granlund et al. 2010; Lewandowski et al. 2009; Luyten et al. 2006; Panangadan et al. 2012; Yang et al. 2009), to systems, which also provide active support for the decision-making by suggesting possible actions (Kalabokidis et al. 2012). On-site ERIS are usually hosted in one of the command vehicles and communicate using mobile technologies.

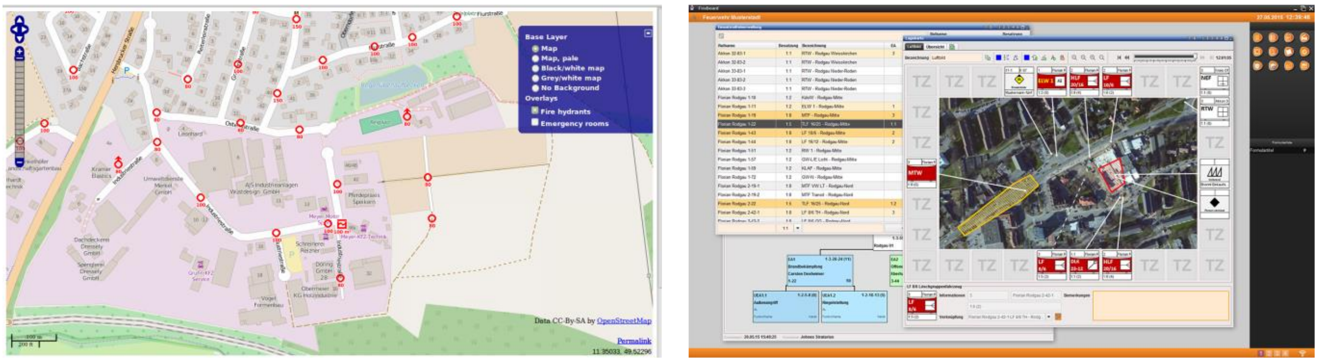

Figure 1. Illustrations for T1 and T2: digital hydrant plan “OpenFireMap” (left side[1]) and on-site ERIS “fireboard” (right side[2])

To facilitate the investigation and monitoring of an emergency site, literature also emphasizes the potential of *unmanned aerial vehicles* (UAVs or drones, T3) (Everaerts 2008; Quaritsch et al. 2011; van Persie et al. 2011; Barrado et al. 2010). Among others, UAVs are recommended to be used to acquire a visual impression of an emergency site, to measure the presence of hazardous contaminants, or to determine the location of fire pockets. They can be used as a singular unit or in combination with other UAVs (i.e., as drone swarms). Usually, they have to be controlled by a ground pilot although approaches building upon autonomous aerial vehicles exist, too (Maza et al. 2011).

To investigate hazardous or otherwise inaccessible areas of emergency sites, literature often suggests the use of *unmanned ground vehicles* (UGVs or on-ground robots, T4) (Hong et al. 2014a; Hong et al. 2014b; Kim et al. 2013). There also exist UGVs to actively support rescue and firefighting operations. Especially the latter types of UGVs are typically equipped with complex technology to transport equipment, extinct fire, or take samples of materials (Hee 2015; White 2015).

To support the execution of emergency response operations, literature furthermore proposes the use of *intelligent protective clothing* (T5). Intelligent protective clothing is presumed to have a particularly high potential to assist firefighters during their operations (Kozlovszky and Pavlinic 2014; Talavera et al. 2012; Smart@fire 2013) as it does not only shield them from the surrounding hazardous environment, but is simultaneously equipped with sensors to measure gases, outside temperature, and to monitor the health status of the firefighter. There also exist approaches to measure and transmit the remaining air

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[1] Cf. http://wiki.openstreetmap.org/w/index.php?title=DE:OpenFireMap&oldid=1210433
[2] Cf. http://fireboard.net/en/fireboard/

supply, the breathing status, or even the distance between foot and ground to prevent fallings in conditions with poor visibility (Carton and Dunne 2013; Park et al. 2015; Salim et al. 2014; Piotrowski et al. 2010).

Figure 2. Examples for T3 and T4: UAV "Phantom 3" (left side[3]), UGVs "taurob tracker" (middle[4]) and "LUF 60" (right side[5])

Several authors moreover suggest the use of *augmented reality* (T6) to display relevant information such as the remaining air supply, temperature, walked distance, or evacuation alerts directly into the field of vision (Klann and Geissler 2012; Juhnke 2011). Among others, literature discusses the use of head-mounted displays or the projection of information onto the breathing mask to achieve this goal (Bretschneider et al. 2006; Wilson J. et al. 2005). More complex systems also aim at visually accentuating important landmarks such as exits, evacuation routes etc. Ideally, they are controlled by gestures.

To support the operations of firefighters, literature additionally proposes the use of technologies that enable *indoor positioning* (T7) (Klann 2009; Klann and Geissler 2012; Ramirez et al. 2009; Ramirez and Dyrks 2010; Ramirez et al. 2012). Such technologies usually build upon ad-hoc networks of sensors (so-called landmarks or breadcrumbs), which firefighters deploy as they move into a building. Once deployed, the landmarks can, for instance, be used to specify the relative locations of various points of interest (e.g. the location of casualties) or to calculate shortest paths to an exit (Liu et al. 2010). Besides, there also exist approaches that aim at an absolute positioning, for instance by triangulating GPS and WLAN information with beacons that are installed outside the building (Wilson et al. 2007; Will et al. 2012).

While novel FITs such as the ones discussed above provide additional functionality that can be helpful when responding to an emergency, they also introduce complexities and risks such as a heightened weight of the equipment, increased dependability concerns, higher administrative efforts, and/or restrictions due to a limited battery run-time. It is hence unclear, if the suggested technologies will indeed be viewed as beneficial or if the disadvantages will prevail in practice.

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[3] Cf. http://www.dji.com/de/product/phantom-3-pro

[4] Cf. http://taurob.com/produkte/ugv-taurob-tracker/

[5] Cf. http://www.luf60.at/ff-luf60-einsatzgebiet/

Figure 3. Illustrations for T5-T7: Transmission of air supply using “alphaCONTROL2” (left side[6]), augmented reality breathing mask “alphaHUD” (middle[7]), and “Landmarks” deployed as bread-crumbs for indoor positioning (right side, Ramirez et al. (2012))

2.2 Related Work

During our literature survey, we therefore specifically searched for articles, in which the acceptance of emerging FITs had been investigated. The results of our survey show that the acceptance of emerging technologies by emergency responders in general hardly has been in the focus of academia. Several articles for instance rather focus on analyzing and managing the response to large-scale disasters such as earthquakes, tsunami or hurricane strikes (Neal 1997; Ainuddin and Routray 2012; Shaw 2006; Mallick et al. 2005; Janssen et al. 2010; Bharosa et al. 2010). While these articles are clearly relevant to the field, they concentrate on a specific aspect. Most of the research described there is focused on the extraordinary situation of a disaster and not aiming at supporting the daily routines of firefighters.

We also found articles that focus on information technologies and information systems that are supposed to support firefighters in their daily work. In particular, the coordination of emergency response activities has been in the focus of various studies (Bunker et al. 2015). Among others, researchers have analyzed coordination patterns, which occur during the response to emergencies, and dependencies, which exist between emergency response systems and information technologies in order to propose coordination mechanisms (Shen and Shaw 2004; Chen et al. 2008). Yet, such approaches rather focus on the management of emergency response processes rather than on the underlying technologies or their acceptance.

As discussed in the previous section, there furthermore exist several articles, which propose the use of novel information technologies to facilitate the work of firefighters. These articles have in common that they propose specific technologies for FDs and discuss the supposed benefits in detail. None of them examines how firefighter teams perceive the proposed technologies, however. For instance, Yang et al. (2009) propose an on-site emergency response system that provides real-time

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[6] Cf. http://s7d9.scene7.com/is/content/minesafetyappliances/alphaPersonalnetwork%20Bulletin%20-%20DE
[7] Cf. http://s7d9.scene7.com/is/content/minesafetyappliances/alphaPersonalnetwork%20Bulletin%20-%20DE

information about the environment, casualties, responders, and available resources to support the decision-making of emergency response teams. While they pronounce that emerging technologies, such as wireless sensor networks, RFID or wireless communication “might make this [such a system] realistic” (Yang et al. 2009), they do not elaborate on the acceptance of such technologies. Instead, they emphasize that the use and the acceptance of such emerging technologies is a prerequisite for the formation of more sophisticated emergency response management systems like the one proposed in their work.

To our best knowledge, there seems to exist only one related approach that analyzes emerging technologies, which have been proposed to support the emergency response process, and systematically focuses on the user acceptance (Schlauderer et al. 2016). Although emerging technologies offer new functionalities, little can hence be said about their true potential to enhance the operations of FDs. It appears therefore necessary to examine the perception of emerging technologies by the end users more closely and to identify the factors that influence the acceptance. Such factors ought to be taken into account from the beginning when designing new information technologies for firefighters in order to ensure that they indeed meet the practical needs of the users.

