Acceptance and Usage Analysis of Information Technologies, Especially Emergency Response Information Systems, in Fire Departments

Dissertation

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Haßfurt, April 2024 Julian Weidinger

Zusammenfassung (German Summary)

Seit Anbeginn der Menschheit sehen sich Gesellschaften mit Gefahren von Katastrophen und Unglücksfällen konfrontiert [1]. Sie gefährden Leben, Eigentum und Kulturgüter. Zur Vorbereitung auf solche Schadensereignisse werden Hilfsorganisationen aufgestellt, die in diesen Fällen unterstützen [1]. Indem sie die öffentliche Sicherheit gewährleisten, tragen diese Organisationen entscheidend zum Funktionieren einer Gesellschaft bei. Feuerwehren gehören zu den wohl vielseitigsten und verbreitetsten dieser Hilfsorganisationen. Sie sind typischerweise zuständig für den abwehrenden Brandschutz, die technische Hilfeleistung sowie den Schutz vor gefährlichen Stoffen und Gütern [2, 3]. Um flächendeckend schnelle Hilfe leisten zu können, basiert das Feuerwehrwesen in vielen Ländern auf einem System von Freiwilligen [2]. Dies unterscheidet die Feuerwehren grundlegend von den meisten anderen Organisationen und insbesondere geschäftlichen Anwendungsbereichen. Feuerwehreinsätze verlaufen in Phasen und beginnen mit einer initialen Lagefeststellung [3, 4]. In Notfallsituationen müssen Feuerwehrleute jedoch häufig zeitkritische Entscheidungen auf Basis unvollständiger Informationen treffen [5, 6].

Aus theoretischer Sicht spielt daher das *Situationsbewusstsein* für Feuerwehrleute eine entscheidende Rolle. Sie müssen die Gegebenheiten wahrnehmen, ihre Zusammenhänge verstehen und zukünftige Entwicklungen abschätzen [7, 8]. Ein verbessertes Situationsbewusstsein führt theoretisch zu besseren Entscheidungen und Leistungen. Um Feuerwehrleute mit den für ihr Situationsbewusstsein benötigten Informationen zu versorgen, werden in der Literatur verschiedene Arten von *Feuerwehrinformationstechnologien* (FIT) vorgeschlagen. Sie umfassen Drohnen [9-11], intelligente Schutzkleidung [12-14] und viele andere. Unter den FIT erscheinen Führungsunterstützungssysteme, im Englischen *emergency response information systems* (ERIS) genannt, als besonders wichtig. Bei ihnen handelt es sich um vielseitige Plattformen, über die einsatzrelevante Informationen verarbeitet und auch Daten anderer Systeme integriert werden können [6, 15-17]. Verglichen mit anderen FIT sind ERIS universell einsetzbar in allen Arten, Ausmaßen und Phasen von Einsätzen. Sie haben damit das wohl größte Potenzial zur Verbesserung des Situationsbewusstseins von Feuerwehleuten.

Trotz dieser theoretischen Potenziale finden ERIS und die meisten anderen FIT bisher nur selten praktische Anwendung in den Feuerwehren. Zur Erklärung der Annahme und Nutzung von Technologien im Allgemeinen finden sich in der Literatur zahlreiche Theorien und Akzeptanzmodelle. Prominente Beispiele umfassen das *Information Systems Success Model*, das *Task-Technology Fit Model* und die *Unified Theory of Acceptance and Use of Technology* [18-20]. Sie alle wurden erfolgreich in verschiedensten privaten und geschäftlichen Kontexten angewendet. Die Technologieakzeptanz in Hilfsorganisationen erscheint allerdings größtenteils unerforscht. Einige Studien gibt es im Bereich des Rettungsdienstes, der Polizei und anderer Organisationen [21-23]. Mit konkretem Fokus auf Feuerwehren existieren zwar entfernt verwandte Arbeiten zu Informationsbedürfnissen, Anwendungsmöglichkeiten und Gestaltungsanforderungen [24-26]. Die Technologieakzeptanz und -nutzung im Feuerwehrbereich wurde jedoch bisher nicht explizit und systematisch erforscht. Diese Dissertation nimmt sich dieser Forschungslücke an und soll die folgende Forschungsfrage beantworten.

Übergeordnete Forschungsfrage: *Unter welchen Umständen werden aufkommende Feuerwehrinformationstechnologien angenommen und eingesetzt?*

Aufgrund der Komplexität dieser Frage wurde ein schrittweises Vorgehen gewählt. Dieses spiegelt sich im dreiteiligen Aufbau der Dissertation wider, die neun Papiere umfasst. In jedem der drei Teile kamen sowohl qualitative als auch quantitative Forschungsmethoden zum Einsatz. Damit ergibt sich insgesamt ein zielgerichteter Mixed-Methods-Ansatz.

Teil 1 erarbeitet zunächst den Status quo der FIT-Domäne aus theoretischer sowie praktischer Perspektive. Aus theoretischer Sicht zeigt eine Literatur-Review die Zersplitterung der bisherigen Forschung in dem Bereich auf einzelne Technologien. Durch die Identifikation von Schlüsselkonzepten wird die Domäne systematisch analysiert. Die resultierende Konzeptmatrix schafft einen strukturierten Überblick und kann als Ausgangspunkt für die Erforschung einzelner Unterbereiche dienen. Weiterhin werden mehrere Forschungslücken abgeleitet. Während einige davon in dieser Dissertation aufgegriffen werden, können sie generell die zukünftige Forschung in diesem Bereich anleiten. Unter anderem wird ein Technologie-getriebener Fokus herausgearbeitet, der dazu neigt, Domänenspezifika zu vernachlässigen. Die Literaturstudie wird ergänzt durch eine Umfrage zur Verbreitung und Wahrnehmung verschiedener FIT. Sie zeigt die geringe Verbreitung der meisten Technologien und allgemeine Skepsis unter Feuerwehrleuten auf. Diese Erkenntnisse verdeutlichen nochmals die Wichtigkeit der oben genannten Forschungsfrage. Durch ihre Beantwortung trägt die Dissertation dazu bei, die theoretischen Grundlagen dieses kleinen, aber unbestritten relevanten Forschungsbereichs zu entwickeln.

Teil 2 identifiziert potenzielle Akzeptanzfaktoren für FIT und zeigt exemplarisch ihre Effekte im Feuerwehreinsatz auf. Mittels Interview-Studie werden zahlreiche Akzeptanzfaktoren sowohl für einzelne Technologien als auch für FIT im Allgemeinen herausgearbeitet. Diese Faktoren stellen einen ersten Baustein für das theoretische Verständnis der Technologieakzeptanz in Feuerwehren dar. Sie ergänzen die Perspektive der Nutzerwahrnehmung, die in der bisherigen Literatur fehlte. Mit sieben FIT-Typen wird eine große

Breite des Forschungsbereichs abgedeckt. Zukünftige Arbeiten können die identifizierten Faktoren in Akzeptanzmodelle integrieren, um sie zu evaluieren und die Akzeptanz der jeweiligen FIT zu erklären. Ergänzt wird diese Studie durch ein Laborexperiment, das exemplarisch den Einfluss des Akzeptanzfaktors *Informationsformat* auf die Leistung von Feuerwehrleuten untersucht. Die Ergebnisse untermauern eine der regelmäßigen Begründungen für die Relevanz von FIT. In Übereinstimmung mit der Theorie des Situationsbewusstseins wird gezeigt, wie verbesserte Informationen zu besseren Entscheidungen und Leistungen führen. Damit kann angenommen werden, dass FIT, die solche Informationen bereitstellen, die Leistung von Feuerwehrleuten positiv beeinflussen.

Teil 3 umfasst die Erarbeitung, Evaluation und Ergänzung eines Akzeptanzmodells für ERIS als spezifischen FIT-Typ. Basierend auf bestehender Literatur und Expertenfeedback wird ein Strukturgleichungsmodell aufgestellt und mithilfe einer Umfrage evaluiert. Das Akzeptanzmodell stellt einen der ersten Versuche dar, die Akzeptanz einer FIT theoretisch zu erklären. Es zeigt die Anwendbarkeit etablierter Modelle in dieser speziellen Domäne und integriert zusätzliche, teilweise domänenspezifische Konstrukte. Weiterhin wird ein bestehender Ansatz zur Verknüpfung von Theorien zu Nutzerzufriedenheit und Technologieakzeptanz überarbeitet. Die quantitative Evaluation gibt Aufschluss über die Signifikanz und jeweilige Wichtigkeit der einzelnen Faktoren. Ergänzt wird das Strukturgleichungsmodell durch eine mehrjährige Ethnographie. Diese bietet praktische Einblicke, ergänzt verbleibende Schwachstellen im Modell und sorgt für seine verstärkte Kontextualisierung. Viele der ethnographisch identifizierten zusätzlichen Faktoren können anhand von Erkenntnissen verschiedener Disziplinen erklärt werden. Darunter sind Pädagogik, Sicherheitswissenschaft, Soziologie, und Psychologie. Damit können sie auch Akzeptanzmodelle für andere Technologien oder in anderen Domänen bereichern.

Neben den bereits erläuterten Implikationen für die Forschung besitzt diese Dissertation auch zahlreiche praktische Anknüpfungspunkte. Aus praktischer Sicht können insbesondere die Anbieter und Beschaffer von FIT sowie die Feuerwehrleute als ihre Nutzer von den Erkenntnissen profitieren. Die identifizierten Akzeptanzfaktoren und insbesondere das Akzeptanzmodell können Anbietern dabei helfen Systeme zu entwickeln, die den Nutzerbedürfnissen entsprechen. Es können Designanforderungen abgeleitet werden, um diese Faktoren zu erfüllen. In ähnlicher Weise können die Beschaffer von FIT die Erkenntnisse nutzen, um bestehende Systeme zu bewerten und das für ihre Feuerwehr passende zu finden. Schließlich können FIT, die Nutzerbedürfnisse besser erfüllen, die Feuerwehrleute auch besser bei ihren Einsätzen unterstützen. Gemäß der Theorie zum Situationsbewusstsein können durch sie bereitgestellte Informationen die Entscheidungen und letztlich auch die Leistungen der Feuerwehrleute verbessern.

Aufgrund der besonderen Bedeutung der Feuerwehren für die öffentliche Sicherheit, besitzt diese Dissertation auch gewisse politische Implikationen. Beispielsweise werden *aufschlussreiche Ereignisse* und *Investitionsmöglichkeiten* als Auslöser für die Absicht zur Nutzung eines ERIS identifiziert. Beide könnten durch entsprechende Ausbildungs- und Förderprogramme bewusst herbeigeführt werden, um die Verbreitung von FIT zu steigern. Um den Datenaustausch über System- und Organisationsgrenzen hinweg zu ermöglichen, erscheinen außerdem einheitliche Schnittstellenspezifikationen als dringend notwendig. Dies sind nur einige Beispiele dafür, wie die Politik die Nutzung von FIT fördern und so die Leistungsfähigkeit der Feuerwehren steigern kann.

Zusammenfassend stellt diese Dissertation die signifikante Weiterentwicklung eines kleinen, vergleichsweise unerforschten, jedoch unbestritten relevanten Forschungsbereichs dar. Sie leistet einen Beitrag dazu, die Akzeptanz und Nutzung von FIT zu verstehen. So trägt sie potenziell dazu bei, Feuerwehrleute zukünftig mit besseren Informationen zu versorgen, ihre Entscheidungen und schließlich ihre Leistungen zu verbessern.

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List of Abbreviations

AR	Augmented Reality
ASQ	After-Scenario Questionnaire
AVE	Average Variance Extracted
CSU	Command Support Unit
DOI	Diffusion of Innovations Theory
EMS	Emergency Medical Service
ERIS	Emergency Response Information Systems
FD	Fire Department
FIT	Firefighter Information Technology
Hazmat	Hazardous Materials
IC	Incident Commander
MPCU	Model of PC Utilization
PlFD	Plant Fire Department
PLS-SEM	Partial Least Squares Structural Equation Modeling
PPE	Personal Protective Equipment
PrFD	Professional Fire Department
SCBA	Self-Contained Breathing Apparatus
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
TTF	Task-Technology Fit
TTFM	Task-Technology Fit Model
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UTAUT	Unified Theory of Acceptance and Use of Technology
VFD	Voluntary Fire Department
VIF	Variance Inflation Factor
VR	Virtual Reality
WSN	Wireless Sensor Network

Introductory Paper

1 Introductory Paper

1.1 Motivation

Since the dawn of mankind, communities are faced with a variety of both natural and man-made disasters [1]. These spontaneously occurring events often come with significant dangers for lives, properties, and cultural assets. To prepare for such dangers, communities assemble specialized emergency response organizations which respond and provide relieve upon a disaster [1]. Ensuring public safety, these organizations play a pivotal role for functioning societies. Fire departments are among the most versatile and widespread of these organizations. Their duties typically include a variety of firefighting, technical rescue, and hazardous materials (hazmat) operations [2, 3]. To achieve the necessary density of fire departments, many countries rely on voluntary structures [2]. This distinguishes fire departments from most other organizations and especially business contexts. Emergency operations are carried out in phases and initiated by the reconnaissance of the situation [3, 4]. Due to the emergency context, firefighters must typically make time-critical decisions in unknown environments and with a deficit of information [5, 6].

From a theoretical perspective, it is therefore important for firefighters to gain situation awareness. That is they must perceive elements of the environment, comprehend their meaning, and project future developments [7, 8]. Improved situation awareness is theorized to support decision-making and ultimately leading to better performance. Generally, the theory of situation awareness applies to all hierarchical levels from the incident commander to the ordinary firefighter. In order to provide firefighters with the information needed for situation awareness, literature suggests several types of firefighter information technologies (FIT). They include unmanned aerial vehicles (UAVs) [9-11], smart personal protective equipment (PPE) [12-14], and many others. Among the FITs, emergency response information systems (ERIS) are of specific importance. They resemble versatile platforms to process mission-critical information and integrate inputs from other systems [6, 15-17]. Compared to most other FITs, ERIS provide universal support for all types, dimensions, and phases of an emergency. They therefore hold the arguably highest potential for improving firefighter situation awareness and performance.

Despite these theoretical potentials, ERIS and most other FITs have so far hardly found their way into the practice of fire departments. To explain the acceptance and use of technologies in general, literature holds a variety of theories and acceptance models. Prominent examples include the Information Systems Success Model, the Task-Technology Fit (TTF) model, and the Unified Theory of Acceptance and Use of Technology (UTAUT)

[18-21]. While all of them have been successfully applied in various private and business contexts, technology acceptance in emergency organizations remains rather unexplored. Some studies can be found in the context of emergency medical service (EMS), police, and other organizations [22-26]. Focusing on fire departments, studies about remotely related topics like information needs, adoption capabilities, or general design requirements can be found [27-29]. However, technology acceptance and use in the firefighter domain has not yet been explicitly and systematically researched. The dissertation at hand therefore addresses this literature gap and tries to answer the following research question.

Overarching Research Question: *Under which circumstances will emerging firefighter information technologies get accepted and used?*

To consider the complexity of this question, we applied a stepwise procedure. It is resembled by the three-part structure of the cumulative dissertation, including nine papers. Part 1 establishes the status quo of the FIT domain from both a theoretical and a practical perspective. Part 2 identifies potential acceptance factors for individual FITs as well as FITs in general and exemplifies their effects in firefighter practice. Part 3 proposes, evaluates, and ethnographically complements an acceptance model for ERIS as a specific technology type. Each of the three parts applies both qualitative and quantitative methods, resulting in a purposeful mixed methods approach. The results are multi-facetted and hold several implications for academia, practice, and policy. Amongst others, the dissertation provides a theoretical foundation of the FIT domain, an explanation of FIT acceptance, a contextualization of existing acceptance models, indications for the design of FITs, and suggestions to facilitate the digitalization of fire departments. Overall, this dissertation resembles a significant evolution of a small, comparably unexplored, but undisputedly relevant research domain.

The introductory paper will proceed as follows. Section 1.2 further illuminates the context in which the dissertation was conducted, deriving specific research questions. Section 1.3 describes the methodology including the overall structure of the dissertation and the applied research methods. Section 1.4 presents the main results of each included study. Section 1.5 summarizes the major implications and limitations. Finally, the introductory paper ends with a conclusion in section 1.6.

1.2 Research Context

The following sections provide basic contextual information for the introductory paper as well as the whole dissertation. They include brief explanations of the firefighter domain, the topic of FITs with ERIS as an example, and related work about technology acceptance in this special domain. Based on these, we derive specific research questions.

1.2.1 The Firefighter Domain

Ever since, communities face various natural and technical hazards [1]. Their occurrence may be referred to as an emergency, disaster, or catastrophe, depending on the dimension of the event. For the purposes of this work, these terms may be used synonymously. All of them resemble highly dynamic events that call for time-critical, context-dependent decisions [5, 6]. Typically, large-scale catastrophes evolve from smaller emergencies and the overall procedure stays the same [3, 4]. To cope with such events, communities assemble emergency response organizations like police, EMS, and other specialized agencies. Fire departments are among the most traditional, widespread, and versatile of these organizations [1]. They also represent a special case in structural terms. In many countries like the United States, China, and Germany, the vast majority of firefighters are volunteers who do their duty alongside their main job [2]. These structures have an impact on several aspects of the fire departments. However, like the other organizations, their main purpose is to respond to emergencies, save lives and properties of those affected.

The versatility of fire departments is reflected in the variety of emergencies they respond to. This broad spectrum can be divided into three primary areas [2, 3]. *Firefighting* operations include compartment, structure, wildland, and all other kinds of fire suppression missions. *Technical rescues* refer to a wide range of activities to prevent harm to people, animals, or things. Amongst others, firefighters respond to road or machine accidents as well as search and rescue missions. *Hazmat* operations include the identification, containment, and neutralization of spilled substances that pose a threat to lives or the environment. Besides these three primary areas, fire departments may have additional duties. They often take a significant part in the response to large-scale catastrophes, even outside their original competences [1, 4]. Beyond that, they may also provide the EMS or operate control and dispatch centers [2]. However, these additional tasks can vary heavily, depending on the individual country, state, or municipality.

In a temporal way, the widely applied disaster management cycle divides an emergency in four phases which are displayed in Figure 1.1 [1]. *Mitigation* refers to limiting the probabilities or effects of emergencies. *Preparation* means achieving readiness and includes, among others, setting up, equipping, and training emergency response organizations. *Response* refers to the immediate intervention activities once an emergency occurs. *Recovery* aims at restoring the initial situation or even enhancing it. As shown in Figure

1.1, firefighter activities mainly concern the preparation and response phase. A firefighter response can be further divided according to mandated incident command systems [3, 4]. During the initial *reconnaissance*, necessary information about the situation and environmental factors is collected. In the *planning* phase, this information gets assessed, resulting in decisions how to proceed. In the *transmission* phase, these decisions are communicated to the subordinate units. The following *execution* may comprise practical actions or a lower-level command process. Either way, the thereby changed situation resembles input for a repeated cycle starting with another reconnaissance.

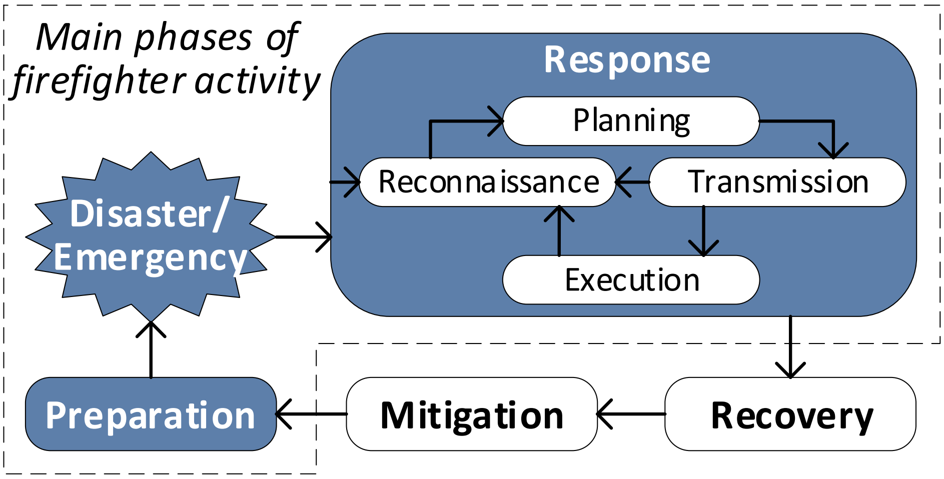

Figure 1.1 Phases of an emergency

1.2.2 Firefighter Information Technologies

During an emergency response, firefighters must typically make time-critical decisions in highly dynamic situations and unfamiliar environments. In such contexts, *situation awareness* is a key determinant for appropriate decisions, leading to improved performance [7, 8]. Figure 1.2 illustrates the three-level structure of situation awareness. On the *perception* level, firefighters must capture relevant information about the incident itself, the environment, and their available resources. On the *comprehension* level, they must connect the various aspects to gain a holistic understanding of the situation. On the *projection* level, the goal is to predict developments of the near future. While situation awareness will improve firefighter decisions and performance, it significantly depends on sufficient information on the lower levels [6]. A practical example for how information quality affects situation awareness and firefighter performance will be given in section 1.4.4. Compared to the command process described above, the levels of situation awareness cover the reconnaissance and parts of the planning phase.

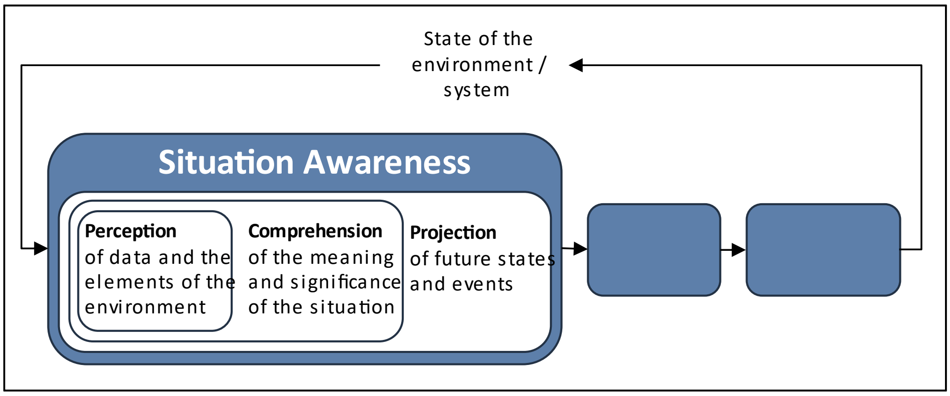

Figure 1.2 Theory of situation awareness (excerpt)

To provide sufficient information for improved situation awareness, literature proposes a variety of FITs. An FIT can be defined as an information technology supposed to be used by firefighters in the context of emergency responses. For example, UAVs can provide images or hazmat measurements from aerial positions [9-11]. Smart PPE can support firefighters with advanced sensory and provide real time monitoring of the health status [12-14]. Indoor navigation systems can help navigate through unknown buildings, especially under difficult conditions of fire and smoke [30-32]. An extensive review of the different FIT types will be given in section 1.4.1. It shows that most of the proposed technologies support the reconnaissance phase of an emergency. In terms of situation awareness, they therefore mainly address the perception level. Furthermore, most FITs specifically focus on firefighting mission.

In contrast to that, ERIS resemble versatile platforms to gather, analyze, and communicate mission-related information [6, 15-17]. They can support the incident commander in virtually all types and dimensions of operations and integrate data from other FITs. While there are various design approaches, most ERIS have some typical functionalities in common. Figure 1.3 displays these features in an exemplary system [15]. They include inventories of available resources (top left), overviews of operation sections and the command structure (bottom left), and a situation map with spatial information (right). Three evolutionary stages of ERIS can be distinguished depending on how real-time incident data is utilized and obtained. Basic ERIS, like most of the currently available systems, provide a platform for manually entered information [15-17]. Advanced systems partially automate data input with sensors for unit positions, water tank levels, or weather conditions [6, 33, 34]. ERIS of the highest stage may also provide decision-making support by suggesting commands based on the received information [35-37]. Integrating various information and partly analyzing it in an automated way, ERIS may also support the comprehension and projection levels of situation awareness. Due to their special potentials, ERIS will be in the focus of the final part of this dissertation.

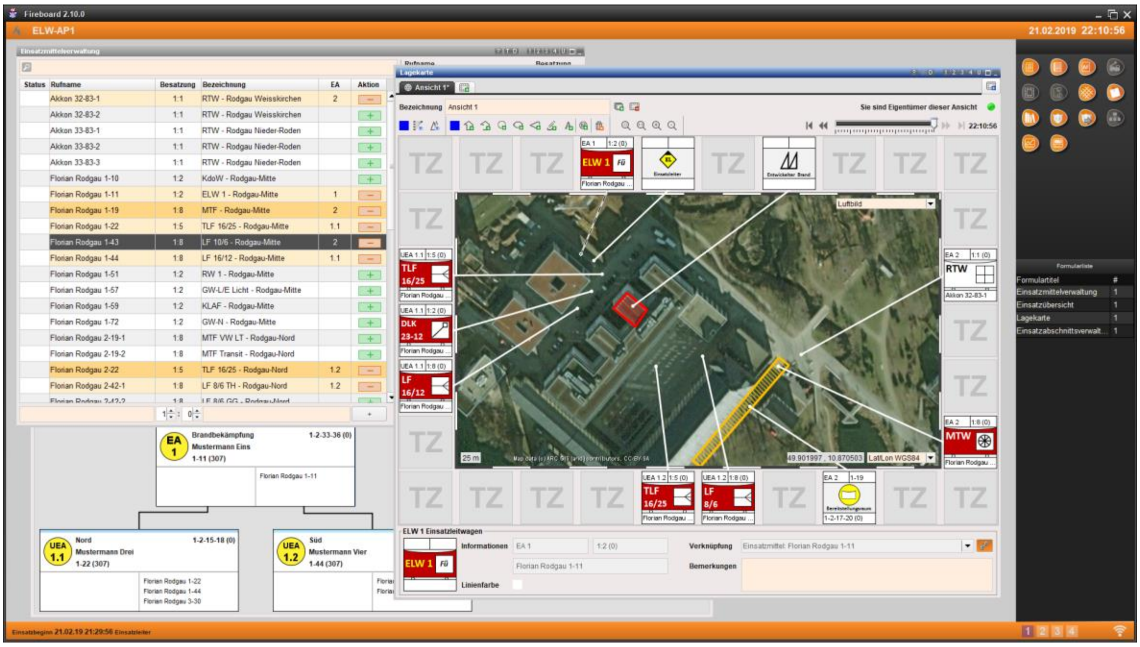

Figure 1.3 Exemplary ERIS "Fireboard"

1.2.3 Acceptance of Firefighter Information Technologies

There are several approaches to explain the adoption of information technologies. The user satisfaction literature aims to explain satisfaction and system use based on the quality of the system itself, the information it provides, and the associated service [18]. The TTF model implies that the technology characteristics must fit with the intended task to realize utilization and performance impacts [19]. The technology acceptance literature takes the user perceptions about using the system into focus. Prominent theories include the Diffusion of Innovations (DOI) theory [38, 39], the Model of Personal Computer Utilization [40], and various Technology Acceptance Model versions [41-43]. As an attempt to integrate these theories in a common model, the UTAUT was proposed [20, 21]. It explains behavioral intention and use behavior based on performance expectancy, effort expectancy, social influence, facilitating conditions, and several moderating variables. Finally, a combined model interpreted user satisfaction aspects as antecedents of perception constructs from the technology acceptance literature, to integrate these approaches [44].

The mentioned theories have been applied to various contexts, mainly in private and business usage scenarios [45, 46]. Emergency responses, however, are shaped by quite special characteristics [1, 5, 6]. To explain technology acceptance under such circumstances, literature calls for the contextualization of generic acceptance models [47]. For the emergency response domain, only few such related works can be found. Most of them concern healthcare, especially in clinical usage scenarios [48, 49]. For medical emergency responses, studies identify acceptance factors for electronic triage systems [22] and propose an acceptance model for mobile devices in EMS [23]. Contextualized models for police responses were used to explain the acceptance of mobile data terminals [24, 25], smartphone apps [26], and the influence of age on technology acceptance by officers [50]. Finally, acceptance models were proposed for control centers [51], the multi-organizational adoption of emergency management information systems in large-scale disasters [52], and the adoption of the RFID technology in emergency management [53].

Limiting the focus on fire departments, hardly any study surrounding the acceptance of information technologies can be found. One of them examines firefighters' most important information needs before arrival and on scene, which could be delivered by digital plans [27]. It is argued that information needs to be enriched and centralized, which may happen in an ERIS [54]. Besides information needs, other studies illuminate characteristics of frontline firefighting to derive implications for system design [55, 56]. General design principles are proposed for UAVs [29, 57] and ERIS [34, 58]. For ERIS, specialized studies also examine how to design user interfaces [59, 60] and system architectures [5, 6, 61]. To evaluate if FITs may be adopted in a fire department, a capability assessment model for emergency management organizations is proposed [62]. Another model explicitly explains an organization's capability to adopt an ERIS [28]. Finally, the inclusion of internet of things technologies into emergency responses is researched using the TTF model [63]. Summing up, hardly any study has explicitly and fully investigated the acceptance of FITs in general or ERIS in particular prior to this dissertation.

1.2.4 Research Questions

As pointed out above, extant literature cannot sufficiently explain under which circumstances a firefighter will adopt an FIT. Therefore, our initially raised research question remains unanswered. To address this literature gap and due to the complexity of the problem, we split the overarching research question into three subordinate questions.

Overall, the literature of the FIT domain appears largely fragmented. The mostly technology-driven approaches typically focus on selected subareas. With the lack of review articles, a systematic overview of the domain is largely missing. Therefore, common concepts, main research areas, and remaining literature gaps appear unclear. Besides the need of structuring, literature must also be complemented with a practical perspective. Beyond the underlying reasons, extant literature cannot even answer if firefighters adopt frequently proposed FITs at all. While their theoretical potentials are undisputed, it remains unclear if practitioners also recognize them. Summing up, the initial research question of this dissertation attempts to establish a status quo of the domain.

Research Question 1: *How are emerging firefighter information technologies perceived by research and practitioners?*

Building on the status quo, underlying aspects of practitioner perceptions come into focus. To assess the practical potentials of FITs, it appears necessary to understand the reasons why a firefighter will accept or reject such a technology. To structure these reasons, they can be conceptualized as acceptance factors. These factors will enable further analyses in different directions. For example, the various heterogenous FIT types must be considered separately to a certain degree. However, acceptance factors equally identified for multiple technologies may serve as candidates for acceptance factors of FITs in general. Further analyses can show how exactly an identified acceptance factor will affect firefighters and their FIT acceptance. Therefore, the second research question of this dissertation aims to conceptualize firefighter perceptions.

Research Question 2: *Which factors affect the acceptance of emerging firefighter information technologies?*

To gain a more systematic understanding of the FIT acceptance, it appears necessary to integrate the various acceptance factors in a common acceptance model. This may explain why a firefighter will intend to use and actually use an FIT. Furthermore, it can illustrate correlations between the factors, provide comparability of their respective influence, and uncover remaining gaps in explanation. These gaps may then be addressed by additional studies. Due to the complexity of the procedure and the uncovered heterogeneity of FITs, it appears necessary to concentrate on one specific technology type. Among the FITs, ERIS appear especially promising due to their universal support of incident command over all phases, types, and dimensions of firefighter responses. Therefore, the final research question of this dissertation will explicitly address the acceptance of ERIS.

Research Question 3: *How can the acceptance of emergency response information systems by firefighters be explained?*

1.3 Research Methodology

The following sections provide an overview of the overall procedure of this dissertation. First, we describe how the proposed research questions will be addressed by the three parts of the dissertation. Second, we summarize the research methods employed throughout the included papers.

1.3.1 Structure of Dissertation

To answer the three research questions, this dissertation is composed of three parts, which are illustrated in Figure 1.4. Part 1 establishes the status quo of FITs. For the theoretical perspective, a literature review structures the domain and identifies remaining literature gaps. For the practical perspective, a survey examines the dissemination and perception of several technologies among firefighters. Part 2 reveals potential factors for the acceptance of FITs. An interview study identifies such factors for various technologies as well as FITs in general. It is complemented by a laboratory experiment that exemplifies the influence of information format on task performance. Part 3 explains the acceptance of ERIS. A specific acceptance model is iteratively developed and evaluated via structural equation modelling. Remaining blind spots are addressed by an ethnography, which adds practical insights. Each of the included studies is presented in one or two papers.

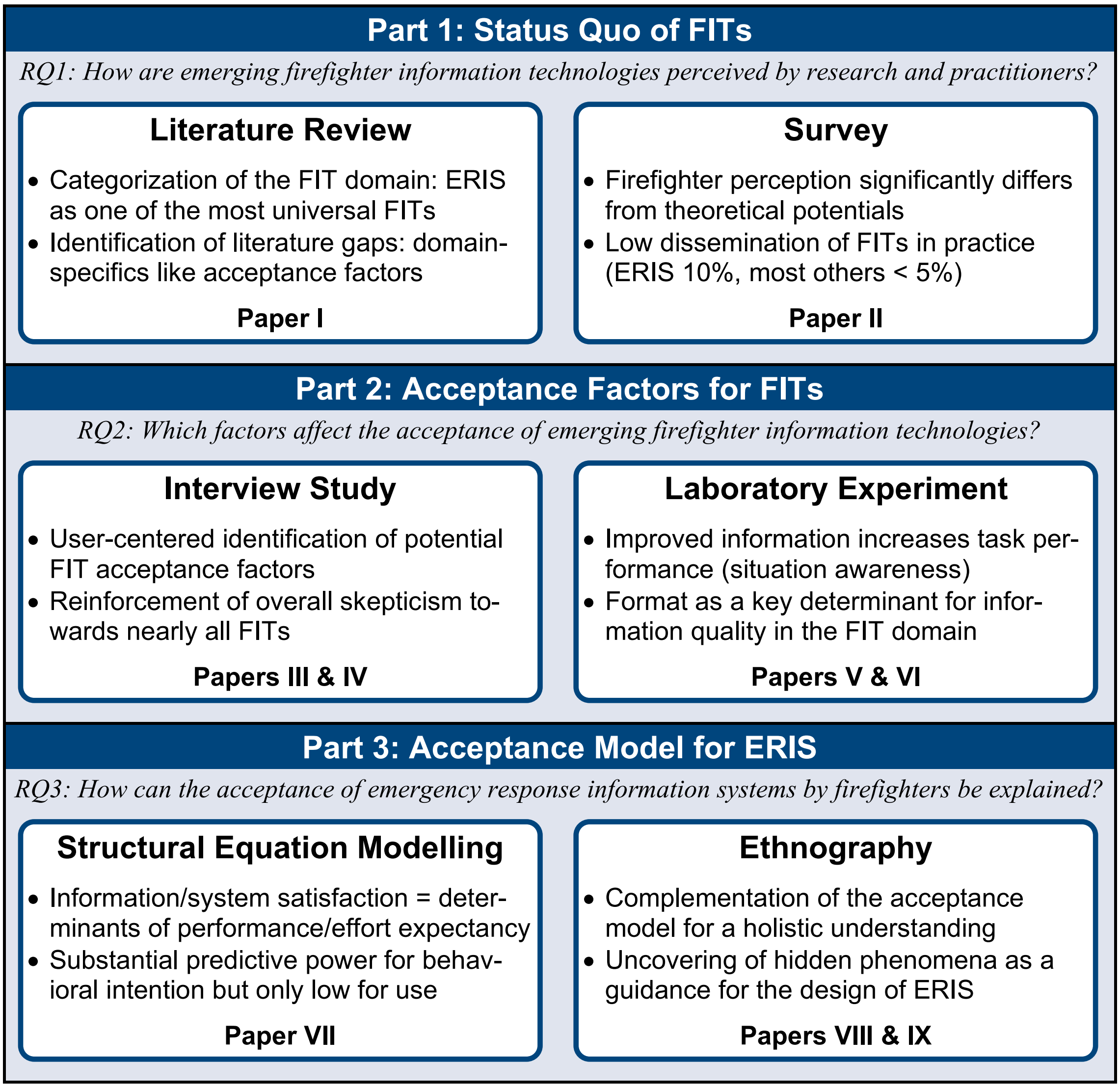

Figure 1.4 Structure of the dissertation

This cumulative dissertation includes nine independent papers, which are summarized in Table 1.1. Four of them are published in peer-reviewed journals, five in peer-reviewed conference proceedings. The papers were integrated in the dissertation without modifications in terms of their contents. For consistency, the heading numbers, table and figure captions, as well as font types and sizes have been reformatted. Note that terminology may slightly vary across the papers since they were developed at various times.

Table 1.1 Overview of included papers

#	**Paper citation**
I	J. Weidinger (2022). What is known and what remains unexplored: A review of the firefighter information technologies literature. *International Journal of Disaster Risk Reduction 78*, 103115. https://doi.org/10.1016/j.ijdrr.2022.103115
II	S. Schlauderer, S. Overhage and J. Weidinger (2016). New Vistas for Firefighter Information Systems? Towards a Systematic Evaluation of Emerging Technologies from a Task-Technology Fit Perspective. *49th Hawaii International Conference on System Sciences (HICSS)*, Koloa, HI, USA, pp. 178-187. https://doi.org/10.1109/HICSS.2016.30
III	J. Weidinger, S. Schlauderer and S. Overhage (2018). The Good, the Bad and the Indispensable - Insights into the Practical Potential of Emergency Response Information Systems and Drones for Firefighters. *51st Hawaii International Conference on System Sciences (HICSS)*, Waikoloa, HI, USA, pp. 2275-2284. https://doi.org/10.24251/HICSS.2018.009
IV	J. Weidinger, S. Schlauderer and S. Overhage (2018). Is the Frontier Shifting into the Right Direction? A Qualitative Analysis of Acceptance Factors for Novel Firefighter Information Technologies. *Information Systems Frontiers 20*, pp. 669–692. https://doi.org/10.1007/s10796-017-9785-8
V	J. Weidinger, M. Robel, S. Schlauderer and S. Overhage (2018). Analyzing the Potential of Graphical Building Information for Emergency Responses: Toward a controlled Experiment. *26th European Conference on Information Systems (ECIS)*. Portsmouth, UK, pp. 1-10. https://aisel.aisnet.org/ecis2018_rip/10
VI	J. Weidinger, S. Schlauderer and S. Overhage (2019). Analyzing the Potential of Graphical Building Information for Fire Emergency Responses: Findings from a Controlled Experiment. *14th International Conference on Wirtschaftsinformatik (WI)*. Siegen, Germany, pp. 1084-1098. https://aisel.aisnet.org/wi2019/track09/papers/6/
VII	J. Weidinger, S. Schlauderer and S. Overhage (2023). Information Technology to the Rescue? Explaining the Acceptance of Emergency Response Information Systems by Firefighters. *IEEE Transactions on Engineering Management 70*(1), pp. 14-28. https://doi.org/10.1109/TEM.2020.3044720
VIII	J. Weidinger, S. Schlauderer and S. Overhage (2022). Which Factors Govern the Use of Emergency Response Information Systems? Insights from an Ethnographical Study of a Voluntary Fire Department. *55th Hawaii International Conference on System Sciences (HICSS)*. Maui, HI, USA, pp. 2511-2520. https://doi.org/10.24251/HICSS.2022.312
IX	J. Weidinger, S. Schlauderer and S. Overhage (2024). Determinants for the Acceptance of Emergency Response Information Systems: Ethnographical Insights into the Digitalization of a Voluntary Fire Department. *International Journal of Disaster Risk Reduction 109*, 104603. https://doi.org/10.1016/j.ijdrr.2024.104603

1.3.2 Applied Research Methods

The dissertation used a variety of research methods to study the acceptance of FITs in multiple steps and from multiple perspectives. Figure 1.5 summarizes which methods were applied in the nine papers. The arrangement according to the *degree of formalization* and *paradigm* is based on the examination of methods of *Wirtschaftsinformatik* by Wilde and Hess [64]. To establish international comparability, they also suggest allocations to methods of *Information Systems* research [65, 66]. Therefore, *literature review* was assigned to *argumentative-deductive analysis*, *interviews* to *qualitative cross-section analysis*, and *survey* to *quantitative cross-section analysis*. For the sake of clarity, papers using multiple methods were allocated to their main method. Most prominently, Paper VII with a brief literature review, interviews for a pre-test as well as surveys for a pilot study and the final evaluation counted as a *quantitative cross-section analysis*.