2.3 The DOI Theory

From a theoretical perspective, the novel functionality added by an emerging FIT can be seen as an innovation. Broadly, an innovation is defined as “an idea, practice, or object that is perceived as new by an individual or other unit of adoption” (Rogers 1995). The assimilation of innovations is explained by innovation diffusion theories such as the Diffusion of Innovations (DOI) Theory, the Technology Acceptance Model (TAM), or the Theory of Planned Behavior (TPB), which describe the assimilation process and generic factors that determine the rate of assimilation. Fundamentally, these theories have many factors in common. In the past, they moreover have successfully been used to explain the assimilation of information systems, tools, and technologies (e.g. Kartas and Goode 2012; Hossain and Quaddus 2015; Zhou 2015). These theories can hence provide a starting point for the identification of specific factors, which determine the assimilation of FITs. For our investigation, we chose the broadly applicable DOI Theory as a lens of analysis because it delivers a well-established perspective that has been widely used in information systems research already (Tornatzky and Klein 1982; Moore and Benbasat 1991). It defines five perceived attributes of innovations as generic factors, which generally affect the willingness of individuals to assimilate those (Rogers 1995):

Relative advantage:	the extent to which an innovation is viewed as better than the concept it supersedes.
Compatibility:	the extent to which an innovation is viewed as consistent with preferred practices.

Complexity:	the extent to which an innovation is viewed as difficult to utilize.
Trialability:	the extent to which an innovation is viewed as easy to experiment with.
Observability:	the extent to which an innovation is viewed as visible to others.

Meta-analyses of already conducted studies show that not all attributes are relevant to explain the adoption of an innovation in a mandatory usage context. In such contexts, the assimilation of an innovation seems not so much to be a matter of accessibility (i.e. trialability) or personal standing (i.e., observability). It rather seems to be a matter of relative advantage, compatibility, and complexity, which were frequently found to be significant determinants in literature (Tornatzky and Klein 1982). For this reason, we decided to use a consolidated model consisting of the above-mentioned three factors as a theoretical fundament to identify specific factors, which determine the acceptance of FITs (cf. Figure 4).

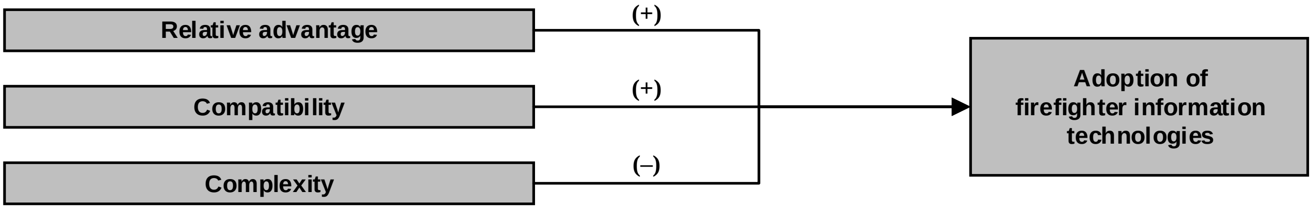

Figure 4. Consolidated model of generic acceptance factors

3 Research Method

As emphasized in the research questions, our goal is to gain a better understanding of the potential of novel FITs and the factors that influence their acceptance in practice. To achieve this goal, we wanted to know how such technologies are perceived, i.e. in how far firefighters expect them to deliver advantages, to be compatible with the way they prefer to work or to increase complexity. In particular, we chose to examine the perception of the emerging FITs that we discussed in section 2.1. In new or emerging research fields, in which little is known about the object of investigation, literature particularly recommends qualitative research designs (Rubin and Babbie 2006). Following this recommendation, we decided to adopt an exploratory, qualitative research method. This not only allowed us to gain in-depth insights into the perception of emerging technologies by their potential users but also to explore why certain technologies are perceived in a specific way.

To obtain the required data, we chose to conduct interviews with experts in the field. Generally, an expert is characterized as someone who has privileged knowledge on the subject matter (Bogner et al. 2009). In our case, the term “expert” hence refers to someone who does not only know about the emerging technologies but also has a profound understanding of the way firefighters work and use technologies on site. Since experts typically contribute extensive insights into the domain that is investigated, the number of interviewees can be rather low as long as they are carefully selected (Bogner et al. 2009). We decided to conduct semi-structured face-to-face interviews, as they are considered the superior data collection technique for interpretive investigations (Yin 2014). By establishing a common, standardized interview guideline, semi-structured interviews ensure comparable results. Yet, by allowing the interviewer to adjust questions and to ask for explanations if necessary, the results also provide a greater breadth than fully structured interviews.

Our interview guideline consisted of three parts. The first part contained questions about general and demographic information, such as what type of FD the interviewee works in, how many emergency response operations the FD approximately conducts in a year, or how many firefighters work in the FD. Besides that, we also gathered information about the personal background of the interviewee, for instance, what kind of qualifications (s)he had, which position (s)he had in the FD, or how (s)he would rate his/her affinity towards information technology. The second interview part began by introducing the seven emerging technologies to ensure that all participants had a common understanding of each technology. Afterwards, we asked for the acceptance of the technologies based on the DOI Theory as lens of analysis. For each technology, we asked the experts for perceived advantages and disadvantages. To find out if a technology fits into the working processes of the firefighters, we furthermore wanted to know how the technologies would have to be designed to be compatible with the way firefighters prefer to work. Third, we asked for characteristics of the technologies that are found to reduce or increase complexity during emergency response operations. In the third interview part, additional open questions were posed. For example, we wanted to know, which technologies were currently in use in the FD, which technologies they intended to introduce in the future, and which potential they see for FITs overall. Altogether, the conducted interviews closely followed the recommendations proposed by Myers and Newman (2007).

We gathered data at seven FDs that were distributed all over Germany. To investigate if the perception of innovative technologies varies between different types of FDs, we included participants from two professional FDs (PrFDs), three volunteer FDs (VFDs), and two private FDs that were housed in large plants (PlFDs) into our study. The investigated PrFDs consisted of 450 to 900 firefighters and conducted between 7.000 and 25.000 emergency fire operations a year. The selected VFDs encompassed 80 to 390 firefighters and conducted 280 to 900 emergency fire operations each year. The examined PlFDs consisted of 70 to 100 firefighters, who were responsible for 200 to 350 emergency fire operations each year.

In each FD, we interviewed three experts, thus resulting in a total of 21 interviewees. We selected the experts carefully so that each expert had profound field experience. Moreover, all chosen experts intensively worked together with the other firefighters of the department and were therefore able to reflect the experiences of the team. We decided to interview experts from all command levels – i.e. the strategic, the tactical, and the operational command level – of each FD. The strategic command level consists of fire chiefs and assistant fire chiefs who are responsible for the administration of the department. Among others, they have to decide about new investments and to drive the strategic development of the FD. The tactical command level is made of platoon leaders who are responsible for the way emergency response operations are conducted. Among others, they have to keep track of personal scheduling and typically act as incident commanders on site. The operational command level consists of squad leaders (leading squads of three to nine members) and ordinary firefighters. They mainly are concerned with the enforcement of activities on site. Interviewing experts from different command levels allowed us to assess in-depth information about the way the technologies are perceived from multiple perspectives. In so doing, we were not only able to gain insights into possible tactical advantages of a new technology, but also into its applicability from an operational perspective. Collecting data from several command levels, therefore, contributed to improving the quality of our results. Unfortunately, some of our designated interview partners were called to emergency responses immediately before or during the interviews. Because of this development, we could not realize our plan of covering all three command levels in two of seven FDs. All in all, we interviewed eight experts who acted as fire chiefs or assistant fire chiefs, six platoon leaders, and seven members of the operational command level. All interviews were conducted face to face in late 2015 and early 2016 in the interviewees' offices. On average, the interviews took 90 minutes and varied between 63 and 138 minutes. All interviews were recorded and transcribed for analysis afterward.

Using the interview statements gathered during the second part of the interviews, we searched for specific factors that hinder or foster the acceptance of a technology. In the first step of the analysis, we used open coding techniques. Doing so allowed us to identify recurrent statements in the data, which we later on thematically grouped in a way that each topic covers a specific acceptance factor (Miles and Huberman 1999). Employing the concept of so-called in-vivo codes (Given 2008), we labeled each topic with a denomination that was predominately used by the interviewees to describe a concept. Following this procedure, we identified several factors that influence the acceptance of the examined technologies and that were recurrently mentioned by the interviewed firefighters. In each group, we furthermore analyzed the data for consistent and diverging statements to get an in-depth understanding of how the examined technologies were perceived and why this was the case. The results of our analysis are described in the following section.

4 Results

We structure the presentation of the results according to the seven technologies (T1-T7), which we introduced in section 2.1. For each technology, we provide a table showing the frequencies of the factors that were mentioned in the interviews. The factors are arranged according to the generic factors of the DOI theory. We furthermore illustrate observed differences between the different interviewee groups, i.e. between FD types and command levels. Group-specific differences of 0.5 standard deviations or more compared to the totally observed factor frequency are marked in bold and discussed in section 5.2. Accompanying the tables, we furthermore depict the most revelatory interview statements for the factors in the text. In so doing, we make our conclusions regarding the factor perceptions transparent. Due to existing space limitations, we limit the discussion to factors that have been emphasized by at least half of the interviewees. We refer to individual interviewees with pseudonyms consisting of the FD type (Pr for PrFDs, V for VFDs, and Pl for PlFDs), the command level (S for strategic, T for tactical, and O for operational) and a sequential number, resulting in codes like Pr-S-1. To make our analysis traceable, we keep original interview statements (which we faithfully translated into English language) and our interpretations separate.

4.1 Digital Plans and Guides

With respect to digital plans and guides (T1), we identified six factors characterizing relative advantages (five advantages and one disadvantage), nine compatibility-related factors, and six factors concerning complexity (cf. Table 1). More than half of the interviewees mentioned compactness (62%), a time advantage (62%), an informational advantage (57%), and higher flexibility (52%) as relative advantages of digital plans and guides over ordinary plans on paper. No relative disadvantage was consistently emphasized by at least half of the participants. Most prominently, the experts found the more compact storage of data to be an advantage of digital devices: "*With large plans on paper, I would almost have to build an extension into my car if I wish to carry everything with me*" (V-T-1). "*For example, think of Hommel [German HAZMAT guide] – a giant volume. We have the complete edition on our command vehicle […] and I could have all this on my tablet as well*" (Pr-S-2). The interviewees also found digital plans and guides to provide a time advantage when it comes to retrieving information: "*When I have this in digital form, […] I can relatively quickly find the things I really need*" (Pr-O-2). "*[…] the squad leaders could already have a look at it during the drive and could get a rough idea where the nearest hydrant is located. This of course means a huge time advantage*" (V-S-1). The interviewees moreover stated that digital plans and guides provide firefighters with all the information needed, thus creating an informational advantage: "*We didn't have such detailed knowledge before. Now […] we can actually zoom into individual floors […]. So, we have new and other options here*" (Pl-S-2, 4.1a). "*If you have a digital plan plus several other databases, which can be accessed, then you have everything you need on your device*" (V-T-3). Finally, the experts perceived digital plans to be more flexible: "*The biggest problems arise if you are given a hydrant map on paper that only contains an excerpt […] and the hydrant located 20 meters* *farther away is not included. […] With digital maps, I can also browse the neighborhood with zoom or search functions*" (V-T-3). "*I can mix different views. I can view hydrants […] but also add gas pipes to the map*" (V-O-1).

Table 1. Acceptance factors for digital plans and guides

Category	**Factor**	**Total**		**Type of FD (%)**			**Command Level (%)**		
		n	**%**	**PrFD**	**VFD**	**PlFD**	**strat.**	**tact.**	**oper.**
Relative Advantage	Compactness (+)	13	62	50	**89**	**33**	50	67	71
	Time advantage (+)	13	62	67	56	67	75	**33**	71
	Informational advantage (+)	12	57	50	56	67	63	50	57
	Flexibility (+)	11	52	**17**	67	67	38	67	57
	Currentness of data (+)	10	48	**17**	56	67	50	67	29
	Dissemination to on-scene forces (–)	4	19	33	11	17	25	17	14
Compatibility	Intelligibility	19	91	100	89	83	100	83	86
	Reliability	17	81	**50**	89	100	63	100	86
	Simplicity	15	71	67	67	83	75	67	71
	Robustness	14	67	67	67	67	63	50	86
	Timing constraints	10	48	50	44	50	50	50	43
	Legal issues / privacy	6	29	50	33	**0**	25	50	14
	Handiness	1	5	0	11	0	13	0	0
	Longevity	1	5	0	11	0	0	0	14
Complexity	Maintenance / updating effort	11	52	33	44	**83**	63	50	43
	Organizational effort	8	38	17	56	33	38	**67**	14
	Training effort	7	33	33	44	17	38	33	29
	Evaluation effort	2	10	0	11	17	0	17	14
	Information overload	1	5	0	11	0	0	**17**	0
	Personnel effort	1	5	0	0	**17**	0	**17**	0

Regarding the compatibility of systems that realize digital plans and guides, 91% of the interviewees addressed the factor intelligibility. At least two-thirds of the experts named reliability (81%), simplicity (71%), and robustness (67%). Above all, the participants emphasized that digital plans need to be intelligible: "*It is important that plans – especially digital ones – are not too overloaded*" (Pl-S-1). "*If it is designed reasonably and clearly […] it is an interesting thing*" (V-S-1). Furthermore, they stated that online as well as offline versions would always need to have a backup solution in order to be reliable: "*If you don't have an online connection, you are screwed. I don't know to what extent such a thing has an offline version – there would have to be a backup*" (V-T-2). "*The whole thing can crash or fail. I need a fallback solution*" (Pl-S-1, 4.1b). The experts stated that the systems providing digital maps and guides have to be simple and intuitively usable: "*Ideally, I do not have to extensively study the manual. Instead, it has to be as self-explanatory as possible*" (V-O-3). "*There is a motto saying the comparative of 'foolproof' is 'firefighter-suitable'*" (Pl-T-2, 4.1c). The robustness of such systems was further highlighted as an important factor for the technology to fit into the work routines of firefighters: "*We are working in environments ranging from minus 20° C to plus 40° C, from freezing rain to bright sunshine. The devices must withstand these conditions*" (V-S-2, 4.1d). "*What if I drop the thing? Then it is broken, as is the plan saved on it. So, it must be a system that can withstand something*" (V-O-2, 4.1e).

Concerning complexity, the maintenance and updating effort was the only factor emphasized by more than half (52%) of the interviewees: “*I permanently have to check if the battery is still charged*” (V-O-2). *“First, I must have access to the data. It is useless having a high-end device if I have no data to display on it*” (Pl-S-3).

4.2 On-Site Emergency Response Information Systems

With respect to on-site ERISs (T2), we found 13 factors characterizing relative advantages (seven advantages, five disadvantages, and one neutral factor that was perceived somewhat inconsistently), eight compatibility-related factors, and six concerning complexity (cf. Table 2). Only one relative advantage, and no disadvantage, was emphasized by more than half of the interviewees, though. 67% of the experts found that on-site ERISs provide an informational advantage: “*You will not get around certain computer-aided technologies. You cannot process all the information you need by hand anymore. It has just become too complex for that*” (V-S-3). “*A real benefit, a real milestone will be reached once I have an electronic situation report, extracting as much information as possible from systems that exist anyway. […] Of course, you could extend this with sensor networks or decision support systems*” (Pl-S-3, 4.2a).

Table 2. Acceptance factors for on-site emergency response information systems

Category	Factor	Total		Type of FD (%)			Command Level (%)		
		n	%	PrFD	VFD	PlFD	strat.	tact.	oper.
Relative Advantage	Informational advantage (+)	14	67	67	78	50	63	67	71
	Increased capacity / documentation (+)	8	38	33	44	33	25	33	57
	Time advantage (+)	8	38	33	33	50	50	33	29
	Accuracy (+)	7	33	33	44	17	**0**	**67**	43
	Load removal from radio (+)	4	19	17	22	17	0	**50**	14
	Compactness (+)	2	10	17	11	0	13	17	0
	Structuring (+)	2	10	0	11	17	13	17	0
	Loss of competences (–)	10	48	67	44	33	50	50	43
	Lack of expressive power (–)	7	33	33	22	50	25	50	29
	Limited range of application (–)	3	14	**33**	11	0	25	0	14
	Less communication (–)	2	10	0	11	17	0	17	14
	Weight (–)	1	5	0	0	**17**	0	**17**	0
	Flexibility (o)	6	29	50	22	17	38	17	29
Compatibility	Intelligibility	18	86	100	78	83	88	83	86
	Simplicity	17	81	100	67	83	75	83	86
	Reliability	12	57	33	67	67	63	67	43
	Robustness	7	33	33	33	33	38	33	29
	Legal issues / privacy	5	24	**50**	11	17	25	33	14
	Timing constraints	5	24	17	33	17	13	17	43
	Adaptability	4	19	17	22	17	25	17	14
	Longevity	2	10	17	11	0	13	17	0
Complexity	Decision-making complexity	11	52	50	44	67	38	50	71
	Training effort	8	38	50	56	**0**	38	17	57
	Information overload	7	33	17	22	**67**	25	50	29
	Personnel effort	6	29	**0**	**56**	17	38	33	14
	Maintenance / updating effort	3	14	17	22	0	25	17	0
	Organizational effort	3	14	17	11	17	25	0	14

The compatibility factors most often stated by the experts were intelligibility (86%), simplicity (81%), and reliability (57%). The factor intelligibility largely refers to the way information is displayed: "*[The way the information is displayed should be] based on common knowledge. […] That is a basic requirement. […] The things displayed must look exactly like the things we had on the blackboard or on paper before*" (Pl-S-2). "*It needs to be organized in a way that you can process all necessary information at a glance*" (Pr-S-1). The participants furthermore emphasized that on-site ERIS must be simple and intuitively usable: "*Concerning the handling, I consciously demand that they are firefighter-proof*" (V-S-3, 4.2b). "*They have to make use of technology, which is known by nearly everybody all over the country*" (Pr-S-2). Regarding the reliability, the participants referred to the consequences of malfunctions: "*Software solutions sometimes have the disadvantage that they don't work failure-free, which would be fatal during an operation*" (Pr-O-1). "*Equipping all firefighters with sensors makes me think of this: the more technology is built into a car, the more can break down*" (V-T-2). "*You cannot blindly rely on such systems. Actually, you always have to act on the assumption that such a system can crash*" (Pl-T-2, 4.2c).

A potential problem with on-site ERISs is seen in an increased decision-making complexity by 52% of the participants. While the before-mentioned informational advantage could facilitate the decision-making, the vast amount of information and the ability to document every decision could also increase complexity: "*Too many moving images in the decision-making room just hamper the decision-making*" (Pl-S-3). "*By default, everything is documented. […] If the district attorney comes to investigate the cause of something that has gone wrong afterwards, this data can, of course, be inspected and used to interrogate or even to hold responsible the decision-maker*" (Pl-T-1). In addition, the potential influence of decision support systems was seen critically: "*There is a danger that one might rely on things proposed by the system too quickly and that it is just an automated decision – but not necessarily the right one. […]. I see that as a danger*" (V-T-1).