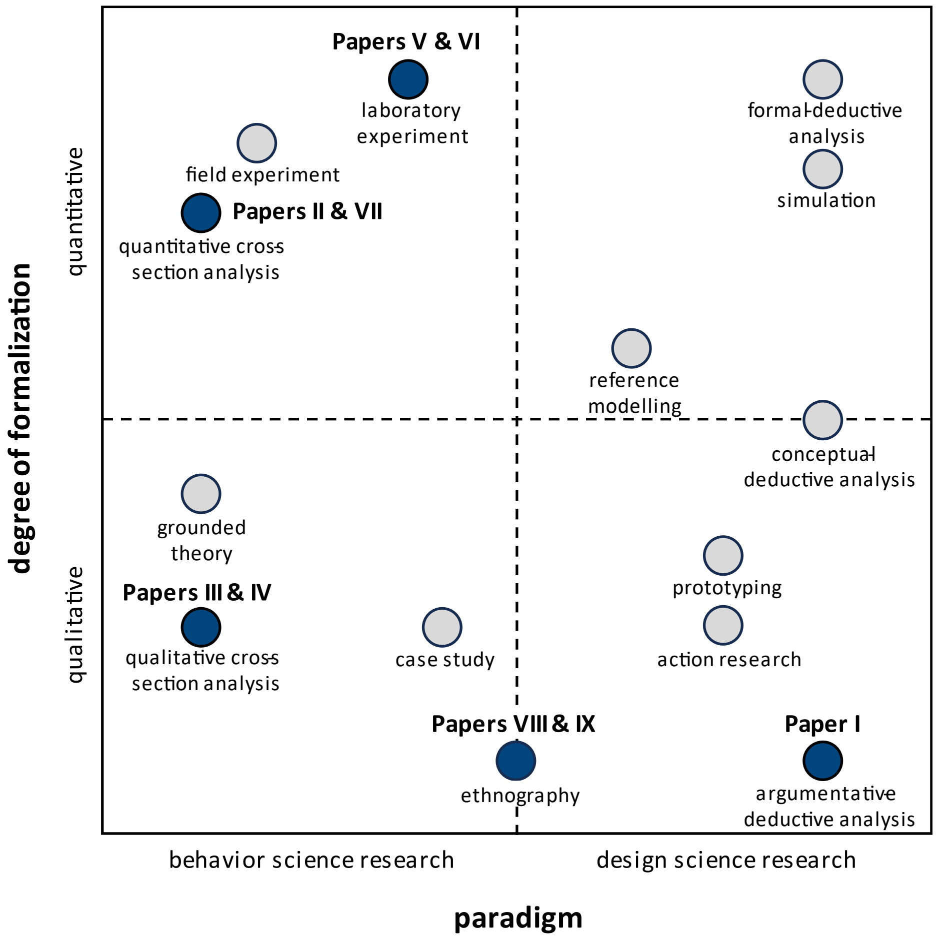

Figure 1.5 Overview of applied research methods

As can be seen in Figure 1.5, each part of the dissertation consists of both quantitative and qualitative components. Quantitative research *"typically uses numerical analysis to illustrate the relationship among factors in the phenomenon studied"* [67]. They aim to measure and statistically analyze phenomena to test hypotheses and theories. In contrast, qualitative research *"emphasizes the description and understanding of the situation behind the factors"* [67]. They aim to explore and reconstruct phenomena to generate hypotheses and theories. Combining both aspects, this dissertation and each of its parts applied a mixed method approach. Regarding paradigm, Wilde and Hess used the problem oriented distinction of problem understanding and problem solving [64, 68]. Behavior science concentrates on theories that *"explain or predict organizational and human phenomena surrounding the analysis, design, implementation, management, and use of information systems"* [68]. In contrast, design science concentrates on artifacts *"through which the analysis, design, implementation, management, and use of information systems can be effectively and efficiently accomplished"* [68]. Trying to explain under which circumstances FITs will get accepted and used, this dissertation is mainly located in the behavior science paradigm.

Part 1 of the dissertation combines qualitative insights of a literature review with quantitative results of a survey. The conducted scoping review aimed to *"examine the extent, range and nature of research activities"* in the FIT domain and *"identify research gaps in the extant literature"* [69]. Its scope was to integrate existing research and identify central issues in a conceptual way according to the taxonomy of Cooper [70]. The overall procedure was guided by the recommendations of vom Brocke, et al. [71] and the resulting 108 papers were summarized in a concept matrix as suggested by Webster and Watson [72]. Quantitative survey results complemented the review with a practitioner perspective. The survey gathered *"information about the characteristics, actions, perceptions, attitudes, or opinions of a large group of units of observations"* [73]. Precisely, it comprises feedback from 807 representatives of German fire departments to an online questionnaire. For seven different FITs they stated if their department currently uses them and how they perceive their respective potentials. Besides overall results, we calculated their correlations with department type and the number of annual emergency operations.

Part 2 includes qualitative results of an interview study and an accompanying quantitative deep dive with a laboratory experiment. The qualitative approach was chosen to *"provide a rich description of a phenomenon as perceived by individuals"* [73]. The semi-structured interviews were based on the DOI theory, covered seven different FITs, and followed the guidelines of Myers and Newman [74]. The interviewed experts were 21 firefighters from different department types and command levels [75]. Their feedback was recorded, transcribed, and thematically grouped, resulting in several potential acceptance factors [76]. The impact of one of these factors was quantitatively analyzed in a laboratory experiment. Such experiments are *"specifically intended to examine cause and effect relationships"* [73]. Our experiment showed the effect on firefighter task performance caused by different information formats. The design and analysis followed the guidelines of Cox and Reid [77]. 69 firefighter squads were randomly allocated to three groups with different treatments. All squads performed the same task under controlled surrounding conditions. We measured task completion, needed time, and via questionnaire [78].

Part 3 contains a structural equation modelling study, which was complemented with an ethnography. Structural equation modelling is a method for *"high quality statistical analysis in survey research"* [73]. The initial acceptance model was based on extant works identified in a literature review [44]. A pre-test contributed feedback from 10 domain experts through semi-structured interviews and a pilot-study with questionnaires from 72 firefighters showed the model's applicability [79, 80]. The final evaluation was conducted with an online survey, which has been completed by 212 firefighters. The results were analyzed using SmartPLS 3 and following the methodology of Hair, et al. [81]. Insufficiently explained aspect of the acceptance model were addressed by an ethnography. This method is especially suited to *"describe situations rarely observed, or for which a better understanding may have important consequences"* [82]. Our ethnography covered the multi-year project of command support digitalization in an exemplary voluntary fire department. It resembles a *realist tale* following the guidelines of Van Maanen [83]. The study's rigor was ensured in terms of contextualization, multiple interpretations, and the remaining principles proposed by Klein and Myers [84].

1.4 Main Research Results

The following sections summarize the dissertation's main results. They are structured along the six major studies introduced in section 1.3.1. For each study, we briefly describe the contents of the associated papers. Then we provide an insight into the respective results. Finally, we set these in context to the other studies and the overall dissertation.

1.4.1 Literature Review of the FIT domain (Paper I)

The literature review published in Paper I brings structure to the versatile and largely fragmented field of FITs. From a set of 108 papers published between 2010 and 2022, we identified ten frequently researched types of technologies as well as their respective characteristics [71, 72]. Analyses along key concepts like the phases and types of firefighter operations revealed several literature gaps regarding non-firefighting missions, support beyond the reconnaissance phase, and integration of information. Furthermore, only few of the identified papers explicitly focused on domain specifics like the acceptance of FITs. Overall, the study constitutes a comprehensive and unique overview of the domain as well as a solid foundation for future research.

As displayed in Table 1.2, the identified papers could be categorized in five technology-oriented sections. *Data-driven approaches* aim to analyze numerical, textual, graphical, or other data. The resulting perceptions can be used to forecast future events and enhance planning activities, or to detect occurring events and monitor their further development. *Conventional means of incident command* comprise evolutions of traditional means rather than revolutionary new approaches. Predecessors of such systems are frequently used in practice, already. *Unmanned vehicles and systems* can be used to expand the operating ranges of firefighters by overcoming the physical limitations of human actors. They can be separated in flying and ground-based vehicles. *Personal firefighter augmentation* aims to augment firefighters themselves. This may, on the one hand, involve technologies to expand information about individual firefighters, their surroundings, and locations. On the other hand, technologies can be used to present this information in an immersive way. *Non-technology specific works* typically resemble foundations of either technological or domain-specific aspects.

Table 1.2 Summary of literature review results

Section	Technology	Preparation	Response			
			Recon-naissance	Planning	Trans-mission	Execution
Data-driven Approaches	Forecasting and Planning Systems	11 (6 | 1 | 4)	-	-	-	-
	Detection and Monitoring Systems	-	9 (8 | 0 | 1)	1 (1 | 0 | 0)	-	-
Conventional Means of Incident Command	Plans and Guides	-	12 (10 | 1 | 1)	-	-	-
	Emergency Response Information Systems	-	15 (6 | 1 | 8)	10 (7 | 1 | 2)	5 (2 | 0 | 3)	-
	Communication Systems	-	-	-	8 (4 | 0 | 4)	-
Unmanned Vehicles / Systems	Unmanned Aerial Vehicles	-	12 (3 | 3 | 6)	-	-	-
	Unmanned Ground Vehicles	-	6 (4 | 2 | 0)	-	1 (1 | 0 | 0)	3 (3 | 0 | 0)
Personal Firefighter Augmentation	Smart Personal Protective Equipment	3 (0 | 0 | 3)	8 (8 | 0 | 0)	-	-	-
	Indoor Navigation Systems	-	13 (13 | 0 | 0)	5 (5 | 0 | 0)	-	-
	Virtual and Augmented Reality Systems	6 (6 | 0 | 0)	3 (1 | 0 | 0)	-	-	-
Non-Technology specific Works	Possible Future Technologies	8 (0 | 0 | 8)				
	Domain specifics	7 (0 | 0 | 7)				

Legend: total number of papers (fire operations | technical rescues or hazmat | unspecific or all operation types)

Many of the identified literature gaps motivate this dissertation's later focus on ERIS as a pivotal technology type. First, ERIS appear far less restricted to fire operations, compared to most other technologies. Instead, they serve as a means of incident command in all kinds of operations. Second, ERIS hold the greatest potential of support beyond the reconnaissance phase. They may inform planning with data analyses or even command recommendations. They also allow the transmission of information apart the regularly used voice radio. Third, ERIS appear suitable to realize the needed integration of information. As a central platform, they can bundle the inputs from several sources like UAVs or smart PPE and prepare them for the incident commander. Overall, the results illustrate that most papers in the FIT domain follow a rather technology-driven approach. Novel technologies are proposed to be used in the domain, based on theoretical potentials. Only few papers examine if and how firefighters will actually accept these technologies and use them in practice. This existing literature gap is addressed by Part 2 and Part 3 of the dissertation. Summing up, the included literature review contributes the following thesis:

Thesis 1: *Literature suggests several types of firefighter information technologies, but the mostly technology-driven approaches tend to neglect domain specifics.*

1.4.2 Survey on Practitioner FIT Perception (Paper II)

The survey published in Paper II sheds light on the dissemination and practical potentials of several FITs. We asked 807 representatives of German fire departments to assess seven emerging technologies from a user-oriented TTF perspective [19]. The results indicate low dissemination rates for nearly all frequently proposed FITs. Regarding practitioner assessment, only some technologies showed a positive tendency. In contrast to the expectations, the potentials of others were found to be limited, though. Overall, the study complements findings from the literature with a practical perspective.

As displayed in Figure 1.6, only digital plans and ERIS had any significant dissemination among the represented fire departments at the time of the survey. All other technologies faced dissemination rates of low single-digit percentages. Regarding practical potentials, only digital plans and indoor navigation received clearly positive ratings (60% and 50% *relevant* or *very relevant*). ERIS, smart PPE, and the continuous transmission of air supply status received mixed feedback with 33-38% positive ratings. Surprisingly, the potentials of UAVs and UGVs were rated rather negatively (48% and 59% *irrelevant* or *very irrelevant*). Additional correlation analyses revealed that the more operations participants responded to per year, the more positively they rated digital plans, ERIS, and UAVs. In contrast to that, the ratings of smart PPE, indoor navigation, and status of air supply were negatively correlated with the number of operations.

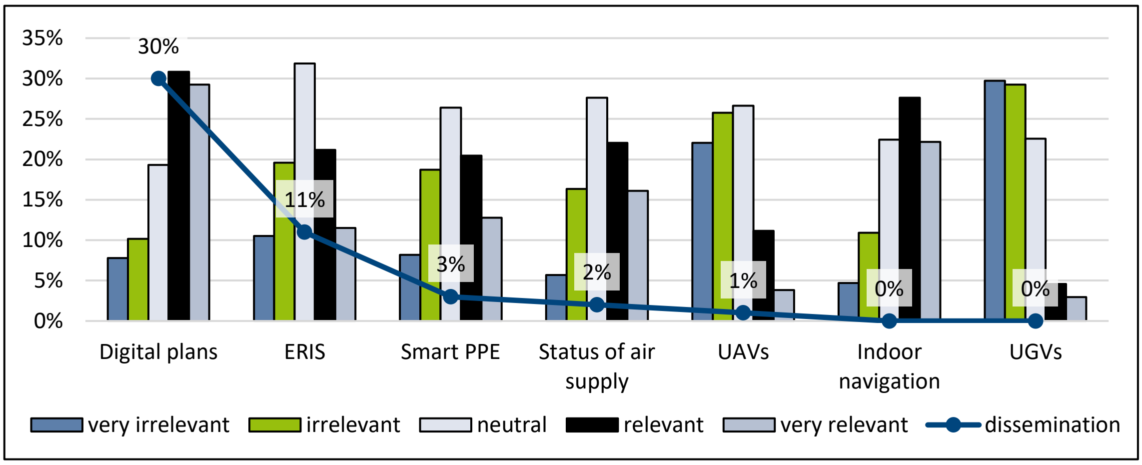

Figure 1.6 Summary of survey results (excluding N/As)

Like the literature review before, the survey further motivates the focus on ERIS in Part 3 of the dissertation. Together with digital plans, it is the only FIT type with relevant practical dissemination. This increases the number of firefighters with practical experiences about the technology itself and its acceptance. In most other terms, however, the practical perspective of the survey somewhat contrasts the theoretical perspective of the literature review. Literature proposes several FITs based on their theoretical benefits but most of them are hardly used by practitioners. Furthermore, many of the FITs are received rather skeptically by firefighters regarding their potentials. Due to the quantitative nature of the data, the reasons behind this apparent contradiction remain unclear. This calls for a detailed analysis of which factors will facilitate or impede the acceptance of FITs by firefighters. Part 2 of the dissertation will address this issue. Summing up, the included survey adds the following thesis to the dissertation:

Thesis 2: *Despite theoretical potentials, currently most firefighter information technologies face low dissemination rates and practitioners do not perceive them as relevant.*

1.4.3 Interview Study on FIT Acceptance Factors (Papers III & IV)

The interview study published in Paper III and Paper IV delivers qualitative insights into the factors affecting the acceptance of different FITs by firefighters. We interviewed 21 members of German fire departments representing different department types and command levels [74]. The preliminary results of Paper III delimit positive and negative perceptions as well as general requirements for ERIS and UAVs. Paper IV analyzes data about seven different FITs from a DOI perspective [39]. We identified several potential acceptance factors for each technology. Beyond that, we derived common aspects that affect all of them and may serve as acceptance factors for FITs in general. Overall, the study delivers in-depth insights into the unexplored topic.

The results confirm the impression of firefighters' skepticism toward most FITs. Digital plans were the only technology for which the interviewees named more positively connotated relative advantages than negatively connotated relative disadvantages and complexities. Smart PPE and AR systems were viewed particularly critically. For the different fire department types and command levels, we identified only slight deviations regarding the stated acceptance factors. The most frequently mentioned factors across all technologies are summarized in Table 1.3. Amongst others, the firefighters attest most FITs some kind of *informational advantage*. However, they stated very high demands regarding *simplicity*, *robustness*, and *reliability*, to ensure compatibility with their work. Besides these relatively universal aspects, most of the identified acceptance factors appear rather specific for individual technologies. For example, *safety* constitutes an advantage only for FITs which are used within danger zones and a *limited range of application* was especially criticized for UGVs.

Table 1.3 Summary of interview results

Category	Factor	Plans and guides	ERIS	UAVs	UGVs	Smart PPE	AR systems	Indoor navigation	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**

Legend: Values describe the percentage of interviewees stating the respective factor

Building upon Paper II, this study illustrates possible reasons behind the firefighter perception of FITs. At the same time, the domain specific analysis addresses one of the major literature gaps identified in Paper I. With the inclusion of different technologies, department types, and command levels, we extensively cover the domain and the problem of technology acceptance within it. Using the DOI as a theoretical foundation, we deliberately took an inductive approach to identify acceptance factors [76]. This way, we could unbiasedly reflect the firefighter opinions. For later studies, these inductive factors were synchronized with existing constructs as far as reasonable. For example, *informational advantage* could be interpreted in diverse ways and was split in *format*, *completeness*, and other aspects. Nevertheless, the identified acceptance factors constitute an initial step toward acceptance models for FITs in general, as well as individual technologies. Overall, the included interview study contributes the following thesis to the dissertation:

Thesis 3: *Certain factors affect the acceptance of all types of firefighter information technologies, while others appear technology specific.*

1.4.4 Laboratory Experiment on Information Format (Papers V & VI)

The laboratory experiment published in Paper V and Paper VI examines the effects of information format on situation awareness in firefighter emergency responses. In Paper V we describe the experiment design [77, 78]. Firefighter squads perform a search and rescue task under realistic conditions. As a briefing they are provided with identical information in different formats. In Paper VI we present the experiment results, in which we analyzed the task performance of 69 squads. They show that graphical information about the building and the location of victims increases firefighters' task performance in comparison to a verbal briefing. A continuous access to such information during the entire mission was found to be less effective, though. Overall, the study provides insights into the effects of format as an exemplary factor of information quality.

Table 1.4 Summary of experiment results

Fact	Group 0 (verbal)		Group 1 (punctual)		Group 2 (continuous)		t-tests (p-values)		
	mean	**SD**	**mean**	**SD**	**mean**	**SD**	**G_0 vs G_1**	**G_0 vs G_2**	**G_1 vs G_2**
Task completion rate (0 or 1)	0.87	0.34	0.96	0.21	0.87	0.34	0.15	0.50	0.15
Task completion time (sec.)	340	100	285	78	289	67	**0.02***	**0.03***	0.41
ASQ 1 (satisfaction ease)	4.30	1.74	5.22	1.59	4.61	1.62	**0.04***	0.27	0.10
ASQ 2 (satisfaction duration)	4.43	1.38	5.17	1.40	4.57	1.50	**0.04***	0.38	0.08
ASQ 3 (satisfaction info)	5.52	1.73	5.96	1.58	5.83	1.56	0.19	0.27	0.39

Legend: ASQ items from 1 = disagree to 7 = agree; *: $p < 0.05$, one-tailed testing, N=69, each group n=23)

The experiment was developed in collaboration with a state firefighting academy and conducted in their facilities. The 69 squads consisting of two firefighters and a squad leader were divided into three groups. The control group G_0 received a verbal briefing about the building layout and the assumed position of a victim. For experiment group G_1, the briefing was graphically supported by a sketch map. Experiment group G_2 additionally had continuous access to the sketch map during the mission. Table 1.4 summarizes the experiment results. There was no significant difference between the groups in terms of task completion rate of reaching the victim. The task completion time needed to find the victim was significantly lower for both G_1 and G_2 compared to G_0. Additionally, an After Scenario Questionnaire (ASQ) revealed that firefighters of G_1 were more satisfied with how easy the task was and how long it took compared to those of G_0.

As described above, Paper III and Paper IV provide a broad overview of several potential acceptance factors. This study complements them with an exemplary deep dive into *format* as a single factor. The experiment was guided by the hypothesis that improved information can raise a firefighter's situation awareness leading to better decisions and consequently performance. Additionally, we identified format as an important determinant of information quality. We could show that firefighters who receive information in a better format will perform their tasks more efficiently and will be more satisfied with them. This confirms our hypothesis. While our experiment used paper prototypes to display graphical information, equally formatted information can also be displayed in technological devices. Therefore, the underlying phenomenon appears transferrable to the FIT domain. Summing up, the included experiment contributes the following thesis to the dissertation:

Thesis 4: *Format, as an exemplary measure of information quality, can significantly raise the efficiency of and satisfaction with firefighter operations.*

1.4.5 Acceptance Model Development for ERIS (Paper VII)

The structural equation modeling study published in Paper VII explains the acceptance of ERIS by firefighters. We propose a detailed, domain-specific acceptance model which combines findings of the user satisfaction and the technology acceptance literature. It was refined through a pre-test with 10 domain experts and a pilot-study with 72 firefighters [79, 80]. The acceptance model was evaluated in a survey with 212 firefighters using the partial least squares structural equation modeling technique [81]. The results indicate that it substantially predicts a firefighter's intention to use an ERIS. For the actual use of an ERIS, it holds at least weak predictive power. The identified acceptance factors provide guidance for the design and evaluation of ERIS, enabling the so far mostly theoretical benefits of ERIS to be transferred into practical applications more effectively. Overall, the study constitutes the first attempt to explicitly explain the acceptance of an FIT.

As displayed in Figure 1.7, the acceptance model is composed of two parts. The left-hand side is based on the user satisfaction literature with *Information Satisfaction* as well as *System Satisfaction* and their respective antecedents [85]. The right-hand part is based on the technology acceptance literature [20, 21]. The combination of both parts was adapted from the approach of Wixom and Todd [44]. The results reveal significant relationships for nine of the 13 quality antecedents and most of the remaining hypothesized paths. The model holds substantial predictive power ($R^2 > 0.75$) for the quality and satisfaction constructs as well as a firefighter's *Behavioral Intention* to use an ERIS. Moderate predictive power ($R^2 > 0.5$) was found for *Performance Expectancy*. For *Effort Expectancy* and the *Use* of an ERIS, the model holds at least weak predictive power ($R^2 > 0.25$). Besides the model evaluation, our survey contained a part about practical aspects like preferred devices and desired features. Most participants wanted to use an ERIS on a desktop PC, notebook, or tablet computer. Only 30% wished for smartphone support. Regarding features, offline and multi-user functionalities, an operation log, and an overview of units and resources were found to be very important.

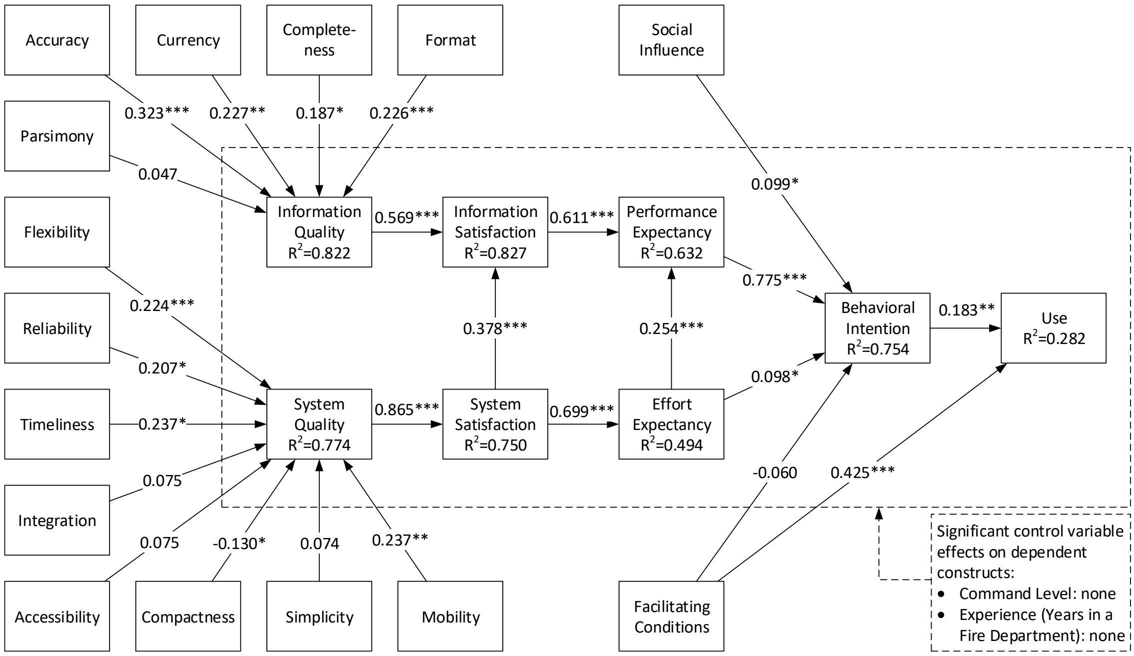

Figure 1.7 Summary of acceptance model results
Legend: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

This study addresses the literature gap identified in Paper I regarding the domain-specific explanation of technology acceptance. In contrast to the former studies with a general FIT focus, we explicitly concentrated on ERIS as a specific FIT type. As described in Paper I, they are promising means for information integration and less restricted in terms of operation types or phases. Paper II additionally showed that they are among the few FITs with significant dissemination among fire departments. This was a prerequisite to find enough firefighters with knowledge about ERIS and experience with their adoption. The inductively identified acceptance factors from Paper III and Paper IV were either transferred into established constructs or directly integrated in the proposed model. The model constitutes an initial attempt to explain the acceptance of an FIT by firefighters. However, especially the aspect of actual use calls for more in-depth analyses, which will be addressed in Paper VIII and Paper IX. Summing up, the included structural equation modeling study contributes the following thesis to the dissertation:

Thesis 5: *A firefighter's intention to use an emergency response information system is substantially determined by information satisfaction, system satisfaction, and their respective, partly domain-specific, antecedents.*

1.4.6 Ethnographical Insights into ERIS Adoption (Papers VIII & IX)

The ethnography published in Paper VIII and Paper IX provides detailed qualitative insights into the adoption of an ERIS. Over multiple years we ethnographically observed a voluntary fire department's project to digitalize its command support and introduce an ERIS [83, 84]. Paper VIII presents initial observations in a loose sequence. In Paper IX, we structure the results and allocate them in existing literature [47]. We identified seven factors acting as triggers for different adoption stages. From overarching characteristics of a voluntary fire department, we derived six additional factors. Amongst others, the results contextualize existing acceptance models and can help firefighters in conducting successful digitalization projects. Overall, the study delivers unique perspectives on the acceptance of ERIS.

Figure 1.8 displays the 13 factors we identified in context of the existing acceptance model for ERIS. We found that *error management culture*, *revealing events*, and *IT affinity of deciders* can trigger the intention to use an ERIS. Actual use may be triggered by an *investment opportunity* and *IT qualifications* among the department members. As a third stage of adoption, we interpreted the long-term appropriation of the technology [86]. Triggers for this stage can be seen in *routine embedding* and *success experiences*. As an overarching characteristics of voluntary fire departments, we identified the emergency context in which they work. This characteristic calls for *process flexibility* and *situational adaptability*. Another characteristic is the needed cooperation between different fire departments and other agencies. This requires *technological compatibility* as well as *process compatibility*. Finally, voluntariness is the most unique characteristic. It implies the significant need for *self-determination* as a key motivator and *personnel availability* as a major determinant. As displayed in Figure 1.8, the factors can be allocated to several different attribute types on the individual level as well as the higher levels of technology acceptance [47].

This study addresses the gaps remaining in the acceptance model proposed in Paper VII. Especially the actual use of ERIS could not be adequately predicted and remained largely unclear. Besides the punctual usage decision, we now also consider the long-term appropriation as an additional stage of adoption. For both aspects, we identified triggering events and organizational attributes as well as an influence of voluntariness as an overall characteristic. Beyond that, the ethnography uncovered several other aspects affecting behavioral intention and anteceding constructs. The results constitute a highly domain-specific contextualization of the acceptance model from Paper VII. This was identified as a major literature gap in Paper I and the general technology acceptance literature [47]. The observational data also complements active firefighter feedback from Paper III and Paper IV. Summing up, the included ethnography contributes the following thesis:

Thesis 6: *The actual usage and long-term appropriation of an emergency response information system can be explained in the light of highly domain-specific triggers and characteristics.*

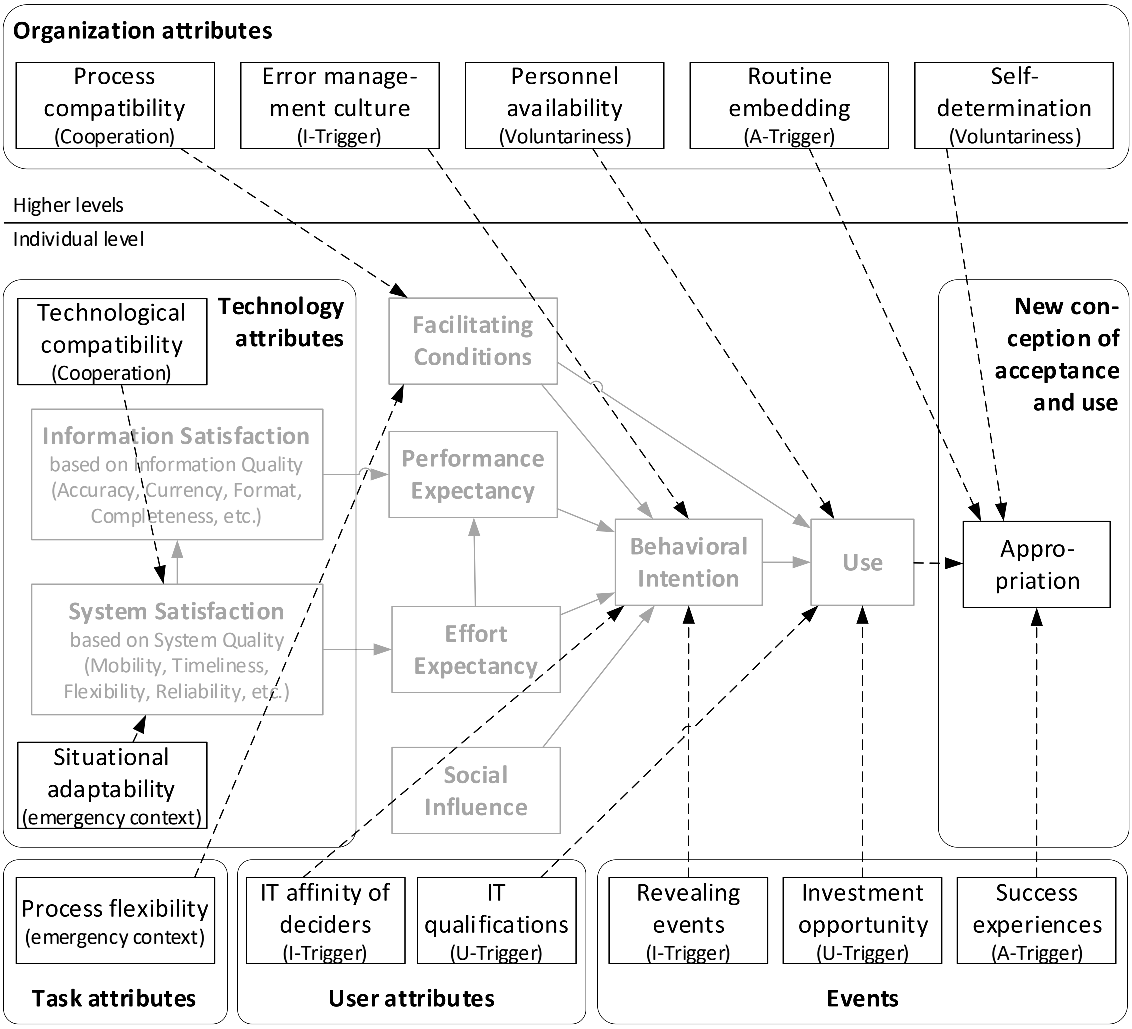

Figure 1.8 Summary of ethnography results
Legend: I-Trigger = Intention trigger; U-Trigger = Use trigger; A-Trigger = Appropriation trigger

1.5 Discussion

The results of the included papers as well as the whole dissertation hold several implications for academia, policy, and practice. The following sections will briefly discuss these implications and remaining limitations.

1.5.1 Implications for Academia

The first part of the dissertation helps understand and structure the FIT domain. It answers the following research question: *How are emerging firefighter information technologies perceived by research and practitioners?* We showed that extant literature is largely fragmented across several individual technologies. Identifying key concepts, we systematically analyzed the domain. The resulting concept matrix can provide researchers with a starting point for studies in any of the subdomains. Beyond that, we derived multiple remaining research gaps. While some of them were addressed by this dissertation, they can generally guide future research in the domain. Among others, we identified a technology-driven focus, tending to neglect domain specifics. At the same time, low practical dissemination and skepticism among firefighters were revealed. Taking these aspects together, the striking need to understand under which circumstances FITs will get accepted and used becomes evident. Addressing this issue, the dissertation at hand helps develop the theoretical foundations of this small but undisputedly relevant research domain.

The second part of the dissertation answers the following research question: *Which factors affect the acceptance of emerging firefighter information technologies?* The identified factors constitute an initial step toward a theoretical understanding of FIT acceptance. They add the important perspective of user perception, which has been lacking in extant literature. With seven different technologies, this part of the dissertation covers a broad range within the domain. For each of them, future research can integrate the identified factors into acceptance models to evaluate them and explain the respective FIT's acceptance. Beyond that, the experimental analysis of information format demonstrates the actual effects of an exemplary acceptance factor. The results proof one of the frequently cited motivators for the relevance of FITs in general. In accordance with the theory of situation awareness, we showed how improved information leads to better decisions and performance of action. Therefore, it can indeed be assumed that FITs providing such improved information will positively affect the performance of firefighters. This finding strengthens the theoretical foundation of the FIT domain as a whole.

Finally, the third part of the dissertation answers the following research question: *How can the acceptance of emergency response information systems by firefighters be explained?* The established acceptance model constitutes one of the first attempts to theoretically explain the acceptance of an FIT in detail. It demonstrates the general applicability of established acceptance models in the special domain and integrates additional, partly domain-specific constructs. Furthermore, it revises an existing attempt to integrate elements of user satisfaction and technology acceptance literature. The quantitative evaluation provides insights into the significance and the comparative importance of the identified factors. Beyond the proposed model, the ethnographically identified factors provide further contextualization. Many of them could be explained in the light of various disciplines like educational theory, safety science, sociology, project management, and psychology. They can also enrich acceptance models for other technologies and domains.

1.5.2 Implications for Practice and Policy

Among the practitioner groups affected by our results are the vendors and procurers of FITs as well as firefighters as the intended users. All groups can use the first part of the dissertation to understand the status quo of the FIT domain. The identified acceptance factors for FITs and especially the acceptance model for ERIS can help vendors of FITs designing systems that actually fit the practitioner needs. They can derive design requirements to meet deciding factors like suitably *formatted*, *accurate*, *current*, and *complete* information while ensuring *flexibility*, *mobility*, *reliability*, and *timeliness* of the system. For ERIS, Paper VII also covers specific device and feature requirements. In a comparable way, procurers of FITs can use our results to evaluate existing systems to find suitable ones for their fire departments. Finally, FITs better fulfilling the user expectations will better support firefighters in their emergency responses. According to the situation awareness theory, the information provided by them can improve firefighter decisions and ultimately their performance. Besides technical implementations like FITs, this might also concern simple procedures during an operation. For example, Paper VI demonstrates that even illustrations of information on a piece of paper can have a significant influence.

Being among the most widespread and versatile emergency response organizations, fire departments play a significant role for the safety of communities. Therefore, the dissertation results also hold political implications. To improve firefighter performance via FITs, some of the identified literature gaps may not only get addressed by academia but also by policy. Amongst others, Paper I shows that information integration across different systems remains a significant limitation of FITs. The specification of universal interfaces on the state or federal level could ensure data exchange and aggregation between systems of different fire departments, other emergency agencies, and political decision-makers. Besides FITs themselves, the dissertation also provides insight into their adoption process. Facilitating this process, policy may increase the diffusion of FITs among fire departments. For example, Paper IX identifies revealing events and investment opportunities as important triggers for the ERIS adoption. Both could be consciously provoked by specialized training and investment programs. With rising numbers and extents of natural and human-caused disasters, such political interventions seem appropriate.

1.5.3 Limitations

There remain some limitations under which the dissertation results should be interpreted. First, most of the empirical data gathered throughout the dissertation is based on German fire departments. Certain aspects like overall duties are comparable across nearly all countries. Others, like the high degree of voluntariness, are at least in line with many large countries like China and the United States. The detailed organization of firefighter work, however, may vary significantly across different countries. Therefore, our results may not be straightforwardly transferred to arbitrary fire departments on the globe. By referring to international literature and general theories, we tried to mitigate this problem.

Second, the last part of the dissertation focused on ERIS as a specific technology type. While this appeared necessary to obtain detailed insights, these findings may not be completely transferrable to other FITs. Nevertheless, at least the chosen procedure as well as the foundations of the earlier dissertation parts can be used to research these technologies.

Third, the applied methods are mainly based in the behavior science paradigm. Thereby, we could explain under which circumstances FITs will get accepted and used. The design of an FIT meeting the identified requirements, following the design science paradigm, was out of scope for this dissertation. This appears as a reasonable next step for future research.

1.6 Conclusion

This dissertation constitutes the first attempt to systematically understand and explain under which circumstances emerging FITs will get accepted and used. Despite the significant practical relevance of the topic, little research has been conducted about it before. We could, therefore, help to lay its theoretical foundations and explore its several unexplored aspects. With our stepwise, mixed method approach we applied a variety of methods in order to illuminate several perspectives. In the end, we were able to give an extensive answer to our research questions and fulfill the goals of the dissertation project. This introductory paper only provided a compact overview of the cumulative dissertation. It summarized its methodology, main results, and implications. The remainder of the dissertation is organized along the three parts introduced in section 1.3.1 and contains the nine papers in full text.

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Part 1:

Status Quo of Firefighter
Information Technologies

2 Paper I: Literature Review of the FIT domain

Table 2.1 Fact sheet paper I

Fact	**Description**
Title	What is Known and What Remains Unexplored: A Review of the Firefighter Information Technologies Literature
Authors	Julian Weidinger[1] julian.weidinger@uni-bamberg.de [1]University of Bamberg An der Weberei 5 96047 Bamberg, Germany
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What is Known and What Remains Unexplored: A Review of the Firefighter Information Technologies Literature

Abstract. *To increase the situation awareness of firefighters, literature frequently proposes the use of novel firefighter information technologies. Due to the versatility of the field and the lack of review papers, the existing body of literature in the domain appears largely fragmented. To bring structure to it and identify remaining literature gaps, this paper presents the results of an extensive literature review. A set of 108 recent papers was analyzed based on key concepts like the phases and types of firefighter operations. In doing so, we identified ten frequently researched types of technologies as well as their respective characteristics. The in-depth analysis of the results revealed several literature gaps regarding non-firefighting missions, support beyond the reconnaissance phase, integration of information, and domain specifics. All in all, the study constitutes a comprehensive and unique overview of the domain as well as a solid foundation for future research.*

Keywords: Firefighter; Information technologies; Emergency management; Literature review

2.1 Introduction

Since the beginning of mankind, communities are faced with the risks of both natural and technological hazards. To cope with spontaneously occurring disasters, effective measures of emergency management are nowadays receiving rising attention [1]. As one of the most versatile and widespread emergency organizations, fire departments play an important role in the response to such events [2]. Due to the pure characteristics of an emergency, firefighters must typically make time critical, context-dependent decisions on site. Basically, this applies for the Incident Commander (IC) who organizes the whole operation as well as for any subordinate firefighter [3, 4]. To make appropriate decisions, they all must gain so-called situation awareness [5]. This widely applied theory is composed of three levels. On perception level, relevant information about the situation must be captured. On comprehension level, the gathered pieces of information must be connected toward a holistic understanding. On projection level, this understanding can be used to anticipate how the situation will develop in the near future. Since the later levels build upon the initial perception, the quality and quantity of available information can significantly affect the outcome of an emergency.

As promising means to improve situation awareness, several types of firefighter information technologies are being proposed in recent literature [6]. While this clearly indicates digitalization potential in the firefighter domain, research in the area appears rather fragmented. Most authors concentrate on the implementation or evaluation of technologies for specific purposes like unmanned aerial vehicles (UAVs) [7-9] or smart personal protective equipment (PPE) [10-12]. All these papers of course include brief literature analyses. However, there are only few authors that explicitly address the structuring of the domain's literature. In addition, most of them rather focus on general emergency contexts than specifically the firefighter domain. Amongst them are reviews about crisis information management [13] and UAVs [14] in diverse application areas. Within the firefighter domain, existing literature reviews typically concentrate on single types of technologies like indoor navigation [15] or virtual simulations for firefighter training [16]. Overall, we could not identify a single recent study that specifically aims at structuring the existing literature in the firefighter information technologies domain. Therefore, interrelations within it as well as remaining gaps are by now largely unexplored.

To close this existing literature gap, the paper at hand answers the following research questions: "*Which aspects have been researched in the firefighter information technologies domain?*" and "*Which research gaps remain in the firefighter information technologies domain?*" To analyze and synthesize such knowledge from existing research, we conducted an extensive literature review [17, 18]. We gathered a representative set of 108 papers and analyzed it based on several key concepts of the domain. Thematical concepts included different types of firefighter operations like firefighting and technical rescues. Temporal ones represented phases like preparation and response. Technologically, we identified ten main types being researched: forecasting / planning systems, detection / monitoring systems, plans / guides, emergency response information systems, communication systems, UAVs, unmanned ground vehicles (UGVs), smart PPE, indoor navigation, and virtual / augmented reality. The analysis revealed multiple existing research gaps resulting from a strong focus on firefighting missions, the reconnaissance phase, and technology-driven studies as well as the neglect of information integration.

We proceed as follows: In section 2.2 we provide background information about the firefighter domain and related research. Section 2.3 describes the methodology of our literature review. Its results are presented in detail in section 2.4, followed by a discussion in section 2.5. The paper ends with a conclusion in section 2.6.

2.2 Background and Related Work

To provide a conceptual foundation for our study, we elaborate on basic aspects of the firefighter domain. Technological concepts are being derived from related literature about firefighter information technologies.

2.2.1 Characteristics of the Firefighter Domain

All around the world and for many centuries, fire departments have been assembled as specialized emergency response organizations. They provide services in several situations, which largely dictate the characteristics of the domain. Depending on the scale of such a situation, literature refers to it as an emergency, disaster, or catastrophe [1]. However, the later ones typically evolve from an initial emergency stage and firefighters act at all the scales. Furthermore, the scale of a situation mainly affects the amount of responding units but not the general procedures [3, 4]. Therefore, we use the terms *disaster* and *emergency* synonymously.

Besides the scale, disasters and emergencies can be classified in a temporal way. The widely applied disaster management cycle suggests four phases: mitigation, preparation, response, and recovery [1]. Mitigation aims at eliminating or reducing probabilities and effects of disasters. Preparation comprises all activities to achieve readiness like establishing emergency services or training their personnel. Response refers to the immediate intervention to save lives and properties once an emergency occurs. Finally, recovery aims at restoring or enhancing the situation as it existed before the disaster. According to these explanations, firefighters mainly operate in the preparation and response phase. Responses of firefighters can be further detailed by the processes that are mandated in incident command systems [3, 4]. A typical command process begins with the reconnaissance in which information about the incident and its surroundings are gathered. In the planning phase, the IC assesses all the available information resulting in decisions how to proceed. These decisions are then transmitted to subordinated units in the form of orders. The following execution may either comprise a lower-level command process, or practical actions like extinguishing a fire. Both result in a change of situation and input for further reconnaissance. The resulting cycle gets repeatedly applied on all command levels from the IC down to the single firefighter. Summing up, Figure 2.1 displays the phases of firefighter activities as the focus of our analysis.

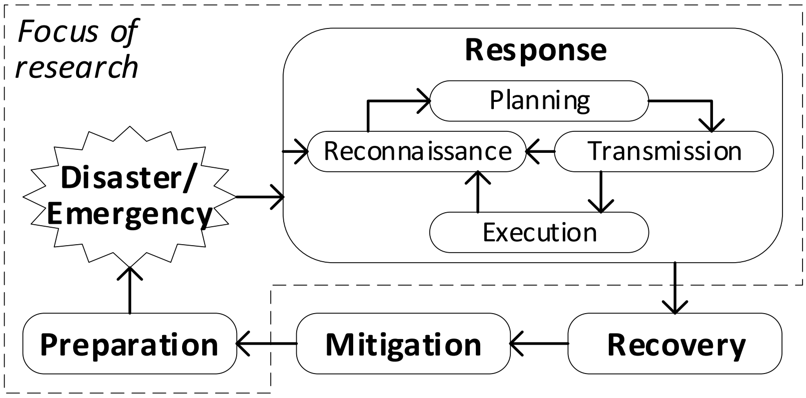

Figure 2.1 Phases of an emergency

As another classification, the broad spectrum of firefighter duties can be thematically separated in three main areas of operation: firefighting, technical rescue, and hazardous materials (hazmat) [2, 3]. Firefighting tasks are being executed in enclosed spaces (i.e., compartment or structure fires) or outdoors (i.e., wildland fires). Technical rescues can include any kinds of activities to prevent harm to people, animals, or things. Amongst others, they include salvages after road or machine accidents, as well as search and rescue in danger zones. In hazmat operations, spilled substances must be identified, contained, and neutralized to limit threats for lives or the environment. In some municipalities, states, or countries, fire departments are additionally entrusted with other tasks like emergency medical services (EMS) or operating command centers. However, since these circumstances vary heavily, we focus on the three main areas of operation explained above.

2.2.2 Firefighter Information Technology Reviews

As pointed out, there is a lack of literature reviews with precise focus on firefighter information technologies. However, certain aspects like categorization concepts may also be derived from distantly related works.

Watts et al. aimed to classify UAVs based on their technological characteristics [14]. Although they do not systematically review existing literature, their classification from "*Micro Air Vehicles*" to "*High Altitude, Long Endurance*" systems can help structure the UAV domain. A similar approach was chosen by Fischer et al., who surveyed indoor navigation systems literature [15]. They also chose characteristics like "*deployment*" mechanism or involved "*components*" for their categorization. While such technological lenses appear reasonable, the before-mentioned constructs are very specific to the respective technologies. To structure the entire domain of firefighter information technologies, higher-level concepts are needed. A starting point for such a categorization can be seen in Weidinger et al. [6]. In a brief review, the authors identified seven distinct technology types within the domain. However, the focus was to study the acceptance of these. It did not include a systematic, in-depth analysis of existing literature. Nevertheless, the seven technology types can serve as concepts for an initial technological categorization of the domain.

Besides this technological lens, related work also supports our temporal categorization along emergency phases. For example, Lee et al. analyzed the literature about crisis informatics enablers based on the common phases of mitigation, preparation, response, and recovery [13]. Williams-Bell et al. conducted a review of serious games and virtual simulation with a focus on training, which belongs to preparation [16]. Like our response phase subdivision proposed in section 2.2.1, the authors further divided training into "*decision making*", "*task level skills*", etc. Furthermore, they thematically delineated "*training*" from "*entertainment*" and "*education*". This comes near to our proposed classification into firefighting, technical rescues, and hazmat.

2.3 Methodology

To answer our research questions, we conducted an extensive literature review. We followed the recommendations of vom Brocke et al. [17] as well as Webster and Watson [18], which are widely applied in information systems research. The goal was to summarize prior knowledge and identify remaining literature gaps. Following the typology of Paré et al., this study can be precisely referred to as a scoping review [19].

First we defined the scope of our review [17]. Applying the taxonomy of Cooper, the scope is summarized in Table 2.2 [20]. We focus on research outcomes and their applications in the domain of firefighter information technologies. One goal is to integrate existing research to derive a generalized overview (research question 1). The other goal is to identify central issues, especially remaining research gaps (research question 2). The review is organized along key concepts [18]. We aim to provide a perspective of neutral representation. The presentation style should be suitable for scholars in general as well as knowledgeable practitioners and policy makers. Finally, the review is supposed to cover the domain in a representative way. With several research disciplines and their outlets overlapping in the considered domain, a truly exhaustive coverage would exceed the scope of this paper.

The next step was to conceptualize our review topic [17]. To this, we defined several key concepts of the domain in section 2.2. Thematical concepts are *compartment or structural firefighting*, *wildland firefighting*, *unspecific or other firefighting*, *technical rescue*, and *hazmat* as defined above. For the temporal concepts, all aspects of training and prearrangements are assigned to the *preparation* phase. All kinds of information gathering about overall situation, location, personnel, apparatus, fire spread, etc. fall into the *reconnaissance* phase. The *planning* phase comprises decision making and the direct support of it. *Transmission* refers to all kinds of communication with subordinate units. *Execution* refers to actual firefighter activities like extinguishing a fire or transporting a casualty. For technological categorization, initial concepts were adopted from earlier research [6]. These included *plans / guides*, *emergency response information systems*, *UAVs*, *UGVs*, *smart PPE*, *indoor navigation*, and *virtual / augmented reality*. Definitions for them are provided in the respective paragraphs in section 2.4.

Table 2.2 Scope of the conducted literature review

Characteristic	**Categories**			
Focus	Research Outcomes	Research Methods	Theories	Applications
Goal	Integration	Criticism	Central Issues	
Organization	Historical	Conceptual	Methodological	
Perspective	Neutral Representation	Espousal of Position		
Audience	Specialized Scholars	General Scholars	Practitioners/Politicians	General Public
Coverage	Exhaustive	Exhaustive and Selective	Representative	Central/Pivotal

As a third step, we conducted the literature search that is summarized in Table 2.3 [17]. We consulted the main databases of information systems research and computer science, which include the leading journals and conference proceedings [18]. The search string included *firefighter* and several related terms. Since the common tasks of firefighting, technical rescue, and hazmat are similar around the world, we waived specific keywords for them [2]. Furthermore, our focus is explicitly on the firefighter domain – not emergency services in general. In non-IT-specific databases we included additional terms in the search string. As shown in Table 2.3, the search resulted in a total of 414 initial hits. These were filtered based on our previously defined scope. A researcher with long-year experience in the domain of firefighter information technologies scanned the titles, abstracts, plus in unclear cases the full texts to identify thematically unmatching works. Inclusion criteria were the focus on the firefighter domain, a relation to information systems or technologies, and the format of completed research papers. In contrast, we excluded research-in-progress and short papers, papers without clear relation to the firefighter domain, information systems or technologies, and duplicates. We also excluded works that mainly concerned other rescue organizations, command centers, or EMS and only briefly featured the firefighter domain. Since we aimed for a representative instead of an exhaustive coverage, we decided to only consider recent papers from this and the previous decade. Consequently, we excluded all reference that were published before

2010. Based on the 77 remaining papers, we then conducted forward and backward searches [18]. Identifying 31 additional references, we ended up with a final set of 108 relevant works (cf. Table 2.3).

Table 2.3 Number of sources per database

Database	Search string	Searched fields	Search filters	Initial hits[3]	Filtered sources
EBSCOhost Business Source Ultimate	Firefighter[1] + IT[2]	Title, Abstract, Keywords	Source Types = Academic Journals; Language = English	38[4]	2
ScienceDirect	Firefighter[1] + IT[2]	Title, Abstract, Keywords	Article type = Review articles / Research articles	56+24	18
SpringerLink IT in Business	Firefighter[1]	All fields	Content Type = Article / Conference Paper	54+20	5
AIS Electronic Library	Firefighter[1]	Title, Abstract, Subject	Publication type = Series / Conference / Journal	17	4
ACM Digital Library	Firefighter[1]	Title, Abstract, Keywords	Publications = Proceedings / Journals	5+128	37
IEEE Computer Society Digital Library	Firefighter[1]	Document Title, Abstract	Category = Conference publications / Journals	16+56	11
Backward Search	-	-	-	-	16
Forward Search	-	-	-	-	15
Total	**-**	**-**	**-**	**414**	**108**

[1]firefighter OR fireman OR firemen OR "fire fighter" OR "fire department" OR "fire brigade" OR "fire service"
[2]software OR "information system" OR "information technology" OR "information technologies" OR digital
[3]last consulted 2022-03-25; multiple URLs necessary because of applied filters, max. URL-length, or max. number of operators
[4]search filters must be manually applied

Based on the final set, the literature was analyzed and synthesized by an experienced researcher of the domain [17]. For this, the contents of the papers were examined for the occurrence of the before-mentioned concepts [18]. To gain an early overview, a first iteration only considered the abstracts. While the concepts proofed suitable for the categorization, we identified several papers that could not be assigned to any of the technological concepts. Therefore, additional concepts for *forecasting / planning systems*, *detection / monitoring systems*, and *communication systems* were introduced. Like the other technological concepts, they are defined in the respective paragraphs in section 2.4. In a second iteration the full texts were consulted for the final concept assignment. Overall, 93 of the 108 papers could be assigned to the given concepts. As proposed by Webster and Watson [18], the final categorization was summarized in a concept matrix (cf. Table 2.4). For the 15 remaining papers, separate concepts for *possible future technologies* and *domain specifics* were additionally introduced. To further categorize the papers within the respective concepts, additional information was retrieved from the full texts. These constitute the characterizations that are presented in section 2.4.

The final step of our review was to assemble a research agenda [17]. Based on the synthesized results as well as own research in the domain and practical firefighter experience, we identified remaining research gaps. These are discussed in section 2.5.

2.4 Results

Table 2.4 Concept matrix

Sec.	Technology	Preparation	Response			
			Reconnaissance	Planning	Transmission	Execution
4.1 Data-driven approaches	Forecasting and Planning Systems	[21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31]	-	-	-	-
	Detection and Monitoring Systems	-	[28], [32], [33], [34], [35], [36], [37], [38]. [39]	[36]	-	-
4.2 Conventional means of incident command	Plans and Guides	-	[38], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50]	-	-	-
	Emergency Response Information Systems	-	[28], [29], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63]	[28], [29], [56], [57], [58], [59], [61], [62], [64], [65]	[28], [52], [53], [54], [55]	-
	Communication Systems	-	-	-	[66], [67], [68], [69], [70], [71], [72], [73]	-
4.3 Unmanned vehicles / syst.	Unmanned Aerial Vehicles	-	[7], [8], [9], [59], [74], [75], [76], [77], [78], [79], [80], [81]	-	-	-
	Unmanned Ground Vehicles	-	[78], [79], [82], [83], [84], [85]	-	[86]	[82], [83], [86]
4.4 Personal firefighter augmentation	Smart Personal Protective Equipment	[10], [87], [88]	[11], [12], [54], [68], [89], [90], [91], [92]	-	-	-
	Indoor Navigation Systems	-	[15], [41], [42], [43], [44], [45], [46], [89], [93], [94], [95], [96], [97]	[42], [43], [44], [45], [46]	-	-
	Virtual and Augmented Reality Systems	[16], [98], [99], [100], [101], [102]	[103], [104], [105]	-	-	-

Legend: compartment or structure fires | wildland fires | unspecific / other fires | technical rescues | hazmat | unspecific / all types

As displayed in Table 2.4, literature about firefighter information technologies is mainly distributed over ten technological concepts. Most of the identified papers can be assigned to one or multiple of these. The same applies for the phases and types of an emergency. Subsequently, we describe the findings in detail. For structuring, we organized the technological concepts in four higher-level themes in sections 2.4.1 through 2.4.4. Afterward, in section 2.4.5 we elaborate on the 15 works that could not be assigned to any of the technological concepts. Finally, we provide a quantitative summary of the results in section 2.4.6.

2.4.1 Data-driven Approaches

Data-driven approaches aim to analyze numerical, textual, graphical, or other data. The resulting perceptions can be used to forecast future events and enhance planning activities or to detect occurring events and monitor their further development.

Forecasting and Planning Systems are used for the several kinds of analyses prior to an incident. Therefore, they all belong to the preparation phase. They can support long-term activities like finding optimal allocations of fire stations [21-23] and units [23, 24]. As a decision support, the use of machine learning is proposed to forecast the number and type of incidents in an area [24, 25]. In the mid- to short-term preparation, the risk of structure fires [26, 27], wildland fires [28-30], or storm incidents [31] can be prognosed.

Detection and Monitoring Systems provide environmental information upon the beginning or during an incident Generally, wildland fires seem of special interest. They may be detected via image processing algorithms [32, 33] or wireless sensor networks (WSN) and artificial intelligence [28, 34, 35]. The propagation of already burning wildland fires may be forecasted with simulations [36]. Besides that, WSN can detect and monitor fire spread and damages in buildings [37] or especially tunnels [38, 39].

2.4.2 Conventional Means of Incident Command

The papers of this theme examine technologies that depict evolutions of traditional means of incident command rather than revolutionary new approaches. Predecessors of such systems are already broadly used in practice and mentioned in regulation texts [3].

During the drive and on site, firefighters can gain information out of various *Plans and Guides*. Approaches are presented for compartment or structure fires [40-47], hazmat operations [48] and emergencies in tunnels [38]. Advanced systems can include three-dimensional real-time information about the affected building [40], its occupants [41-43], detected fires [43-45], and stored hazmat [41]. These systems also hold potential regarding indoor navigation. In general, the availability of graphical building information is seen to potentially raise the situation awareness of firefighters [47]. Besides that, geographical information systems can support firefighters on the way from station to incident area [49]. A comprehensive evaluation demonstrates the most important information needs before arrival, on scene, and for attack and mitigation [50].

Compared to the before-mentioned technologies, *Emergency Response Information Systems* (ERIS) support the command process more extensively. They typically process real-time information about the whole incident like situation maps with the locations of units, danger zones, etc. Basic ERIS require the manual input of such information [51], whereas more advanced systems may also receive it automatically from sensors [52-55]. Besides that, ERIS can provide a platform to process data received from other systems [8, 78]. Generally, the collaborative collection of information [51, 55] as well as exchanging it amongst the units on scene and with command centers [52, 53] are seen advantageous. Therefore, many ERIS also include explicit communication features like text messaging to transmit orders [28, 52-55]. Based on the collected information, ERIS of the highest evolutionary stage can directly support ICs in the planning phase by forecasting trends [29, 56, 57], calculating priorities [58], or even recommending commands [28, 64, 65]. Such decision support systems are presented for wildfires [28, 29, 64], compartment or structure fires [65], and urban search and rescue [58]. Regarding the user perspective, qualitative studies examine potentials and risks in using ERIS [59] as well as an organization's capability of adopting them [60]. Multiple works examine how to design their user interfaces [56, 57] and how to implement them in a system architecture [61] to suit the needs of different firefighter roles. Further design implications comprise the inclusion of internet of things technologies [62] and the enrichment or centralization of information [63].

Communication Systems are used to transmit information. They can replace the commonly used voice communication via radio [66] or complement it with the transmission of text [67, 68], video [69, 70], or other data [66, 68]. Most systems are proposed for the application in indoor firefighting missions [66-68] or wildland fires [71]. Different kinds of ad-hoc, multi-hop networks are the most prominent technological basis [66, 68, 69, 71, 72]. Multiple studies examine suitable routing protocols [66, 72] and connection patterns [71, 73] in such networks.

2.4.3 Unmanned Vehicles and Systems

Unmanned vehicles and systems can be used to expand the operating ranges of firefighters by overcoming the physical limitations of human actors. They can be separated in flying and ground-based vehicles.

Unmanned Aerial Vehicles (UAVs) are mainly used for the on-site reconnaissance from above. They can be employed in fire emergencies [7, 74-77], technical rescues [7, 78, 79], search missions [8, 74, 78-80], and hazmat situations [7, 78-80]. Traditional UAVs are remotely controlled by a pilot [78, 79]. In contrast, recent studies largely focus on their autonomous operation [7-9, 74-77, 80, 81]. Amongst others, autonomous UAVs can gather information even before the arrival of responding units [7]. Design principles are examined to ensure easy operation [9, 74, 75, 78, 81] and improve situation awareness [8]. For this purpose, information gathered by UAVs can also be integrated into ERIS [8, 78]. Further studies examine potentials and risks in the adoption of UAVs [59] and the emotional effects on their pilots during a mission [79].

The use of *Unmanned Ground Vehicles* (UGVs) is mostly proposed in dangerous environments of fires [82-86] and hazmat operations [78, 79]. Besides mere reconnaissance, UGVs can support firefighters in the execution of tasks like extinguishing fires [82, 83, 86]. Similar to UAVs, ground robots may be remotely controlled [78, 79] or operate autonomously [82, 84-86]. In mixed teams of humans and robots, UGVs are employed to improve orientation in smoke [84] and monitor surrounding sounds for important information [85]. For easy communication in such mixed teams, the use of natural language is examined [86].

2.4.4 Personal Firefighter Augmentation

Opposed to the before-mentioned technologies, the following ones aim to augment firefighters themselves. This may on the one hand involve technologies to expand information about individual firefighters and their surroundings. On the other hand, technologies can be used to present this information in an intelligible way.

Smart Personal Protective Equipment (PPE) constitutes the expansion of conventional PPE with smart technologies, especially sensors. The main areas of application are firefighting missions [11, 12, 54, 68, 89-92]. Information gathered about firefighters themselves mainly concerns temperature related measures [10, 89-92], heart rate [10, 89-91], performance indicators [87], and other biometric data. A main goal is seen in estimating the human's core temperature to detect the phenomenon of thermal stress [11, 90]. To capture the surroundings, studies examine sensors for air pressure in the breathing apparatus [68], GPS positions [54], environmental temperatures [54, 68, 89], distances to obstacles or other firefighters [12, 88], and the detection of holes in the ground [12]. Technological implementations range from using smartphones or other carry-on devices [54, 87, 88], to undergarments like sensor shirts [11, 90, 92], and the integration into coats

[89], breathing masks [10], or gloves [12] of existing PPE. Most studies focus on analyzing and using the gathered information during operations [11, 12, 54, 68, 89, 90, 92]. Others propose to only use it outside the response phase for after-mission analyses and training purposes [10, 87, 88]. Regarding the adoption of smart PPE, a case study highlights identity conflicts, organizational structures, power and authority as major challenges [10].

Indoor Navigation Systems are proposed to support the firefighters' orientation and navigation inside buildings, especially during compartment fire operations. A comprehensive review describes various systems proposed in this domain up to the year 2010 [15]. Since then, research is mainly concentrated on three types of systems. In the first type, studies try to capture the positions of firefighters relatively to ad-hoc deployed breadcrumbs [93-95]. These breadcrumbs can either be deployed manually [93, 94], or automatically as the firefighters move inside a building [95]. Opposed to that, multiple works try to determine firefighter locations in an absolute way, rather than relatively to breadcrumbs [89, 96, 97]. However, such systems either require extensive pre-installation of sensors inside the building or by deploying UAVs [96, 97], or they cannot provide the required precision [89]. Systems of a third type are closely connected with the building information modelling approach. They provide detailed, three-dimensional building information including real time data about occupants and fire detections [41-46]. Additionally, such systems can support an IC's planning by simulating the behavior of building users [43], forecasting fire spreading [45], calculating optimal routes for firefighters [42-45] and positions for ladder trucks [46].

Virtual and Augmented Reality Systems (VR, AR) can be used to enrich a firefighter's natural perception with additional information. VR is mainly researched as a means for immersive firefighter training within the preparation phase [16, 98-102]. A focus is laid on the realistic illustration of fire and smoke [98-100] as well as the simulation of stressful experiences [101]. An empirical study examines key factors to improve user experience regarding presence, reality, meaning, and play [102]. A review structures findings about several VR games in firefighter training [16]. Opposed to VR, AR is mainly proposed for operational use [103-105]. Such systems may raise an actor's attention for alerts [103, 105] or provide relevant information based on their location and surroundings [104]. Most VR and AR systems use visual [98, 102-104] and auditory [102, 103] presentation channels. Some approaches also include additional channels like tactile vibrations [103, 105], odors [105], and heat [99].

2.4.5 Non-technology-specific Works

Besides the above mentioned, there are publications that could not be assigned to any specific technological concept. They typically resemble foundations of either technological or domain-specific aspects.

Possible future technologies may serve as base for other firefighter technologies or evolve to independent technologies in the future. Multiple studies examine algorithms and systems for simulation purposes. Most of them focus on the simulation of fire spread in buildings [106, 107] or wildlands [108, 109]. Another approach is presented to simulate the ergonomic removal of equipment from a fire truck [110]. Such simulations can be used in VR training systems or integrated in ERIS and indoor navigation systems to forecast future developments. A further topic is the design and evaluation of systems for the automatic deployment of breadcrumbs with reliable connectivity [111, 112]. They can be used to transfer data in communication, indoor navigation, or smart PPE applications. A comprehensive data model is developed to structure data about fire related incidents [113]. This mainly supports the exchange of information between different systems.

Papers explicitly concerning *domain specifics* can help understand the firefighter domain as well as technology requirements and acceptance within it. Since the paper at hand contributes to the structuring of the domain, it would fall under this concept, as well. Besides that, a model was proposed to assess the overall capability of emergency management organizations [114]. It may help identify possible areas of improvement. To understand the specific characteristics of frontline firefighting, three main patterns determining its processes were identified [115]. These were further enhanced toward a complete language including 16 patterns, which is proofed to raise an understanding for the domain [116]. A quantitative study revealed low dissemination rates of several firefighter information technologies [117]. A subsequent qualitative analysis compiles a set of acceptance factors to explain their adoption [6]. Such factors were used to construct and evaluate an acceptance model for ERIS [118]. Finally, a method named goal-directed information analysis is presented [119]. It is supposed to specifically suit the unique features of emergency response and helps to systematically identify information requirements.

2.4.6 Quantitative Results

Besides the qualitative insights, our analysis also holds multiple quantitative results. As Table 2.4 shows, 93 of the 108 identified studies could be assigned to specific technologies, phases, and operation types.

Of the different technologies, ERIS and indoor navigation systems are the most prominent ones with 17 and 13 papers addressing them. They are followed by plans/guides and UAVs (both 12), smart PPE (11), forecasting/planning systems (10), VR/AR systems and detection/monitoring systems (both 9). The least papers stated communication systems (8) and UGVs (7) as their focus. 15 papers addressed multiple technologies, whereas most relations can be observed between plans/guides and indoor navigation. In terms of emergency phase, most of the 93 papers in Table 2.4 cover reconnaissance (65), followed by preparation (20) and planning (16). 14 papers concern transmission and only 3 papers cover technologies for the concrete execution of firefighter tasks. In 22 papers multiple phases are covered, most often in ERIS. Regarding the type of operation, 59 out of the 93 papers state firefighting as their research focus. More specifically, 37 address compartment or structure fires, 16 wildland fires, and 6 state other or no specific types of fires. In contrast to that, only 5 name technical rescues and 1 names hazmat as their focus. The 28 remaining papers either address all or no specific operation types.

2.5 Discussion

Based on the results of our literature review, we derive a number of findings and highlight remaining literature gaps that may be addressed by future research. We furthermore elaborate on implications and limitations of our analysis.

2.5.1 Findings and Identified Literature Gaps

Both the qualitative and the quantitative results of our analysis reveal a very clear focus on firefighting missions. Nearly two-thirds of the technology-specific works (59 of 93) addressed firefighting scenarios. Several authors argue that especially these kinds of operations involve many impairments which must be addressed. Amongst them are breathing and vision restrictions due to smoke as well as heat and spreading risk of flames. While we absolutely agree with this assessment, the focus still contradicts the practical reality of today's fire departments. In many countries, conventional firefighting plays an ever declining role compared to other types of operations [2]. Despite significant differences around the world, most firefighters are more frequently engaged in technical rescues than in firefighting. Consequently, we plead that future research must also concentrate on impairments and solutions in other types of operations. Information technologies may not only support firefighters at fires but also at car accidents, building collapses, spilling of chemicals, and so on. Therefore, our first open research question is: *How can* *information technologies support firefighters in non-firefighting missions like technical rescues and hazmat operations?*

Regarding the phases of an emergency, it appears obvious that most of the identified studies concentrate on reconnaissance that is all about gathering information. Our review shows a quite extensive support for this phase of an emergency. All the identified technologies can provide information about the situation, the firefighters themselves, the location, or other important parameters. However, only few works try to partly take over planning activities from the IC like calculating optimal routes inside a building. High decision complexities in emergency situations might be a major obstacle for more holistic approaches. One promising approach to overcome these problems might be artificial intelligence. All in all, research should identify additional areas in which ICs might be partly supported in their planning efforts. Acknowledging the high complexity, future works must precisely follow the principles of situation awareness. As a planning basis, ICs require not just much, but especially the right information to be able to comprehend it and project future developments. Apart command activities, the concrete execution of firefighter tasks has, by now, only been examined for UGVs. Other application areas like material transports by UAVs or fire suppression controlled by detection and monitoring systems might be of interest for future studies. Summing up, our second open research question is: *How can information technologies support firefighters in the phases beyond reconnaissance – especially in planning and execution?*

Our results further reveal a certain potential of interconnectivity between the identified technologies. 15 of the 93 technology-specific papers explicitly examine combinations of multiple ones. Many others at least mention possible connections. Most prominently, ERIS are seen as potential platforms to incorporate data coming from other systems. However, while the interorganizational exchange of information recently came to the focus of research, works about the holistic integration of information within the firefighter domain are largely missing. As mentioned before, an IC depends on a sufficient base of information to gain best possible situation awareness. Therefore, future research must examine requirements and implementations of such integrative approaches. Interfaces and unified exchange formats, as well as the evolution of ERIS toward open platforms seem of special importance. Our third open research question is: *How can different firefighter information technologies be integrated to form a holistic situation picture?*

One reason for the low attention on integration may be seen in another observation: research in the domain is mainly technology driven. As displayed in Table 2.3, searches in the more technical computer science databases like ACM resulted in much more hits than in information systems outlets like AIS. Also looking at the individual papers, most of them present the design or evaluation of prototypes, systems, algorithms, or architectures. Only few explicitly address the quite delicate specifics of the firefighter domain, in which their artifacts are supposed to be applied. Of course, some papers (7 of 108) directly focus on these theoretical aspects like the maturity of departments, the firefighters' requirements, or the adoption of technologies. Nevertheless, many aspects of the domain and the resulting consequences for the adoption of information technologies remain largely unclear. For example, in many countries, including China, Germany, and the US, the vast majority of firefighters are volunteers [2]. Hardly any paper in our review addressed this fact and its consequences for the design and use of information technologies. Designing innovative technologies without a theoretical understanding of the domain holds the risk of missing the actual needs, resulting in low dissemination rates as they were recently presented [117]. Therefore, future research must increase efforts in exploring such theoretical foundations and answer our fourth open research question: *Which specifics of the firefighter domain influence the use of information technologies and how can they be considered in the design of technologies?*

2.5.2 Implications

The paper at hand aimed to expand the existing literature about firefighter information technologies by answering two research questions. The first one asked which aspects have already been researched in the domain. We answered this question by conducting an extensive literature review and structuring the results along several key concepts as they are summed up in Table 2.4. In doing so, we provide a unique overview of this fragmented research domain. Two aspects indicate that the employed concepts and categories are indeed appropriate to structure the body of literature. First, we could identify several papers for each category, proving them as self-contained clusters. Second, each identified paper could be assigned to at least one of the categories per concept, indicating a high coverage for all the concepts. Overall, our review may serve as an orientation and starting point for other authors. For example, additional works can extend our literature review by studying each of the identified concepts in more detail. Researchers as well as practitioners can use the review to identify relevant literature for certain application areas like *reconnaissance* in *wildland fires* using *unmanned aerial vehicles*.

The second research question asked which research gaps remain in the domain. We answered it by analyzing both the qualitative and quantitative results of our review. As Table 2.4 shows most prominently, there are several blind spots uncovered by our review. During the discussion, we elaborated on four exemplary areas in which little to no research has been done by now. They include non-firefighting missions, support beyond the reconnaissance phase, integration of information, and domain specifics. These existing gaps must be addressed by future research. Closing them will, on the one hand, help to advance the maturity of the whole research domain. On the other hand, it may help to support practitioners in a more holistic way. All in all, the paper at hand itself closed an existing literature gap, since no other study could provide a comparably comprehensive overview of the domain by now.

2.5.3 Limitations

There remain some limitations, under which this work must be interpreted. First, the presented analysis constitutes a representative rather than an exhaustive literature review. We decided to focus on the most important outlets of information systems research and computer science. This resulted in a reasonable set of papers in the domain of firefighter information technologies but did deliberately not consider findings of practitioner outlets or emergency management specific databases. Besides that, we only considered papers published in the current and the previous decade. While this ensured the focus on recent findings, we might have overlooked key findings from before 2010. Another filtering criterium was the precise focus on firefighter-specific papers. Considering works in related domains like police or EMS, and about interorganizational aspects might have held further insights. Therefore, this study presented a concise and focused review that leaves room for future extensions.

Regarding the review process, we analyzed the resulting papers based on a limited set of concepts. Besides the categorization along emergency phase, type, and technologies, other concepts like research paradigm or research method might have revealed additional patterns. The review was conducted by an experienced researcher in the firefighter information technologies domain. Nevertheless, subjective interpretations may have biased the process. Scoping reviews like the one at hand are generally much less formalized than, for example, systematic reviews. However, this type was best suited to summarize prior knowledge and identify remaining literature gaps [19]. To still ensure the rigor of our study, we followed established methodologies of information systems research.

2.6 Conclusion

Summing up, the paper at hand provides a unique overview of the domain of firefighter information technologies. While the use of such technologies is frequently proposed to improve firefighters' situation awareness, the body of literature appears largely fragmented. To structure it and derive remaining research gaps, we have presented the results of a representative literature review. A set of 108 papers was analyzed along key concepts like the phases and types of emergencies. Thereby, we identified ten main types of technologies. Finally, we elaborated on several research gaps regarding non-firefighting missions, support beyond the reconnaissance phase, integration of information, and domain specifics. The review constitutes a unique overview of the domain. It contributes to the structuring of existing research and provides a multitude of starting points for future research.

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3 Paper II: Survey on Practitioner FIT Perception

Table 3.1 Fact sheet paper II

Fact	Description
Title	New Vistas for Firefighter Information Systems? Towards a Systematic Evaluation of Emerging Technologies from a Task-Technology Fit Perspective
Authors	Sebastian Schlauderer[1] sebastian.schlauderer@uni-bamberg.de Sven Overhage[1] sven.overhage@uni-bamberg.de Julian Weidinger[1] julian.weidinger@uni-bamberg.de [1]University of Bamberg An der Weberei 5 96047 Bamberg, Germany
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New Vistas for Firefighter Information Systems? Towards a Systematic Evaluation of Emerging Technologies from a Task-Technology Fit Perspective

Abstract. *During the response to an emergency, firefighters inevitably have to make critical, context-dependent decisions on site. To improve the ability of firefighters to comprehend both the situation at hand and the capabilities of the available resources, it is frequently proposed in literature to use new and emerging information technologies to gather, share, and present real-time information in so-called on-site emergency response systems. In this paper, we present the results of a survey-based study, in which we asked representatives of German fire brigades to assess the potential of seven emerging technologies from a user-oriented task-technology fit perspective. The results indicate that digital maps, indoor navigation support, the continuous transmission of the air supply status, and integrated on-site emergency response systems indeed might have the potential to expedite the emergency response process. In contrast to the expectations, the potential of drones, on-ground robots, and intelligent clothing was found to be limited, though.*

Keywords: Firefighter information systems, Emergency response systems, Quantitative study

3.1 Introduction

As a consequence of significant man-made and natural disasters such as terrorist attacks, earthquakes, hurricane strikes, or wildland fires, the need to improve the efficacy of emergency first responders has received increased attention in academia and practice. During the last years, substantial efforts have been made to further enhance the organization of fire and rescue brigades and to optimize their emergency response processes [1, 2]. However, to successfully respond to emergencies, firefighters and rescue services inevitably have to make critical, context-dependent decisions on site. The quality of such decisions depends on the ability of the emergency responders to comprehend the situation at hand and the capabilities of the available resources [3]. To a considerable extent, the factual efficacy of emergency responses is hence determined by the information that is available on the site of the emergency [4, 5].

Typically, however, firefighters and other first responders only have limited access to real-time information about the emergency site such as the environmental conditions within a building, or the status of available resources. To improve this situation, it is recommended in literature to utilize new and emerging information technologies to gather, share, and present such real-time information in the appropriate format and to the right person [6-9]. Several ideas have been described how new and emerging technologies could be leveraged and integrated into on-site emergency response information systems [5, 10-12]. To the best of our knowledge, most of these approaches are still theoretical in nature, though. Hence, little is known about the definite potential of new and emerging technologies to deliver information, which is considered essential to facilitate the on-site decision making of emergency responders such as firefighters.

With the study presented in the paper at hand, we contribute to the closure of this research gap. The presented study was conducted as an initial step of an ongoing research endeavor to systematically explore the potential of emerging technologies to deliver adequate information about the disaster site, which specifically supports the decision-making of firefighters. Taking the task-technology fit model [13] as a theoretical lens of analysis, we address the following research questions: "*Which emerging technologies are perceived as suitable to support on-site decisions by firefighters? Are emerging technologies supposed to provide a comparative advantage compared to the current state of the art?*" To examine both research questions, we designed and conducted an online survey, in which we asked members of fire brigades about their perception of several emerging technologies, which are currently being discussed in academia and practice. In particular, we wanted to know if the technologies were felt to deliver information that is able to facilitate the on-site decision-making process.

We decided to conduct our survey among German fire brigades because we were able to get the support of the German firefighter association. As in countries such as the United States, France, or Belgium, the German firefighter service is maintained both by voluntary and professional fire brigades. The chosen setting hence allowed us to study the perception of the members of both groups. The results of the study provide empirically justified indications regarding the potential of new and emerging technologies to facilitate the on-site decision-making of firefighters. They hence provide a basis to further examine the use of particular technologies in more detail.

The remainder of the paper is organized as follows: in section 3.2, we describe the background of our study and discuss related work. In section 3.3, we describe the research method. In section 3.4, we discuss the results of our study. We conclude by describing implications for academia and practice and giving an outlook on future research directions in section 3.5.

3.2 Background and Related Work

3.2.1 Firefighter Information Systems

Emergency response information systems are used by organizations to assist in responding to an emergency situation [5]. These systems ought to support emergency response activities such as information gathering and analysis, communication, management of responder resources, and on-site decision making. Since the efficacy of emergency responses is significantly determined by the information that is available on-site, we concentrate on on-site information systems that support the dynamic gathering, sharing, and presentation of information on the site of the emergency. In this paper, we moreover focus on the information systems used by fire brigades. Such systems are also called firefighter information systems in literature.

The goal of firefighter information systems is to facilitate the emergency response process of fire brigades. The emergency response process differs slightly from country to country. As we focus on German fire brigades in our study, we concentrate on the German fire emergency response process, which consists of four basic stages [14]: alerting, investigation, coordination, and enforcement.

The *alerting* of the brigade is the first step in response to an emergency call. The goal of this stage is to dispatch those response teams, which are required to respond to a certain kind of emergency and are within the shortest distance. Professional fire brigades are typically alerted using a system that is installed in the fire station. Voluntary fire brigades and colleagues off duty are usually alerted by radio or other communication media. They can also be alerted by public sirens.

After reaching the site of the emergency, the first task is to *investigate* the situation. The goal of this phase is to *gather information* about the emergency site (i.e. the damage, the damaged objects, the extent of the damage, the location of hazards etc.), the strength and capabilities of the teams on site, the available resources to respond to the emergency, and the relevant weather conditions.

Using the information gathered during the investigation, the next task is to *coordinate* the response. This task comprises the *planning* of alternative responses and the *decision making*. The goal is to achieve the best response using as little resources as possible. To reach a decision, it is necessary to know which dangers have been identified, which dangers need to be addressed first, which possible responses exist and how they affect members of the fire teams. The decision is then communicated to the team members.

Once the decision has been made, the team members begin to *enforce* the response. To successfully implement a decision, it is necessary to inform the team members of the overall status and to communicate real-time information about the emergency site.

Responding to an emergency typically is an iterative process. First decisions likely have to be made although the investigation of the site is not yet complete. Moreover, the dynamic development of the situation and the continuous feedback received during the enforcement activities probably make it necessary to reconsider decisions or to alert reinforcements.

Analyzing the before-mentioned process and the activities in each stage in detail, we identified different kinds of information that need to be gathered, shared, and presented in an on-site firefighter information system to ensure the success of the emergency response and to protect the responders. In line with the literature, we found four categories of information [5, 8]:

1. *Environmental conditions*. Firefighters need to know details about the site such as the structure of a building/landscape, the kinds of damage, the location of hazards, or the weather conditions.

2. *Response participants*. Firefighters need to know details about the available capabilities, the status of the individual team members, and their assignment to response activities.

3. *Available resources*. Firefighters need to know details about the available equipment, the available resources on the spot (e.g. fire hydrants, sprinkler systems, water reservoirs etc.), and the options for replenishment.

4. *Casualties*. Firefighters need to know the location and the status of victims.

On-site emergency response information systems for firefighters hence ought to support the gathering, presentation, analysis, and communication of these kinds of information. In practice, however, the capabilities of such systems are quite limited.

3.2.2 Related Work

To analyze in how far on-site emergency response information systems in general and firefighter information systems in particular have been discussed in academia, we conducted a systematic literature review. Doing so not only helped us to systematically assess the current body of knowledge, but also to highlight the research gap. Following the recommendations of Webster and Watson [15], we began by querying various databases including Google Scholar, IEEE Xplore, or the ACM Digital Library. We thereby used keywords like “firefighter”, “emergency”, or “disaster” in combination with search terms such as “information systems”, or “information technology”.

Of the resulting articles, we first inspected the titles and abstracts to sort out irrelevant results. The remaining articles were then inspected in detail using a narrative review method [16]. In a second step, we conducted backward and forward searches based on those articles that we perceived to be particularly relevant to the field of firefighter information systems [15].