4.3 Unmanned Aerial Vehicles

With respect to the acceptance of UAVs (T3), we identified six factors referring to relative advantages (four advantages and two disadvantages), eight that influence the perceived compatibility, and eight factors concerning complexity (cf. Table 3). Regarding the relative (dis-)advantages, all experts emphasized that UAVs provide an informational advantage compared to traditional means of intelligence. 57% of the interviewees furthermore pointed to a time advantage. As a relative disadvantage, 57.14% of the participants saw the limited range of application. The informational advantage is created by providing an additional perspective on the incident area. This perspective helps to form a personal impression of the situation: "W*e are certainly lacking intelligence from above […]. And that would definitely be beneficial*" (Pr-T-1, 4.3a). "*I could have a live picture from the distance. If I send in a firefighter, I can only hear what he reports over radio and don't have an overview* *of my own*” (Pr-S-1). Deploying UAVs can furthermore accelerate intelligence processes, especially when facing difficult areas: “*I’m probably faster with an unmanned aerial vehicle*” (Pl-T-1). “*Often there are no access points to an object so that one cannot see much from the ground. If you have an aerial view or a thermal image from above, you acquire a situational overview faster*” (V-S-1). The limited range of application was, however, seen as a disadvantage: “*I would […] deploy it selectively and would not let it take off during tasks such as fighting room fires […]. I don’t think that I would rely on an unmanned aerial vehicle in those situations*” (V-S-2). “*How often will such a thing be deployed?*” (Pr-O-2).

Table 3. Acceptance factors for unmanned aerial vehicles

Category	**Factor**	**Total**		**Type of FD (%)**			**Command Level (%)**		
		n	**%**	**PrFD**	**VFD**	**PlFD**	**strat.**	**tact.**	**oper.**
Relative Advantage	Informational advantage (+)	21	100	100	100	100	100	100	100
	Time advantage (+)	12	57	33	78	50	50	**83**	43
	Currentness of data (+)	8	38	17	56	33	50	33	29
	Safety (+)	4	19	33	22	0	0	0	**57**
	Limited range of application (–)	12	57	**83**	44	50	50	33	**86**
	Space requirements (–)	2	10	17	0	17	**25**	0	0
Compatibility	Robustness	17	81	100	67	83	75	83	86
	Simplicity	17	81	100	78	67	88	67	86
	Legal issues / privacy	10	48	33	**78**	**17**	63	50	29
	Operating time	8	38	50	33	33	25	17	**71**
	Reliability	6	29	17	33	33	**0**	**83**	14
	Range	3	14	0	**33**	0	13	**33**	0
	Loading capacity	2	10	17	11	0	**25**	0	0
	Timing constraints	1	5	0	11	0	0	0	14
Complexity	Personnel effort	14	67	67	67	67	75	67	57
	Training effort	12	57	**100**	56	**17**	50	67	57
	Operational complexity	11	52	67	56	33	63	33	57
	Maintenance / updating effort	10	48	**17**	56	67	50	50	43
	Organizational effort	10	48	50	44	50	63	67	**14**
	Evaluation effort	4	19	17	22	17	25	17	14
	Information overload	2	10	17	0	17	13	0	14
	Decision making complexity	1	5	**17**	0	0	0	**17**	0

Robustness and simplicity were each stated by 81% of the interviewees as important compatibility factors. Robustness is required as the UAVs must withstand weather conditions and other extremes present at the incident area: “*It would have to be able to fly in the rain […] and it should be autonomous enough to compensate wind drifts*” (Pr-S-1, 4.3b). “*How close can I fly above a fire source without getting problems due to the thermal lift? These things don’t have much weight, so […] they will quickly get problems with thermal lift*” (V-O-2, 4.3c). Simplicity seems to be important as the UAV has “*to be operated easily*” (Pr-O-3). “*I want to put it on the ground, specify the point of the disaster on a map […] and the flying altitude […] and it automatically approaches the destination to deliver the image*” (V-S-1).

Two-thirds of the interview partners stated the personnel effort as a factor that increases complexity. 57% of the experts moreover mentioned the required training effort. 52% criticized the operational complexity. The personnel effort apparently is a pressing issue: "*If UAVs shall be available anytime, you need several people on every shift who can operate or fly these things. I see it in our department: personnel is scarce. […] The question is who operates them*" (Pl-T-1). The training effort needed for operating an UAV is stated as a complexity factor as well: "*If you need people who operate them, then there will certainly be an according training effort*" (Pl-S-2). "*I find that problematic: not everyone can do that and you will definitely need people who have trained it*" (V-T-3). The interviewees stated several issues that increase operational complexity: "*Airspace security must be considered, of course. Especially in large-scale responses, where police and rescue helicopters are on scene as well*" (V-S-1). "*Having smoke emission, I can easily get into some blind spots. […] So, I need to know where to move, what the wind direction is, and so on*" (V-S-3).

4.4 Unmanned Ground Vehicles

Regarding the acceptance of UGVs (T4), we identified eight factors that characterize relative advantages (four advantages and four disadvantages), eight compatibility factors, and four concerning complexity (cf. Table 4). With respect to relative advantages, all interview partners stated that dispatching UGVs instead of human forces increases safety. 67% furthermore highlighted that robots could open up new fields of operation. Opposed to that, there are three relative disadvantages that were each named by more than 67% of the participants. Those are the limited range of application (85%), the slowness (76%), and the limited set of capabilities (71%). Regarding safety, the loss of an UGV was found to be acceptable compared to putting human life into jeopardy: "*There simply is no human life in danger. If necessary, UGVs can be sacrificed. Whether such a thing costs tens, hundreds, or thousands of Euros – it still is nothing compared to a human life. And that is a fact, which you cannot disregard*" (V-O-3, 4.4a). "*If the situation is very critical, especially in hazardous or explosive areas, it is common [… and] absolutely reasonable as you are able to decrease the risk*" (Pl-S-2). Apparently, robots can moreover open up new fields of operation: "*In case of a giant fire, I can't send anyone in there anyway – I can, however, send that thing in and still fight the fire from inside*" (V-S-2, 4.4b). "*It can provide capabilities that humans can absolutely not provide, especially by carrying heavy equipment into areas that are very difficult to access*" (Pl-S-3). The range of application of UGVs was, however, estimated to be rather limited: "*To collect intelligence in the context of hazardous materials, radioactivity, or collapses, UGVs might be good – for firefighting activities they are rather not*" (V-T-1). "*The question is how many operations in everyday life such a robot really has. I rather see this suitable for special operations but currently not for daily routines*" (Pr-O-2). For many applications, UGVs were moreover found to be too slow: "*They are brutally slow. And I think that alone is an obstacle for fire departments*" (V-O-3). "*The actual firefighting procedure gets postponed. Because it more or less only explores the area and does not initiate any firefighting procedures. If my men go in, they have water with them*

[…] and can immediately get to work" (Pl-S-1). Moreover, the interviewees criticized the limited set of capabilities during search and rescue missions: "*What it cannot do compared to humans equipped with respiratory protection is, for instance, open a wardrobe door and look if a child is hiding inside. […] The robot would say the room is cleared although someone is still in there. I think during inside operations I would not use such a thing, because it lacks the capabilities of a human, namely to look underneath a bed, to open a wardrobe, or to strobe a bed's surface*" (V-T-1, 4.4e). "*They quickly reach their limits when encountering doors or barriers which are often insurmountable for them*" (Pr-O-3).

Table 4. Acceptance factors for unmanned ground vehicles

Category	Factor	Total		Type of FD (%)			Command Level (%)		
		n	%	PrFD	VFD	PlFD	strat.	tact.	oper.
Relative Advantage	Safety (+)	21	100	100	100	100	100	100	100
	New fields of operation (+)	14	67	83	56	67	75	67	57
	Informational advantage (+)	8	38	33	33	50	**13**	50	57
	Time advantage (+)	2	10	0	0	**33**	0	17	14
	Limited range of application (–)	18	86	83	89	83	75	100	86
	Slowness (–)	16	76	**50**	**100**	67	75	83	71
	Limited set of capabilities (–)	15	71	67	78	67	88	**33**	86
	Space requirements (–)	8	38	17	56	33	50	33	29
Compatibility	Simplicity	16	76	**100**	67	67	75	83	71
	Robustness	15	71	83	67	67	75	83	57
	Adaptability	8	38	**67**	33	17	38	50	29
	Operating time	4	19	33	11	17	13	0	**43**
	Range	4	19	17	11	33	0	17	**43**
	Reliability	3	14	17	22	0	13	**33**	0
	Timing constraints	3	14	17	0	**33**	13	17	14
	Legal issues / privacy	1	5	0	11	0	0	**17**	0
Complexity	Training effort	10	48	50	44	50	50	67	29
	Personnel effort	8	38	50	44	17	25	50	43
	Maintenance / updating effort	6	29	17	44	17	25	33	29
	Organizational effort	4	19	17	11	33	**50**	0	0

Similar to the UAVs, a large part of the experts found simplicity (76%) and robustness (71%) to be factors determining the compatibility of UGVs. UGVs have to be "*as easily to use as possible. I have to provide firefighters with simple things that are easy to operate. […] One has to consider a lot of things during an operation, so I don't want to think about how to operate some electronic device*" (Pl-S-1, 4.4c). "*It would have to be as autonomous as possible*" (Pr-S-1). Like drones, UGVs must withstand all kinds of weather and hazardous conditions: "*They must be deployable in all kinds of weather, in fog, at night, early in the morning*" (Pr-T-1). "*A fire in a tunnel or an underground garage creates huge heat. I don't know if they will work there*" (V-O-2, 4.4d). Regarding complexity, no factors were mentioned by at least half of the interviewees.