The results of our literature survey show that current research is especially focused on the response to large-scale disasters such as earthquakes, tsunami, or hurricane strikes. Several articles address the management of such disasters, e.g. in terms of the disaster phases [17], the various responders and their collaboration [10, 18-20], or the use of social media and social technologies to support disaster management [12, 21, 22]. While these articles are clearly relevant to the field, they focus on a specific aspect, i.e. the management of large-scale disasters. Most of the research described there is hence targeted to the extraordinary situation of a disaster [e.g. 21, 22] and not aiming to support the daily routines of firefighters. Such approaches are not in the focus of the work at hand.

We also identified articles that focus on information systems, which are supposed to support firefighters in their daily work on site. In particular, there exists a research stream that investigates the coordination of emergency response activities. Among others, researchers have analyzed which coordination patterns occur in emergency response processes [2] or which dependencies exist between emergency response systems and IT in order to propose coordination mechanisms [1]. Yet, such approaches rather focus on the management of emergency processes and their coordination rather than on the underlying technologies.

Other articles propose the use of new information technologies to facilitate the work of firefighters. For example, Luyten, et al. [11] propose a mobile system with ruggedized tablets or PDAs to support firefighters in quickly gaining an overview of the situation on site. Further articles suggest the use of head-mounted displays for firefighters [23, 24], the integration of mobile navigation into firefighting practices [25], or the use of large displays for incident management [26]. These articles have in common that they propose specific technologies to support fire brigades. However, none of them gives an overview of currently existing technologies or assesses in how far such technologies are perceived as potentially useful by firefighter teams.

Yang, et al. [5] propose an on-site emergency response system that provides real-time 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", 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 seem to be no related approaches that discuss, which emerging technologies overall exist to support the advancement of on-site firefighter information systems and how these technologies are perceived by the users. To contribute to the closure of this literature gap, we discuss several identified emerging technologies for firefighter information systems and evaluate them in a survey.

3.2.3 Emerging Technologies

To improve the effectiveness of on-site firefighter information systems, various new and emerging information technologies are proposed in literature. Based on the results of our literature survey, we discuss seven frequently mentioned technologies (T1-T7), which are deemed to support the emergency response process (see Figure 3.1).

To facilitate the *investigation* of an emergency site, literature particularly discusses the use of specialized *digital maps* (T1) with information about the internal structure of buildings (so-called fire control plans) and the surrounding landscape [22, 27]. Such digital maps can easily be fitted with information relevant to first responders (e.g. the location of fire hydrants, supply lines etc.), updated, searched, and presented using various mobile devices. In addition, literature emphasizes the potential of so-called *unmanned aerial vehicles* (drones, T2) to get a visual impression of an emergency site, to measure the presence of hazardous contaminants, or to determine the location of fire pockets [28, 29]. Thirdly, *on-ground robots* (T3) are often proposed to investigate hazardous or otherwise inaccessible areas of the emergency site [30, 31].

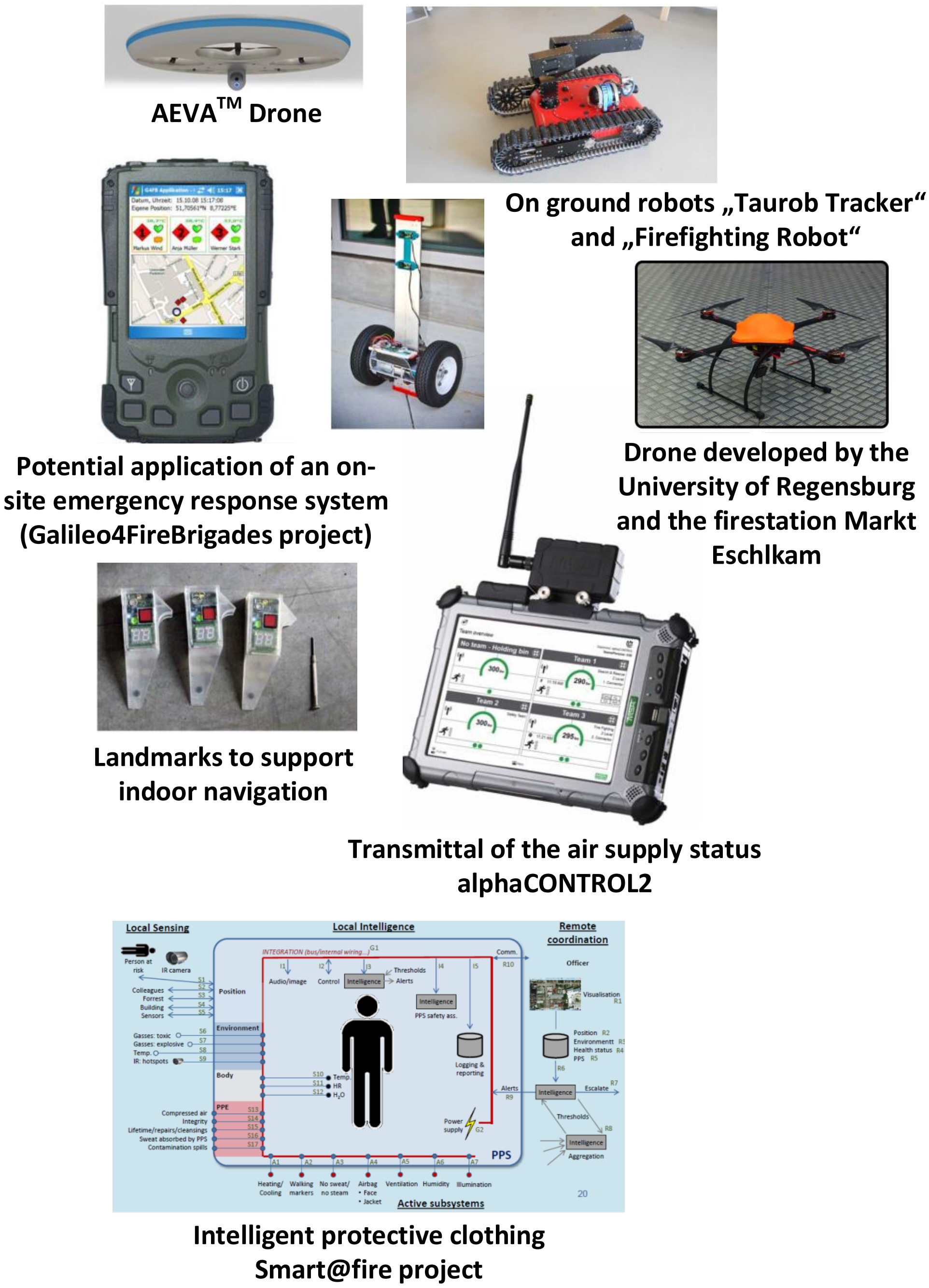

Figure 3.1 Examples for emerging technologies © 2016 IEEE

To support the *coordination* of emergency responses, it is frequently proposed to introduce *integrated on-site emergency response information systems* (T4) [5, 10-12]. Such systems introduce a shared platform to gather, present, and share relevant information on site. In principle, they can also support the decision-making by providing access to a central knowledge-management system. Usually, the shared platform is hosted in one of the emergency command vehicles and implemented using mobile communication technologies.

To assist firefighters during the *enforcement* of response decisions, literature proposes a variety of measures. One such measure is the introduction of *intelligent protective clothing* (T5) that is equipped with sensors to measure gases, outside temperature, and the health status of the firefighter [32, 33]. In addition, literature proposes to establish indoor *navigation support* (T6) and traceability of firefighters by using an ad-hoc network of sensors (so-called landmarks) that firefighters deploy during an intervention [34, 35]. As firefighters often have to wear a breathing apparatus, which provides support only for a limited period of time, navigation support can be a crucial instrument to help finding a way out of a danger zone before the air supply is exhausted. In this context, it is also discussed in literature to use wireless technologies to continuously *transmit the status of air supplies* (T7) so that teams can better monitor their interventions [36].

3.2.4 Task-Technology Fit Model

Emergency response systems are only used sporadically, but have to function well when needed. In particular, they have to be easily and efficiently usable as an "emergency response system that is not used regularly won't be used in an actual emergency" [5]. While the before-mentioned technologies might be suited to increase the functionality of on-site emergency response systems, they also introduce complexities and risks such as a heightened weight of the equipment, increased dependability concerns, higher administrative efforts, or restrictions due to the limited run-time of the batteries. It is hence unclear, if the technologies will indeed be viewed as beneficial by firefighters or if the disadvantages will prevail in practice.

To explain the adoption of information technologies, acceptance theories such as the Technology Acceptance Model (TAM) [37], the Diffusion of Innovations Theory (DOI), and the Task-Technology Fit Model (TTFM) [13] have been proposed. Among these theories, the TTFM appears to be particularly suited to assess the potential of information technologies to improve the effectiveness of on-site emergency response systems. Other than the TAM or DOI, the TTFM does not focus on the use of the system, i.e. the user behavior. Instead, it focuses on the performance of the system, which results from the perceived fit, i.e. the correspondence, between task requirements and the functionality provided by the technology (cf. Figure 3.2).

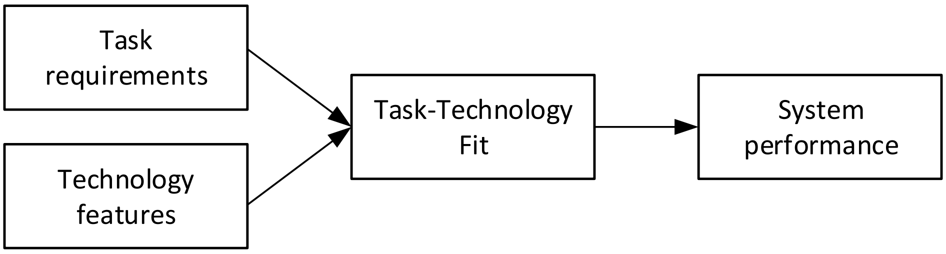

Figure 3.2 Task-Technology Fit Model © 2016 IEEE

Admittedly, the theoretical and empirical background of the TTFM is considerably less strong than that of the TAM or the DOI. It is hence still debated, which factors (e.g. compatibility, reliability, ease of use) determine the fit of a task and a technology in general. Nevertheless, the TTFM provides a unique theoretical basis to examine if a technology provides features that "fit the requirements of a task" [13]. As this objective corresponds precisely to the goals of our study, we decided to adopt the TTFM as lens of analysis. However, we decided to examine the perceived fit in general during the first iteration of our research endeavor and to investigate specific factors that determine the task-technology fit in future iterations.

3.3 Research Method

To assess the perceived potential of the before-mentioned technologies to facilitate the on-site emergency response process, we conducted a nation-wide online survey with firefighters from Germany as participants. To achieve good coverage, the German firefighter association and its state departments agreed to forward our survey invitation to the fire brigades throughout the country. Each fire brigade was asked to choose one expert (ideally the officer in chief) as representative that participates in the survey.

The survey consisted of three parts. In the first part, we asked for general and demographic information. For example, we wanted to know in which state the fire brigade is located, if it consists of a professional or a voluntary team, and how many emergency response operations it approximately conducts in one year. In the second survey part, we assessed which technologies the fire brigade used to find out how widespread certain technologies are and to determine the current state of the art. We specifically asked if certain technologies already were in use at a fire brigade. The answers were measured on a scale from 0 (no) to 1 (yes). In the third part of the survey, we asked how the participants perceived the potential of the before-mentioned technologies T1-T7 to facilitate the emergency response process. For each technology, we wanted to know if its functionality fits the task requirements of the fire brigade. Regarding the potential of drones, we asked for example: "How important do you find the use of drones in your fire brigade to investigate the emergency site?" All questions regarding the fit were measured on a five point Likert scale, ranging from 1 (not relevant at all) to 5 (very relevant).

To reveal the background of the participants, we firstly analyzed the demographic information. We then investigated to what extent the technologies are used in practice already. Thereafter, we evaluated the perceived potential of the technologies and tried to find possible reasons for the assessment. Finally, we cross-checked if the results vary depending on the amount of operations of the brigade or the professional status of the teams (i.e. professional vs. voluntary brigades). We therefore conducted rank correlation analyses for the respective variables.

3.4 Results and Discussion

The survey started in July 2014 and was online for approximately 6 weeks. In total, we received 912 responses. After excluding data sets where the majority of questions was left unanswered, we ended up with 807 responses to include into the analysis. All in all, we had a comparably low number of incomplete responses (11%), which could be due to the fact that the participants were invited by their association.

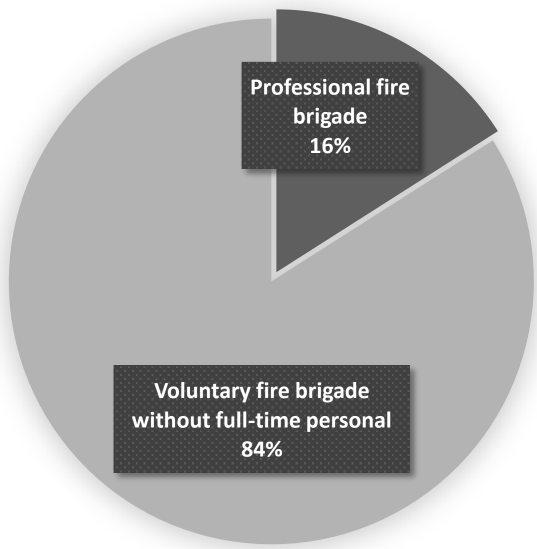

Figure 3.3 Professional status of the participants © 2016 IEEE

The geographic distribution of the participants was comparable to the distribution of fire brigades in Germany. Most of the participants worked in voluntary fire brigades. As can be seen from Figure 3.3, 84% of the participants were members of voluntary fire brigades. The remaining 16% were members of professional fire brigades, which are mostly composed of full-time employees. While this might seem to be an uneven distribution at first, it can be explained with the German firefighter landscape, in which approximately 95% of the firefighters are members of voluntary brigades [38]. All in all, we found our data set to represent the population of German fire brigades well.

We also wanted to know how many emergency response operations the participating fire brigades typically have in one year. Doing so allowed us to examine if certain technologies might be perceived as more valuable if the firefighters had a higher workload. Figure 3.4 summarizes the number of emergency response operations the fire brigades have per annum. As can be seen, most of them have between 20 and 100 response operations each year. Approximately one third of the brigades has less than 20 operations each year. Yet, 25% had more than 100 operations per year, including 60 (7%) fire brigades with even more than 500 emergency response operations each year.

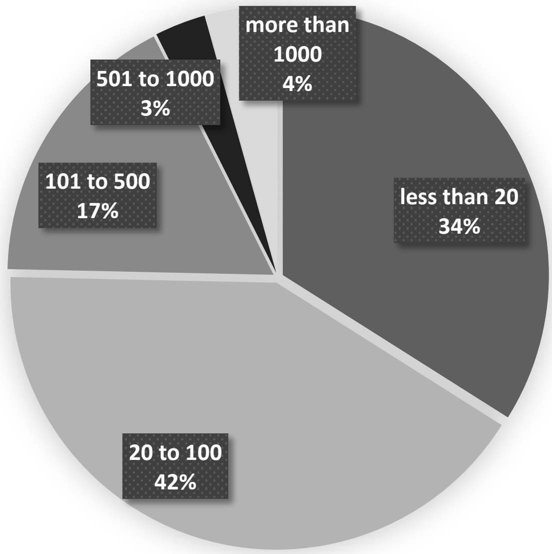

Figure 3.4 Number of emergency operations per year © 2016 IEEE

Regarding the potential of the technologies that shall support the *investigation of the emergency site*, the results of our survey reveal a rather mixed attitude of the participants. Although a majority of participants has no access to *digital maps* (T1) yet, most of them valued them to be an important tool that would facilitate their daily work. Of the participants, approximately 70% stated that their fire brigade does not yet work with digital maps and only 30% said that they already do have access to digital maps. As can be seen from Figure 3.5, 60% of the participants perceived the potential of digital maps to be either very high (29%) or at least high (31%). Only 18% saw little or very little value in digital maps. Accordingly, the participants attested a comparably high potential for digital maps, which they can use on mobile devices, for instance to quickly locate fire hydrants and supply lines.

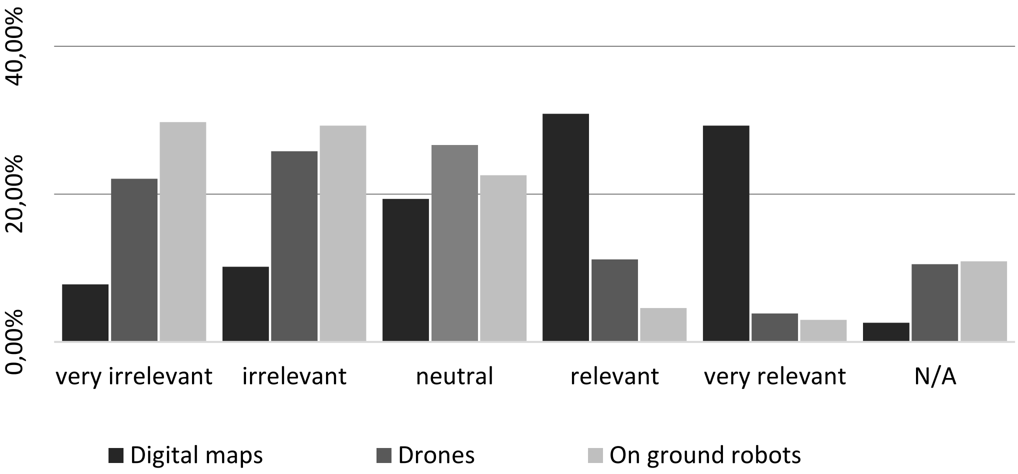

Figure 3.5 Potential of investigation technologies © 2016 IEEE

Compared to digital maps, *drones* (T2) are even more rarely used so far. In our survey, only seven fire brigades (approx. 1% of the participants) stated that they employ drones to investigate an emergency site. 8% noted that they were at least planning to employ drones either in the long-term (5%) or in the mid / short-term (3%). While the majority of the participants perceived the use of digital maps to be fruitful, the results for using drones are considerably less positive. Almost half of the participants (48%) found the relevance of drones to explore the emergency site to be either very low (22%) or low (26%). Furthermore, 27% gave a neutral score and 10% had no opinion to this question. This results in only 15% of the participants who saw the use of drones to be relevant (11%) or very relevant (4%). Surprisingly, the support for the use of drones to gain a better overview in emergency situations and to explore dangerous areas was rather low. Whether this is due to the fact that the range and operating time of firefighting drones usually is very limited, especially compared to military drones [28], or due to the fact that the resources necessary to navigate the drones might pose a possible barrier to adoption, has to be investigated more closely in future.

A similar picture can be seen regarding *on-ground robots* (T3). Of the 807 participants, only three stated that their fire brigade already uses on-ground robots. Even more surprising is that only 13 participants answered that their brigade is at least planning to employ on-ground robots at some point at the future. Not only are on-ground robots currently not really used in the German firefighting landscape, their potential seems also to be regarded as very low. Almost 60% of the participants saw little value in the use of on-ground robots and hence ranked them to be either very irrelevant (30%) or irrelevant (29%). Compared to that, the potential of on-ground robots received little appreciation with only 5% of the participants ranking them to be relevant and 3% noting that they are very relevant to expedite the investigation of an emergency site. Looking at the potential application scenarios of unmanned on-ground robots that are described in literature, this is an unexpected result. Such robots are typically thought to greatly expedite the work of firefighters when hazardous areas are to be explored, trapped or buried humans need to be freed, or in other situations where the involvement of human emergency responders is dangerous. However, the participants of our study did not see much value in the use of such on-ground robots. Whether this is due to the fact that they would rather prefer equipment which allows them to act in such situations themselves or whether they do not have enough trust in the often limited capabilities of today's robots to rely on them in emergency situations will have to be investigated more closely. Interestingly, the perceived potential of drones and the perceived potential of digital maps are significantly ($p<0.01$) positively correlated with the amount of emergency operations the fire brigade has each year. That means that the more operations the participants have each year, the more they value the existence of digital maps or drones. For on-ground robots, this relationship was insignificant though ($p=0.8$).

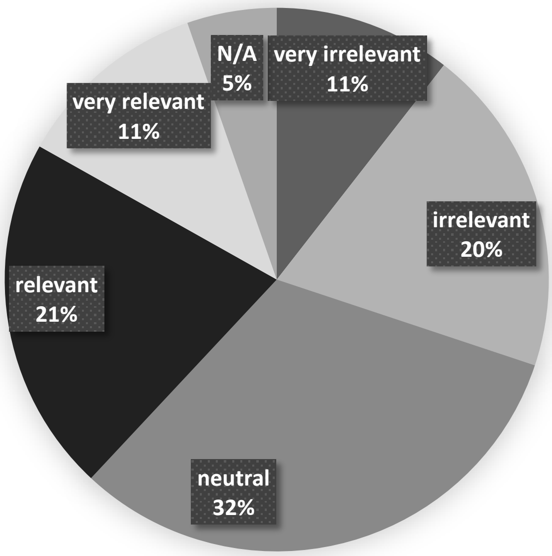

Figure 3.6 Potential of integrated on-site emergency response systems © 2016 IEEE

Regarding the *coordination* phase, we examined if *integrated on-site emergency response systems* (T4) are used in practice and in how far they are perceived to have a potential to expedite emergency response activities. As such systems are often recommended in scientific literature [5, 10-12], it was particularly interesting for us to see how they are perceived in practice. Of the participating fire brigades, around 30% already worked with an integrated on-site emergency response system. Compared to other emerging technologies, such as drones or on-ground robots, this is a relatively large number. As shown in Figure 3.6, the perceived relevance of such systems is very balanced. Almost the same amount of participants perceived such systems to be either (very / somewhat) irrelevant or (very / somewhat) relevant. Accordingly, we could not find a clear trend regarding their potential at first.

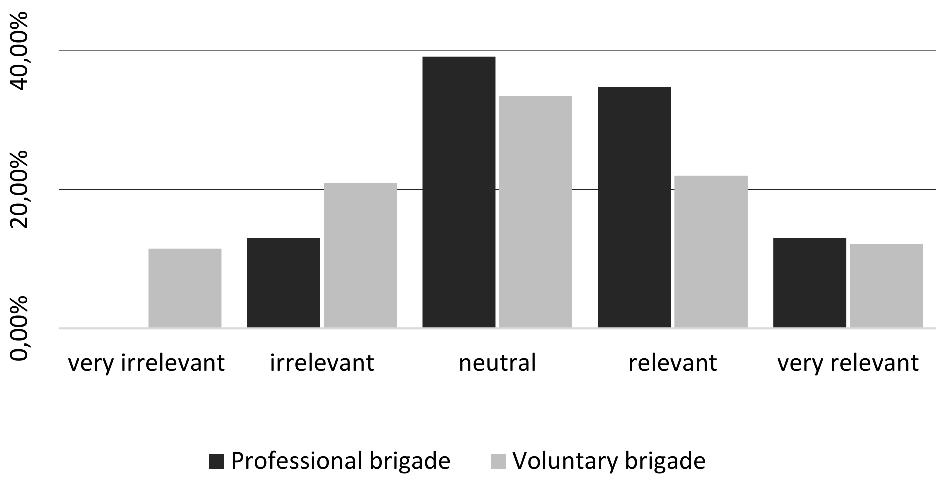

Figure 3.7 Potential of on-site ERIS for voluntary and professional brigades © 2016 IEEE

We therefore decided to take a deeper look into the data and analyzed, if the perceived potential of such systems varies depending on the amount of emergency operations that a fire brigade is involved in, or if there is a difference between voluntary and professional firefighters. With respect to voluntary and professional fire brigades, there was a significant correlation between the assessment and the status of the brigade. The conducted correlation analysis showed a significant ($p<0.01$) influence. It confirmed that professional firefighters ranked the relevance of integrated on-site emergency response systems higher than voluntary firefighters (see Figure 3.7). Likewise, the amount of emergency operations of a fire brigade is significantly ($p<0.01$) correlated with the perceived relevance of integrated on-site emergency systems. The more operations a fire brigade has, the more the members felt that such systems have a potential to expedite their work. A reason for this observation could be that the more operations a team has, the more complex is the coordination of teams. Hence, a system to efficiently coordinate these processes becomes more valuable. This suggests that the more complex and professionally organized the fire brigades are, the more important are integrated on-site emergency systems to quickly and efficiently coordinate the teams. This also stands in line with the task-technology fit model, which proposes that the employed technology has to fit to the corresponding task characteristics to achieve a wide acceptance of users [13]. However, this result also suggests that there might exist fire brigades for which the use of complex on-site emergency systems is not beneficial since the task complexity of their response operations is not high enough to merit the introduction of such systems.

With respect to the technologies supporting the enforcement stage, the dissemination consistently was rather low in practice. With 21 fire brigades (2.6%) stating to already use intelligent protective clothing in practice, T5 was the most frequently used technology in the enforcement category. It was closely followed by technologies for the continuous transmittal of the air supply status, which were used by 19 (2.4%) brigades. Technologies for indoor navigation support (T6) were so far only used by three (0.4%) fire brigades.

Compared to the current use in practice, the perceived potential of the technologies was regarded differently. As can be seen from Figure 3.8, indoor navigation support technologies were found to have the highest potential. With 50% of the participants giving a positive feedback, including 22% stating that indoor navigation support is very relevant and an additional 28% saying that it is relevant, this technology received a support well above-average. Only 15% perceived this technology to be very irrelevant or irrelevant. One explanation for the high support is that the participants saw an immediate value in this technology, since it enables them to navigate in areas where smoke typically makes it very hard to find the right path.

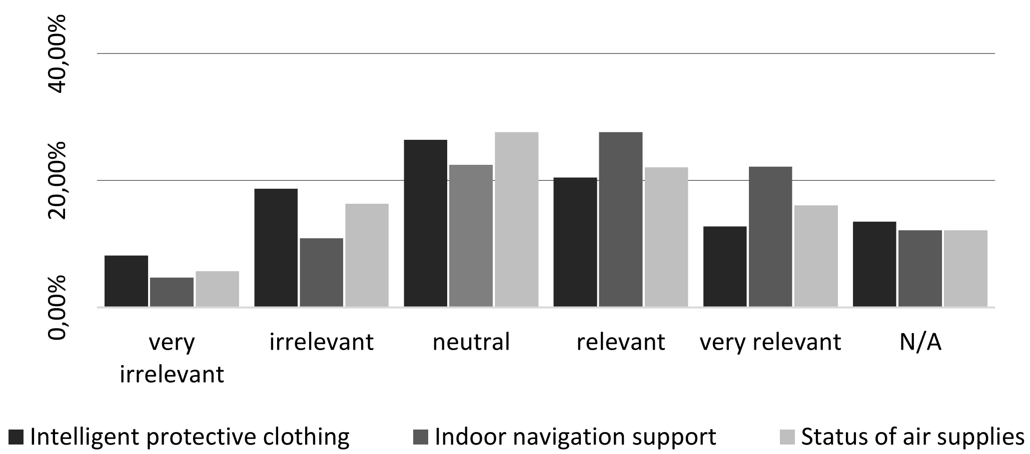

Figure 3.8 Potential of enforcement technologies © 2016 IEEE

The continuous *transmission of the air supply status* (T7) received a somewhat lower support. However, with 38% finding this technology to be relevant or very relevant, and only 22% perceiving the technology to very irrelevant or irrelevant, the technology still received an echo which is overall positive. Yet, the majority of participants was indecisive regarding that technology and hence ranked it neutrally. The lowest support in this category received the use of *intelligent protective clothing* (T5). Having almost equally as much participants who perceive this technology to have a potential to expedite the process as those who do not, the technology has a mean value only very slightly above the neutral value three. This is a surprising result, since there exist several dedicated projects to develop intelligent protective clothing for firefighters (e.g. the “smart@fire” project that is funded by the European Union). Possible explanations for the low support could be that the equipment is expected to be rather expensive, that the battery life is deemed to be rather low [39], the additional weight of the clothing, or the additional effort for the transportation and the time to apply the clothing.

The correlation analysis further revealed that all technologies in the enforcement category are significantly ($p<0.01$) negatively correlated to the amount of operations a fire brigade has each year. The more operations a firefighting brigade had in the survey, the less they obviously perceived the technologies to be relevant. This might be explained by the additional effort that the technologies require. The additional effort is seemingly perceived to be the more severe, the more often the firefighter teams have to work with them and hence have to invest the additional effort.

3.5 Conclusion

Little research has examined how the potential of emerging technologies to facilitate the activities on the site of an emergency is perceived by the first responders. To contribute to the closure of this literature gap, we have presented the results of a study, in which we asked German firefighters to assess the potential of seven emerging technologies to facilitate the investigation, coordination, and enforcement tasks on site.

The presented results provide a unique overview of frequently discussed emerging technologies and their perceived potential to expedite the emergency response process. In line with the expectations in literature, the participants found digital maps, indoor navigation support, and the continuous transmission of the air supply status to facilitate the emergency response process. Our results also indicate that the potential of technologies can vary considerably depending on the complexity of the emergency response operations and the (voluntary vs. professional) status of the emergency responders. The introduction of integrated on-site response management systems, for instance, received a controversial feedback. Nevertheless, it was perceived to be beneficial in complex emergency scenarios. In contrast to the expectations in literature, however, the potential of drones, on-ground robots, and intelligent clothing was found to be rather limited.

The results of our study have implications for academia and practice alike. Regarding academia, the implications are twofold. Firstly, our results signal a need to evaluate emerging technologies for on-site emergency response systems from the perspective of the end users. 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. It is therefore strictly necessary to provide only such functionality, which is required to support the emergency response process. In addition, the gain in functionality needs to be carefully balanced with the additional overhead and/or restrictions that arise for the end users. If these critical design principles are not taken into account from the beginning, the resulting systems run a significant risk of missing the market needs.

Secondly, we show that the Task-Technology Fit Model can provide a theoretical basis to assess the potential of emerging technologies to improve on-site emergency response systems from a user perspective. Other than most acceptance theories, which explain the use of a system, the TTFM specifically aims at explaining the performance of a system. To ensure a good performance, it is accordingly important to examine whether the functionality of a technology corresponds to the characteristics of the task that it is intended to support.

For practice, the results of our study provide indications of the potential of several frequently discussed technologies to improve the capabilities of on-site firefighter information systems. In contrast to the claims that can be found in literature, our results indicate that the potential of many technologies might be rather limited when examined from the perspective of the users. Apparently, the additional complexities, risks, and limitations that come with new technologies often overcompensate expected benefits. For the administrators and managers of fire brigades, our results hence send a signal to introduce new technologies with care.

However, there also exist several limitations, in the light of which the results ought to be interpreted. Most prominently, we have only surveyed German fire brigades so far. As the emergency response process and the percentage of professional firefighters vary in other countries, the potential of the examined technologies might be perceived differently there. Moreover, we so far have only focused on those technologies that were most frequently discussed in the analyzed literature. We restricted ourselves to these technologies because we deemed them to be well known by the participants as well. In future iterations of our research endeavor, we will have to examine additional technologies such as augmented reality visors for firefighters. Although we restricted our survey to prominently discussed technologies, it is still likely that the results were influenced by the ability of the participants to imagine the technologies or by individual experiences with differing implementations of these technologies. While we have strived to level such differences by choosing a large sample for the presented study, we plan to more systematically investigate different technology implementations and their effects on the task-technology fit in future. Without qualitative data, we can finally only speculate about the reasons behind the technology perceptions. It is even conceivable that firefighters might just be reluctant to changes in general because of the critical importance of their proven job routines. To gain a more in-depth understanding of the survey results, we hence plan to conduct in-depth expert interviews on the subject matter. On this basis, we intend to find and examine specific factors (e.g. reliability, ease of use) and usage scenarios that determine the task-technology fit. In addition, we will analyze the variations among different user groups in more depth to better delineate the potential of the technologies.

Despite these limitations, the study results already provide a reference against which emerging technologies to improve the capabilities of on-site firefighter information systems can be evaluated from a user perspective. With the presented findings, we hope to provide a starting point for such endeavors.

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Part 2:

Acceptance Factors for Firefighter Information Technologies

4 Paper III: Interview Study on FIT Acceptance Factors – Preliminary Results

Table 4.1 Fact sheet paper III

Fact	**Description**
Title	The Good, the Bad and the Indispensable – Insights into the Practical Potential of Emergency Response Information Systems and Drones for Firefighters
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The Good, the Bad and the Indispensable – Insights into the Practical Potential of Emergency Response Information Systems and Drones for Firefighters

Abstract. *The introduction of innovative information technologies is frequently pursued to improve the on-site decision-making and hence the effectiveness of emergency response processes. Yet, the practical potential of innovative firefighter information technologies hardly has been investigated so far. In this paper, we present the results of a study, in which we interviewed 21 members of German fire departments about the potential of emergency response information systems and drones. The results suggest that firefighters find both technologies to deliver potential improvements. They also pointed to several possible drawbacks and critical requirements, however. The results of our study do not only provide a multifaceted overview of the potential benefits and risks that ought to be taken into account when introducing emergency response information systems or drones for firefighters. They also call for a systematic investigation of the practical potential of firefighter information technologies in general.*

Keywords: Drones, Emergency response information systems, Firefighter information technologies, Qualitative study, User acceptance

4.1 Introduction

As a result of the ongoing rapid technological progress, several innovative information technologies have been suggested to better support the emergency response operations of firefighters. Emerging technologies such as drones, robots, smart clothing, or indoor navigation approaches are supposed to support context-dependent on-site decisions with new sources of real-time information and hence bear a significant potential to change traditional emergency response processes. Both in scientific and practitioner literature, it is often assumed that the adoption and use of such technologies will increase the efficacy of emergency responses.

However, the adoption and use of new information technologies also introduce additional complexities for the firefighters who operate and maintain them on site. Any gain in functionality will thus have to be weighed against the additional overload or restrictions that arise for the users. Despite this challenge, the acceptance of innovative information technologies for firefighters has hardly been in the focus of research so far. As many of the proposed technologies moreover are not yet widespread in practice, little is known about their definite potential to support the on-site decision making and to increase the efficacy of emergency responses.

With the study presented in this paper, we intend to gain insights into the practical potential of innovative firefighter information technologies (FITs). To narrow its scope, we decided to examine the practical potential of unmanned aerial vehicles (UAVs, or drones) and emergency response information systems (ERIS), which are currently discussed in literature as two innovative FITs. In particular, we address the following research questions: "*What is the practical potential of innovative firefighter technologies? Which factors increase or limit their potential in practice?*"

To examine both research questions, we adopted a qualitative, interview-based research design. Such a design allows us to gain rich insights into the context and the reasons behind the results. Following this goal, we interviewed 21 members of German fire departments (FDs) about the potential of UAVs and ERIS. In an exploratory manner, we interpreted the results and derived conclusions regarding the factors that increase or limit the potential of the examined FITs in practice. Note that we did not specifically examine the potential of the two FITs to support extraordinary scenarios such as major disasters, but analyzed their ability to support the practices of firefighters in general. In so doing, we gained broader insights and were also able to study the potential of the FITs to support the daily routines of firefighters.

The findings of our research contribute to explaining the practical potential of emerging FITs. Emergency response processes have specific characteristics regarding time, effort, and complexity. If such characteristics are not identified and taken into account from the beginning, FITs run a risk of missing the needs of the users. In this context, the results of our study can provide an initial step to develop specific theories that explain the adoption of FITs. We proceed as follows: in section 4.2, we discuss the background and related work. In section 4.3, we describe our research approach in detail. The results of our study are presented and discussed in section 4.4. We conclude by summarizing key findings and giving an outlook on future research in section 4.5.

4.2 Background and Related Work

During the response to an emergency, firefighters make time-critical, context-dependent decisions on site. Their quality depends on the commanders' situation awareness [1]. The availability of information hence is one of the major determinants of a successful operation [2, 3]. Typically, however, commanders only have limited information about the status of casualties, the conditions inside a burning house, the status of responding units, etc.

Consequently, decisions often have to be made with a high level of uncertainty and risk. To improve the situation awareness of firefighters, several new FITs have been proposed in academia and practice.

4.2.1 Information Technologies for Firefighters

To get an overview of novel FITs, we reviewed the literature following Webster's and Watson's [4] guidelines. We queried several databases including Google Scholar, AIS Library, IEEE Xplore, and the ACM Digital Library using keywords such as "firefighter", "fire brigade", "fire department", or "firemen" together with "information system", "information technology", or specific keywords like "UAV". We inspected the titles and abstracts of the resulting articles to eliminate irrelevant results. The remaining articles were analyzed using a narrative review method [5]. We also conducted backward and forward searches. Note that we did not include articles in practitioner outlets as they lack scientific rigor and rather provide anecdotal evidence.

The results of our review show that considerable work in the field is devoted to the analysis of and the response to large-scale disasters [6-11]. In recent years, especially social media and the inclusion of citizens into the response process were discussed [12-15]. Such approaches concentrate on the use of technologies in the specific event of major disasters, though. In contrast, we examine the use of FITs in general and hence also focus on their ability to facilitate the daily work of firefighters.

There also exist articles that treat FITs to support daily routines [16-20]. These articles typically concentrate on introducing specific FITs, however. In addition, they are typically technology-driven in nature. This means that they focus on proposing new technologies and discussing their theoretical potential based on their features. Usually, they do not examine how firefighters perceive such innovative technologies in practice. Literature on situation awareness shows that, in general, the introduction of additional information technologies might be beneficial. It also provides indications that the situation awareness can be hampered due to additional complexities and other disadvantages, though [21, 22].

Despite the unclear effects of novel FITs, we found only one article that analyzes their potential and specifically studies their perception in practice. In this article, six types of emerging FITs were identified [23]: digital plans/guides, ERIS, UAVs, unmanned ground vehicles, intelligent protective clothing, and indoor positioning. In a survey with over 900 responses, many of these technologies received a feedback that was contrary to the expectations in literature. Moreover, the perception of some technologies varied considerably indicating that their use in practice might be dependent on specific factors. Due to the quantitative nature of the study, the authors could not definitely identify reasons for the varying perception so that the results remained “controversial” [23]. This was especially true for drones, which received a surprisingly negative feedback. Their dissemination in practice was found to be limited, too. ERIS, on the other hand, seemed to be more widespread in practice. Comparatively, they were also seen more positive but nevertheless found to be too complex for smaller departments. We hence decided to concentrate on these two rather unexpectedly assessed technologies to evaluate and identify possible causes for the perceptions.

4.2.2 Emergency Response Information Systems

ERIS aim at improving the coordination of emergency responses by providing a platform to gather and share relevant information on site (Figure 4.1). There are several types of ERIS being proposed in literature and practice. They differ in functionality and complexity.

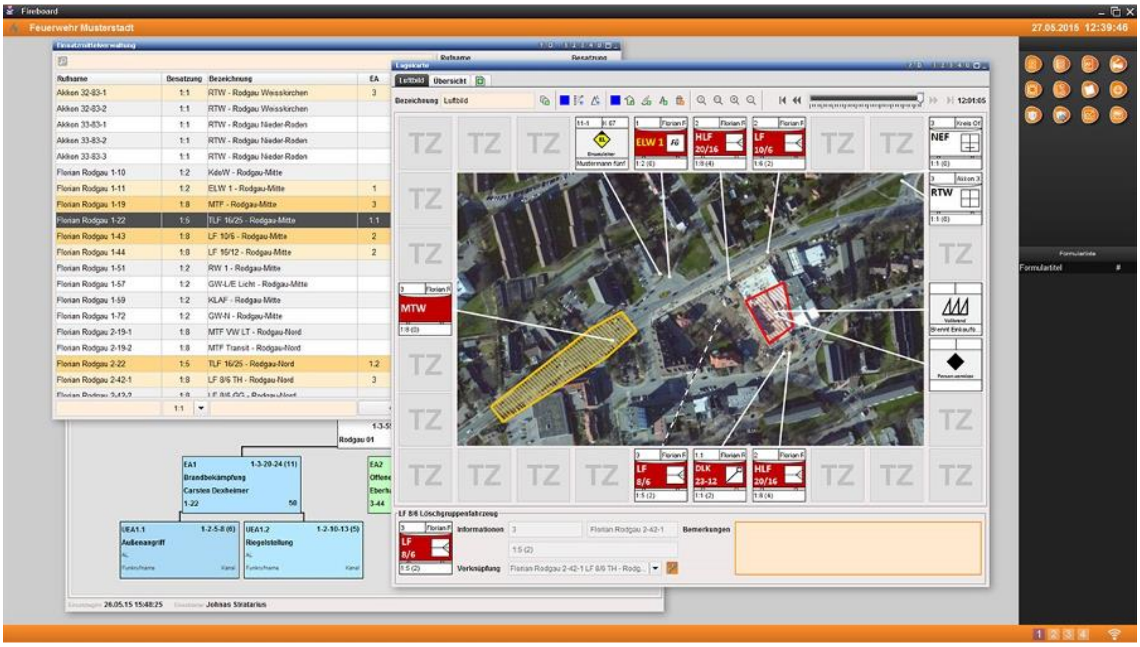

Figure 4.1 ERIS “Fireboard”, cf. http://fire-board.net/en/fireboard/

The different types of ERIS particularly vary with respect to the way they obtain and utilize real-time data from the site. The functionality of basic ERIS is limited to the *processing* and *presentation* of information. The input of information usually is done manually [24]. This means that firefighters must feed the system with information during a response to benefit from its use. Many ERIS provided in practice can be assigned to this category [25, 26]. Apart from such comparatively simple systems, there also exist ERIS that *capture* real-time information using sensor networks [3, 27-31]. The captured information typically comprises the position of deployed units, tank levels of engines, outside temperature, wind direction etc. A third category of ERIS furthermore introduces *decision support* functionality [32, 33]. Those systems do not only present information to users. They also calculate and suggest possible decisions or commands based on the available information.

4.2.3 Unmanned Aerial Vehicles

To facilitate the exploration of an emergency site, literature frequently emphasizes the potential of UAVs. Both in academia and practice, various types of drones have been proposed to support firefighters (Figure 4.2).

Figure 4.2 UAVs "TUB-H" [34] and "Phantom 3", cf. http://www.dji.com/phantom-3-pro

First, UAVs can be categorized by the tasks they are supposed to execute. A main application area for UAVs is the *surveillance* of the emergency site. Drones can, for instance, be used to detect and observe forest fires [35-39]. However, they can also be used for general reconnaissance tasks, which are required in any type of emergency operation [40, 41]. UAVs are also suggested to improve the on-site *communication*, for instance by establishing ad-hoc radio communication networks or increasing the range of existing ones [42, 43]. Drones can furthermore help during incidents with hazardous materials [44]. To *measure* the concentration of poisonous substances in the air, they are supposed to be more suitable than common on-ground measuring tools. Another task that is supposed to be supported is the *search* of victims or injured firefighters [34]. All in all, UAVs shall increase the commander's situation awareness.

UAVs can also be distinguished by their size and type of construction. In literature, rather *small* drones are supposed to be most suitable for FDs. They are typically designed as quad-, hexa-, or octocopters [44, 45]. Miniature helicopters are proposed as well [34, 37, 40]. In contrast, *large* drones - as used by the military - are proposed for specific tasks only. These types of UAVs resemble small planes [35]. A detailed categorization of drones based on their size can be found in literature [46].

UAVs also differ with respect to the way they are controlled by the user. On the one hand, there exist remotely *controlled* devices [36, 40]. They are piloted by an operator, who must either keep them in his/her sight or steer them by video transmission. On the other hand, *autonomous* UAVs have been suggested [37, 41, 44]. Such devices are for example assigned to a certain spot or area. A suitable route for reaching or covering this area is then computed and followed automatically.

Lastly, the number of drones deployed can be distinguished. Often, a *single* UAV is used [34, 36, 40], which can only provide information from a single point of view at any time. Other approaches require the deployment of *multiple* UAVs, so-called swarms [37, 39, 41, 44]. They can provide information from multiple locations within an area and are supposed to be especially suitable to surveil large areas or the spreading of poisonous gases.

4.3 Research Method

In new and emerging fields where little is known about the object of investigation, literature recommends employing qualitative research designs [47]. As shown in section 4.2, FITs mainly have been investigated from a technology rather than from a user perspective so far. Since little research exists that examines how FITs are perceived by their users, we decided to adopt an exploratory, qualitative research design. Doing so allowed us to gather in-depth insights into the perceived potential of the technologies. This research design also allowed us to gain an understanding of the reasons behind the perceptions. As emerging technologies are continuously adjusted and redeveloped, the reasons behind the perceptions of users are of practical interest as well and hence build an essential part of our research endeavor. Since emerging technologies furthermore often exist in different instantiations and not all participants might have the same understanding of a technology, we used the direct contact to the experts to make sure that they had a common understanding of the subject matter.

We decided to conduct semi-structured face-to-face interviews as they are considered the superior data collection technique for qualitative study designs [48]. Following a common, standardized interview guideline, semi-structured interviews shall ensure comparable results. But as the interviewer can adjust questions or ask for explanations if necessary, this interviewing form provides a greater breadth of results than rigorously structured interviews. Our interview guideline consisted of three parts. First, we asked for demographic information to gain insights into the interviewee's background and the FD. For instance, we asked for the number of firefighters working in the FD, the number of operations in one year, and the interviewee's qualifications. In the second part, we introduced the FITs to ensure common understanding. Afterward, we asked how the participants perceive the potential of the technologies. To identify positive and negative factors that influence the acceptance, we asked for perceived advantages, disadvantages and properties of the FITs affecting complexity. Also, we asked which requirements the FITs need to fulfill to be usable. During the third part, open questions were asked. For example, we wanted to know which technologies were already in use or intended to be introduced. Altogether, the interviews closely followed the guidelines given by Myers and Newman [49].

All interviewees were experts in the field. Generally, literature defines an expert as someone with privileged knowledge about the subject matter [50]. Regarding our research endeavor, an expert is someone who not only knows about the examined FITs but also has an extensive background in the way firefighters work and use such technologies on site. As experts typically are able to provide profound insights regarding the subject matter, their number can be rather low as long as they are selected carefully [50]. We decided to interview experts from the strategic, tactical, and operational command level of different FDs. The strategic command level consists of (assistant) fire chiefs responsible for principal matters and leading large-scale responses. The tactical command level is made of platoon leaders typically acting as incident commanders. The operational command level consists of squad leaders enforcing activities on site. In the role of command assistants, they will also be the ones to use the two examined technologies. With our strategy, we could hence gather perceptions from multiple perspectives and enhance the validity of the results. In total, we interviewed 21 firefighters that were nominated as experts according to the above-mentioned criteria by their FDs and had profound field experiences. The interviews were conducted in seven FDs distributed across Germany: two plant FDs, two professional FDs, and three voluntary FDs. They consisted of 70 to 900 firefighters and had 200 to 25.000 operations a year.

The gathered interview statements were analyzed for positive and negative perceptions as well as technology requirements. First, we used open coding techniques to identify recurrent statements that we grouped into topics. We then used in-vivo codes to name each topic with the denomination predominantly used by the experts. In so doing, we identified several factors that seem to determine the practical potential of ERIS and UAVs.

4.4 Results and Discussion

For each of the technologies, we describe the positive and negative factors as well as the existing requirements that have been emphasized by the interviewees. Aspects that have been mentioned by at least 33% of the participants are discussed in detail. To refer to individual interviewees, we numbered them consecutively.

4.4.1 Emergency Response Information Systems

Regarding the practical potential of ERIS, we identified seven positive, one neutral, 13 negative factors, and eight general requirements (cf. Table 4.2).

Table 4.2 Assessment of ERIS

	Factor	n	%
Positive	Informational advantage	14	67
	Increased capacity / documentation	8	38
	Time advantage	8	38
	Accuracy	7	33
	Load removal from radio	4	19
	Compactness	2	10
	Structuring	2	10
Neut.	Flexibility	6	29
Negative	Decision-making complexity	11	52
	Costs	11	52
	Loss of competences	10	48
	Resistance to change	9	43
	Training effort	8	38
	Lack of expressive power	7	33
	Information overload	7	33
	Personnel effort	6	29
	Limited range of application	3	14
	Maintenance / updating effort	3	14
	Organizational effort	3	14
	Less communication	2	10
	Weight	1	5
Requirements	Intelligibility	18	86
	Simplicity	17	81
	Reliability	12	57
	Robustness	7	33
	Legal issues / privacy	5	24
	Time restriction	5	24
	Flexibility	4	19
	Long lifespans in FDs	2	10

Positive. 67% of the experts found that ERIS offer an informational advantage: "A real benefit […] will be reached once I have an electronic situation report that includes as much information as possible from systems that exist anyway. […] Of course, you could extend this with sensor networks or decision support systems" (20). The automatic gathering of information using sensors is also seen positively: "Being able to see who is where at what point of time is an excellent basis to get an overview of an operation but also to assess the operation in case of accidents and to study what didn't work" (15).

An increased capacity and documentation was found positive by 38%: "I can document the situation dynamically. With flipcharts, I always have the problem of changing or saving recordings" (3). "This would help the commander with respect to documentation, which is becoming ever more important due to legal issues" (7).

A time advantage was attested by 38%: "Such a software is a wonderful supplement for a fast, transparent situation report" (2). Especially for sensor networks, the "real-time presentation" (20) was stated to be a benefit.

An increased accuracy was seen as advantageous by 33% of the experts: "The huge advantage is that your situation reports are more accurate. So, I can coordinate or brief my units more accurately, as well" (14).

Negative. While the before-mentioned informational advantage could facilitate the decision-making, 52% of the experts found that a vast amount of information and a documentation of every decision could also make decision-making more complex: "Too many moving images in the decision-making room just hamper the decision-making" (20). "It documents everything. […] Afterward, if the district attorney comes to investigate the cause of something that has gone wrong, this data can, of course, be inspected and used to interrogate or to hold responsible the decision-maker" (17). 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" (8).

52% of the interviewees mentioned costs as a negative factor: "That will probably fail due to its cost" (10). This concern also applies to sensor networks: "Sensor technology would increase the costs of vehicles and equipment, which will not prevail, I think" (18).

As a specific problem of decision support systems, the potential loss of competences was addressed as a problem by 48%: "For such things, I have my personnel. My team at the front is supposed to estimate and tell me, how things are going" (12). Introducing such systems would mean "a qualitative shift since I already have a manual assessment by the commander or the people in charge that would fall away" (19).

Especially for decision support systems, 43% saw the resistance to change in their departments problematic: "This is a great thing, and you can see the tactical necessity, also the benefit. But if you have someone saying ‘I don’t want to use that’, then he will not use it. So, you must convince your team to use the system” (2).

38% of the experts also stated an increasing training effort: “The ones operating those systems must be trained and experienced in operating them” (10).

33% also mentioned the lack of expressive power as a drawback of sensor networks: “Sensors are built for a certain physical unit. They can capture changes in those units, but nothing else. They can, for example, not capture if someone is in stress. So, there is the danger of getting values that are incomplete or do not necessarily match the reality” (9). This concern also applies to decision support systems: “There are so many parameters to be considered. I don’t think that you could supply a decision support system with all that information. You will still need people with practical experience to estimate the situation” (2).

According to 33% of the experts, information overload is another disadvantage of sensor networks and decision support systems: “If there is a suggestion created for everything, I will have no time for anything but saying ‘yes’ or ‘no’ anymore” (10).

Requirements. 86% of the interviewees mentioned the intelligibility of the displayed information as a requirement: “[The display has to be organized] based on common knowledge. […] That is a basic requirement. […] The things displayed must look exactly as the things we had on the blackboard or on paper before” (19). “It needs to be organized in a way that you can process all necessary information at a single glance” (1).

81% of the participants emphasized that ERIS must be simple and intuitively usable: “Concerning the handling, I demand that they are firefighter-proof” (13). “They have to make use of technology, which is known by nearly everybody” (4).

57% emphasized reliability as a requirement: “Software solutions sometimes […] don’t work failure-free, which would be fatal during an operation” (3). “Equipping all firefighters with sensors makes me think of this: the more technology is built into a car, the more can break down” (11). “You cannot blindly rely on such systems. Actually, you always have to act on the assumption that such a system can crash” (21).

33% of the interview partners also addressed robustness as an essential characteristic. Especially if devices are to be carried on site, they must withstand outdoor conditions: “You are not in an office, where everything is clean. If it is raining, it must still be working” (5).

4.4.2 Unmanned Aerial Vehicles

Regarding the practical potential of UAVs, we identified four positive factors, twelve negatives, and eight general requirements (cf. Table 4.3).

Table 4.3 Assessment of UAVs

	Factor	n	%
Positive	Informational advantage	21	100
	Time advantage	12	57
	Currentness of data	8	38
	Safety	4	19
Negative	Personnel effort	14	67
	Costs	13	62
	Limited range of application	12	57
	Training effort	12	57
	Operation complexity	11	52
	Maintenance / updating effort	10	48
	Organizational effort	10	48
	Evaluation effort	4	19
	Resistance to change	3	14
	Space requirements	2	10
	Information overload	2	10
	Decision-making complexity	1	5
Requirements	Robustness	17	81
	Simplicity	17	81
	Legal issues / privacy	10	48
	Operating time	8	38
	Reliability	6	29
	Range	3	14
	Loading capacity	2	10
	Time restriction	1	5

Positive. All experts found that UAVs can provide an informational advantage by expanding the commanders' perspective: "W*e are certainly lacking intelligence from above […]. And that would definitely be beneficial*" (2). "*I could have a live picture from the distance. If I send in a firefighter, I can only hear what he reports […] and don't have an overview of my own*" (1).

57% of the interviewees stated that drones provide a time advantage: "*I'm probably faster with an UAV*" (17). "*Often there are no access points to an object so that you cannot see much from the ground. If you have an aerial view or a thermal image from above, you get a situational overview faster*" (7).

38% of the participants emphasized the currentness of data delivered by UAVs as another positive factor: "*I can capture the current situation with an UAV. And not only the static situation, but the dynamic situation*" (10). "*Commonly, you will use Google maps excerpts which are one year, two years, perhaps only one day old. But they don't express the current situation*" (13).

Negative. 67% of the experts criticized the personnel effort to use UAVs: “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” (17).

High costs were stated as another negative factor by 62%: “Acquisition costs and operating costs. Operating a drone in an FD means providing multiple batteries for switching, which is an expensive part of such a device” (14). “If I wanted to make a safe aircraft out of it, the thing would become so expensive that you couldn’t use it for such purposes anymore” (9).

57% of the interviewees mentioned the limited range of application as a negative aspect: “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 UAV in those situations” (10). “How frequently will such a thing be deployed?” (5).

The high training effort required to operate UAVs is criticized by 57% of the experts: “If you need people who operate them – well then there will certainly be an according training effort” (19). “I find that problematic: not everyone can do that and you will definitely need people who have trained it” (14).

52% of the interview partners also mentioned the operational complexity as a problem: “Airspace security must be considered. Especially in large-scale responses, where police and rescue helicopters are on the scene as well” (7). “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” (13).

48% of the interviewees named the maintenance or updating effort as a drawback: “If they are equipped with several sensor technologies […] it will not only be an expensive, but also a high-maintenance device” (16).

The organizational effort was criticized by 48%: “You would need to establish a distinct group of people responsible for it” (1). Especially the deployment of autonomous UAVs is seen critical: “They will need an allocated air corridor; they will need a license” (8).

Requirements. Robustness was mentioned as a requirement by 81% of the experts, since UAVs would have to withstand weather and other extreme conditions in the incident area: “It would have to be able to fly in the rain […] and it should be autonomous enough to compensate wind drifts” (1). “How close can I fly above a fire source without getting problems with the thermal lift? These things don’t have much weight, so […] they will quickly get problems with thermal lift” (12).

81% stated simplicity as an essential factor since UAVs have "to be operated easily" (6). In particular, a certain degree of autonomy was desired: "I want to put it on the ground, specify the point of the disaster […] and the flying altitude […] and it should automatically approach the destination and deliver the image" (7).

48% of the experts emphasized that legal issues and privacy concerns must be solved before introducing UAVs: "Legally unclear things like how I may use drones or what's happening with pictures I randomly record which may restrict people in their privacy" (8).

38% demanded a long operating time: "Half an hour at least. If I must patrol a sector once or multiple times, it must stay in the air for quite some time" (5).

4.4.3 Discussion

The interviewees found both FITs to deliver potential improvements. However, they also pointed to several potential drawbacks and constraints, which have to be fulfilled. All in all, each interview partner stated four positive factors, eight negative factors, and six requirements. We hence observed a rather diverse attitude, which contradicts unilaterally positive expectations that are often found in literature. The results rather emphasize that FITs are indeed delicate artifacts that have to be designed carefully and with acceptance-related factors closely kept in mind from the beginning.

In particular, the identified requirements seem to be critical success factors that ought to be fulfilled during the design of ERIS or UAVs for firefighters. We suppose that the acceptance of a specific technology can be significantly facilitated if the design fulfills the identified requirements. If a design fails to meet the stated requirements, its acceptance might be in jeopardy.

In comparison, it appears that the practical potential of ERIS is perceived as somewhat more positive than that of UAVs. Summing up the frequencies of positive and negative factors, the data contains 45 mentions of positive factors and 81 mentions of negative factors for ERIS. For UAVs, the data contains 45 mentions of positive factors and 94 mentions of negative factors. The ratio of positive and negative statements hence is slightly more positive for ERIS. As we cannot quantitatively express the relative influence of each factor on the acceptance, it only provides a first indication, though.

Table 4.4 shows factors that were mentioned both for ERIS and UAVs and compares the frequencies of mentions. We can conclude that UAVs were primarily seen as a means to gather information faster. However, they appear to be also perceived as rather expensive, requiring a high amount of personnel, and being limited in their range of application. Besides, simplicity, robustness and privacy were found to be important requirements that need to be fulfilled by UAVs. ERIS were found to also deliver an informational advantage. The added complexity during the decision-making process and the risk of introducing an information overload were found to be negative, though. We also found that the resistance to change might be higher for ERIS than for drones, which primarily support the gathering of data while ERIS have a direct influence on critical decisions. Accordingly, reliability and timing constraints were uttered more prominently for ERIS than for UAVs.

Table 4.4 Comparison of ERIS and UAVs

	Factor	% ERIS	% UAVs
Pos.	Informational advantage	67	100
	Time advantage	38	57
Negative	Costs	52	62
	Training effort	38	57
	Personnel effort	29	67
	Limited range of application	14	57
	Maintenance / updating effort	14	48
	Organizational effort	14	48
	Resistance to change	43	14
	Decision-making complexity	52	5
	Information overload	33	10
Require-ments	Simplicity	81	81
	Robustness	33	81
	Reliability	57	29
	Legal issues / privacy	24	48
	Time restriction	24	5

The results of our study corroborate and explain findings of a quantitative study that was recently conducted to examine the potential and the diffusion of emerging FITs [23]. That study showed that ERIS were both more widespread in use and perceived to have a greater potential to expedite the emergency response process than UAVs. The results of our study furthermore uncover the reasons behind these perceptions.

We also found indications that the attitude towards FITs might be influenced by resistance to change, which was mentioned for both technologies (Table 4.4). Obviously, firefighters are consciously reluctant to change established practices that have proven to be reliable. To some extent, this might explain why the FITs generally were viewed rather skeptically and the frequency of negative factors was higher than that of positive factors.

Altogether, the results indicate that introducing innovative FITs is a potentially complex topic. Even aspects which are perceived as beneficial at first might ultimately result in a drawback. For example, the most frequently stated positive factor of both ERIS and

UAVs was an informational advantage. At the same time, however, it was feared that this advantage could lead to an information overload or raise the decision-making complexity. This shows that the design of innovative FITs requires a high amount of user involvement. A thorough evaluation by the users appears to be important to ensure that the technology will indeed support the firefighters during their work in the aspired way.

4.4.4 Implications

The provided insights into the potential of ERIS and UAVs have implications for academia and practice. Regarding academia, we provide a multifaceted overview of the benefits and risks that affect the potential acceptance of ERIS and UAVs. Next to that, we also identified requirements that the surveyed technologies have to fulfill in order to be usable in a practical setting. From a theoretical perspective, our results provide an initial set of acceptance factors for FITs. These factors can be used to evaluate the acceptance of FITs in more detail in quantitative studies. They furthermore contribute to the building of acceptance theories in this field. To arrive at a more general theory, future research will have to extend the amount of investigated FITs and to consolidate the identified factors, though. Next, the possible influence of command levels and FD types on the assessment of FITs should be investigated. A quantitative study could furthermore provide insights into the relative influence of the factors in comparison to each other, for instance by using path analyses or related methods.

Regarding practice, our work particularly has implications for FDs and FIT developers. The identified factors provide a means to assist FDs in contemplating the right questions when deciding on the acquisition of a FIT. For developers of FITs, our results can be employed as an instrument to evaluate their products and better adapt them to the needs of the FDs. In this context, the identified requirements might be of particular interest because they describe how the FITs ought to be designed to be more compatible to the way firefighters work.

4.4.5 Limitations

We have taken several precautions to ensure the validity of our results. To obtain comparable, unbiased data, we decided to conduct semi-structured interviews. By interviewing experts from different command levels, FD types, and regions, we tried to obtain a representative data set. During the coding stage, the team furthermore discussed the emerging codes repeatedly. Since the results stem from an analysis of qualitative data, they only constitute well-grounded assumptions, however. Ideally, they should be verified quantitatively. So far, we furthermore interviewed experts from German FDs only. Since the organization and the processes of FDs may differ, the results should not straightforwardly be transferred to other countries. The generalizability of our results instead remains to be validated, for instance by interviewing experts from different countries. Finally, we discussed only two FITs. Although the results of our study provide indications for relevant acceptance factors, they are not general enough to formulate a universal theory on the acceptance of FITs. To achieve such a goal, other types of FITs have to be examined as well.

At this stage, we also cannot yet say much about the relative influence that the identified factors have on the acceptance. The relative influence of the factors has to be analyzed more closely in quantitative studies. It may also vary depending on the scenario, in which a FIT is used. When responding to a major disaster, for instance, other factors might be important than during daily operations. Generally, researchers should also examine the practices of firefighters more intensively and formulate requirements and needs for FITs based on the identified use cases. Such endeavors could lead to further insights into desirable properties of FITs and complement the results of our study, which focused on evaluating FITs and hence is somewhat technology-centric in nature, too.

4.5 Conclusion

Although it is repeatedly proposed in literature to equip firefighters with innovative technologies, the practical potential of emerging FITs hardly has been in the focus of research. To contribute to the closure of this research gap, we presented the results of a qualitative study, in which we interviewed 21 German firefighters about the practical potential of ERIS und UAVs.

From the gathered data, we obtained rich insights into the aspects that facilitate or hinder the adoption of these FITs as well as the existing requirements. The results of our study hence provide a unique overview of factors that determine the acceptance of ERIS and UAVs. In contrast to the expectations, the practitioners' attitude towards these technologies appeared to be rather cautious. In particular, we encountered several concerns and constraints that can outweigh the expected benefits in practice if they are not managed carefully during the design and introduction of novel FITs.

While the presented results specifically apply to ERIS and UAVs, they call for an in-depth analysis and a more systematic consideration of acceptance-related factors when designing new FITs in general. It appears that emerging technologies are often arbitrarily used as a means to create new functionalities for emergency responders because of their desirable features. Such technology-driven approaches run a risk of neglecting the observation that information technologies are delicate artifacts for emergency responders, for which tight constraints and requirements have to be met.

To provide further insights into this particular field of application, future studies ought to verify our results in other regions and contexts. They should also evaluate the practical potential of additional emerging FITs such as unmanned ground vehicles or intelligent protective clothing. Based on such additional findings, it might be conceivable to derive a theory that explains the acceptance of emerging FITs. We hope that the results of our study can be a step into this direction.

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5 Paper IV: Interview Study on FIT Acceptance Factors – Final Results

Table 5.1 Fact sheet paper IV

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

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

5.1 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 5.2, we describe the background of our study and discuss related work in order to emphasize the existing research gap. In section 5.3, we describe our research approach in more detail. The results of our study are presented in section 5.4. In section 5.5, 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 5.6.

5.2 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.

5.2.1 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. Figure 5.1 to Figure 5.3 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.

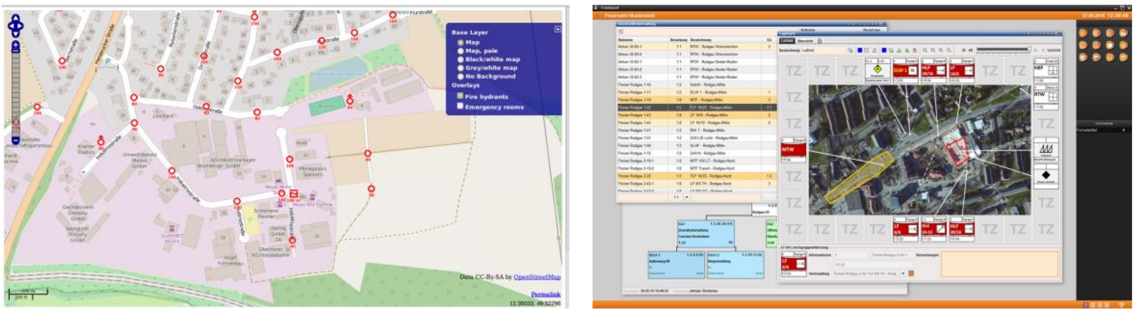

Figure 5.1 Illustrations for T1 and T2:
digital hydrant plan “OpenFireMap” (left side [1]) and on-site ERIS “fireboard” (right side[2])

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).

Figure 5.2 Examples for T3 and T4:
UAV “Phantom 3” (left side[3]), UGVs “taurob tracker” (middle[4]) and “LUF 60” (right side[5])

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

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

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 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).

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.

Figure 5.3 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))

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

[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

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.

5.2.2 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 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.

5.2.3 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 them (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 5.4).

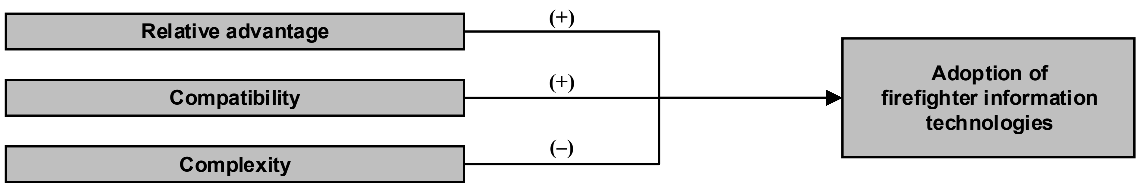

Figure 5.4 Consolidated model of generic acceptance factors

5.3 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 5.2.1. 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.

5.4 Results

We structure the presentation of the results according to the seven technologies (T1-T7), which we introduced in section 5.2.1. 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 5.5.2. 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.

5.4.1 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 5.2). 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).

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).

Table 5.2 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

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).

5.4.2 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 5.3). 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 ER-ISs 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 5.3 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).

5.4.3 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 5.4). 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 5.4 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).

5.4.4 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 5.5). 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 5.5 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.

5.4.5 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 5.6). 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 5.6 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).

5.4.6 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 5.7). 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 5.7 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).

5.4.7 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 5.8). 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).

Table 5.8 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

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).

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).

5.5 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 5.4 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 5.4.

5.5.1 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.

To visually examine the attitudes towards the technologies, we depict the results in Figure 5.5. 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.

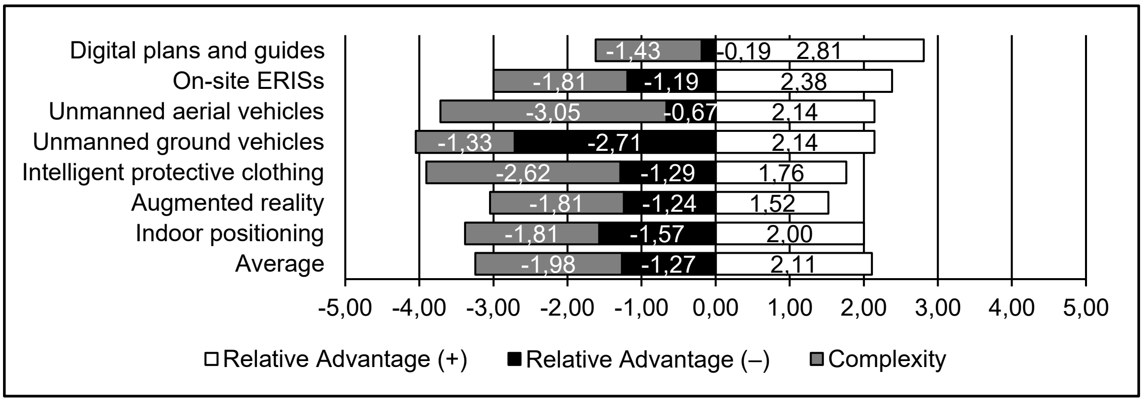

Figure 5.5 Average factor frequencies per interviewee grouped by factor category

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:

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

The differing attitude towards the technologies becomes obvious in Table 5.9. 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.

Table 5.9 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

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.

5.5.2 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 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).

Table 5.2 to Table 5.8) 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.

5.5.3 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 5.10. 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 5.10, four factors comply with these requirements.

Table 5.10 Most frequently highlighted acceptance factors (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 (+)	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 5.5.1), 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 5.6 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.

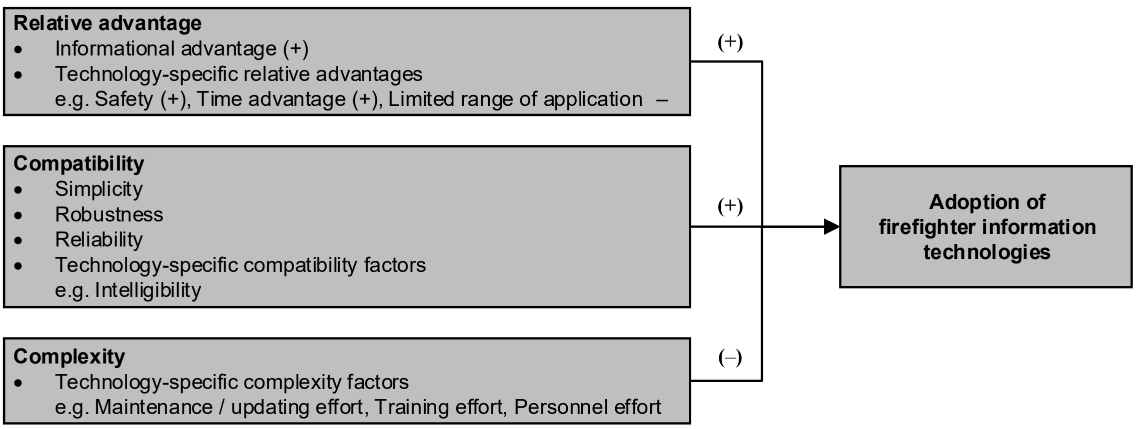

Figure 5.6 Theory on the acceptance of FITs

5.5.4 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 5.6 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.

5.5.5 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 5.2.3). 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.

5.6 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.

5.7 Appendix

Table 5.11 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 protective 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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6 Paper V: Laboratory Experiment on Information Format – Setup

Table 6.1 Fact sheet paper V

Fact	Description
Title	Analyzing the Potential of Graphical Building Information for Emergency Responses: Toward a controlled Experiment
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Analyzing the Potential of Graphical Building Information for Emergency Responses: Toward a controlled Experiment

Abstract. *Improving the efficacy of emergency agencies like fire departments is receiving increased attention in academia and practice. In recent times, novel firefighter information technologies like digital plans and augmented reality systems have been proposed to better support the work of firefighters. These technologies, however, mostly result from technology-driven approaches and run a risk of failing the actual needs of the users. In this paper, we present the design of a controlled study to more rigorously examine firefighters' needs for information. Considering the search and rescue task during a building fire as an exemplary case, we first identify informational potentials to support the work on site. Based on theories of situation awareness and cognitive science, we then hypothesize that graphical building information can facilitate the search and rescue task. To examine the hypotheses, we propose the design of a controlled, yet realistic laboratory experiment that was developed in cooperation with a Bavarian state firefighting academy. During the experiment, firefighter squads will be provided with different kinds of building information and evaluated with respect to their task performance. The results of the experiment are expected to provide implications for the design of novel firefighter information technologies and firefighters' working routines.*

Keywords: Firefighter information technologies, Situation awareness, Cognitive science, Laboratory experiment.

6.1 Introduction

As a response to significant disasters such as terrorist attacks, earthquakes, hurricane strikes, or wildfires, improving the effectiveness of emergency responses is receiving increased attention in academia and practice (Lee et al., 2017, Pfeifer et al., 2004). During the last years, multiple strategies have been developed to enhance the organization of fire and rescue departments and to optimize their response processes. One of those strategies is to equip firefighters with new and emerging information technologies in order to increase their situation awareness and hence support the making of critical context-dependent decisions on site. Innovative information technologies such as digital plans (Johnson, 2005, Takahagi et al., 2015), intelligent protective clothing (Smart@fire, 2016, Salim et al., 2014), augmented reality (Klann and Geissler, 2012, Bretschneider et al., 2006), on-site emergency response information systems (Yang et al., 2009, Ha, 2012), or unmanned aerial vehicles (van Persie et al., 2011, Barrado et al., 2010) are supposed to help gathering, sharing, and presenting real-time information about the emergency site. Augmented with such novel information technologies, firefighters should theoretically be able to better understand the situation and the capabilities of available resources.

Looking at the assessment of those novel information technologies in practice, however, a recent study showed that most of them are perceived rather skeptically and are hardly disseminated (Schlauderer et al., 2016). One supposed reason for this is that the use of novel information technologies is mainly proposed based on their innovative features and the presumably resulting functional potential to support emergency response processes. Such mainly technology-driven approaches tend to neglect the specific nature of emergency responses, which impose tight usage constraints. Although information technologies are hence delicate artifacts for firefighters, literature hardly discusses if and under which circumstances a novel information technology might be viewed as beneficial by them. To the best of our knowledge, the only recent study addressing this issue was done by Weidinger et al. (2017). Among others, this study identified potential key factors for the acceptance of novel firefighter information technologies, and confirmed the skeptical assessment of such technologies in practice.

To ensure that firefighter information technologies indeed meet the needs of the intended users, it appears thus necessary to investigate more rigorously, (i) which kinds of information are effective in enhancing the situation awareness of firefighters and (ii) how technologies should be designed to deliver the respective information in an effective and efficient manner. With the study proposed in the paper at hand, we intend to contribute to the closure of this literature gap. Focusing on the provisioning of information about a building on fire and the location of a victim inside, which has been chosen as the study object because the search and rescue of victims is the subject of typical daily operations, we examine the following research questions: *"Can the presentation of a graphical plan of a building and the location of a victim during the mission briefing improve firefighters' search and rescue tasks compared to a verbal description? Does the continuous availability of a graphical plan during the mission further improve firefighters' search and rescue tasks?"* To achieve rigorous results, we intend to conduct a controlled experiment, in which we provide firefighter squads with information about the building and the victim inside in different formats. The experiment shall be conducted in cooperation with a Bavarian state firefighting academy, which will make available a building that has been designed for fire training purposes and resembles a typical small apartment house in Germany. The experiment design is guided by findings from cognitive science, which imply that in many contexts graphical information can be better recalled and comprehended than verbal information, and that continuous instead of punctual access to such information can additionally reduce the risk of cognitive overload.

The results of our study provide indications in how far graphical building information is effective in enhancing the situation awareness during search and rescue operations. As shown in Figure 6.1, our proposed study constitutes only the first step in a larger research endeavor. The results of our study are supposed to provide an empirically grounded basis for the design of corresponding information technologies. Depending on the results, the information is supposed to be implemented in digital plans, on-site emergency response information systems (that could be used to present the information punctually during mission briefings), or augmented reality devices (that could be used to present the information continuously during the mission). The results gathered in the emergency response domain might also complement findings on the effectiveness of different kinds of information from the field of cognitive science. So far, it has not been investigated yet in how far existing findings also apply to emergency response processes, which – amongst others – differ with respect to the level of stress, the timing constraints, the margin for error, and the level of certainty.

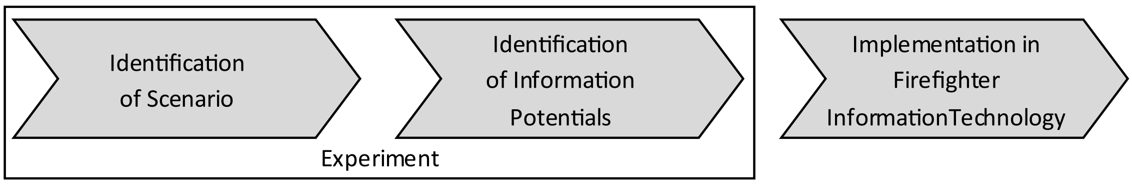

Figure 6.1 Research Agenda

We proceed as follows: in section 6.2, we develop the hypotheses and the research model that underlie the design of our experiment. In section 6.3, we present the design of the experiment in detail. The expected contributions to academia and practice are discussed in section 6.4.

6.2 Hypotheses and Research Model

In this section, we elaborate on the theoretical background of our study. First, we develop preliminary assumptions from theories of different research disciplines in section 6.2.1. In section 6.2.2 we deduce our research hypotheses and build a research model that will be tested in our experiment.

6.2.1 Development of Hypotheses

Firefighters face the challenge of making time-critical decisions in a dynamic environment. Supporting firefighters' work in such a context considerably depends on providing sufficient information about the situation. Based on such information, firefighters can gain so-called situation awareness (Endsley, 1995, Endsley, 2000). Considering situation awareness as an abstract construct, it is applicable and relevant to various domains, in which critical decisions must be made. Besides soldiers or pilots, it also applies to emergency responders like firefighters. The construct is described as the result of a three-level process from the perception of environmental elements to the comprehension of their meaning to their projection in the near future (Endsley, 1995). In the perception phase, one must perceive the characteristics of the relevant elements such as the status, attributes, and dynamics. In the comprehension phase the perceived, disjoint elements must be assembled in the sense of creating patterns to develop a holistic understanding of the environment. Finally, based on perception and comprehension, it is possible to make predictions in the short term about the elements in the environment. All levels, especially perception, rely on effective information in terms of quantity and quality. Amongst others, information technologies – in our context firefighter information technologies – can deliver such information. However, research on situation awareness in the emergency management domain mainly concentrates on higher levels of severity, e.g. the handling of extraordinary disasters or the coordination of multiple agencies (Pagotto and O'Donnell, 2012, Ley et al., 2012). Situation awareness in the daily routines of firefighters, as we want to examine it in our experiment, has hardly been in the focus of research. To bridge this gap, we intend to address the problem of providing information in appropriate quantity and quality in everyday-scenarios. Based on this information, the different levels of situation awareness can be achieved, potentially resulting in higher performance and better decisions.

To identify how this information can be provided, we studied potentially relevant concepts of cognitive science. We wanted to identify potentials for effectively presenting information to humans in a general context. Various studies in this field show that graphical information can be superior to other forms of presentation, such as written words or natural language. On the one hand, graphical information can be better recalled than written words (Kaplan et al., 1968, Paivio et al., 1968, Sampson, 1970). A reason for this is the different encoding of words and pictures. According to Kaplan et al. (1968), pictures are double-coded (i.e., both verbally and graphically), which leads to better recallability due to the association with words. On the other hand, Larkin and Simon (1987) show that diagrams enable better comprehension because of the support of numerous perceptual interferences and the grouping of related information. Furthermore, the combination of graphical and verbal information seems to be beneficial (Mousavi et al., 1995). This especially applies to inexperienced persons (Mayer and Sims, 1994). Firefighters who do not have any previous knowledge about the building they are operating in can be characterized as such inexperienced persons.

Altogether, while those insights are well grounded in the field of cognitive science, it remains unclear if they also hold in the special domain of firefighters. The fact that a person can better recall graphical information in an unstressed, quiet environment might not be straightforwardly transferable to the more chaotic scenario of a burning house with lives at stake. Such scenarios are characterized by high emotional strain due to the urgency of the situation. It thus remains unproven if graphical building information will support firefighters in their search and rescue tasks. If such graphical information will still have a positive influence in this special scenario, will be the first question to be answered in our experiment. We assume that Firefighters provided with graphical instead of only verbal building information will be able to perform their search and rescue task better.

Because of the before-mentioned special characteristics of the firefighter domain, there is an increased danger of so-called cognitive overload (Mayer and Roxana, 2003). This means that a person's cognitive abilities do not suffice to process the given information. Visualizing the hectic conditions of a critical emergency with countless environmental impressions, firefighters could more quickly experience such a cognitive overload. In this case, they might not be able to memorize the information that was given to them at a certain point in time. Because of this, we further assume that having continuous access to the graphical building information - which represents a higher degree of graphical information - might be better than having to memorize it. Consequently, we hypothesize that firefighters provided with continuous instead of only punctual graphical building information will be able to perform the task better.

6.2.2 Research Model

Building upon the theoretical background, we propose a research model to summarize our hypotheses. In particular, the research model helps us to examine to what extent the provisioning of punctual or continuous graphical information supports the firefighters in fulfilling their task. Referring to our assumptions, we expect that the use of a graphical notation will increase the usability of the provided information for firefighters. In general, usability is determined by three different aspects (Frøkjær et al., 2000, ISO/IEC, 1998):

the effectiveness, i.e. the accuracy with which a task is fulfilled, the efficiency, i.e. the effectiveness in relation to the effort needed to complete a task, and the satisfaction, i.e. the users' comfort when performing a task. Accordingly, we formulate our hypotheses as follows:

- **H_1**: Firefighters provided with a higher degree of graphical building information will be able to perform the task more accurately.
- **H_2**: Firefighters provided with a higher degree of graphical building information will need less time to perform the task accurately.
- **H_3**: Firefighters provided with a higher degree of graphical building information will be more satisfied while performing the task.