4.5 Intelligent Protective Clothing

Concerning the acceptance of intelligent protective clothing (T5), we identified seven factors pointing to advantages (three advantages and four disadvantages), seven compatibility-related factors, and six factors concerning complexity (cf. Table

5). As benefits of intelligent protective clothing in comparison to conventional protective clothing, the experts most often mentioned an informational advantage (71%) and increased safety (57%). No relative disadvantages were stated by at least half of the participants. Regarding the informational advantage, the experts found that: “*With the additional sensor technology, I can possibly detect phenomena which I cannot capture in the conventional way*” (Pl-S-3, 4.5a). “*There are three to four parameters which certainly are important and which provide the outside forces with information about how the team is moving forward, if they are in distress, if they have any problems. Accordingly, you can send in a rapid intervention team or an additional supporting team*” (Pr-O-2). The provided information also contributes to increasing safety: “*Things are safer if I have early warning systems that say something could happen or something is developing – I can take the team out of danger*” (V-T-2). “*Well, an advantage of a clever sensor technology would be that I […] only allow a predefined maximum exposure of the wearer. And that I willfully […] pull the colleague off the danger zone if thresholds are being reached, which were defined previously. Regardless if the goal was reached or not, the worker takes the central role*” (Pl-S-3, 4.5b).

Table 5. Acceptance factors for intelligent protective clothing

Category	**Factor**	**Total**		**Type of FD (%)**			**Command Level (%)**		
		n	**%**	**PrFD**	**VFD**	**PlFD**	**strat.**	**tact.**	**oper.**
Relative Advantage	Informational advantage (+)	15	71	50	78	83	75	67	71
	Safety (+)	12	57	50	78	33	**25**	**83**	71
	Load removal from radio (+)	10	48	67	56	**17**	50	33	57
	Lack of personal contact (–)	10	48	50	33	67	50	50	43
	Weight (–)	10	48	33	33	**83**	50	50	43
	Blind faith in technology (–)	4	19	33	11	17	0	33	29
	Electric smog (–)	3	14	17	22	0	0	**50**	0
Compatibility	Simplicity	20	95	100	89	100	100	100	86
	Reliability	12	57	50	67	50	50	67	57
	Robustness	9	43	**17**	56	50	50	50	29
	Selection of sensors	9	43	50	44	33	25	67	43
	Range	7	33	17	44	33	25	33	43
	Timing constraints	7	33	**67**	22	17	38	33	29
	Legal issues / privacy	4	19	17	11	33	25	0	29
Complexity	Evaluation effort	14	67	50	67	83	**100**	67	**29**
	Information overload	11	52	50	67	33	63	50	43
	Maintenance / updating effort	11	52	33	78	33	**25**	**83**	57
	Organizational effort	8	38	33	44	33	**75**	33	**0**
	Training effort	7	33	17	44	33	50	17	29
	Personnel effort	4	19	0	33	17	38	0	14

Concerning the compatibility of intelligent protective clothing, simplicity was stated most often as a factor (95%). 57% of the experts also highlighted reliability. Intelligent protective clothing has to be simple and easily usable for the wearer: “*Such clothing would have to be designed in a way that it can be put on quickly and easily. If I, for example, must fasten any belts or buckle on any breast straps for having an acceptable transmission, then there is no acceptance*” (Pr-O-3, 4.5c). “*If the things are built in a way that you only have to put it on and have a couple of buttons […] and it is kept simple for the operator, then all is in order*” (V-T-3). It also has to be simple and easily usable for the person monitoring the incoming data: "*The evaluation has to be self-explanatory […] and with many automated procedures. Thresholds must pop up, I do not need a continuous report on how the pressure is, but as soon as it is getting critical, I need to know*" (Pl-S-2). Regarding reliability, the system stability and the reliability of sensors were discussed: "*It has to be 100% available, even in extreme situations. If safety depends on it, I cannot [work] with security levels that are common in IT – 'well, we have 99.5' – no*" (Pl-S-2, 4.5d). "*You can certainly get wrong measuring results if sensors fail*" (V-S-3).

67% of the interviewees named the evaluation effort as a complexity factor. 52% moreover mentioned the updating/maintenance effort as well as the information overload as possible problems. The participants stated that surveilling the vital signs of the wearer and evaluating the data, which is gathered by the sensor technology, requires much effort: "*I believe this to be nonsense because somebody has to evaluate all the data. What do I do if he has a body temperature of 39° C? Shall I recall him? Shall I leave him inside? What if he has 41°? Somebody has to professionally evaluate this*" (V-S-2). "*There is no point in having a giant data overload and not being able to evaluate it or not having the personnel to evaluate it*" (Pl-S-1). "*That will need to be calibrated to a standard firefighter […] I don't know how that could work.*" (V-T-1). Another problem is the maintenance effort: "*Everything that is connected to additional sensors or devices is maintenance-intensive*" (Pr-T-1). "*The protective clothing is getting stressed heavily. That means it must be cleaned afterward. […] If all [sensors] have to be dismounted before cleaning – that will be massive effort*" (V-O-3). Besides, an information overload for the wearer was feared: "*With this amount of information, I believe it to be important to limit it to a necessary extent*" (V-S-1). "*In the worst case, it could distract him so much that he loses track of the objective or doesn't recognize a danger*" (Pl-S-1).

4.6 Augmented Reality

Regarding the acceptance of augmented reality (T6), we found nine factors that describe relative advantages (three advantages and six disadvantages), six compatibility-related factors, and six concerning complexity (cf. Table 6). With respect to the relative advantages, 95% of the experts found augmented reality to provide an informational advantage over current techniques such as using a manometer as the only visual information device. 52% of the interview partners also addressed safety as a relative advantage. None of the relative disadvantages was mentioned by at least half of the experts. Through augmented reality, information can be made accessible more easily for the firefighter: "*A system in which I can, for example, see the cylinder pressure or the remaining operating time is okay. I have the advantage of looking on it more often. [Using a manometer] you have to somehow search the thing, then you sometimes can only read it partly, depending on how dark it is*" (V-O-1). "*The manometer certainly is good if I can look on it. In an HAZMAT-suit, I can't. […] This would be optimal if I have information about my status or my air pressure in sight*" (V-T-2, 4.6a). Having additional and more accessible information was supposed to raise safety: “*Information about available air or developments, for example, something that might collapse, is crucial. If I get an optical signal in addition to the radio signal it is beneficial*” (Pr-O-2, 4.6b).

Table 6. Acceptance factors for augmented reality

Category	**Factor**	**Total**		**Type of FD (%)**			**Command Level (%)**		
		n	**%**	**PrFD**	**VFD**	**PlFD**	**strat.**	**tact.**	**oper.**
Relative Advantage	Informational advantage (+)	20	95	**83**	100	100	100	100	86
	Safety (+)	11	52	67	56	33	50	**83**	29
	Time advantage (+)	1	5	0	0	**17**	0	0	14
	Weight (–)	7	33	33	22	50	38	33	29
	Limited substitutability (–)	7	33	33	33	33	38	50	14
	Blind faith in technology (–)	6	29	50	11	33	13	33	43
	Limited range of application (–)	5	24	33	33	**0**	**0**	33	43
	Electric smog (–)	1	5	0	11	0	0	**17**	0
Compatibility	Simplicity	16	76	83	56	**100**	88	67	71
	Reliability	13	62	83	78	**17**	38	83	71
	Intelligibility	10	48	50	33	67	63	50	29
	Robustness	9	43	33	56	33	**13**	67	57
	Range	6	29	33	22	33	25	50	14
	Timing constraints	4	19	33	11	17	13	17	29
Complexity	Information overload	15	71	**100**	56	67	88	67	57
	Training effort	9	43	50	44	33	50	50	29
	Maintenance / updating effort	8	38	33	33	50	25	50	43
	Personnel effort	4	19	0	22	33	38	0	14
	Evaluation effort	1	5	0	0	**17**	0	**17**	0
	Organizational effort	1	5	0	0	**17**	0	0	14

The most frequently named compatibility factors for augmented reality technologies are simplicity (76%) and reliability (61%). Regarding simplicity, most of the interviewees pleaded for systems that ideally do not require any interaction. If any interaction is needed, it is supposed to be kept simple: “*Ideally, you have no handling at all, just a display that is simply running. When I put on my respiratory protection gear and it instantly displays me how the pressure in the cylinder is without any interaction that would be best*” (Pr-S-1). “*Operating should mean watching, or using a couple of buttons, […] nothing major, nothing complicated, no parameter adjustments. It all has to be simple*” (V-S-3). Again, reliability was addressed as well: “*If it works, it is good. But it is an additional technical appliance which can fail*” (Pl-T-2). “*In fire departments, I need a fallback if anything fails. The insurance will say ‘we cannot rely on this system only’*” (V-T-2, 4.6c).

Regarding complexity, information overload is the most frequently stated problem (71%). Particularly complex augmented reality systems were rated critically concerning a possible overload: “*Perhaps you don’t perform your task correctly if you keep yourself busy with handling any interactive elements. I think that would oftentimes distract from the actual task*” (Pr-S-1). “*Think about being a member of a team working with respiratory protection somewhere and all the unintended triggering the thing might create. If I wear protective clothing and the keyboard isn’t working right, I will permanently have some images or flickering or I have the war of the ants on the screen – that is a no-go*” (Pr-T-1). “*You always have these* *light reflections in there. If you are crawling through a totally smoke-filled area, having zero sight anyway and the mask is misted and you additionally get some color impressions projected into the mask […] it is distracting*" (Pr-O-3).