Figure 6.2 summarizes our research model. In the following, we provide more information on how we measure the model constructs, the design of our experiment and information about the participants.

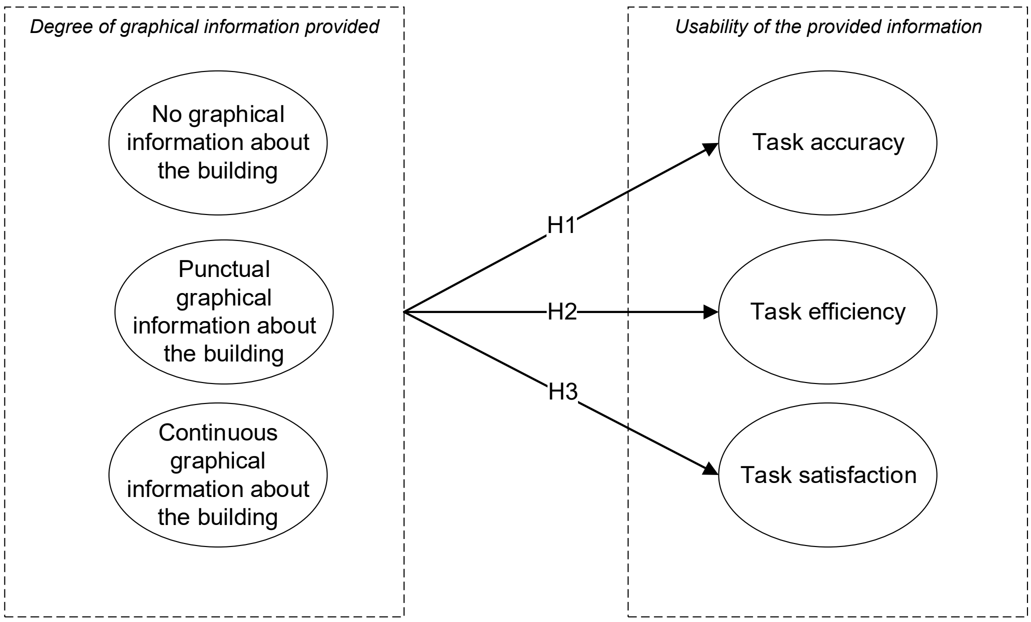

Figure 6.2 Research model

6.3 Experimental Design

To examine the hypotheses, we intend to conduct a controlled experiment with several firefighters as subjects. Hypotheses H_1 and H_2 will be tested in the experiment itself. The following section describes this in detail. Hypothesis H_3 will be tested in interviews that we are going to conduct following the experiment. Those are explained in section 6.3.2.

6.3.1 Controlled Laboratory Experiment

The experiment will take place at the Bavarian state firefighting academy in Würzburg. In this academy, voluntary as well as professional firefighters from all over the state Bavaria are trained in several kinds of firefighter tasks. Using the training facilities of the academy, we will be able to conduct a controlled, yet realistic laboratory experiment. For the design of the experiment, we are following the guidelines given by Cox and Reid (2000).

The experimental scenario was developed in a roundtable session with instructors of the firefighting academy in late 2017. A squad of firefighters will respond to a simulated apartment fire on the second floor of a multi-level building. The building will be represented by the fire training building of the academy (cf. Figure 6.3). The building emulates a typical residential building with multiple apartments. With remotely controlled gas-fires and fog machines simulating smoke inside the building, the scenario will be designed like a real-world apartment fire. As the task, we selected the search and rescue of a missing person (represented by a dummy) from the apartment. For our experiment, the responding squads will consist of one squad leader and a team of two firefighters. The squad leader commands the task. (S)he will first explore the incident site and then brief the team. The team will be ordered to enter the building, search, and rescue the dummy from a certain room inside the building. Other members that are part of a real-world squad (e.g. the operator of the fire engine) will not be considered in the experiment, which constitutes the virtually only unrealistic element of our experiment.

Figure 6.3 Fire training building (cf. http://www.sfs-w.de)

The subjects for the experiment will be retrieved from participants of firefighting courses at the academy and composed to squads. The number of participants in that realistic courses is very limited and each Bavarian fire department is allowed to send only a small number of firefighters to such courses each year. This itself results in highly mixed and randomized groups of subjects in the first place. To examine our hypotheses, each squad will be randomly assigned to one of three groups which will all be of equal size (Cox and Reid, 2000). $\mathbf{G_0}$ is the control group. Teams of this group will receive a verbal briefing by their squad leader without any graphical resources. The command will look like this: "There's an apartment fire on the second floor, one person is missing in the third room on the right-hand side. Your team is going in for search and rescue with the first hose line to the second floor via the main staircase." $\mathbf{G_1}$ is the first treatment group. The treatment received by this group is a sketch-map of the building that the squad leader will draw and then use as an additional graphical resource to brief the team besides the verbal command. However, the team members will only see this map during the briefing and must not take it along when entering the building. Therefore, they will only have punctual access to the graphical information. $\mathbf{G_2}$ is the second treatment group. Like in G_1, the treatment received by this group is a sketch-map of the building in addition to the verbal command. Unlike G_1, however, the teams of G_2 will not only be briefed using this map but will also be allowed to take it with them when entering the building. Therefore, they will have continuous access to the graphical information. The map for both G_1 and G_2 will be drawn on paper. For G_2, it will be wrapped in a heat-resistant packaging. As discussed later (cf. section 6.4), the real-world application of especially the continuous building information will call for the employment of information technology. However, since we want to measure the effects of the information itself in a first step, we use paper as a simple (yet effective) approximation.

To examine H_1, we will compare the task completion rates of the three groups. A task is rated as complete if the team could find the dummy and retrieve it from the building. If the punctual graphical building information increases the task accuracy, the percentage of successful tasks in G_1 will exceed that of G_0. If the continuous information further increases the task accuracy, the completion rate of G_2 will exceed those of G_0 and G_1.

For each squad, we are going to take the time of four different activities. $\mathbf{t_{recon}}$ is the time needed for the squad leader to explore the incident site. During this period, (s)he will try to get a comprehensive impression of the site by looking at the different sides of the building, questioning attendants, and so on. In G_1 and G_2 (s)he will also draw the sketch-map based on the gathered information during this period. $\mathbf{t_{brief}}$ is the time needed to brief the team. The squad leader will give the team a rough situation report and issue his/her commands. As pointed out above, the squad leader will have a sketch-map to support the verbal briefing in G_1 and G_2. In G_0 the briefing will be done verbally only. $\mathbf{t_{in}}$ is the time needed for the team to reach the dummy. This period will start with the team entering the building. The time will be taken once the team radios to the squad leader that they have reached their ordered destination and found the dummy. $\mathbf{t_{out}}$ is the time needed for the team to get out of the building together with the rescued dummy. This period will directly connect to the end of t_{in} and the time will be taken once both team members and the dummy have left the building.

Hypothesis H_2 will be tested by comparing the average times needed to complete the task between the three groups. If the punctual graphical building information indeed increases the task efficiency, the squads of G_1 will on average complete their tasks faster than those of G_0. If the continuous information further increases the task efficiency, the completion times of G_2 will be below those of both G_0 and G_1. Due to the partitioning into four periods, we will also be able to identify in which periods time advantages or disadvantages occur. Table 6.2 summarizes the experimental design.

Table 6.2 Summary of the experimental design

Groups	Time Measurements	Test of Hypotheses
G_0: verbal only information G_1: punctual graphical information G_2: continuous graphical information	t_{recon}: investigation (+drawing sketch map t_{brief}: briefing of the team t_{in}: finding the dummy in the apartment t_{out}: getting the dummy out of the building	H_1: task completion rate H_2: task completion time H_3: interviews (cf. 3.2)

As suggested by Cox and Reid (2000), we will take measures to ensure both internal and external validity of our experiment. To ensure internal validity, we want to make our treatments the only varying factor within the experiment. First, the chosen task allows us to control most surrounding conditions. The time needed to find and rescue the dummy will mostly depend on the teams' orientation capabilities inside the building. Those capabilities may be influenced by our treatments. Looking at other scenarios, there would be many more unknown factors. In a firefighting scenario, for example, the time to find and extinguish the fire would also depend on the teams' hose management, the extinguishing technique, and other factors. Next, the dummy, being the task destination, will be at the same position inside the same room for all teams. This way the length and complexity of the path toward it will be identical. As another measure, the participants will have no prior knowledge about the fire training building and the squads will be separated. This means that none of them will be allowed to watch other squads of the same or another group before its own task. Also, the squads will not know the building or its structure prior to the task. This way all squads will have identical previous knowledge upon entering their task and there will be no learning effect for the teams. Finally, to eliminate interference with our experiment, we will capture several statistical control variables. This will be done by means of interviews after the experiment (cf. 3.2). Several measures shall ensure the external validity of our experiment as well. As stated above, the experiment will be conducted in a fire training building. This building was specifically designed to represent real-world apartment fires in the most realistic way that is achievable under safe and controlled conditions. Several elements of a real-world apartment fire will be simulated during the experiment. Amongst others, there will be real flames from remotely controlled gas-fires, thick smoke from fog machines, and acoustic stimuli like crackling or screams from loudspeakers. Therefore, the overall situation will be comparable to the one in a real emergency. Besides the general situation, also the specific task is realistic. It was designed in a roundtable session with instructors of the academy and represents an every-day task for firefighters. Next, the task will be performed by firefighters that perform this kind of tasks in real operations, as well. The participants will come from both professional and voluntary fire departments from all over Bavaria. Therefore, there will be a great diversity among our subjects. This makes our results transferable to multiple types of departments and regions. Overall, we expect our results to be both internally and externally valid.

6.3.2 Interviews

Each squad will be interviewed shortly after they have conducted their task. The interviews will consist of two parts. In the first part, we are going to capture general and demographic information from the firefighters. We want to capture several attributes that might have an influence on their task performance besides our treatments. One factor might be the firefighters' experience in their job. We intend to estimate the experience by the number of years they have been working as a firefighter and by the average number of incidents they are responding to per year. Next, we want to ask the firefighters about the type of fire department they are working for. In fact, members of voluntary and professional fire departments perform virtually the same tasks in Germany. There might, however, be differences in the level of training. Finally, we are going to capture the age and gender of our subjects.

In the second part of the interviews, we intend to evaluate the task satisfaction of the participants, as it was mentioned in hypothesis H_3. Due to previous experiences with interviewing firefighters, we want to keep the evaluation as quickly and easily, as possible. As a suitable method to be employed in usability studies, we identified the After-Scenario Questionnaire (Lewis, 1991). This questionnaire consists of three items that we slightly adapted:

- Overall, I am satisfied with the ease of completing the tasks in this scenario
- Overall, I am satisfied with the amount of time it took to complete the tasks in this scenario
- Overall, I am satisfied with the supporting information when completing the tasks in this scenario

Each of the three items is supposed to be assessed by the firefighters on a seven-point scale ranging from 1 (strongly agree) to 7 (strongly disagree). There will also be "not applicable" points outside the scales.

Hypothesis H_3 can then be tested by comparing the firefighters' average assessments between the three groups. If the punctual graphical building information indeed increases the task satisfaction, the squads of G_1 will on average rate the three items more positively than the ones of G_0. If the continuous information further increases the task satisfaction, the average ratings of G_2 will be above the ones of both G_0 and G_1. We will also be able to identify possible differences between the three items.

6.4 Discussion and Outlook

To examine the usefulness of various kinds of building information in emergency response processes, we presented the design of a controlled laboratory experiment. Based on theories of situation awareness and findings from the cognitive science domain, we hypothesize that graphical building information will better support search and rescue tasks in burning buildings. The hypotheses were refined and summarized into a research model that we are going to evaluate in a controlled, yet realistic environment. On the basis of the experiment, we expect to identify how punctual and/or continuous graphical building information will increase firefighters' accuracy, efficiency, and satisfaction during search and rescue tasks in a burning building.

We expect the results of our study to have implications for academia and practice alike. For academia, our study creates several avenues for future research. If graphical building information is indeed found to better support firefighters, the corresponding information should be made available using appropriate information technologies. Among the currently discussed firefighter information technologies (Weidinger et al., 2017), two approaches seem to specifically suited for such a goal. Digital plans or on-site emergency response information systems might be a means to support punctual graphical building information during the mission briefing. The provisioning of continuous graphical building information will, however, require the employment of more intricate information technologies. First, the produced sketch-map would have to be copied in real-time. This way, not only each team member could take an instance with him/her, but the squad leader could also keep an instance for his/her duties on site. Second, to access the information inside a burning building, the used medium would have to withstand heat, water, and other influences. Outside a laboratory context, simple paper sheets as used in our experiment would probably not be durable enough to withstand such conditions. However, it would be conceivable to use augmented reality systems that can for example be installed inside the firefighters' breathing masks. This way the information would be protected from outside influences. As such technologies bring additional complexities and limitations with them, they should be evaluated in further experiments. In so doing, it is possible to differ between the effects coming from the underlying information itself (as they are examined in our proposed experiment) and the effects stemming from the use of the technology. As pointed out above, this will also be in the focus of our own future research. Besides the examined task of search and rescue in a burning house, the demand for information in other firefighter tasks could be examined using a similar procedure. From salvage operations in car accidents to forest fires, many scenarios exist, which ought to be analyzed for possible information needs of the users. Based on the results, technologies to provide these kinds of information can be developed and again tested. Such an approach might help to develop technologies that better fit the practical needs of firefighters than the ones resulting from a usually technology-driven approach.

As regards practice, we expect our results to provide an indication whether it is worth investing precious time to produce graphical information in time-critical situations. If the results show that there is an improvement of task accuracy and/or efficiency, firefighters should consider changing the common procedure of getting to work the fastest way possible, even with little information. Instead, it might be wiser to spend more time to improve situation awareness at the beginning of an operation in order to ensure its success. Using efficient information technologies, it could be tried to minimize the time needed to establish situation awareness as best as possible. If, on the other hand, our results show that graphical building information does not deliver significant advantages, this could be seen as a confirmation of the current approach on site. Either way, the experiment can sensitize the participating firefighters for possible advantages but also for disadvantages of additional information during an operation. This way they can be enabled to better assess information technologies that are supposed to support their work and identify those that truly hold this assumption.

Although we implemented several measures to ensure internal and external validity of our experiment, several limitations pertain to our study. First, we are going to provide graphical building information on paper in order to examine the original effects of the additional information. Providing it using a complex medium, such as a tablet computer, might possibly bias these effects. However, using paper-based information is not a reliable option in practice. Also, the experiment is designed to be as realistic as it is possible under controlled and safe conditions – it can, however, not capture all aspects of a real-life operation in every detail. Furthermore, with the search and rescue task in a burning building, we concentrate on a critical every-day, yet specific scenario. The results of our study can, therefore, not simply be transferred to other firefighter tasks.

As the next step of our ongoing research endeavor, we plan to conduct the experiment as described in the paper at hand. If the graphical building information will indeed support the participating firefighters, we plan to implement the information in different kinds of information technology and repeat the experiment using these technologies to provide the information and again examine the results.

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7 Paper VI: Laboratory Experiment on Information Format – Final Results

Table 7.1 Fact sheet paper VI

Fact	**Description**
Title	Analyzing the Potential of Graphical Building Information for Fire Emergency Responses: Findings from a Controlled Experiment
Authors	Julian Weidinger[1] julian.weidinger@uni-bamberg.de Sebastian Schlauderer[1] sebastian.schlauderer@uni-bamberg.de Sven Overhage[1] sven.overhage@uni-bamberg.de [1]University of Bamberg An der Weberei 5 96047 Bamberg, Germany
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Analyzing the Potential of Graphical Building Information for Fire Emergency Responses: Findings from a Controlled Experiment

Abstract. *To better support firefighters during emergency response processes, novel information technologies are frequently being presented in research and practice. While such approaches are often technology-driven in nature, we present a task-centered approach to identify the actual information demand during emergency response scenarios. As an important example, we examine the search and rescue task. Combining the theory of situation awareness with findings from cognitive science, we hypothesize that providing graphical information about the building and the location of victims increases firefighters' task performance in comparison to a verbal briefing. Findings from a controlled experiment that was developed in cooperation with a state firefighting academy show that such information might indeed facilitate the task performance. A continuous access to such information during the entire mission was found to be less effective, though. Our findings have implications for the development of novel information technologies and call for an adaption of current working routines.*

Keywords: Firefighter information technologies, Situation awareness, Cognitive Science, Laboratory experiment.

7.1 Introduction

Newly emerging firefighter information technologies (FITs) such as digital plans [1, 2], unmanned aerial vehicles [3, 4], on-site emergency response systems [5, 6], augmented reality devices [7, 8], or intelligent protective clothing [9, 10] open up novel opportunities to gather, process, and present real-time information about the site of a fire emergency. They are hence supposed to bear a significant potential to facilitate the making of context-dependent decisions and, accordingly, to support the emergency response process. Currently, however, novel FITs are developed and proposed mainly based on their innovative capabilities and the presumably resulting potential to support the emergency response process. Recent studies indicate that such technology-driven approaches run a risk to neglect the specific nature of emergency response processes and might miss the actual demand for information [11].

During emergency responses, firefighters make time-critical decisions in a dynamic environment. By improving the information base, new and emerging information technologies might facilitate the decision-making process. However, there also exist tight constraints, for instance with respect to the time and the margin for error. The provided information hence needs to be succinct, easy to process and straightforwardly understandable without distraction. To make sure that firefighter information technologies indeed meet the demand that exists on site, it appears thus necessary to investigate, (i) which kind of information is effective in enhancing the performance of firefighters during their operations and (ii) how information technologies should be designed to deliver the information adequately. Yet, so far literature hardly discusses under which circumstances (and subject to which task-specific requirements) novel FITs are viewed as beneficial by prospective users.

With the work at hand, we intend to contribute to the closure of this literature gap. Narrowing the scope, we focus on examining, which kind of information is effective in supporting the search and rescue task. This task was identified as an appropriate study object during a roundtable discussion with instructors of a firefighting academy for several reasons: first, the task frequently occurs during daily emergency responses. Second, firefighters typically suffer from an insufficient information basis during this task. Third, emerging FITs like digital plans and on-site emergency response systems are proposed in literature to better support this task (among others). In our study, we examine the following research questions: "Does an up-front presentation of a graphical building plan and the location of a victim during the mission briefing improve the search and rescue task compared to a verbal description? Does the continuous availability of a graphical plan during the mission further improve the task?"

To achieve rigorous results, we conducted a controlled experiment, in which 69 firefighter squads were provided with information about the building and the victim location in different formats and with different forms of availability. The experiment was conducted in cooperation with a Bavarian firefighting academy, which made available a building that has been designed for fire emergency response training purposes and resembles a typical small apartment house in Germany. The design of the experiment is informed by findings from cognitive science on the processing of information formats and on cognitive overload. The experiment results indicate in how far graphical building information is effective in enhancing typical fire emergency response operations. Accordingly, they provide an empirically grounded basis for the design of firefighter information technologies such as digital plans, on-site emergency response systems, or augmented reality devices, which shall make available such information to firefighters during the emergency response. As domains with high stress levels, strict timing constraints, and low margins for error hardly have been in the focus of research so far, the results of our study furthermore complement existing findings from cognitive sciences.

In section 7.2, we discuss the background of our study. Furthermore, we develop the hypotheses and the research model underlying the design of our experiment. In section 7.3, we describe the experiment design. Section 7.4 presents the obtained results. We discuss the results and the implications for academia and practice in section 7.5. In section 7.6, we conclude by summarizing the findings and outlining future research directions.

7.2 Background, Hypotheses, and Research Model

During fire emergency response operations, firefighters make time-critical decisions in highly dynamic situations. Because of the existing time constraints, they often must decide on a basis of insufficient information. Improving the information basis and increasing the so-called situation awareness is hence supposed to be a critical success factor to achieve better and/or quicker decisions [12, 13]. The theory of situation awareness can be applied to various domains, in which actors make time-critical decisions in stressful situations. Besides emergency responders like firefighters, it has also been applied to pilots and soldiers. Generally, situation awareness is established in a three-level process of perception, comprehension, and projection [12]. In the perception phase, the actor must capture all relevant aspects of the situation. In a simplified example, a firefighter would have to realize that there is smoke coming from an open window on the second floor or that the house door is closed. In the comprehension phase, the actor must try to connect the different aspects to build a holistic understanding of the situation. The firefighter would have to understand that there is a fire, which could be reached by breaking the door or using a ladder to reach the window. Finally, based on perception and comprehension, the actor can make projections about the near future. The firefighter could predict that the fire might spread to other rooms and could be reached faster through the window. All three levels of situation awareness demand qualitatively and quantitatively sufficient information. In this context, information technologies such as the FITs mentioned in the previous section can be an effective means to deliver this information. Looking at the research conducted on situation awareness in emergency response management, however, there is a strong focus on large-scale phenomena like the handling of extraordinary disasters or the coordination of multiple agencies [14, 15]. To our best knowledge, the theory has not yet been applied to study daily routines of firefighters such as search and rescue of victims.

7.2.1 Development of Hypotheses

To identify how information needs to be presented in such a scenario to increase situation awareness, we consulted relevant literature of cognitive science. Various studies in this field indicate that especially graphical information can be used to effectively and understandably provide information to humans. The graphical format often proved to be superior to other forms of presentation like natural language or written words. Generally, humans seem to better recall pictures and other graphical information than the identical information coded in words [16-18]. As an explanation for this, Kaplan, Kaplan and Sampson [16] showed that the human brain double-codes pictures (i.e., both verbally and visually). This mental connection between graphics and words enables people to better recall the information. A special form of graphical information are diagrams. Due to the support of numerous perceptual interferences and the grouping of related information, they can further improve comprehensibility [19]. Mousavi, Low and Sweller [20] showed that another improvement can be achieved by connecting the graphical information with corresponding verbal explanations. According to Mayer and Sims [21], these effects specifically apply to inexperienced persons. Since firefighters typically are not acquainted with the concrete situation and environmental conditions when responding to an emergency (in our scenario the apartment they will be operating in), they can also be characterized as inexperienced. Deducing from the above findings of cognitive science, we assume that firefighters with access to graphical information about a building shall be able to better recall this information during a mission. Accordingly, they should also be able to perform search and rescue tasks better. With our study, we apply the general findings of cognitive science to the practical and very special domain of firefighters. Firefighters typically work under high emotional stress and time pressure in chaotic situations. Yet, according to instructors of the firefighting academy who supported this study, the use of graphical information during responses has by now hardly been identified as a means to overcome these problems in practice. By applying existing findings of cognitive science to this special and comparably unexplored domain, we hence test (and might further increase) their general validity.

The specific characteristics of the firefighter domain, however, also imply a risk that firefighters' cognitive abilities might not suffice to process all information they are receiving. This problem is referred to as cognitive overload [22]. In an emergency, responders are confronted with countless environmental and emotional impressions that need to be processed. Once reaching the point of cognitive overload, they may not be able to completely perceive and memorize information like the graphical building plan examined in our study. For these reasons, we assume that making graphical information available continuously during the mission further enhances the task performance as the information would not have to be memorized but could be looked up when needed. We hypothesize that such a higher degree (of availability) of graphical information will have a positive effect on its usability and, accordingly, the task performance.

7.2.2 Research Model

To capture the background of our study more precisely, we integrate our assumptions into a research model. We postulate that different degrees of graphical information provide differing support for firefighters during their tasks. Particularly, we expect the different degrees of information to have an impact on their usability for firefighters. Usability as such can be further operationalized into three aspects: the effectiveness (i.e., the accuracy with which a task is fulfilled), the efficiency (i.e., the effectiveness in relation to the effort needed to complete a task), and the satisfaction (i.e., the users' comfort while performing a task) [23, 24]. Following this definition, we concretize our three hypotheses as follows (the resulting research model is summarized in Figure 7.1):

- **H_1**: Firefighters provided with a higher degree of graphical building information will be able to perform the task more accurately.
- **H_2**: Firefighters provided with a higher degree of graphical building information will need less time to perform the task accurately.
- **H_3**: Firefighters provided with a higher degree of graphical building information will be more satisfied while performing the task.

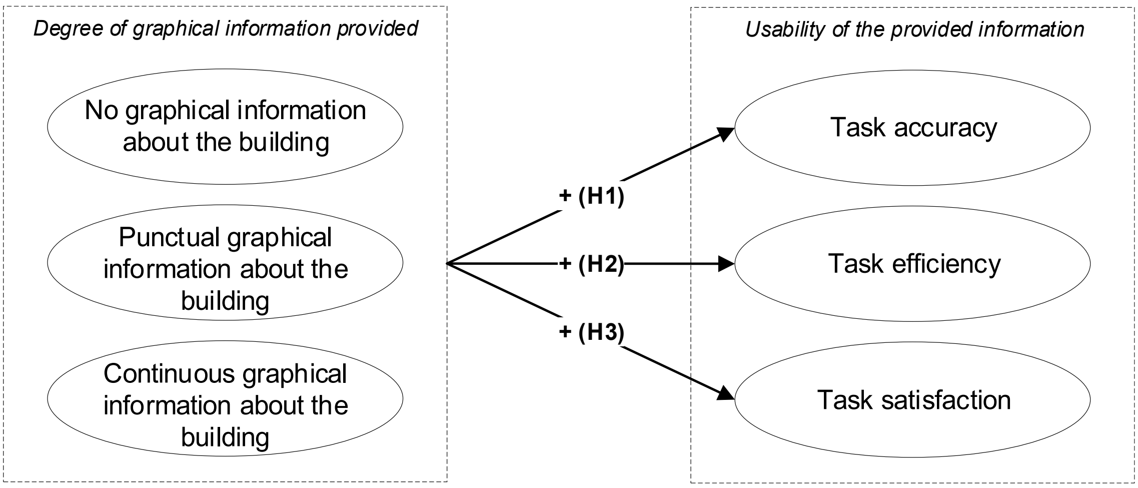

Figure 7.1 Research model

7.3 Research Procedure

To examine H_1-H_3, we conducted a controlled laboratory experiment. Next, we present the design of this experiment to evaluate H_1 and H_2. Thereafter, we describe the questionnaire that accompanied the experiment and was used to examine H_3.

7.3.1 Controlled Laboratory Experiment

Our experiment was developed and conducted in cooperation with the Bavarian state firefighting academy in Würzburg, Germany. In this academy, firefighters from all over Bavaria are trained in several tasks like salvage rescue, firefighting, and incident command. By means of the academy's specialized training facilities, we were able to simulate a realistic scenario under safe conditions. Despite providing a realistic scenario, the environment nevertheless allowed us to control surrounding factors in order to conduct a laboratory experiment following the guidelines given by Cox and Reid [25].

The experimental setting was developed in a collaboration with a group of instructors of the firefighting academy. Beginning with a roundtable session in late 2017, we identified various everyday tasks in which firefighters typically suffer from a lack of information. As one of the most critical of these scenarios, the instructors introduced the search and rescue of a victim during an apartment or house fire. Based on this scenario, we developed our concrete experiment in a second roundtable session.

In our experiment, a squad of firefighters responded to an apartment fire in the basement of a two-story building. The building was represented by the academy's fire training building (cf. Figure 7.2). It emulates a typical residential building and was specifically designed to simulate apartment fires by means of remotely controlled gas-fires and simulated smoke from fog machines. Inside the burning apartment, a life-size dummy depicted a missing, unconscious person. The squad responding to the apartment fire consisted of a squad leader and a team of two firefighters. The squad leader commanded the response by first investigating the scene and then briefing the team. In the experiment, the squad leader was represented by a member of our research team. In so doing, we could control the equality of the briefings. The team's performance, consequently, was not influenced by the abilities of its squad leader but only by the received information. The firefighter team got a briefing on the situation and was then commanded to enter the burning apartment to search and rescue the missing person. The positions of the team were taken by random firefighters wearing self-contained breathing apparatuses (SCBA). Other positions of a real-life squad like the operator of the fire engine and a second team of firefighters on standby have not been included in the experiment, because they would have had no connection to our experimental interventions.

The subjects who acted as team members were retrieved from firefighting courses, which took place from March to July 2018. Due to capacity restrictions, places in those courses are limited and distributed among all Bavarian fire departments. This resulted in a diverse, random sample of subjects. Each team consisted of two subjects and was randomly assigned to one of three equally sized groups [25]: G_0, G_1, and G_2. **G_0** was the control group. Teams of this group received a verbal briefing and command without any graphical resources, which represents the current state of the art for such rescue missions. The teams were briefed with the following standardized phrase: “There’s an apartment fire in the basement, one person is missing but we know their presumable location. Heading down the stairs, there are four doors: one ahead, two on your left, and one at your left back. To reach the person, you must take the farer left door. Then cross the following corridor straight ahead. In the room after the corridor, you must go to the right around a room divider. There, you should find the person. Intervention team for search and rescue with the first hose line to the basement via the stairs, go!”

G_1 was the first treatment group. As treatment, teams of this group received punctual access to a sketch-map of the apartment during the briefing. As shown in Figure 7.2, the map contained the apartment’s layout including stairs, walls, doors and the victim’s location. The squad leader briefed them with the identical phrase that was also used in the control group. This time, however, he visualized the verbal information in the map, for example by pointing toward the doors the team was supposed to go through. After the briefing, the team entered the building without any further access to the sketch-map.

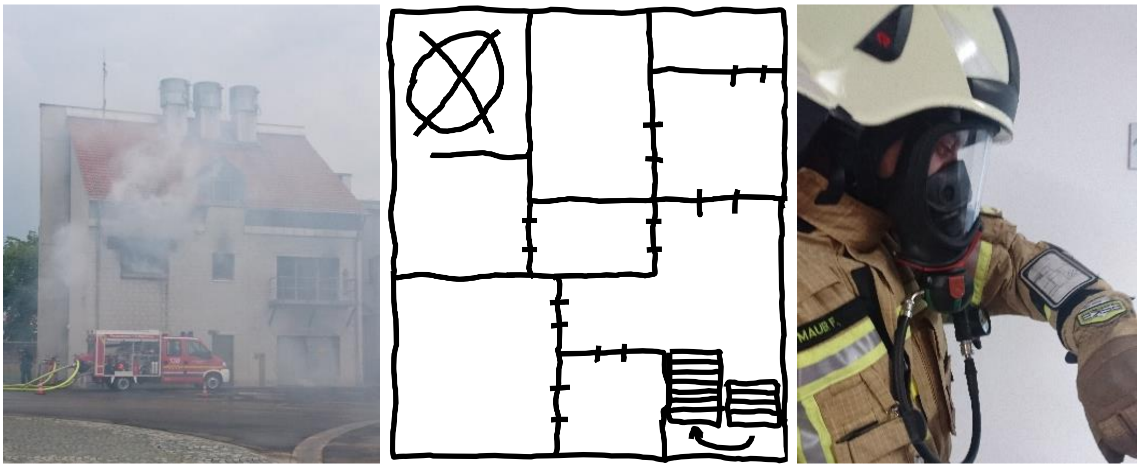

Figure 7.2 Experiment Setup
Fire training building (left), sketch-map (middle), and small-scale copy on the team leader’s sleeve for continuous access (right)

G_2 was the second treatment group. The treatment received by teams of this group was continuous access to the before-mentioned sketch-map. Like the teams of G_1, they were briefed with the standardized phrase supported by the graphical information of the map. In addition, they also took the graphical information with them during the rescue mission. To simulate an information device, they were equipped with a small-scale copy of the sketch-map that was wrapped in a protective cover and fastened on the team leader's sleeve (cf. Figure 7.2). As discussed in section 7.5, the real-world application of our treatments – especially the continuous access to the map – will inevitably require the use of information technology. As an approximation to measure the resulting effects, however, we decided to stick with the paper-based solution.

To examine **H_1**, we compared the average task completion rates of the three groups. A task was rated as completed if the team could find the dummy and bring it outside. To examine **H_2**, we took the time the firefighters needed to complete the task. Precisely, we took the time the teams needed to find the dummy inside the apartment. The period began once the first team member crossed the door sill and ended once the first team member reached the dummy. Since there was no visual contact with the team, an instructor (who was following the team for security reasons anyway) radioed to the squad leader once the dummy had been found. By comparing the average times needed to find the dummy for the three groups (task completion time), we could test **H_2**. Finally, to examine **H_3**, we captured the task satisfaction of the participants by means of a questionnaire as described in the next subsection. Table 7.2 summarizes the experimental design.

Table 7.2 Summary of the different groups and summary of the tests of Hypotheses

Groups	*Test of Hypotheses*
G_0: verbal only information	**H_1**: task completion rate
G_1: verbal + punctual graphical information	**H_2**: task completion time
G_2: verbal + continuous graphical information	**H_3**: After-Scenario Questionnaire (cf. 3.2)

Following the requirements of a laboratory experiment, we took several measures to ensure the internal and external validity of our results [25]. Regarding internal validity, we tried to make our treatments the only varying factor between the different groups. Consequently, we controlled the surrounding conditions as far as possible. First, all teams had to perform the identical task. The dummy had been positioned at the identical spot in the same room for all teams. The doors on the way were equally closed, and the rooms had been equally filled with smoke. All in all, the briefing at the beginning of the task was the only varying factor between the groups.

Also, the search and rescue task was chosen with the goal to ensure internal validity in mind. In a firefighting task, for example, several other factors like hose management and extinguishing technique might have affected the task completion time much more than our treatments. In our scenario, on the other hand, the teams' orientation abilities inside the apartment were the major determinant for how long it took to find the dummy. As another measure, we ensured that the participants had no prior knowledge of the apartment or the task. The teams were separated and not allowed to watch other teams during their briefings or the tasks itself. This way, we could rule out learning effects and keep the conditions equal for all teams. Finally, we captured several control variables like the firefighters' experience, age, and other in the questionnaire to rule out differences based on those factors (cf. Section 7.3.2).

We maximized external validity mainly by choosing the fire training building as a realistic site. Since it was specifically designed to simulate apartment fires, the task could be reproduced as realistically as possible under safe and controlled conditions. Remotely controlled gas-fires provided heat and real flames. Multiple fog machines simulated realistic smoke and limited the sight to only a few centimeters. Loudspeakers played acoustic stimuli like the crackling of the fire. All in all, the surrounding conditions of the experiment were closely comparable to those of a real-world emergency. Besides, the scenario itself was developed in roundtable sessions with instructors of the firefighting academy and characterized as a realistic everyday scenario for firefighters. Furthermore, the sample of subjects contributed to ensuring external validity. All participants were firefighters that also conduct this kind of tasks in real operations. We hence assume that our results are transferable to comparable real-life emergency operations of firefighters.

7.3.2 After Scenario Questionnaire

To capture feedback from our participants and assess their task satisfaction, we used a questionnaire. In its first part, we asked about general and demographic information. This way, we wanted to record several control variables that could have an influence on our results. To assess the firefighters' experience, we asked both team members for how long they have been members of a fire department and for how long they have been trained to wear SCBA. Besides that, we captured the average number of emergencies and SCBA-operations they are responding to per year. Furthermore, we asked for the command level they are normally working in and the type of fire department they are working for. Finally, the age and gender of our participants were captured. This first part of the questionnaire was filled out prior to the task.

In the second part of the questionnaire, we wanted to assess the participants' task satisfaction to examine **H3**. This part was filled out by the firefighters right after completing their task. Due to previous experiences in questioning firefighters in or shortly after stressful situations, we wanted to keep this part as short and simple as possible. Consequently, we decided to use the easy, yet well-established After-Scenario Questionnaire (ASQ) [26]. The ASQ consists of three items that we slightly adapted:

- Overall, I am satisfied with the ease of completing the task in this scenario
- Overall, I am satisfied with how long it took to complete the task in this scenario
- Overall, I am satisfied with the available supporting information when completing the task in this scenario

All three items had to be rated by the teams on a seven-point scale ranging from 1 (strongly disagree) to 7 (strongly agree), as well as an n/a-point. To gather additional qualitative feedback, we included open-ended questions about what the firefighters perceived as positive and negative about the available information.

7.4 Results

During the experiment, we observed the performance of 150 firefighters that were composed to 75 teams. We could, however, not use all 75 observations for various reasons. For example, one team already knew the fire training building from a previous visit, another accidentally activated an emergency shutdown button, and one team was interrupted by a technical fault. All in all, we had to delete six observations from our initial sample, which resulted in an adjusted sample of 69 teams. Those remaining teams were equally distributed among the three groups, resulting in 23 observations per group.

Regarding our control variables, the participants were 27 years old on average, mainly male (>98%), have been members of a fire department for 12 years, and trained to wear SCBA for 7 years. On average, they respond to 26.48 emergency operations per year. Of those operations, they are wearing and actually applying SCBA 3.62 times a year. Looking at the command level, 24 of our participants had a team member qualification, 56 had a team leader qualification, 50 had a squad leader qualification, and the highest qualification of eight was the one of a platoon leader. Finally, most of our participants (>98%) were members of voluntary fire departments. To rule out possible influences, we calculated the correlation coefficients between our control and dependent variables. None of those coefficients are significant, however.

As stated before, our dependent variables are the task completion rate, the task completion time, and the three items of the ASQ (satisfaction with ease, satisfaction with time needed, and satisfaction with available information). We summarize the means and standard deviations of those factors for the three groups in Table 7.3. For all factors, there are first impressions of superiority for **G_1** and **G_2**, which had graphical information available. Most dominantly, the means of the task completion times of **G_1** and **G_2** were lower than that of **G_0**. Looking at the ASQ items, **G_1** showed the highest agreement, whereas **G_0** showed the lowest. Interestingly, it was not **G_2** with continuous graphical information that showed the best results, as our hypotheses implied. Instead, **G_1** with only punctual access to graphical information performed better.

Table 7.3 Descriptive summary and test statistics

	Group 0		*Group 1*		*Group 2*		*t-tests (p-values)*		
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*G_0 vs G_1*	*G_0 vs G_2*	*G_1 vs G_2*
Task completion rate (0 or 1)	0.87	0.34	0.96	0.21	0.87	0.34	0.15	0.50	0.15
Task completion time (sec.)	340	100	285	78	289	67	0.02*	0.03*	0.41
ASQ 1	4.30	1.74	5.22	1.59	4.61	1.62	0.04*	0.27	0.10
ASQ 2	4.43	1.38	5.17	1.40	4.57	1.50	0.04*	0.38	0.08
ASQ 3	5.52	1.73	5.96	1.58	5.83	1.56	0.19	0.27	0.39

Legend: ASQ items from 1=disagree to 7=agree; *: $p < 0.05$, one-tailed testing, N=69, each group n=23)

To examine the statistical significance of those impressions, we employed t-tests to check for differences between the groups. Since our hypotheses implied an increased task completion rate, decreased task completion time, and increased task satisfaction for **G_1** and **G_2**, we used one-tailed, unpaired t-tests. The test results are summarized in Table 7.3. As can be seen, there were no significant differences between the groups regarding task completion rate. Consequently, **H_1**, which implies that a higher degree of graphical building information would help firefighters to perform their task more accurately, cannot be accepted. We could not identify any significant differences between control group **G_0** and treatment groups **G_1** and **G_2**.

For task completion time, Table 7.3 indicates that the teams of both treatment groups **G_1** and **G_2** were significantly faster than the teams of control group **G_0**. However, a significant difference between the two treatment groups could not be observed. For a more detailed insight into the task completion times, we generated boxplots that are shown in Figure 7.3. The more robust measures of the boxplots confirm the beforementioned results. The medians and quartiles of **G_1** and **G_2** are consistently below the ones of **G_0**. The only visible difference between the treatment groups is the slightly higher median of **G_2**. Overall, **H_2**, which implies that firefighters provided with a higher degree of graphical building information would need less time to complete their task, can be partially accepted. Both forms of graphical information did make a significant difference compared to the verbal instruction. The degree of graphical information (i.e., punctual or continuous access) showed no further impact.

Looking at the task satisfaction, there are two significant differences in the ASQ item values (cf. Table 7.3). Members of $\mathbf{G_1}$ were more satisfied with the ease of completing the task and the time needed to complete it than members of $\mathbf{G_0}$. On the other hand, there were no significant differences regarding the satisfaction with the available information. In addition, the values of $\mathbf{G_2}$ show no significant difference to the other groups at all. Consequently, $\mathbf{H_3}$, which implies that a higher degree of graphical building information increases firefighters' task satisfaction, can again be partially accepted. The punctual access to graphical information during the briefing did raise the task satisfaction, while the continuous access to graphical information during the mission did not.

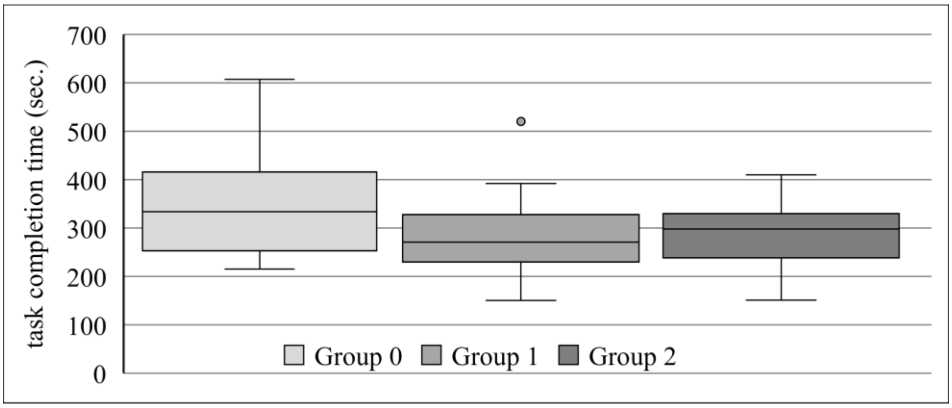

Figure 7.3 Boxplots for task completion time by groups

7.5 Discussion

In this section, we discuss our results in more detail. The discussion is informed by qualitative feedback gathered during the experiment, insights from reviewing the results with instructors of the firefighting academy, and scientific literature.

As shown in the previous section, our results only partially support the hypotheses. Regarding the task completion rate, there were no significant differences between the groups at all. Looking at the firefighters' qualitative feedback, all teams that were not able to complete their task stated physical exhaustion as the reason. They all managed to find the dummy but had to give up on their way out. None of the tasks failed due to insufficient information or lost orientation. Consequently, it seems that there has been no impact of our treatments toward the task completion rate.

With punctual graphical information, however, the firefighters could perform their task faster and were more satisfied than with verbal information. This outcome also corresponds to qualitative feedback from the participants. In **G_0**, they criticized that they received *"too much information in a short time"* and that the information was *"misleading."* In **G_1**, on the other hand, they praised the *"short overview"* that was *"well understandable"* and allowed a *"better orientation."* Opposed to our hypotheses, the continuous access to the graphical information did not bring further improvements. The firefighters belonging to **G_2** could perform their task faster than those of **G_0**. The task satisfaction, however, was not significantly different. Between **G_1** and **G_2**, there were no differences, at all. Possible reasons for this can again be found in the qualitative feedback. In **G_2**, the firefighters saw a too strong *"distraction"* and *"fixation"* to the map that led to the problem of *"blindly relying on it"* and *"overlooking things."* Consulting the instructors of the firefighting academy, we identified the low complexity of the building as an additional explanation why there were no advantages in the continuous access to the graphical information. The layout of the apartment and the way to the dummy as it is displayed in Figure 7.2 might have been simple enough that the firefighters did not experience cognitive overload [22]. According to the instructors, though, a real-world apartment fire is rarely more complicated. It seems that for the scenario of apartment fires, a short look on the map simply suffices. In larger events with more complicated layouts like multiple burning apartments or a burning hospital, however, they see potential in the continuous access to the information.

Looking at the practical adoption, our experiment did not include the creation of the sketch-map. Since we wanted to provide the teams with standardized briefings for internal validity, the squad leader position was taken by a member of the research team. In reality, the squad leader would have to ask the house owner or neighbors for information about the building and draw the map according to it. The time effort of drawing must, of course, be opposed to the time gained by completing the task faster. According to the instructors, however, the squad leader would question knowledgeable attendants anyway. He would also have some short time to draw a map while the team is grabbing their equipment and preparing to enter the building. Of course, the much more favorable solution would be that the graphical building information is available already in advance to an emergency. This would save time and is not depending on the availability of attendants. One solution would be that house owners provide their local fire department with building plans and the department stores them in a database.

As stated before, the application in practice might benefit from using information technology. Of course, the first treatment of punctually presenting the graphical information may also work with simpler means like pen and paper. It is, however, unclear if the squad leader could be able to draw a sketch-map faster with electronic means like a drawing software on a tablet computer which provides predefined design elements. This should be examined in further experiments. In the previously discussed case that the graphical information might be available prior to an emergency, the pure amount of data would call for the use of information technology. Corresponding FITs that are discussed in literature are digital plans [1, 2] and on-site emergency response information systems [5, 6]. Making the information available continuously will, however, require the use of additional, more intricate information technologies. On the one hand, the information would have to be duplicated in real-time. While the sketch-map is given to the team, another instance of it should remain with the squad leader for his commanding duties on site. On the other hand, the map taken by the team would have to be heat-resistant, waterproof and readable in dark smoke. Instead of the paper approximation that we used in our experiment (cf. Figure 7.2), different FITs might be used in practice. Displays could be integrated into the sleeves of intelligent protective clothing [9]. Also, augmented reality systems could be used to display the graphical information in the firefighters' breathing masks [7]. A third approach was proposed by one of the participants. For the search for fires and victims, firefighters often carry infrared cameras with them. The displays of those cameras could also be used to show the sketch-map. This way, the firefighters would not have to carry any additional devices with them but could use systems they are already used to. It might indeed be the simplest, yet most acceptable solution for the practitioners. The performance of all those technological solutions should be examined in future research.

All in all, our results hold several implications for both academia and practice. Regarding academia, we present a task-centered approach to identify information potentials for a specific scenario and propose suitable technological solutions for firefighters. This constitutes an alternative approach compared to the mostly technology-driven development of FITs. The overall procedure can be transferred to many other problems. First, other scenarios from the firefighter domain can be examined in a similar way. From salvage rescues after car accidents to forest fires, there are many possible scenarios. Besides, the procedure can be applied to scenarios of other first responders like police or rescue departments as well. In the work at hand, we build on the theory of situation awareness. While this theory is well established in emergency management, it has by now mainly been used to examine higher levels of severity. In our study, we demonstrate its applicability in a comparably small-scale and everyday scenario. To increase situation awareness, we furthermore combine this theory with findings from cognitive science. In so doing, we also show the applicability of those findings in the special domain of firefighting and could even partly confirm them.

Regarding implications for practice, we showed a potential adaption of the firefighters' conventional procedure of getting to work as fast as possible, even with insufficient information. In our experiment, we could demonstrate the positive effects of improved situation awareness. By providing the firefighters with suitable and easy to process information like a sketch-map, the task completion time could be significantly reduced. Consequently, it might make sense for the squad leaders to take a little more time to establish situation awareness in order to gain overall time advantages. The involved instructors of the firefighting academy also support the findings of the experiment. They meanwhile integrate those findings into the squad leader courses held at the academy. They try to sensitize the firefighters for the importance of situation awareness even in time-critical operations and discuss how it can be established. All in all, our study demonstrates the potential of specific information for the firefighters. The developers of FITs can use our findings to provide firefighters with such information.

Although we implemented several measures to ensure internal and external validity, there are some limitations. First, we concentrated on the specific scenario of an apartment fire. Accordingly, our results will only be transferable to real operations of this type. By now, we only used paper approximations to display the information. Employing information technologies might increase or decrease the identified effects. Therefore, as a point of future research, the graphical information should be implemented in according technologies and analyzed in additional experiments. As stated above, the scenario was realistic but not very complex. To examine the potential of continuous access to the information in detail, more complex scenarios than search and rescue during an apartment fire should be analyzed. Furthermore, 98% of our subjects were members of a voluntary fire department. While voluntary and professional firefighters perform equal tasks in Germany, there might still be differences regarding the fitness level or training frequency. To strengthen our results, an additional experiment with professional firefighters might be wise. Finally, our sample of subjects consisted of firefighters from all over Bavaria. Since firefighting tasks and training are comparable in Germany, our results can be transferred to German firefighters. Due to differences in the organization of fire departments and emergency response processes, however, we cannot straightforwardly transfer the results to other countries.

7.6 Conclusion and Outlook

In an attempt to facilitate the design and implementation of suitable information technologies that provide adequate support for firefighters during critical everyday missions, we presented the results of a controlled experiment, in which we examined the efficacy of different kinds of information during the search and rescue task. During the planning of our study, the search and rescue task was identified as an important task, in which the performance might be affected negatively due to an insufficient information base. At the same time, various FITs have been suggested to also facilitate this task. In our study, we found indications that certain kinds of information about the building and the victims might be effective in enhancing the task performance. However, our findings also provide indications that the continuous access to such information (as it is, for instance provided with augmented reality devices) might not provide a further improvement. Judging from the findings of our study, the design of FITs hence ought to be carefully aligned to the task that is to be supported and the information demands.

In future iterations, we plan to strengthen both the theoretical implications and the conceptual foundations of our research. To examine the robustness of our findings, we will further increase the sample size. Moreover, we plan to re-evaluate our results in different scenarios and settings, for instance with varying building and situation complexity, with members of other types of departments (such as professional firefighters), or in settings where the squad leader only has ambiguous or incomplete information. Based on the gathered results, we plan to implement and test FITs that provide theoretically grounded and empirically proven support for the search and rescue task. To better guide the implementation of such FITs, we also intend to connect our findings to existing literature about indoor-navigation, wearable IT, and other domains, which might deliver additional insights for the task-centered design of FITs.

Although we have not formally tested it, we believe that the proposed procedure to examine the existing information demand and to explore ways to provide an adequate information basis before designing and implementing FITs based on their technological capabilities can also be used to support other tasks during the fire emergency response process. In future iterations, we therefore also intend to deduce a generally usable methodology to design FITs based on relevant theories and empirical evidence. With the presented study, we hope to provide a starting point to change the development of FITs from a primarily technology-driven into a mainly demand-driven process.

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Part 3:

Acceptance Model for Emergency Response Information Systems

8 Paper VII: Acceptance Model Development for ERIS

Table 8.1 Fact sheet paper VII

Fact	Description
Title	Information Technology to the Rescue? Explaining the Acceptance of Emergency Response Information Systems by Firefighters
Authors	Julian Weidinger[1] julian.weidinger@uni-bamberg.de Sebastian Schlauderer[1] sebastian.schlauderer@uni-bamberg.de Sven Overhage[1] sven.overhage@uni-bamberg.de [1]University of Bamberg An der Weberei 5 96047 Bamberg, Germany
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Information Technology to the Rescue? Explaining the Acceptance of Emergency Response Information Systems by Firefighters

Abstract. *Improving the efficacy of emergency responses with digital means is receiving increasing attention. Currently, several innovative information technologies and systems are being developed to raise the situation awareness of first responders like firefighters. Among them, emergency response information systems (ERIS) appear to provide a particularly promising platform, which helps to gather, analyze, and share relevant information during emergencies. However, the conditions under which firefighters accept or reject such systems remain unclear. Existing theories explain the acceptance of information technologies only on a general level that does not consider the specific usage constraints existing in the firefighter domain. To fill this literature gap, we propose a detailed, domain-specific acceptance model with factors that explain the acceptance of ERIS by firefighters. It combines findings of the user satisfaction and the technology acceptance literature and was developed based on the input of 82 domain experts. An evaluation of the acceptance model in a survey with 212 firefighters from Germany indicates that it is effective in predicting a firefighter's intention to use an ERIS. The identified acceptance factors provide guidance for the design and evaluation of ERIS, enabling the so far mostly theoretical benefits of ERIS to be transferred into practical applications more effectively.*

Keywords: Acceptance Factors, Emergency Services, Firefighter Information Technologies, Model Development, Partial Least Squares, Quantitative Research.

Managerial Relevance Statement. *The presented acceptance model provides a unique overview of the factors determining the acceptance and usage of emergency response information systems (ERIS) by firefighters. Achieving an in-depth understanding of the practical requirements and constraints governing the usage of ERIS is important as they are meant to support the coordination of emergency operations with lives at stake. The presented acceptance model can thus provide benefits for several stakeholder groups: ERIS developers can build upon the identified acceptance factors and the feedback of 212 experienced firefighters to improve the design of their systems. ERIS procurers can use the acceptance factors as a benchmark to evaluate existing ERIS and identify the best suited candidate for their fire department. Eventually, the proposed acceptance model* *can also benefit firefighters as the actual system users. By considering the identified acceptance factors in their design, ERIS can better meet the practical needs and will thus likely be better able to support time-critical operations on site.*

8.1 Introduction

With increasingly occurring human-made and natural disasters such as terrorist assaults, earthquakes, or wildfires, improving the efficacy of emergency first responders receives more attention around the globe. Over the last years, significant efforts have been made to improve emergency response processes and to provide a better infrastructure for first responders such as firefighters [1]. While these efforts have led to notable achievements, the efficacy of emergency responses remains considerably dependent on the ability of incident commanders to adapt to the encountered situation and make context-dependent decisions on how to proceed [2, 3]. As a critical determinant for the quality of such decisions, the situation awareness – that is, the perception of environmental elements, the comprehension of their meaning, and the projection of their future status – has been widely emphasized in the literature [4, 5]. Typically, however, firefighters still have limited access to real-time information about the emergency site such as the locations of responding units, the status of available resources, or environmental conditions at the incident area. Increasing the situation awareness hence continues to be an important goal to make emergency responses more effective.

To better achieve this goal, several approaches to utilize emergency response information systems (ERIS) and other novel firefighter information technologies (FITs) have recently been described in the literature [6]. Among them, ERIS appear to be particularly suited to improve the current state of the art, because such systems introduce a versatile, generic platform that facilitates the gathering, analysis, and communication of mission-critical information in order to support the dynamic management of the resources available on site. In general, ERIS can hence even establish the technological basis required to integrate the information delivered by other novel FITs such as digital plans, intelligent clothing, drones, or ground robots.

Despite their potential to improve the situation awareness, the acceptance of ERIS in practice has remained rather unexplored, however. So far, the use of ERIS is instead suggested mainly due to their innovative features and their assumed potential to expedite emergency responses. Such technology-driven approaches risk neglecting that information technologies are particularly delicate artifacts for emergency responders, because several tight usage constraints exist in practice [7]. Any gain in functionality hence needs to be weighed against the additional efforts or restrictions that arise for the users. Since the factors that positively or negatively impact the acceptance of ERIS hardly have been explored so far, it remains unclear, if and under which conditions such systems might indeed be viewed as beneficial and used by firefighters.

To provide insights into the usage conditions, we present the results of a study, in which we explored the factors that determine the acceptance or rejection of ERIS by firefighters. Using generic theories, which explain the acceptance of information technologies, as theoretical foundation and considering the specific usage constraints existing in the firefighter domain, we examine the following research questions: "*Which factors determine the acceptance of emergency response information systems by firefighters? How do the identified factors influence the design of emergency response information systems?*"

As a means to answer these questions, we introduce a new acceptance model that explains the acceptance of ERIS and propose a corresponding measurement instrument. Following methodological guidelines that we adopted from the literature [8, 9], the acceptance model and the measurement instrument were iteratively developed based on the feedback of 10 domain experts and 72 pilot testers. The final version was then used to examine the acceptance of ERIS in a survey of 212 German firefighters, which had practical experiences with these systems. The developed acceptance model introduces a new theoretical basis that considers several domain-specific factors to explain the acceptance of ERIS. By considering the specific usage constraints, which exist in the firefighter domain, we complement existing general-purpose acceptance theories with a tailor-made perspective that might also be able to better explain the acceptance of other innovative FITs. The survey results moreover provide a unique overview of the factors that determine the acceptance of ERIS. As these factors should be fulfilled to facilitate the acceptance, the survey results provide guidance for the design of new ERIS and can be used as a benchmark to evaluate existing systems.

We proceed as follows: in the next section, we describe the concept of ERIS and existing acceptance theories in detail. We also argue why these theories do not adequately describe the acceptance of FITs. Against this background, we introduce a new acceptance model to explain the usage of ERIS and describe its development in 8.3. Section 8.4 contains the results of the survey that we conducted to evaluate the acceptance of ERIS based on the final version of our model. We discuss the results and elaborate on the implications for academia and practice in section 8.5. Section 8.6 concludes the paper and gives an outlook on future research.

8.2 Theoretical Background and Related Work

8.2.1 Emergency Response Information Systems for Firefighters

To increase the situation awareness on site, several novel FITs are being discussed in academia and practice. While many of them still rather exist on the drawing board, a recent survey found that especially ERIS have already gained a more widespread diffusion in practice [7]. Generally, an ERIS introduces a versatile platform to gather, analyze, and communicate mission-critical information to support the dynamic management and coordination of emergency operations [3, 10-13]. It is meant to support the incident commander as well as the responding units. As versatile systems, ERIS can basically support operations ranging from daily routine to large-scale disasters, in which multiple units from different agencies must be coordinated [10-13]. ERIS were hence found to be of particular interest to practitioners in a recent study [6].

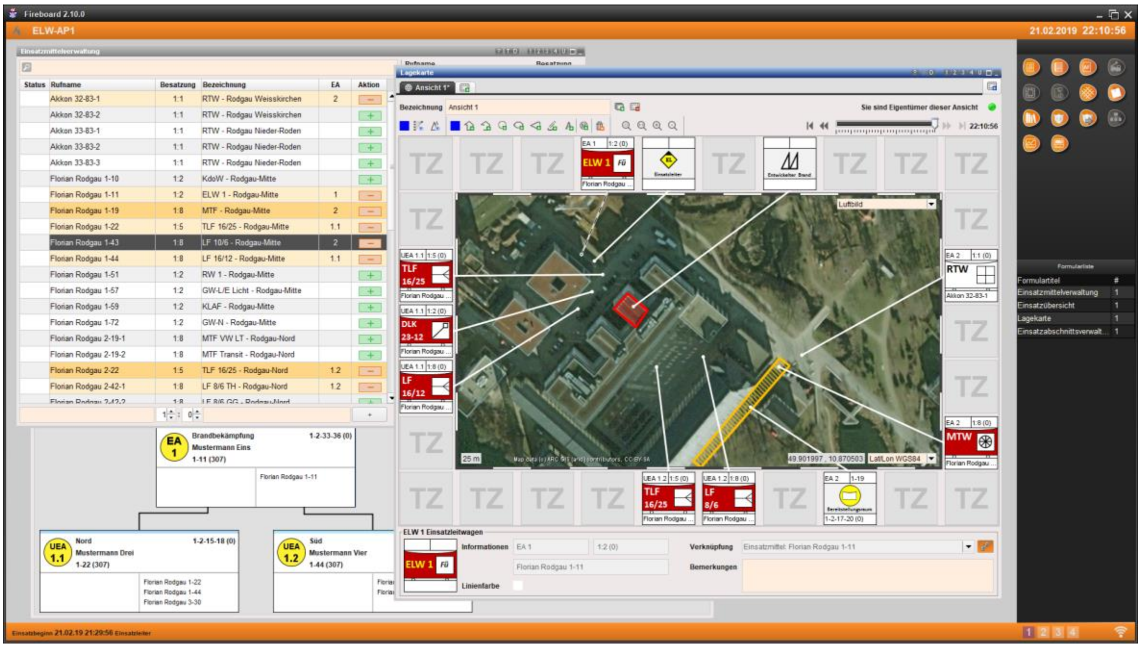

Figure 8.1 Exemplary Implementation of an ERIS in the software "Fireboard" © 2023 IEEE

Various approaches to realize ERIS have been presented in academia and practice. The approaches differ with respect to the platform design and the provided functionality, but also share several basic features. In the following, we illustrate some of these features using an exemplary approach from practice (see Figure 8.1, [13]). Typically, ERIS maintain inventories with information about the units responding to the incident and additionally available resources. The information regarding the responding units consists of the call sign to initiate radio contact, the number and qualification of the unit members, and the type of apparatus the unit operates (see Figure 8.1, top left). To better structure larger-scaled responses, the units can be assigned to different operation sections [14]. In the illustrated approach, these sections are depicted in hierarchical order according to the command structure (see Figure 8.1, bottom left). A situation map moreover depicts spatial information about the incident area such as the positions of units, danger zones, or staging areas (see Figure 8.1, right). It can be based on a geographical map, but also utilize building plans or aerial images delivered by a drone.

Regarding the provided functionality, three basic categories or evolutionary stages of ERIS can be distinguished. They differ with respect to the way, in which real-time data from the incident site is obtained and utilized. Basic ERIS introduce a platform to present and communicate information, which has been manually entered by its users [10-13, 15]. During an emergency response, such a system must be constantly fed with updates by hand. Most currently available systems belong to this category [10-13]. In addition, literature also describes ERIS of a second category, which (partially) automate the data input. In particular, such ERIS are able to obtain real-time data from sensor networks, which have been developed to capture positions of responding units, levels of water tanks, weather conditions, etc. [3, 16-20]. In principle, an ERIS of this category could hence also be used to gather data that is generated by other emerging FITs such as drones, ground robots, or intelligent clothing [6]. While the data input is automated, however, the data must still be processed manually to derive appropriate reactions and commands. This step is partially automated by ERIS of the third category, which also provide decision-making support. ERIS belonging to this category calculate and actively suggest possible commands based on the received information [21-23].

8.2.2 Acceptance of Information Technologies

To explain the acceptance of information technologies and systems, several generic theories have been proposed in the literature. For example, Moore and Benbasat adapted the Diffusion of Innovations Theory to describe the *Relative Advantage*, *Compatibility*, and *Ease of Use* of information technologies as key factors governing their adoption by the user [24]. The Model of PC Utilization (MPCU) specifically explains the acceptance of personal computers and introduces additional factors like *Facilitating Conditions* or *Job-fit* [25]. One of the most widespread theories on the acceptance of information systems instead is based on the Theory of Reasoned Action. This theory states that, in general, an individual's *Attitude* and the *Subjective Norm* will influence the *Intention* toward a specific behavior and ultimately the *Behavior* itself [26]. It was later supplemented with *Perceived Behavioral Control* as an additional factor in the Theory of Planned Behavior [27].

As a technology-specific successor of these theories, the Technology Acceptance Model (TAM) evolved [28]. It introduced *Perceived Usefulness* and *Perceived Ease of Use* as the main factors affecting the *Attitude* towards the technology but left out *Subjective Norm* and *Perceived Behavioral Control*. Revised versions (TAM2 and TAM3) found the *Attitude* to be omittable and established a direct link from *Perceived Usefulness* and *Perceived Ease of Use* to the *Intention* to use a technology [29-31].

Despite their different roots, the before-mentioned theories have several acceptance factors in common. The Unified Theory of Acceptance and Use of Technology (UTAUT) is an attempt to integrate the acceptance factors of these theories into a unified approach [32]. The UTAUT summarizes the most important factors of existing theories in four combined constructs: *Performance Expectancy*, *Effort Expectancy*, *Social Influence*, and *Facilitating Conditions*. The first three constructs were found to influence the *Intention* to use a technology while *Facilitating Conditions* directly influences *Use Behavior*. The revised version (UTAUT2) also introduces a connection between *Facilitating Conditions* and *Intention* for certain domain contexts [33].

The introduced technology acceptance models concentrate on the user's perceptions about using a system to predict the system's acceptance. In contrast, the user satisfaction literature aims to explain a user's satisfaction with a system based on the actual characteristics of the system and the information it provides [34]. It proposes that *System Satisfaction* and *Information Satisfaction* are mainly determined by the *System Quality* and *Information Quality*. For these two quality measures, several factors have been identified as determinants [35]. In an effort to combine the findings of the user satisfaction literature and the technology acceptance literature, Wixom and Todd showed that *System Satisfaction* and *Information Satisfaction* are sufficient antecedences of the TAM's *Perceived Usefulness* and *Perceived Ease of Use* [36].

8.2.3 Acceptance of Emergency Response Information Systems

The acceptance of information technologies and IT-based systems already has been explored intensively during the last decade, especially in business [37, 38] and private usage contexts [39, 40]. However, literature emphasizes that the firefighter and the emergency domain are shaped by several specific characteristics that set it apart from business or private contexts [1, 3, 41]. It hence appears necessary to determine in how far the acceptance of information technologies and systems has already been examined in this specific domain.

Therefore, we conducted a systematic literature review following the guidelines given by Webster and Watson [42]. To obtain a broad overview, we searched the databases of ScienceDirect, SpringerLink, and EBSCOhost as well as the digital libraries of ACM, AIS, IEEE, and the particularly relevant ISCRAM community. We combined search terms such as “firefighter” and “emergency” with “acceptance” and “adoption” to identify prior work related to our study. The titles and abstracts of the resulting articles were inspected for relevance and irrelevant articles were excluded. For the sake of clarity, we limited the analysis to information technologies used within emergency organizations and omitted alerting and social media systems involving civilians. Based on the references of the remaining articles, we conducted forward and backward searches to identify additional related work. In the following, we highlight the areas, in which the acceptance of information technologies and systems has been investigated in the emergency domain.

We found that the acceptance of information technologies has been addressed most intensively in the healthcare domain. However, most papers concentrate on clinical usage scenarios rather than emergency responses. For instance, Despont-Gros et al. studied the human-computer interaction with data acquisition devices in a hospital [43]. Moores and Handayani et al. developed TAM-based acceptance models for information technologies in clinics [44, 45]. Neill et al. combined existing acceptance models to study the adoption of wearable technologies in hospitals [46]. One of the few papers concentrating on emergency responses used the UTAUT to examine the acceptance of mobile devices in the emergency medical service [47]. Elmasllari and Reiners moreover identified acceptance factors for electronic triage systems [48].

In other emergency domains, technology acceptance has been studied only sporadically. A refined TAM was proposed to explain the acceptance of mobile data terminals in a UK police force [49, 50]. Kurkinen used the TAM to examine the effects of age on the acceptance of technologies by police officers [51]. Aedo et al. developed cooperation strategies for the multi-organizational adoption of emergency management information systems in large-scale disasters [52]. In a multiple case study, the Task-Technology-Fit (TTF) Model was used to examine the adoption of the RFID technology in emergency management [53]. Prasanna et al. developed an acceptance model for information systems in emergency operation centers [54].

Technology acceptance in the firefighter domain has been studied by only a few authors so far. Using fire departments as example, Santos et al. developed a theoretical model to assess an emergency response organization’s maturity in adopting novel technologies [55]. A quantitative study moreover used the TTF Model to evaluate the practical potential of ERIS and other emerging FITs [7]. Based on interviews with domain experts, a subsequent qualitative study identified an initial set of factors that might foster or impede the use of ERIS and the other FITs [6]. However, the identified factors have not yet been evaluated.

Overall, we found that the body of literature treating technology acceptance in the emergency domain is still quite small. When limiting the scope to the on-site response to emergencies or to the firefighter domain, related work narrows to only a few studies. While especially ERIS are supposed to have a significant potential to increase the situation awareness of firefighters, prior research has mainly focused on determining general design principles and information demands of various stakeholders [1, 3, 20, 41]. It therefore remains difficult to assess under which circumstances ERIS might be accepted and used in practice.

8.3 Model and Instrument Development

To close this literature gap and identify the factors governing the practical adoption of ERIS, we propose a new, tailor-made acceptance model that explains the adoption and use of ERIS by firefighters. Building upon the German firefighter landscape as a specific yet typical field of study, the proposed model deliberately considers the usage constraints that exist in the firefighter domain. Therefore, we combined generic theories like the TAM or UTAUT with domain-specific acceptance factors that we derived from the firefighting literature. In addition, we developed a corresponding measurement instrument. To ensure a rigorous development of the acceptance model and the associated measurement instrument, we followed established guidelines for instrument development [8, 9]. In the following, we describe the development process. We begin by discussing the hypotheses that led to the initial acceptance model and instrument. We then explain the conducted revisions and present the final instrument that was used to examine the acceptance of ERIS.

8.3.1 Initial Acceptance Model

As a foundation for our acceptance model, we adopted the approach of Wixom and Todd [36] that integrates the findings of the technology acceptance and user satisfaction literature into a unified model (see section 8.2.2). However, taking recent developments of the underlying theories and the specific conditions in the firefighter domain into account, we made several modifications to enhance the original model. The resulting model containing all presumed acceptance factors and their relationships is displayed in Figure 8.2 later on.

Like the original model proposed by Wixom and Todd, the right-hand part of our model explains the acceptance of information technologies or systems. We extensively refined this part since the original model incorporated the initial and meanwhile outdated version of TAM with *Perceived Usefulness* and *Perceived Ease of Use* determining *Attitude*. As explained before, *Attitude* has been found to be omittable in more recent approaches like the refined TAM versions or the UTAUT [29-32]. Consequently, we also omitted *Attitude* and instead assumed a direct path toward *Intention*. Furthermore, we replaced *Perceived Usefulness* and *Perceived Ease of Use* with the UTAUT's expectancy constructs *Performance Expectancy* and *Effort Expectancy*. These encompass similar constructs from several other established acceptance theories [32].

Finally, we added *Social Influence* and *Facilitating Conditions* as additional constructs to our model. *Social Influence* and related constructs are contained in the newer TAM versions and many other models [24, 25, 30-32]. It seems reasonable that firefighters' beliefs will be influenced by their colleagues' opinions as well since they typically are committed team players. Prior studies also found a high degree of resistance to change in the firefighter domain, which might at least partly stem from the *Social Influence* of conservative colleagues [6]. *Facilitating Conditions* and related constructs are featured in several established models, as well [24, 27, 32]. We assume connections from *Facilitating Conditions* to *Intention* and to *Use* as it was established by the UTAUT2. The connections were motivated by the specific area of application and the fact that "*facilitation in the environment that is available to each consumer can vary significantly*" [33]. A high degree of variance also is typical for the German firefighter domain as the firefighting service is assigned to the communal level. The concrete *Facilitating Conditions* can vary considerably from city to city and will probably influence both a firefighter's actual system *Use* and his/her initial *Intention* to use it.

Regarding the left-hand part of our acceptance model, we adopted the basic structure of Wixom and Todd with *Information Quality*, *Information Satisfaction*, *System Quality*, and *System Satisfaction* [36]. As regards the antecedents of the two *Quality* constructs, we took over the existing constructs from the original model, like *Accuracy*, *Completeness*, *Reliability,* etc. Those constructs represent a best-practice collection in the user satisfaction literature for information technologies in general [35]. Besides that, we introduced additional constructs to represent specific factors that are relevant in the firefighter domain. Based on our analysis of related work, we found that especially three factors were not yet adequately represented in the model [6]: *Parsimony*, *Compactness*, and *Simplicity*. Based on the definition of these factors, *Parsimony* was added as an antecedent of *Information Quality*, *Compactness* and *Simplicity* as antecedents of *System Quality*. To link the two model parts, we connected *Information Satisfaction* and *System Satisfaction* to *Performance Expectancy* and *Effort Expectancy*. As defined by Venkatesh et al., the UTAUT's expectancy constructs correspond to the TAM's *Perceived Usefulness* and *Perceived Ease of Use* constructs [32]. In the original model of Wixom and Todd, *Information Satisfaction* and *System Satisfaction* were interpreted as object-based attitudes and treated as external variables for the before-mentioned TAM constructs [36]. Analogously, we assume the satisfaction constructs to be antecedents of the UTAUT's expectancy constructs.

For all constructs, we included multiple survey items to form a corresponding measurement instrument. Most of the items were adopted from established instruments but had to be rephrased to fit into the domain-specific context. Additional items for existing constructs, as well as the items for the newly introduced constructs, were formulated based on findings of related work [6]. Due to page limitations, we do not display the initial list of items. Instead, we only present the final list after describing the refinement steps that led toward it.

8.3.2 Pre-Test and Pilot-Study

The first step to refine our initial acceptance model and instrument was a pre-test [8, 9]. To include feedback from various perspectives, we consulted experts from different domains. To represent the academic information systems perspective, we interviewed two senior researchers from that field. To represent the information systems practitioner perspective, we consulted two developers and managers of a leading ERIS provider in Germany. To cover the academic firefighter perspective, two instructors of a state firefighting academy were consulted. Finally, we interviewed four firefighters of professional and voluntary fire departments to also include the perspective of firefighter practitioners. The experts were asked to complete the instrument and make suggestions for its improvement. Concretely, they were asked to assess the format, content, understandability, terminology, and completion effort. Furthermore, they were asked to name items that should be added or removed or assigned to different or additional constructs. The experts' feedback was analyzed by the research team and used to adjust both the acceptance model and the instrument. Most notably, we added *Mobility* as an additional construct since it was suggested by multiple experts.

As a second refinement step, we conducted a pilot-study to receive feedback from members of the final survey population [8, 9]. In our case, the population consisted of German firefighters. As pilot-testers, we acquired participants of several firefighting and command courses at a state firefighting academy. These courses are attended by firefighters from different regions and from all kinds of fire departments, ranging from small to large and from voluntary to professional departments. By including different types of courses, we were able to consider firefighters from all command levels. Like in the pre-test, the participants were asked to fill out the instrument. Afterwards, they were asked to provide feedback on experienced difficulties and missing or unnecessary items. All in all, we received feedback from 72 respondents. The results of the pilot-study showed support for our acceptance model. Amongst others, Cronbach's Alphas were above 0.70 for most of the constructs, which is seen as appropriate for early stages of research [56]. Also, many paths between the constructs showed significant correlations. The feedback was again used to further refine the instrument. The resulting final list of items is summarized in Table 8.4 (see Appendix). In the Source column, we indicate if the respective item originates from literature (references) or from the pre-test ("pre").

8.3.3 Final Instrument

After completing the refinement steps, we defined the final instrument and implemented it as an online survey. At the beginning of the survey, we described its goal, defined the term ERIS, stated the target population of firefighters knowledgeable of ERIS, and gave editing instructions. The survey itself consisted of four parts. In the first part, we asked if the respondents use an ERIS in emergency operations and how frequently and to which extent they do so. Furthermore, the respondents had to identify the particular ERIS they were referring to during the survey. For this purpose, we provided a list of popular ERIS in Germany. All listed ERIS offered comparable sets of basic features to fulfill the applying legal regulations [14] and were in the same evolutionary stage (see section 8.2.1). As the evaluated acceptance factors are generic in nature and hence should apply to all ERIS, we deem the heterogeneity of the sample regarding the used systems to not produce severe adverse effects [36, 54]. In the second part, we presented the instrument items in randomized order. Each item had to be rated on a seven-point Likert scale ranging from "*do not agree at all*" to "*totally agree*". In the third part, we collected demographic information of our participants like gender, age, experience as a firefighter in years, amount of firefighting operations, command level, and the type of department they work in. Following the suggestions of multiple experts from the pre-test, the last part of the survey covered practical aspects. For instance, the respondents were asked to rate common features of ERIS regarding their perceived importance and to state if their department is planning to purchase or replace an ERIS. The survey invitation was disseminated using mailing lists and newsletters of the German Firefighter Association. In addition, we asked for participation in an expert forum and other appropriate social networks.

8.4 Results

Overall, 228 firefighters completed our survey. Because of missing values or other response anomalies, we had to exclude 16 responses, resulting in a sample of 212 participants. On average, they were 40 years old, were members of a fire department for 24 years and responded to approximately 94 emergency operations per year. 98% of the participants were male. 28% belonged to the operational command level (squad leaders and below), 27% to the tactical command level (platoon leaders), and 42% to the strategic command level (above platoon leaders). 90% worked at voluntary, 14% at professional, 6% at plant fire departments, and 6% were instructors at a firefighting academy (note that some firefighters stated to work for multiple institutions). Their departments conducted 1,315 annual operations on average.

To increase the validity of our results and account for confounding effects, we included some demographic information as control variables into our analysis. As advised in the literature, we particularly included the participants' current job role (command level) and their experience as control variables [3]. We then applied the partial least squares structural equation modeling technique (PLS-SEM) with SmartPLS 3 [57] to analyze our model. We did so for several reasons. In contrast to covariance-based approaches, PLS-SEM is especially suited for highly complex models, smaller sample sizes, and exploratory research with the goal of predicting key driver constructs [58-60]. While these characteristics match well with the study at hand, the size of our sample is still larger than "*10 times the largest number of structural paths directed at a particular construct in the structural model*", which is required to use PLS-SEM [60]. Following the guidelines of Hair, et al. [60], we employed bootstrapping in the bias-corrected and accelerated version with 5,000 samples and two-tailed testing with a 0.05 significance level to calculate the significances of our results. In the following, we separately describe the measurement model assessment and the structural model analysis. Finally, we present the results of the survey with respect to the practical aspects of ERIS.

8.4.1 Measurement Model Assessment

The measurement model assessment focuses on the relationships between the items and the constructs they are assigned to. First, we evaluated the internal consistency reliability of each construct by determining the Cronbach's Alpha and Composite Reliability. As shown in Table 8.2, the results lie well above the lower threshold of 0.70 for all constructs [56]. Only the Composite Reliabilities of *System Quality*, *System Satisfaction* and *Effort Expectancy* slightly exceed the upper threshold of 0.95 while Cronbach's Alphas lie well below it. As the internal consistency reliability typically lies between the tendentially underestimating Cronbach's Alpha and the overestimating Composite Reliability [60], the results are within the desired range.

As a second criterion, we investigated the convergent validity. Convergent validity is established if the outer loadings of all items are significant and above 0.708. Furthermore, every construct's average variance extracted (AVE) is supposed to lie above 0.5 [61]. As shown in Table 8.4 (see Appendix), the outer loadings of all items are significant. However, the loadings of two *Facilitating Conditions* items were below 0.708. We therefore further examined these two items. Among others, we tested a segmentation of the construct into *Organizational* and *Technological Facilitating Conditions*. Since this did not deliver a significant improvement, we dropped the two items from the instrument [60]. Table 8.2 shows that the AVE values of the remaining constructs lie well above the threshold of 0.5.

Table 8.2 Measurement model results © 2023 IEEE

Construct	Internal Consistency		Convergent Validity
	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Format	0.906	0.941	0.842
Completeness	0.802	0.884	0.719
Currency	0.836	0.901	0.753
Accuracy	0.854	0.911	0.774
Parsimony	0.751	0.859	0.671
Information Quality	0.888	0.931	0.818
Information Satisfaction	0.859	0.934	0.877
Flexibility	0.831	0.899	0.748
Reliability	0.865	0.917	0.788
Timeliness	0.870	0.920	0.794
Integration	0.834	0.900	0.751
Accessibility	0.836	0.901	0.753
Compactness	0.888	0.930	0.817
Simplicity	0.878	0.924	0.803
Mobility	0.788	0.876	0.703
System Quality	0.924	0.952	0.868
System Satisfaction	0.905	0.955	0.913
Performance Expectancy	0.894	0.934	0.825
Effort Expectancy	0.925	0.952	0.870
Social Influence	0.852	0.910	0.771
Facilitating Conditions	0.833	0.889	0.668
Behavioral Intention	0.916	0.947	0.856

Lastly, we examined the discriminant validity. On the item level, it is established if all items have higher loadings on the construct they are assigned to than on any other construct [60]. On the construct level, it is established if the square root of each construct's AVE is greater than its correlation with all other constructs [58]. As Table 8.5 and Table 8.6 (see Appendix) show, the results satisfy the criteria on both item and construct level. Taken together, our measurement model fulfills the criteria given to establish internal consistency reliability, convergent validity, and discriminant validity.

8.4.2 Structural Model Evaluation

After assessing the measurement model, we examined the relationships in the structural model. In a first step, we ruled out collinearity issues by analyzing the variance inflation factors (VIF). As shown in Table 8.7 (see Appendix), the VIFs for all paths of our model except one are below the recommended threshold of 5 [60]. Since the VIF between *Timeliness* and *System Satisfaction* is 5.13, we examined this part of the model in more detail. Deleting *Timeliness* from the model increases both the coefficient and the significance of the path from *Reliability* to *System Quality*. However, it reduces *System Quality*'s R^2. Therefore, and because *Timeliness* is an important factor from a theoretical perspective, we decided to keep it in the model.

The results of the model analysis are shown in Figure 8.2. With respect to the main model, nine of the 13 antecedents of the *Quality* constructs show significant relationships. Surprisingly, the path from *Compactness* is significantly negative. The paths between the *Quality*, *Satisfaction*, and *Expectancy* constructs all show sufficient coefficients and significances. The path from *Facilitating Conditions* to *Behavioral Intention* is the only one in the right-hand part of our model that is not significant. Altogether, the results support most of the hypothesized relationships. The path coefficients of the control variables and their significance levels can be seen in Table 8.8 (see Appendix). None of the control variables had a significant effect on any latent variable. As including them enhanced the R^2 values and hence the model quality, we kept them in the model.

Regarding our model's predictive power, we display the coefficients of determination (R^2) for all endogenous constructs in Figure 8.2. Roughly, an R^2 above 0.75, 0.50, and 0.25 can respectively be interpreted as substantial, moderate, and weak predictive power [60]. As the results indicate, our model exhibits substantial predictive power for the *Quality* and *Satisfaction* constructs as well as for *Behavioral Intention*. The *Expectancy* constructs are predicted with moderate strength while the actual system use is predicted only weakly.