4.7 Indoor Positioning

Regarding the acceptance of indoor positioning systems, we identified seven factors concerning relative advantages (three advantages and four disadvantages), seven compatibility-related factors, and four concerning complexity (cf. Table 7). With respect to the advantages, 95% of the interviewees found indoor positioning systems to deliver an informational advantage compared to having a traditional retreat path assured by using fire hose or rope. More than half of the experts also stated a time advantage (57%). 67% of the interviewees found the fact that such systems could not substitute existing tools and procedures to be disadvantageous. The use of indoor positioning systems improves the information available to the teams: "*Being on the way with two or three teams, you see where the others went or colored markings help you seeing what has already been searched and what hasn't been searched yet. […] It happens really fast with multiple teams […] that some rooms are checked twice and others not at all*" (V-O-1). "*Indoor positioning would certainly be great. I imagine a digital building where I can see where my team is – that would be ideal*" (Pl-T-2). On the one hand, a time advantage was found to be achieved by being able to better coordinate teams. On the other hand, the rescue of injured firefighters could be accelerated: "*If I have someone monitoring who says 'stop, the other team was there already, you can continue to search back there on the left', then you will be faster and more effective*" (Pl-O-1). "*The good thing is, if something happens to the team working under respiratory protection, which is deployed there, I will certainly find them faster*" (Pl-T-1). Opposed to that, the interviewees did not see a chance of substituting procedures like the conventional retreat path assurances: "*Nevertheless, it does not replace any traditional retreat path assurances, like rope or hose*" (Pl-S-1). "*Everyone who has ever got lost in an area is happy to have a rope guidance. This optical and acoustic signaling – especially the acoustic signaling […] will not work sometimes. As only rope guidance works there […] one cannot replace that*" (Pr-T-1).

The most frequently mentioned compatibility factor is simplicity (95.24%), followed by reliability (66.67%) and range (52.38%). Systems that require the deployment of breadcrumbs by the team have to be intuitively usable: "*Well, of course as easy as possible, so that the team can just do that along the way. Whether he puts in his wooden wedge or the plastic wedge and then additionally presses the button doesn't matter – it has to be just as easy and quickly as possible*" (Pr-S-1). "*I think the device carried by the firefighter will just be carried along, so there is no handling needed. […] Merely the device for visualizing the positioning must be operated. If a certain group of people is capable of that, if the visualization is illustrated in a way that it can be interpreted quickly and well, then it will be easy to manage*" (V-S-1). The reliability of the systems was seen as particularly important: “*Like I said, the technology has to be mature. It must be safe as well. Otherwise, the system is of no use for me*” (Pr-O-3, 4.7a). “*There is the human factor and the required discipline to place them even if in hurry [...] so that they are in the right place and stay there, not that the next team bumps them with their boots and they slide through the room*” (V-S-3). Range was named as another important compatibility factor: “*You will rather soon have some building parts in which the system reaches its physical limits. For a common residential building, it will be working, I think. But I think that the system cannot function across 200 or 300 meters*” (V-O-1). “*That you can apply it arbitrarily on every kind of building – three-story, five-story, or ten-story, spacious or not. It has to be independent of that*” (Pl-S-2).

Table 7. Acceptance factors for indoor positioning

Category	**Factor**	**Total**		**Type of FD (%)**			**Command Level (%)**		
		n	**%**	**PrFD**	**VFD**	**PlFD**	**strat.**	**tact.**	**oper.**
Relative Advantage	Informational advantage (+)	20	95	100	100	**83**	88	100	100
	Time advantage (+)	12	57	50	56	67	63	33	71
	Safety (+)	10	48	50	33	67	**75**	**17**	43
	Limited substitutability (–)	14	67	83	67	50	63	**100**	43
	Weight (–)	8	38	17	56	33	25	33	57
	Limited range of application (–)	7	33	33	44	17	13	**67**	29
	Blind faith in technology (–)	4	19	0	33	17	13	**50**	0
Compatibility	Simplicity	20	95	100	89	100	100	**83**	100
	Reliability	14	67	67	89	**33**	50	83	71
	Range	11	52	50	56	50	50	33	71
	Robustness	7	33	17	22	**67**	13	**67**	29
	Intelligibility	3	14	17	0	**33**	25	17	0
	Timing constraints	3	14	0	22	17	0	**50**	0
	Legal issues / privacy	2	10	0	22	0	13	17	0
Complexity	Maintenance / updating effort	14	67	67	67	67	75	83	43
	Training effort	9	43	33	44	50	50	33	43
	Evaluation effort	8	38	50	44	17	63	33	14
	Personnel effort	7	33	50	33	17	25	50	29

Concerning the complexity of indoor positioning systems, the most frequently stated factor is the maintenance and updating effort (66.67%). A critical resource to identify the concrete position of firefighters is the required building plan: “*The fundamental problem of indoor positioning [...] remains the layout of the building. The question is not only ‘where is the person’ but ‘how do I get there’*” (Pl-S-3). “*Well, it’s not practical, because [...] I would need a plan for actually every building, I would have to possess a three-dimensional image. [...] I must be able to identify stairways, [...] doors, elevator shafts, whatever. And this is immense concerning data administration – and I would need it for every object. Even considering doing it only for objects with an automatic fire detection system [...] would include more than a thousand objects in our city. And administrating over a thousand object plans with three dimensions – that is a huge task*” (Pr-T-1).

5 Discussion, Implications, and Limitations

In the following, we discuss several findings that can be derived from the results of our study. In particular, we elaborate on the acceptance of the examined novel information technologies in FDs, the possible influence of the type of FD and command level, and the generic acceptance factors for FITs. Furthermore, we describe the implications and limitations of our work. During the discussion, we will cite several interview statements that were depicted in section 4 to justify our arguments. We refer to these statements by indicating the respective subsection combined with a consecutive letter, resulting in codes like *4.1a*. These codes have been included in parentheses behind the original statements as anchors in section 4.

5.1 Acceptance of Novel Information Technologies in Fire Departments

During the analysis of the interviews, we gained the impression that the overall attitude of the experts is rather critical and that the perceptions vary considerably between the examined technologies. Some technologies seemed to be perceived more positively than others. To verify the impression and answer our first research question, we quantified the data by adding up the frequencies of the mentioned relative advantages, disadvantages, the compatibility, and the complexity factors. We then divided the results by the number of interviewees to calculate the average frequencies of these factor categories per interviewee. This was done for each of the seven technologies. We also calculated the average values across the technologies.

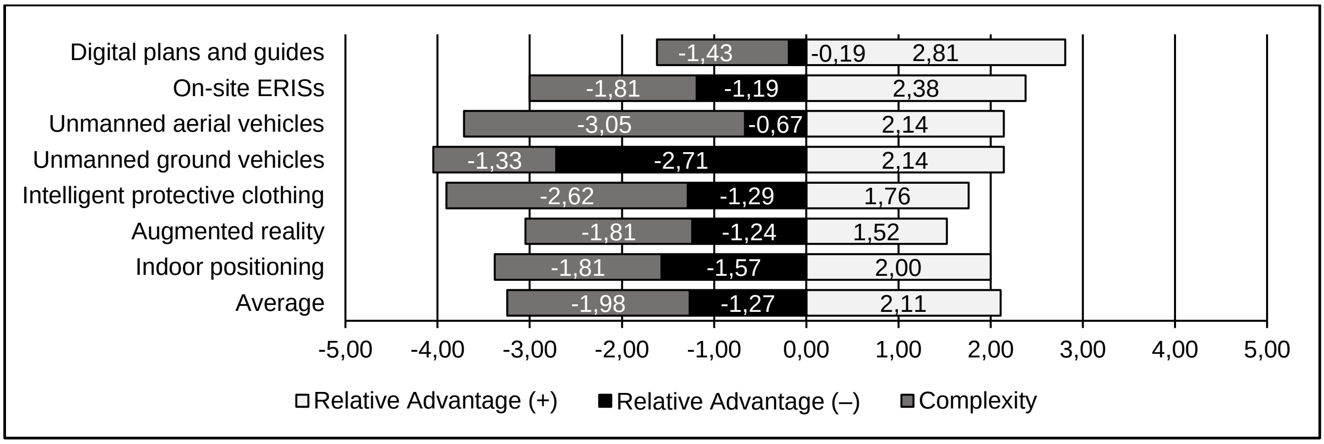

Figure 5. Average factor frequencies per interviewee grouped by factor category

To visually examine the attitudes towards the technologies, we depict the results in Figure 5. We attributed values in the relative advantage category with a positive prefix, since they facilitate the adoption of the respective FIT. For example, each interview partner on average stated 2.81 factors in the relative advantage category for digital plans and guides. Opposed to that, factors in the relative disadvantage and complexity categories were attributed with a negative prefix. They hinder the adoption of the respective technology. In the case of digital plans and guides, each interviewee on average mentioned 0.19

factors concerning relative disadvantages and 1.43 factors regarding complexity. Note that we did not include compatibility-related factors into this analysis because they rather represent technology requirements. Their impact hence highly depends on the concrete design of the information technology. If the design fulfills the compatibility-related factors, this will probably facilitate the acceptance of the technology, whereas the acceptance will likely be hindered otherwise.

The results of the analysis confirm the impression we initially gained. For every technology except digital plans and guides, the interviewees on average stated more negative than positive factors. Overall, each interview partner on average mentioned 2.11 relative advantages, 1.27 relative disadvantages, and 1.98 complexity factors per technology. Ranging from 2.57 to 3.95 between the different technologies, the average number of compatibility factors moreover is 3.11. The compliance with the mentioned compatibility factors hence seems to be crucial for the adoption of FITs. Considering the interview statements, complying with the compatibility-related factors appears to be a challenging task in many cases, though. With respect to the *reliability,* for example, some of the mentioned constraints are rather tough requirements (cf. *4.1b*, *4.2c*, *4.5d*, *4.6c*). Altogether, we hence found indications that firefighters might not easily accept and adopt innovative FITs.

To express the attitude towards the technologies in an aggregated form, we calculated the following ratio of positively and negatively connoted statements. This ratio is meant to be an approximate value for the overall perception:

$$Attitude = \frac{\bar{n}\ (relative\ advantage)}{\bar{n}\ (relative\ disadvantage) + \bar{n}\ (complexity)}$$

Table 8. Attitude toward technologies

	Digital plans and guides	On-site ERISs	Unmanned aerial vehicles	Unmanned ground vehicles	Intelligent protective clothing	Augmented reality	Indoor positioning
Attitude	1.74	0.79	0.58	0.53	0.45	0.50	0.59

The differing attitude towards the technologies becomes obvious in Table 8. The ratio for digital plans and guides lies more than 0.5 standard deviations above the average ratio. The ratios for intelligent protective clothing and augmented reality lie more than 0.5 standard deviations below. It can be argued, that digital plans and guides are assessed comparatively positively and hence have a better chance of being adopted in practice – in contrast to the other two technologies. The rest of the technologies differs only little from the average. While on-site ERISs were seen slightly more positive, indoor positioning systems, UAVs, and UGVs were seen slightly more negative. Interestingly, the findings largely corroborate the results of a recent quantitative study (Schlauderer et al. 2016). This study also identified digital plans and guides as the emerging technology with both the highest perceived potential and the highest rate of adoption in practice. Furthermore, on-site ERISs and indoor positioning systems were found to have a certain potential in practice. Intelligent protective clothing, UAVs, and UGVs instead were reported to have limited potential. Augmented reality technologies had not been considered in that study.

Another interesting observation is the differing composition of the ratio that describes the overall attitude towards the technologies. For UAVs and intelligent protective clothing, comparatively few relative disadvantages were stated. They are, however, perceived to add several sources of complexity. UGVs and indoor positioning systems were found to have a higher number of relative disadvantages, which leads to a rather negative attitude overall as well. The negative attitude towards augmented reality systems instead mainly appears to be the result of a lack of relative advantages. This observation indicates that the acceptance and adoption of FITs is a complex topic with many aspects to consider. It is, therefore, advisable to continuously keep in mind the users' perspective during the development of novel FITs.

5.2 Influence of Fire Department Type and Command Level

We also analyzed the results for differences in the interviewees' attitude that might stem from the type of FD and/or command level they work in. Therefore, we inspected all factors that were stated notably more or less frequently by one of the groups for multiple technologies. We considered discrepancies of 0.5 standard deviations as a threshold (cf. markings in Tables 1 to 7) to search for possible explanations.

Interviewees working in PrFDs addressed the factor *limited range of application* notably more often than those working in PlFDs for two technologies. The greater emphasis on the range of application can be explained by the fact that PrFDs are general-purpose departments and their members hence might have a preference for general-purpose technologies. In contrast, PlFDs typically are much more specialized to particular operational areas and/or types of incidents. The interviewees working in PlFDs more often mentioned *weight* and *time advantages* as relevant factors for two technologies that obviously fitted into their specific context. *Training effort*, *Reliability*, and *legal issues/privacy* were instead stated less often for two technologies. The lower emphasis on training effort could be explained by the typically lower number of emergency operations in PlFDs in comparison to PrFDs. Accordingly, there likely remains more time for training in PlFDs.

Concerning the influence of the command level, interviewees working in the strategic command level stated an *organizational effort* notably more frequently for two technologies. Since members of the strategic command level are responsible for organizational matters, the emphasis on this factor seems reasonable. Interview partners working on the operational level, in contrast, stated an *operational effort* notably less often and *operating time* notably more frequently for two technologies. In contrast to the strategic command level, members working on the operational level are less concerned with organizational matters, but rather with the manual work on site. Interviewees working on the tactical command level stated the factors *electric smog*, *reliability*, and *safety* more frequently for multiple technologies. *Time advantage* is more often addressed for one and less often addressed for another technology. The greater emphasis on *reliability* and *safety* can be explained by the fact that members of the tactical command level oversee on-site operations in most instances. They are therefore particularly concerned about the on-site performance of technologies and the safety of the forces commanded by them.

Overall, we could not identify major discrepancies between the attitudes of experts from different types of FDs or command levels, however. None of the previously discussed differences were observed for more than two technologies. Therefore, we do not assume any significant influence of the type of FD or command level on the assessment of the examined FITs.

5.3 Generic Acceptance Factors

By viewing together the factors stated for the individual technologies, we could furthermore identify acceptance factors that are relevant for several FITs and therefore might be generic factors describing the acceptance of FITs in general. To achieve such an overview and to answer our second research question, we depict the frequencies of the identified factors across all technologies as shown in Table 9. In order to keep the table comprehensible, we limit ourselves to factors, which have been addressed by at least 25% of the interviewees on average. The complete table with all factors can be seen in the appendix. As candidates for generic factors that might affect the acceptance of FITs in general, we consider the factors complying with two requirements. First, such a factor should have been mentioned for all seven technologies. Second, it should have been stated by at least 50% of the interviewees on average. As can be seen in Table 9, four factors comply with these requirements.

Table 9. Most frequently highlighted acceptance factors (values in %)

Category	**Factor**	**Digital plans and guides**	**On-site ERISs**	**Unmanned aerial vehicles**	**Unmanned ground vehicles**	**Intelligent protective clothing**	**Augmented reality**	**Indoor positioning**	**Average**
Relative Advantage	*Informational advantage* (+)	57	67	100	38	71	95	95	**75**
	Safety (+)	0	0	19	100	57	52	48	**39**
	Time advantage (+)	62	38	57	10	0	5	57	**33**
	Limited range of application (–)	0	14	57	86	0	24	33	**31**
Compatibility	*Simplicity*	71	81	81	76	95	76	95	**82**
	Robustness	67	33	81	71	43	43	33	**53**
	Reliability	81	57	29	14	57	62	67	**52**
	Intelligibility	91	86	0	0	0	48	14	**34**
Complexity	Maintenance / updating effort	52	14	48	29	52	38	67	**43**
	Training effort	33	38	57	48	33	43	43	**42**
	Personnel effort	5	29	67	38	19	19	33	**30**

The only generic factor in the relative advantage category appears to be the *informational advantage* (75%). Since the main function of innovative FITs is to help gathering, sharing, and presenting real-time information in order to allow emergency responders to better comprehend the situation at hand and the capabilities of the available resources (Barrado et al. 2010; Carton and Dunne 2013; Juhnke 2011; Kozlovszky and Pavlinic 2014), it seems reasonable that a general benchmark should be the actually provided informational advantage. The kind of informational advantage, however, can vary highly between the different technologies (cf. *4.1a*, *4.2a*, *4.3a*, *4.5a*, *4.6a*).

Simplicity, *robustness*, and *reliability* appear to be generic compatibility factors. With an average frequency of 82%, *simplicity* is not only the most often mentioned compatibility factor, but also the most often stated factor over all DOI categories. It can therefore be argued that the question whether it is simple to use is most important when introducing a new FIT. This can be explained by considering the working conditions of firefighters in general (which are characterized by tight timing constraints, spontaneous actions, and a significant amount of stress), and some of the interview statements in particular (cf. *4.1c*, *4.2b*, *4.4c*, *4.5c*). As another generic compatibility factor, we identified *robustness*, which was highlighted by 53% of the interviewees on average. The importance of this factor again can be explained with the specific conditions, in which firefighters have to work. In particular, technologies employed by firefighters must withstand extreme conditions (cf. *4.1d*, *4.3b*) and other influences present in the incident area (cf. *4.1e*, *4.3c*, *4.4d*). The factor *reliability* was nearly as frequently mentioned for all technologies, resulting in an average frequency of 52%. As firefighters work in dangerous environments, in which lives are at stake, they have a high demand for technologies they can rely on (cf. *4.2c, 4.5d*, *4.7a*). A frequently highlighted feature to ensure reliability is the availability of fallback solutions (cf. *4.1b*, *4.6c*). Such solutions should hence be part of critical FITs. Regarding complexity, we identified no factors complying with our requirements. It seems, that complexity is rather caused by specific characteristics of FITs than by generic factors.

Besides factors, which seem to be important for the acceptance of FITs in general, others appear to be relevant for specific technologies only. *Safety* as a relative advantage, for example, seems to be more relevant for UGVs (cf. *4.4a*) and technologies that support teams working under respiratory protection (cf. *4.5b*, *4.6b*) than for others. We even observed factors like *new fields of operation* (cf. *4.4b*) or *limited set of capabilities* (cf. *4.4e*), which were highlighted very often for UGVs as a specific technology (67% and 71%), but were not mentioned for other technologies at all. While the interviewees had a rather negative attitude towards six of seven technologies (cf. section 5.1), we found only one relative disadvantage and three complexity factors that were addressed by at least 25% of them on average. From the obtained results, we can hence conclude that specific factors seem to be responsible for the negative perception. As we identified several different factors – mainly relative disadvantages – that were mentioned by only a small number of experts, we can conclude that there apparently exist many different potential barriers to acceptance that have to be taken into account when designing a novel FIT.

Consequently, the identified generic factors obviously are not sufficient to assess the potential of FITs. They rather constitute a catalog of factors, which needs to be extended with specific factors to examine the characteristics of certain technologies.

In conclusion, we can hence derive an initial theory on the factors influencing the adoption of FITs as depicted in Figure 6 from the results of our study. The factor *informational advantage* contributes to the adoption as a generic relative advantage, whereas the compatibility of a FIT is determined by the generic factors *simplicity*, *robustness*, and *reliability*. Besides these generic factors, several technology-specific factors will also have a positive or negative influence on the acceptance of FITs.

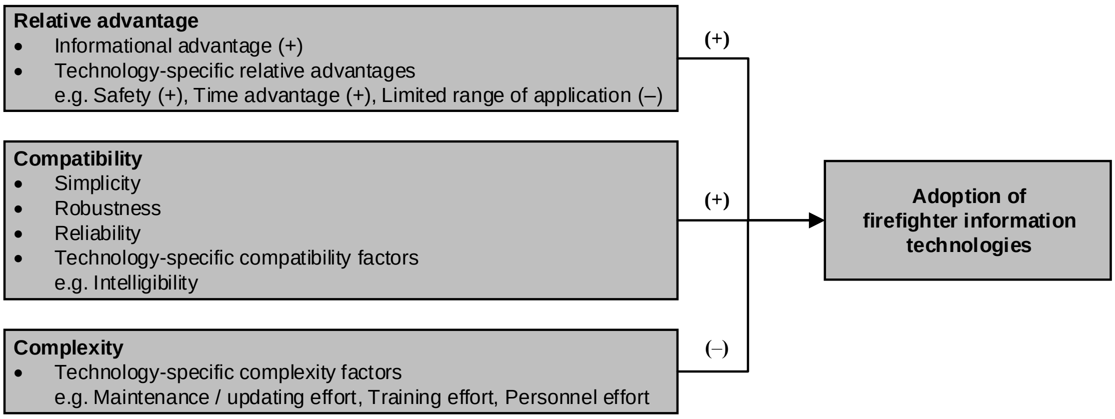

Figure 6. Theory on the acceptance of FITs

5.4 Implications

To the best of our knowledge, this is the first approach aiming to derive a theory of the factors that determine the acceptance of FITs. By identifying acceptance factors for seven different types of technologies, which are currently being discussed in academia and practice, we furthermore provide a unique overview with merit for researchers and practitioners alike.

As regards practice, the results of our study facilitate the assessment of several frequently discussed technologies, which are currently under development. We pointed out several specific acceptance factors for the different technologies as well as factors that seem to determine the acceptance of FITs in general. For FDs, the provided factors provide a basis to systematically evaluate FITs and contemplate the right questions when deciding upon the acquisition of a FIT. In particular, they assist FDs in identifying technologies that truly support their work processes instead of complicating them. Since we found the potential of several technologies to be rather limited in the eyes of our interviewees, such an assistance seems to be even more important. For developers of innovative FITs, the provided acceptance factors can be used as a benchmark to evaluate their products. In particular, we provide detailed insights into the requirements that innovative technologies ought to fulfill to be of advantage and to be compatible with the way firefighters prefer to work, while not adding too much complexity. By providing such a benchmark, the results of our research might contribute to the development of FITs that better meet the practical needs of firefighters. This statement should not imply that product testing and requirements engineering initiatives do not exist in practice already. The results of our research are rather meant as a means to further support such approaches by providing an additional, theoretically grounded benchmark that has been carefully derived during our study.

The results of our study also have implications for academia and particularly provide several avenues for future research. With the identified factors, we contribute to the development of an acceptance theory for information technologies in the domain of emergency response information systems. The initial theory depicted in Figure 6 provides a foundation for additional research. On the one side, the acceptance of FITs needs to be further investigated in an international context in order to reexamine our findings and to account for cultural differences such as the organization of FDs. It is conceivable that differences with respect to command levels and the professional status of the firefighters might have an influence on the factors that are perceived as relevant. On the other side, a quantitative evaluation could not only verify the identified factors, it could moreover provide more information about the comparative relevance of the factors. Employing path analyses or comparable methods could be a way to gain insights about the strength, with which the factors influence the acceptance of a technology. Compared to such analyses, our research method only allowed us to deduce an initial theory with factors, but it also helped us to understand why certain factors are perceived as positive or negative. Furthermore, our results are a call for academia to identify and develop novel information technologies for emergency first responders that truly meet the practical demand. Based on the results of our study, it would seem that not all currently discussed technologies are seen as beneficial by the firefighters who are supposed to use them ultimately.

5.5 Limitations

We have taken several precautions to ensure the validity of our results. Next to a careful selection of experts as interviewees, we decided to conduct semi-structured interviews as the standardized interview guideline helps to produce comparable results and to mitigate biases caused by the interviewer. Moreover, we repeatedly assessed the results in discussion rounds during the coding step. Nevertheless, there exist several limitations in the light of which the results of our study should be interpreted. First, we only examined the perceptions of German firefighters so far. Although we controlled regional differences by examining the perceptions of firefighters from FDs all over the country, the results of our study might not be straightforwardly transferable to other countries, in which the organization of FDs and response processes differs. As in many other qualitative studies, the results might furthermore suffer from an interviewer bias and the rather small sample size, thus limiting their external validity. For this reason, we will have to validate our findings in future research iterations. Another limitation might arise from the decision to not investigate factors related to the observability and trialability of FITs (cf. section 2.3). Although such factors have repeatedly been shown to be of limited importance in contexts such as ours, our strategy bears the risk of overlooking important factors. Furthermore, we so far examined only a limited set of technologies, which are currently being discussed intensively in literature. This selection is not necessarily complete and, in particular, might not include technologies, which are mainly discussed in practice.

6 Conclusion

It is frequently proposed in literature to equip firefighters with innovative information technologies in order to improve the efficacy of emergency response processes. So far, however, little research has examined how the potential of emerging technologies to facilitate the activities on the site of an emergency is perceived by the users. To contribute to the closure of this literature gap, we presented the results of a qualitative study, in which we interviewed 21 German firefighters about their perception of seven emerging technologies that are currently pursued in academia and practice. Taking the DOI Theory as a lens of analysis, we were able to obtain rich insights into the factors that determine the acceptance of emerging technologies by firefighters and their perception in practice. Based on the results, we could derive a theory with generic and specific factors to explain the acceptance of new information technologies in the firefighting domain.

The presented results moreover provide a unique overview of frequently discussed emerging technologies and their perceived potential to expedite the emergency response process. In general, we encountered a rather cautious attitude towards new technologies that expresses itself in several concerns regarding relative disadvantages, compatibility and complexity. The assessment of the individual technologies that we examined varied considerably. While digital plans and guides were seen relatively positive, the potential of augmented reality and intelligent protective clothing was found to be limited. At first sight, this seems to be a surprising result, since there particularly exist several dedicated and partially state-funded projects to develop intelligent protective clothing for firefighters (e.g. the “smart@fire” project that is funded by the European Union). It seems, however, that concerns regarding the battery life, the additional weight of the clothing, the additional effort for the transportation, and the time to apply the clothing could outweigh the expected advantages in practice.

Generally, our results hence call for a more systematic analysis and consideration of acceptance-related factors when designing new technologies to mitigate the risk that they might fail to meet the market needs. Presently, emerging technologies are often arbitrarily used as a means to create new functionalities for on-site emergency response systems because of their desirable features and characteristics. However, such technology-driven approaches tend to neglect the requirement that on-site emergency response systems have to be easily and efficiently usable. With the results of our study, we hope to provide a starting point to more systematically evaluate acceptance-related factors of firefighter information technologies.

Appendix

Table 10. Overview of the acceptance factors highlighted by the experts (values in %)

Category	**Factor**	**Digital plans and guides**	**On-site ERISs**	**Unmanned aerial vehicles**	**Unmanned ground vehicles**	**Intelligent pro-tective clothing**	**Augmented reality**	**Indoor positioning**	**Average**
Relative Advantage	Informational advantage (+)	57	67	100	38	71	95	95	**75**
	Safety (+)			19	100	57	52	48	**39**
	Time advantage (+)	62	38	57	10		5	57	**33**
	Currentness of data (+)	48		38					**12**
	Compactness (+)	62	10						**10**
	New fields of operation (+)				67				**10**
	Load removal from radio (+)		19			48			**10**
	Flexibility (+)	52							**7**
	Increased capacity / documentation (+)		38						**5**
	Accuracy (+)		33						**5**
	Structuring (+)		10						**1**
	Limited range of application (–)		14	57	86		24	33	**31**
	Weight (–)		5			48	33	38	**18**
	Limited substitutability (–)						33	67	**14**
	Slowness (–)				76				**11**
	Limited set of capabilities (–)				71				**10**
	Blind faith in technology (–)					19	29	19	**10**
	Space requirements (–)			10	38				**7**
	Loss of competences (–)		48						**7**
	Lack of personal contact (–)					48			**7**
	Lack of expressive power (–)		33						**5**
	Dissemination to on-scene forces (–)	19							**3**
	Electric smog (–)					14	5		**3**
	Less communication (–)		10						**1**
	Flexibility (o)		29						**4**
Compatibility	Simplicity	71	81	81	76	95	76	95	**82**
	Robustness	67	33	81	71	43	43	33	**53**
	Reliability	81	57	29	14	57	62	67	**52**
	Intelligibility	91	86				48	14	**34**
	Timing constraints	48	24	5	14	33	19	14	**22**
	Range			14	19	33	29	52	**21**
	Legal issues / privacy	29	24	48	5	19		10	**19**
	Adaptability		19		38				**8**
	Operating time			38	19				**8**
	Selection of sensors					43			**6**
	Longevity	5	10						**2**
	Loading capacity			10					**1**
	Handiness	5							**1**
Complexity	Maintenance / updating effort	52	14	48	29	52	38	67	**43**
	Training effort	33	38	57	48	33	43	43	**42**
	Personnel effort	5	29	67	38	19	19	33	**30**
	Information overload	5	33	10		52	71		**24**
	Organizational effort	38	14	48	19	38	5		**23**
	Evaluation effort	10		19		67	5	38	**20**
	Decision-making complexity		52	5					**8**
	Operation complexity			52					**7**

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