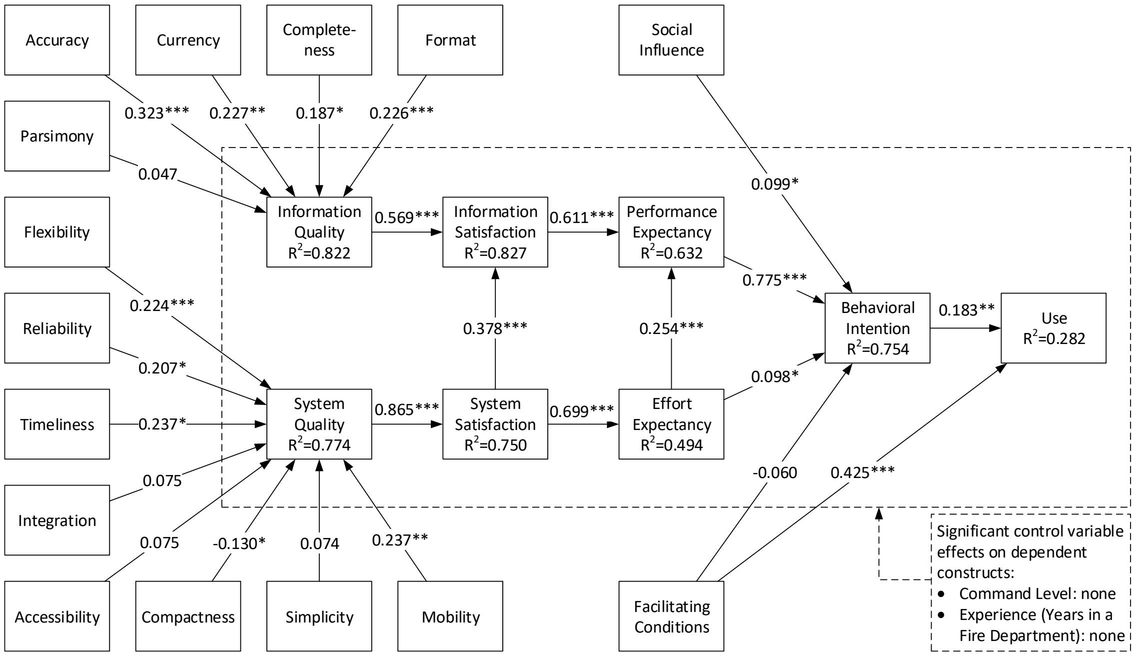

Figure 8.2 Structural Model Results © 2023 IEEE
Legend: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

We additionally calculated the effect sizes (f^2) of all paths in the model. As a rule of thumb, f^2 values above 0.35, 0.15, and 0.02 represent large, medium, and small effects [62]. As can be seen in Table 8.7 (see Appendix), all significant paths of the model show at least a weak effect size above 0.02. Large effects can be observed on the paths from *Information Quality* to *Information Satisfaction* to *Performance Expectancy* to *Behavioral Intention* and from *System Quality* to *System Satisfaction* to *Effort Expectancy*.

To assess the model's out-of-sample predictive power, we calculated the predictive relevance (Q^2). It is determined by employing blindfolding, in which – in our case – every seventh observation of the sample is omitted from the calculations. After seven calculation runs, every observation has been omitted once. Whenever Q^2 exceeds 0, the model has a generalizable predictive relevance for the respective endogenous construct [63]. As displayed in Table 8.7 (see Appendix), this is the case for all our constructs.

8.4.3 Device and Feature Expectations

136 of the 212 participants agreed to answer an additional survey part with questions regarding practical aspects such as the preferred devices and desired features. First, they were shown a list of eleven different ERIS that are currently available on the market. On average, the participants stated to know 2.6 of these systems. Fireboard [13] was known by 76% of the participants while TecBOS.Command [12] was known by 34% and CommandX [10] by 33%. The best-informed respondent knew nine of the eleven systems. In

addition, 25% of the participants stated that their department is planning to purchase a new or replace an existing ERIS either in a short (10%), medium (7%), or long term (8%).

Regarding the preferred devices, most participants wanted to use ERIS on a desktop PC (93%), a notebook (96%), or a tablet computer (87%). Only 30% viewed smartphones as devices that should be supported by an ERIS. The systems should consequently offer a certain level of mobility, but obviously do not necessarily have to be optimized for small devices. The respondents were also asked to rate the importance of 16 common features. Each feature had to be rated on a seven-point scale ranging from 1 = "*not important at all*" to 7 = "*very important*". As shown in Table 8.3, offline and multi-user functionalities, an operation log, and an overview of units and resources were found to be very important. Interfaces to other systems, situation maps, messaging functionality, and the ability to store additional plans were moreover viewed as important.

Table 8.3 Importance of features © 2023 IEEE

Feature	Mean	SD
Offline Functionality	6.74	0.55
Operation Log	6.60	0.86
Multi-User Functionality	6.54	0.92
Resource Overview	6.49	0.78
Situational Map	6.21	1.17
Messaging Functionality	5.91	1.46
Pre-Planning of Operations	5.54	1.27
Customizing Functionality	4.48	1.68
Interface for Alarm Information	6.00	1.22
Interface for Unit Statuses	5.82	1.34
Interface to the Control Center	5.74	1.39
Other Interfaces	5.32	1.35
Storing of Fire/Operation Plans	6.13	1.17
Storing of Hydrant Plans	5.85	1.32
Storing of HAZMAT Information	5.30	1.69
Storing of other Plans or Guides	5.48	1.53

Note: rated on a scale from 1 = "not important at all" to 7 = "very important"

The participants had the opportunity to describe additional features that they perceive as essential. The most common responses specified precise system requirements regarding *Flexibility*, *Reliability*, and *Mobility*, which are included as generic attributes in the acceptance model. For instance, the hardware running the ERIS should be "*backed up by an emergency power supply*", and the incident commander should be able to "*access the most important data on his tablet*" anywhere. Regarding the processed information, the most desired feature was the integration of GPS data to "*display the position of units on the situational map*". In the acceptance model, most of the features desired with respect to the processed information are reflected by the factors *Accuracy*, *Currency*, and *Com-*

pleteness. Another common response was that the ERIS should "*use standardized protocols*" or have "*appropriate interfaces*" to systems of other fire departments or government organizations. Finally, low or reasonable costs have been frequently stated as an important requirement.

8.5 Discussion

In the following section, we discuss and interpret the previously described results of our study. To gain deeper insights, we also link the measurement and structural model results to the practitioners' practical device and feature expectations. Furthermore, we elaborate on academical and practical implications that can be derived from our findings as well as the limitations pertinent to our study.

8.5.1 Factors Determining the Acceptance of an ERIS

Information Quality is very well predicted by the constructs contained in the acceptance model (R^2=82%). The most significant determinants turned out to be the *Accuracy*, *Format*, and *Currency* of information, which seems reasonable considering the usage context. In time-critical situations with lives at stake, firefighters demand accurate and current information that is displayed in an understandable way. Another significant factor is *Completeness*, whereas *Parsimony* was insignificant. Obviously, firefighters seem to tolerate a certain amount of unnecessary information in an ERIS as long as none of the required information is missing. Accordingly, none of the features typically provided by an ERIS was found to be omittable (see Table 8.3). Future generations of ERIS should therefore utilize more rather than less information. A way to better address many of the *Information Quality* determinants may be a transitioning to the second evolution stage (see section 8.2.1) and to leverage sensor data [16-19]. For instance, the participants stated that the inclusion of GPS positions in the situational map can lead to more accurate, current, and complete information. The results of our survey indicate that the practitioners seem to be ready for such an evolution.

System Quality is also very well predicted by the constructs contained in the model (R^2=77%). Its most significant determinants are *Flexibility*, *Reliability*, *Timeliness*, and *Mobility* of the ERIS. Considering the domain and the participants' qualitative feedback, the importance of those determinants seems reasonable as well. The fact that each emergency is unique must be considered by an ERIS, which needs to support a certain degree of flexibility in its use. In time-critical situations, the system furthermore must not delay the operation and must not fail in any case. Features like the implementation of offline functionality and an emergency power supply were hence explicitly demanded by the participants. The *Mobility* construct was only added to the model based on the feedback obtained during the pre-test, but ultimately proofed to be indeed a significant determinant of system quality. The fact that 87% of the participants desire an ERIS, which is available on a tablet computer, additionally underlines the importance of this topic. The *Integration*, *Accessibility*, and *Simplicity* of an ERIS also have a positive, yet comparably smaller effect on the perceived system quality. While these factors hence seem to determine System Quality rather circumstantially, *Compactness* turned out to have a negative effect. In contrast to our initial assumption, firefighters thus seem to prefer extensive rather than compact systems. This finding seems to be corroborated by a study that found large displays to be effective in supporting incident commanders [64]. As ERIS will likely be used in command vehicles to a large part, optimizing them for small devices like smartphones hence rather seems to be counterproductive.

Determined by the *Quality* constructs, the *Satisfaction* constructs are also very well predicted by our acceptance model (R^2=83 and 75%). However, it has a slightly lower predictive power regarding the subsequent *Expectancy* constructs (R^2=63 and 49%). Hence, there must also exist further determinants that have not yet been considered. The answers to the open questions point to some additional factors that might be relevant. Some respondents mentioned the service of the ERIS providers, which could be covered by the *Service Quality* construct from the user satisfaction literature [34]. Some participants moreover stated their ERIS is fun to work with. This might be reflected by the *Perceived Enjoyment* construct from the technology acceptance literature [31]. The inclusion of such constructs might further increase the model's predictive power. However, as it would also increase its complexity, we only plead for modest, goal-driven extensions.

Regarding the model's right-hand part, the firefighters' *Behavioral Intention* to use an ERIS is substantially well predicted (R^2=75%). As proposed by the underlying theories, *Performance Expectancy* seems to be a suitable predictor construct in our context as well [29-32]. *Social Influence* and *Effort Expectancy* also show a significant, but smaller influence. In contrast to the theoretical expectations, however, the *Facilitating Conditions* do not seem to have a significant influence on the *Behavioral Intention*. The participants hence seem to determine their intention to use an ERIS independently from additional measures to facilitate its use.

Nevertheless, the *Facilitating Conditions* still largely determine the actual system *Use*, on which they even have a higher influence than the *Behavioral Intention*. This observation implies that the intentions of individual firefighters are only one determinant that forms the actual usage decision. Even if the firefighters might acknowledge the potential of an ERIS, the use of such systems in practice can still be facilitated or hindered by other aspects that are out of the scope of this study. The actual *Use* can hence only be partially predicted by our acceptance model (R^2=28%). However, some answers to the open survey questions also name additional determinants that might be relevant for the usage decision determinants. The participants particularly highlighted the technical compatibility and costs. To represent compatibility considerations in our model, we originally had included two items into the *Facilitating Conditions* construct (see Table 8.4, Appendix). While we had to drop them from the instrument due to their poor convergent validity, it appears to be worthwhile to further explore such factors in future.

Altogether, the developed acceptance model seems to be well suited to explain firefighters' personal opinions and intentions to use ERIS. It covers the important perspective of the users and explains under which conditions they perceive ERIS as beneficial. Nevertheless, it can explain the actual usage of such systems only to some extent as the usage decision is influenced by other personal and organizational factors as well.

8.5.2 Implications for Academia

The findings gained in our study have implications for academia and practice. As regards academia, our findings enrich the research stream that investigates the acceptance of information technologies and systems. In this context, neither the acceptance of information technologies by firefighters nor the acceptance of ERIS in particular has been in the focus so far. As the results of our study show, the acceptance of information technologies in the firefighter domain also seems to be determined by several domain-specific factors, which resemble the existing tight usage constraints. As existing acceptance theories do not adequately consider these usage constraints, they are not well suited to explain the acceptance of FITs. The presented, domain-specific acceptance model contributes to achieving an in-depth understanding why firefighters accept or reject ERIS. By considering well-established generic as well as specific factors, it provides a unique overview of the circumstances that influence firefighters' intention to use an ERIS. The results of the conducted quantitative evaluation additionally provide insights into the significance and the comparative importance of the identified factors. While the acceptance model has been developed specifically to explain the acceptance of ERIS, we assume that the identified factors could also provide a more refined theoretical basis to understand the acceptance of other FITs, thus providing better support for their ongoing development.

With the presented acceptance model, we furthermore combine findings from the user satisfaction and the technology acceptance literature. In so doing, we answer a call to more closely "*examine the influence of design characteristics on user acceptance*" [31]. The results of our study do not only show that information and system characteristics of ERIS are important determinants for the acceptance of these systems. Building upon and confirming the work of Wixom and Todd, we also demonstrate how recent findings in the user satisfaction and technology acceptance domains can be brought together to form a holistic theoretical foundation that explains the acceptance of information technologies and systems in general.

8.5.3 Implications for Practice

The findings of our study are also relevant for practice. In particular, the identified acceptance factors have numerous implications for the design of ERIS, which ought to account for existing usage constraints and user requirements in the best possible way. From the results of our quantitative study, we can infer that the information provided by ERIS must be presented in a straightforwardly understandable *Format*. In addition, it needs to be *accurate*, *current*, and *complete*. According to the study results, the system itself should moreover be designed in a way that ensures its *Flexibility*, *Mobility*, *Reliability*, and the *Timeliness* of its operations. At the same time, a system design that overly emphasizes *Compactness* (e.g., to run on a smartphone) was rejected by the prospective users. The before-mentioned design implications are primarily relevant for the developers of ERIS, who should optimize their systems to fulfill the identified user requirements in the best possible manner. The developers of ERIS could also consider implementing the specific device and feature requirements that we have gathered in the open survey part. Regarding the developers of ERIS, the study results can hence provide a basis to make better-informed design decisions and thus help to facilitate the development of ERIS that eventually meet the practitioners' needs.

Basically, however, the identified design requirements can also serve as a benchmark to evaluate the suitability of currently available ERIS. Accordingly, the procurers of ERIS can benefit from the findings of our study as well. In future research endeavors, even currently still quite abstract constructs like *Accuracy* or *Reliability* can be further refined, thus leading to a catalog of requirements that allows procurers to objectively evaluate ERIS and choose a suitable product for their fire department. Ultimately, the results of our study should also affect firefighters as the actual users of ERIS. In line with the situation awareness theory, we expect that firefighters' decision-making abilities are largely determined by the availability of suitable information [4, 5]. As ERIS, which adequately reflect existing usage constraints and fulfill the identified user requirements, should provide a better information base, the findings of our study should contribute to further improving firefighters' decision-making and, consequently, to increasing their efficacy on site.

8.5.4 Limitations

We have taken various precautions to ensure the validity of our results. During a pre-test, we conducted interviews with ten experts who brought in different perspectives on the subject matter. In addition, we conducted a pilot-study with 72 participants. In both stages, we used the results to refine the acceptance model and the corresponding instrument. Nevertheless, there exist several limitations, in the light of which the presented results ought to be interpreted. First, the sample size obtained during the final survey still is comparably small as we only included participants that had a firefighter background and experiences with ERIS. In so doing, we could gain realistic feedback about the use of particular systems in practice. Second, we limited our analysis to German firefighters. While we tried to control for regional and other differences within the country by including participants from all over Germany with varying experience levels and from different types of fire departments, the results may not be straightforwardly transferable to other countries. The main reason for this is that the response processes and the organizational structures might differ in other countries. Accordingly, we expect that some aspects might be more or less important in other countries. As the existing usage constraints during emergency responses appear to be largely comparable, however, we believe that the provided model will also be usable to explore the acceptance of ERIS on a global scale. Third, we were not able to ensure that all participants were in the exact same phase of implementing their ERIS. A longitudinal study of acceptance factors might hence provide further insights into the acceptance of ERIS, since user perceptions might change with the prolonged use of an information technology or system.

8.6 Conclusion

To explain the acceptance of ERIS, we presented a new acceptance model. Next to generic factors, it contains several domain-specific factors that determine a firefighter's intention to use an ERIS and the actual system usage. We found that firefighters' intention to use an ERIS is determined by several factors that characterize the quality of the system and that of the provided information. In particular, the flexibility, reliability, timeliness, and mobility of the system itself, as well as the accuracy, format, and currency of the provided information turned out to be important acceptance factors. From an academic perspective, the new acceptance model extends existing general-purpose acceptance theories and provides a domain-specific lens of analysis that might also be used to explain the acceptance of other novel FITs. For practice, the results of our study yield several design implications, which can guide the development of ERIS and be used as a benchmark to evaluate existing approaches. We therefore hope that the results of our study can help to better transfer the so far mostly theoretical benefits of ERIS into practical applications and to facilitate the development of systems, which are closely aligned to the users' needs.

However, the results of our study also provide several avenues for future research. So far, the acceptance and usage of information technologies in emergency domains has been investigated only sporadically. With respect to the presented findings, future research endeavors could, for instance, test the presented acceptance model in an international setting. To examine the generalizability of the presented acceptance model, future research could also explore if it is suitable to explain the acceptance of other FITs like drones, on-ground robots, or intelligent protective clothing. With the presented acceptance model and the measurement instrument, we also hope to provide a starting point for such endeavors.

8.7 Appendix

Table 8.4 Survey items, descriptive statistics, outer loadings © 2023 IEEE

Construct	Item	Source	Mean	SD	Loading
Format	The information provided by the ERIS is well formatted.	[6, 36]	5.155	1.349	0.912***
	The information provided by the ERIS is well laid out.	[6, 36]	5.243	1.292	0.927***
	The information provided by the ERIS is clearly presented.	[6, 36]	5.313	1.406	0.913***
Completeness	The ERIS enables me to capture a complete set of information.	[6, 36]	5.466	1.300	0.885***
	The ERIS produces and documents comprehensive information.	[6, 36]	5.986	1.093	0.769***
	The ERIS enables me to process all the information I need.	[6, 36]	5.327	1.311	0.884***
Currency	The ERIS provides me with the most recent information about the current mission.	[36]	5.263	1.377	0.859***
	The ERIS enables me to process the most current information.	[36]	5.716	1.218	0.877***
	The ERIS provides me with a recent overview of the mission situation.	[36]	5.687	1.316	0.868***
Accuracy	The ERIS produces correct information.	[6, 36]	5.435	1.201	0.890***
	The ERIS enables me to process information precisely.	[6, 36]	4.822	1.478	0.853***
	The information provided by the ERIS is accurate.	[6, 36]	5.406	1.171	0.896***
Parsimony	The ERIS provides me much needless information. (RC)	[6]	4.612	1.405	0.712***
	The ERIS does not provide me any unnecessary information.	[6]	4.552	1.490	0.861***
	The ERIs provides me only the information I need.	[6]	4.459	1.518	0.874***
Information Quality	Overall, I would give the information from the ERIS high marks.	[36]	5.636	1.171	0.914***
	In terms of information quality, I would rate the ERIS highly.	[36]	5.462	1.204	0.920***
	In general, the ERIS provides me with high-quality information.	[36]	5.464	1.250	0.879***
Information Satisfaction	Overall the information I get from the ERIS is very satisfying.	[36]	5.405	1.321	0.932***
	I am very satisfied with the information I receive from the ERIS.	[36]	5.416	1.292	0.941***
Flexibility	The ERIS can be adapted to meet a variety of mission situations.	[6, 36]	5.565	1.382	0.859***
	The ERIS can be flexibly adjusted to new demands or conditions.	[6, 36]	4.787	1.543	0.893***
	The ERIS is versatile in addressing needs as they arise.	[6, 36]	4.770	1.557	0.842***
Reliability	The ERIS operates reliably.	[6, 36]	5.392	1.400	0.925***
	The ERIS performs dependably.	[6, 36]	5.286	1.404	0.928***
	The ERIS is fail safe.	[6, 36]	4.034	1.730	0.804***
Timeliness	The ERIS reacts to my requests quickly.	[6, 36]	5.629	1.304	0.882***
	The ERIS provides information in a timely fashion.	[6, 36]	5.290	1.233	0.880***
	The ERIS can be operated smoothly.	[6, 36]	5.310	1.406	0.911***
Integration	The ERIS enables me to link data from different sources.	[36]	5.121	1.535	0.881***
	The ERIS pulls together information that used to come from different sources.	[36]	5.450	1.282	0.839***
	The ERIS effectively combines data from different sources.	[36]	5.113	1.456	0.878***
Accessibility	The ERIS makes information very accessible.	[36]	5.626	1.227	0.860***
	The ERIS makes information easy to access.	[36]	5.493	1.233	0.892***
	The ERIS makes information accessible at all times.	[36]	5.524	1.319	0.850***
Compactness	The space requirements of the ERIS are low.	[6]	5.426	1.446	0.908***
	The ERIS is space-saving.	[6]	5.325	1.509	0.918***
	The ERIS can be used in narrow spaces.	[6]	5.507	1.398	0.886***
Simplicity	The ERIS has a simple structure.	[6]	4.976	1.554	0.927***
	The ERIS can be used Intuitively.	[6]	4.809	1.695	0.926***
	The ERIS is structured complicatedly. (RC)	[6]	4.649	1.588	0.832***
Mobility	The ERIS is suitable for the mobile application.	Pre	5.729	1.379	0.875***
	The ERIS is easy to transport.	Pre	5.372	1.689	0.811***
	The ERIS can be used at various locations.	Pre	5.948	1.217	0.827***
System Quality	In terms of system quality, I would rate the ERIS highly.	[36]	5.362	1.417	0.930***
	Overall, the ERIS is of high quality.	[36]	5.493	1.358	0.941***
	Overall, I would give the quality of the ERIS a high rating.	[36]	5.476	1.369	0.924***
System Satisfaction	All things considered, I am very satisfied with the ERIS.	[36]	5.379	1.521	0.956***
	Overall, my Interaction with the ERIS is very satisfying.	[36]	5.291	1.452	0.955***
Performance Expectancy	I would find the ERIS useful in my work.	[24, 28, 32]	5.743	1.317	0.906***
	Using the ERIS enables me to accomplish tasks more quickly.	[24, 28, 32]	5.327	1.487	0.900***
	Using the ERIS improves the quality of the work I do.	[24]	5.521	1.357	0.919***
Effort Expectancy	I would find the ERIS easy to use.	[24, 28, 32]	5.090	1.623	0.930***
	It would be easy for me to become skillful at using the ERIS.	[28, 32]	5.295	1.558	0.945***
	Learning to operate the ERIS would be easy for me.	[24, 28, 32]	5.399	1.434	0.923***
Social Influence	Colleagues of my fire department think that using the ERIS is wise.	[28, 32]	5.200	1.366	0.863***
	Colleagues of other fire departments think that using the ERIS is wise.	[28, 32]	5.182	1.370	0.901***
	Colleagues of other organizations think that using the ERIS is wise.	[28, 32]	5.410	1.319	0.869***
Facilitating Conditions	In my dept., a specific person or group is available for assistance with system difficulties.	[25, 32]	5.320	1.834	0.856***
	In my department, a specific person or group is available for assistance with using the ERIS.	[25, 32]	5.515	1.819	0.838***
	In my department, there are rules on how to apply the ERIS.	Pre	4.468	2.010	0.724***
	The ERIS is integrated into the command organization of my department.	Pre	4.950	1.929	0.844***
(dropped items)	The ERIS is not compatible with other systems I use. (RC)	[27, 32]	3.929	1.752	0.190**
	The ERIS is compatible with systems used by other fire dept. and organizations I work with.	[27, 32]	4.309	1.781	0.282***
Behavioral Intention	Generally, I Intend to use the ERIS.	[32]	6.038	1.170	0.936***
	Given that I had the possibility, I predict that I would use the ERIS.	[30]	5.886	1.362	0.919***
	Assuming I had access to the ERIS, I Intend to use it.	[30]	6.067	1.252	0.919***

Legend: *p < 0.05; **p < 0.01; ***p < 0.001; RC = reverse coded

Table 8.5 Discriminant validity on item level (loadings- / cross-loadings-matrix) © 2023 IEEE

Construct	Item	Construct 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Format	1	**.91**	.68	.70	.69	.62	.75	.76	.73	.66	.70	.57	.69	.50	.66	.54	.74	.71	.57	.58	.46	.40	.49	.28
	2	**.93**	.72	.70	.66	.57	.75	.78	.71	.69	.74	.55	.68	.46	.70	.58	.78	.78	.63	.65	.40	.41	.57	.35
	3	**.91**	.66	.67	.66	.52	.71	.73	.70	.61	.69	.55	.71	.55	.68	.51	.73	.76	.62	.63	.39	.35	.53	.34
2 Completeness	1	.67	**.88**	.75	.69	.57	.72	.76	.72	.69	.72	.57	.71	.49	.58	.53	.72	.69	.64	.53	.40	.41	.51	.31
	2	.53	**.77**	.61	.56	.42	.62	.63	.48	.47	.55	.47	.59	.28	.43	.42	.55	.60	.60	.43	.30	.39	.58	.25
	3	.70	**.88**	.71	.68	.54	.73	.72	.78	.65	.68	.60	.70	.49	.62	.58	.71	.72	.64	.57	.47	.36	.58	.29
3 Currency	1	.58	.66	**.86**	.63	.57	.66	.62	.58	.59	.63	.55	.60	.51	.51	.47	.59	.57	.59	.41	.44	.45	.52	.25
	2	.68	.73	**.88**	.65	.53	.77	.77	.68	.69	.75	.58	.74	.55	.61	.56	.71	.70	.69	.57	.47	.38	.63	.20
	3	.70	.73	**.87**	.69	.51	.71	.69	.65	.61	.67	.49	.65	.41	.57	.44	.68	.68	.65	.53	.38	.34	.59	.24
4 Accuracy	1	.69	.70	.69	**.89**	.57	.76	.74	.61	.67	.67	.54	.68	.53	.58	.57	.69	.67	.63	.56	.40	.35	.57	.24
	2	.62	.68	.65	**.85**	.63	.68	.65	.64	.67	.67	.55	.63	.47	.60	.47	.60	.67	.66	.54	.38	.33	.59	.40
	3	.62	.63	.66	**.90**	.53	.76	.70	.59	.66	.66	.59	.67	.51	.50	.51	.65	.63	.60	.49	.38	.40	.52	.28
5 Parsimony	1	.41	.43	.44	.46	**.71**	.47	.45	.41	.46	.44	.41	.37	.28	.45	.25	.39	.39	.44	.36	.36	.24	.40	.24
	2	.55	.53	.54	.54	**.86**	.55	.55	.47	.48	.54	.37	.47	.31	.44	.28	.50	.53	.44	.39	.39	.28	.42	.29
	3	.56	.52	.53	.59	**.87**	.58	.55	.50	.57	.56	.39	.49	.38	.51	.32	.50	.55	.51	.50	.38	.31	.48	.35
6 Information Quality	1	.78	.77	.78	.75	.62	**.91**	.83	.71	.71	.72	.68	.75	.49	.59	.56	.81	.80	.71	.53	.54	.44	.67	.31
	3	.72	.73	.76	.75	.59	**.92**	.81	.67	.69	.72	.63	.74	.53	.56	.59	.77	.76	.69	.53	.50	.43	.62	.33
	2	.67	.71	.69	.77	.56	**.88**	.77	.65	.69	.71	.66	.76	.55	.59	.57	.70	.71	.72	.59	.40	.36	.64	.22
7 Information Satisfaction	1	.75	.76	.74	.73	.56	.81	**.93**	.70	.70	.76	.60	.74	.55	.58	.57	.77	.78	.69	.55	.47	.42	.61	.32
	2	.80	.79	.77	.76	.63	.85	**.94**	.72	.72	.75	.61	.77	.49	.65	.58	.81	.82	.75	.62	.51	.44	.66	.35
8 Flexibility	1	.68	.70	.65	.58	.50	.66	.69	**.86**	.56	.58	.53	.60	.42	.49	.46	.68	.68	.56	.47	.41	.36	.50	.28
	2	.68	.65	.60	.61	.45	.62	.61	**.89**	.62	.59	.59	.62	.45	.55	.50	.65	.62	.51	.47	.39	.33	.46	.23
	3	.66	.69	.66	.62	.51	.67	.67	**.84**	.68	.64	.57	.68	.57	.64	.51	.61	.66	.63	.57	.41	.36	.59	.26
9 Reliability	1	.69	.70	.71	.70	.57	.72	.74	.69	**.92**	.80	.57	.71	.59	.70	.65	.76	.76	.68	.63	.39	.38	.65	.31
	2	.68	.70	.70	.71	.56	.73	.72	.67	**.93**	.80	.60	.72	.55	.68	.62	.76	.75	.64	.62	.40	.37	.56	.24
	3	.52	.49	.51	.60	.50	.59	.55	.54	**.80**	.58	.49	.54	.38	.52	.36	.56	.60	.56	.46	.36	.40	.52	.23
10 Timeliness	1	.67	.67	.73	.65	.52	.70	.70	.61	.72	**.88**	.54	.71	.58	.65	.55	.67	.70	.62	.61	.38	.38	.56	.26
	2	.64	.71	.71	.69	.58	.74	.72	.62	.70	**.88**	.56	.74	.54	.65	.52	.68	.70	.68	.62	.40	.48	.59	.30
	3	.76	.69	.68	.68	.58	.69	.73	.64	.79	**.91**	.50	.69	.56	.80	.60	.77	.77	.68	.76	.41	.46	.57	.34
11 Integration	1	.50	.55	.51	.57	.39	.59	.53	.57	.57	.51	**.88**	.57	.40	.45	.48	.57	.55	.52	.37	.33	.28	.42	.15
	2	.55	.57	.58	.57	.44	.67	.59	.54	.58	.55	**.84**	.61	.41	.49	.47	.58	.58	.57	.42	.33	.19	.48	.13
	3	.53	.56	.52	.51	.39	.63	.55	.58	.47	.48	**.88**	.54	.41	.43	.45	.53	.59	.51	.38	.36	.30	.46	.10
12 Accessibility	1	.67	.64	.62	.62	.41	.72	.70	.60	.61	.66	.60	**.86**	.52	.56	.55	.66	.66	.63	.51	.41	.38	.56	.23
	2	.69	.71	.72	.69	.53	.76	.72	.65	.67	.73	.62	**.89**	.50	.67	.55	.69	.74	.72	.66	.40	.40	.65	.28
	3	.61	.70	.66	.64	.48	.66	.67	.65	.67	.69	.50	**.85**	.52	.63	.50	.62	.58	.58	.59	.32	.35	.53	.20
13 Compactness	1	.48	.37	.44	.49	.33	.47	.46	.45	.51	.55	.36	.48	**.91**	.50	.57	.49	.50	.47	.47	.27	.15	.42	.25
	2	.52	.49	.53	.55	.39	.57	.52	.52	.55	.57	.48	.57	**.92**	.54	.65	.52	.55	.55	.50	.30	.29	.46	.25
	3	.49	.50	.56	.52	.36	.51	.52	.52	.52	.59	.43	.56	**.89**	.50	.64	.47	.48	.50	.50	.29	.30	.46	.23
14 Simplicity	1	.74	.65	.66	.65	.55	.66	.67	.62	.72	.78	.51	.70	.56	**.93**	.60	.70	.72	.65	.81	.36	.39	.60	.38
	2	.68	.63	.59	.60	.52	.61	.63	.64	.70	.74	.52	.69	.53	**.93**	.56	.69	.70	.65	.82	.41	.39	.61	.33
	3	.56	.42	.48	.43	.44	.43	.45	.44	.49	.59	.36	.51	.41	**.83**	.42	.52	.54	.46	.67	.21	.30	.41	.31
15 Mobility	1	.51	.49	.47	.51	.32	.52	.50	.46	.53	.55	.43	.48	.59	.48	**.88**	.57	.56	.46	.45	.34	.28	.40	.21
	2	.46	.47	.43	.46	.29	.48	.47	.47	.53	.50	.45	.46	.64	.49	**.81**	.53	.50	.42	.40	.25	.20	.39	.33
	3	.52	.54	.52	.51	.26	.59	.56	.50	.52	.54	.47	.59	.50	.52	**.83**	.62	.55	.47	.50	.29	.28	.44	.24
16 System Quality	1	.73	.70	.67	.65	.55	.75	.76	.71	.79	.74	.57	.68	.52	.65	.60	**.93**	.80	.66	.59	.52	.38	.59	.35
	2	.79	.75	.74	.73	.54	.81	.82	.71	.75	.77	.63	.76	.53	.69	.69	**.94**	.82	.70	.63	.43	.38	.62	.33
	3	.77	.75	.71	.67	.52	.79	.79	.69	.67	.71	.61	.67	.47	.67	.63	**.92**	.80	.66	.61	.50	.39	.63	.33
17 System Satisfaction	1	.78	.76	.70	.71	.57	.79	.82	.73	.76	.77	.62	.73	.52	.71	.63	.85	**.96**	.75	.66	.47	.40	.69	.38
	2	.79	.75	.73	.72	.59	.81	.82	.72	.76	.78	.64	.73	.56	.69	.59	.81	**.96**	.79	.68	.50	.49	.73	.39
18 Performance Expectancy	1	.63	.71	.69	.63	.49	.72	.73	.64	.63	.69	.59	.71	.49	.63	.54	.70	.77	**.91**	.60	.48	.49	.83	.43
	2	.61	.65	.69	.69	.52	.72	.69	.59	.67	.70	.58	.67	.54	.62	.44	.65	.72	**.90**	.60	.49	.47	.73	.36
	3	.56	.65	.66	.64	.53	.68	.68	.56	.64	.63	.51	.64	.50	.55	.47	.63	.70	**.92**	.53	.45	.43	.77	.39
19 Effort Expectancy	1	.68	.61	.58	.58	.48	.59	.62	.60	.67	.76	.46	.68	.54	.88	.54	.67	.71	.62	**.93**	.30	.39	.58	.32
	2	.63	.56	.55	.56	.50	.57	.59	.54	.60	.68	.40	.63	.50	.78	.49	.60	.68	.61	**.94**	.30	.41	.60	.35
	3	.58	.51	.50	.53	.45	.53	.53	.48	.54	.65	.40	.58	.48	.74	.49	.55	.55	.55	**.92**	.23	.37	.49	.29
20 Social Influence	1	.39	.43	.43	.37	.37	.46	.46	.41	.40	.40	.37	.39	.26	.33	.34	.46	.48	.49	.24	**.86**	.39	.49	.19
	2	.36	.34	.38	.37	.40	.43	.41	.38	.37	.35	.29	.33	.26	.30	.31	.41	.40	.41	.24	**.90**	.19	.40	.14
	3	.44	.45	.48	.41	.44	.51	.50	.43	.36	.42	.36	.41	.32	.35	.27	.48	.45	.46	.29	**.87**	.22	.45	.15
21 Facilitating Conditions	1	.38	.39	.36	.39	.29	.42	.41	.36	.39	.44	.28	.39	.25	.34	.26	.38	.41	.43	.32	.28	**.86**	.36	.37
	2	.32	.34	.32	.30	.24	.34	.36	.32	.33	.38	.21	.31	.19	.29	.23	.31	.34	.39	.29	.27	**.84**	.31	.34
	3	.23	.28	.31	.22	.20	.28	.29	.21	.23	.27	.15	.28	.13	.21	.15	.25	.28	.33	.26	.12	**.72**	.26	.39
	4	.42	.46	.45	.39	.35	.42	.43	.40	.42	.49	.30	.42	.29	.45	.32	.39	.46	.50	.47	.33	**.84**	.38	.48
22 Behavioral Intention	1	.52	.64	.62	.58	.46	.67	.63	.56	.59	.57	.49	.64	.44	.55	.47	.62	.68	.78	.54	.48	.41	**.94**	.33
	2	.50	.57	.61	.58	.48	.62	.60	.53	.59	.59	.44	.60	.45	.57	.44	.57	.66	.77	.56	.43	.37	**.92**	.41
	3	.58	.61	.63	.59	.53	.69	.66	.56	.63	.62	.52	.62	.49	.58	.47	.63	.73	.83	.56	.50	.35	**.92**	.27
23 Use	1	.35	.33	.27	.34	.36	.32	.36	.30	.29	.34	.15	.27	.27	.38	.31	.36	.40	.43	.34	.18	.49	.36	**1.0**

Table 8.6 Discriminant validity on construct level (Fornell-Larcker-Criterion) © 2023 IEEE

Construct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Format	**.92**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Completeness	.75	**.85**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 Currency	.75	.82	**.87**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 Accuracy	.73	.76	.76	**.88**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Parsimony	.62	.60	.62	.65	**.82**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 Information Quality	.80	.82	.82	.83	.65	**.90**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7 Information Satisfaction	.83	.83	.80	.80	.63	.89	**.94**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Flexibility	.78	.79	.74	.70	.57	.75	.76	**.86**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9 Reliability	.72	.72	.73	.76	.62	.77	.76	.72	**.89**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Timeliness	.78	.77	.79	.76	.63	.80	.81	.70	.83	**.89**	-	-	-	-	-	-	-	-	-	-	-	-	-
11 Integration	.61	.65	.62	.64	.47	.73	.65	.65	.63	.59	**.87**	-	-	-	-	-	-	-	-	-	-	-	-
12 Accessibility	.76	.79	.77	.75	.55	.83	.81	.73	.75	.80	.66	**.87**	-	-	-	-	-	-	-	-	-	-	-
13 Compactness	.55	.50	.56	.57	.40	.58	.55	.55	.58	.63	.47	.59	**.90**	-	-	-	-	-	-	-	-	-	-
14 Simplicity	.74	.65	.65	.63	.57	.64	.66	.64	.72	.79	.53	.71	.57	**.90**	-	-	-	-	-	-	-	-	-
15 Mobility	.59	.60	.57	.59	.35	.63	.61	.57	.63	.63	.54	.61	.69	.60	**.84**	-	-	-	-	-	-	-	-
16 System Quality	.82	.79	.76	.74	.57	.84	.85	.75	.79	.79	.65	.76	.55	.72	.68	**.93**	-	-	-	-	-	-	-
17 System Satisfaction	.82	.79	.75	.75	.60	.84	.85	.75	.80	.81	.66	.76	.57	.73	.64	.87	**.96**	-	-	-	-	-	-
18 Performance Expectancy	.66	.74	.75	.72	.57	.78	.77	.65	.71	.74	.62	.75	.56	.66	.54	.72	.80	**.91**	-	-	-	-	-
19 Effort Expectancy	.68	.60	.58	.60	.51	.61	.63	.58	.65	.75	.45	.68	.54	.86	.54	.65	.70	.64	**.93**	-	-	-	-
20 Social Influence	.45	.47	.49	.44	.46	.53	.52	.47	.43	.45	.39	.44	.32	.37	.35	.52	.51	.52	.30	**.88**	-	-	-
21 Facilitating Conditions	.42	.46	.45	.41	.34	.45	.46	.41	.43	.49	.30	.43	.27	.41	.30	.41	.47	.51	.42	.31	**.82**	-	-
22 Behavioral Intention	.58	.65	.67	.63	.53	.71	.68	.60	.65	.64	.52	.67	.49	.61	.49	.66	.75	.86	.60	.51	.41	**.92**	-
23 Use	.35	.33	.27	.34	.36	.32	.36	.30	.29	.34	.15	.27	.27	.38	.31	.36	.40	.43	.34	.18	.49	.36	**1.00**

Note: Bold numbers on the diagonal show the square roots of the AVEs; numbers below represent construct correlations

Table 8.7 Structural model results © 2023 IEEE

Construct	Variance Inflation Factor (VIF)								Effect Size (f^2)								Q^2
	6	7	16	17	18	19	22	23	6	7	16	17	18	19	22	23	
1 Format	2.99	-	-	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-
2 Completeness	3.76	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-
3 Currency	3.81	-	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-	-
4 Accuracy	3.23	-	-	-	-	-	-	-	0.18	-	-	-	-	-	-	-	-
5 Parsimony	1.95	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-
6 Information Quality	-	3.36	-	-	-	-	-	-	-	0.56	-	-	-	-	-	-	0.63
7 Information Satisfaction	-	-	-	-	1.65	-	-	-	-	-	-	-	0.61	-	-	-	0.69
8 Flexibility	-	-	2.78	-	-	-	-	-	-	-	0.08	-	-	-	-	-	-
9 Reliability	-	-	3.87	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-
10 Timeliness	-	-	5.13	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-
11 Integration	-	-	2.10	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-
12 Accessibility	-	-	3.73	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-
13 Compactness	-	-	2.20	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-
14 Simplicity	-	-	3.08	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-
15 Mobility	-	-	2.37	-	-	-	-	-	-	-	0.11	-	-	-	-	-	-
16 System Quality	-	-	-	1.01	-	-	-	-	-	-	-	2.98	-	-	-	-	0.62
17 System Satisfaction	-	3.37	-	-	-	1.01	-	-	-	0.25	-	-	-	0.96	-	-	0.65
18 Performance Expectancy	-	-	-	-	-	-	2.32	-	-	-	-	-	-	-	1.05	-	0.49
19 Effort Expectancy	-	-	-	-	1.65	-	1.73	-	-	-	-	-	0.11	-	0.02	-	0.39
20 Social Influence	-	-	-	-	-	-	1.39	-	-	-	-	-	-	-	0.03	-	-
21 Facilitating Conditions	-	-	-	-	-	-	1.43	1.23	-	-	-	-	-	-	0.01	0.20	-
22 Behavioral Intention	-	-	-	-	-	-	-	1.22	-	-	-	-	-	-	-	0.04	0.60
23 Use	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.24

Table 8.8 Path coefficients of control variables © 2023 IEEE

Path	Coefficient	p-Value	Path	Coefficient	p-Value
Command Level => Information Quality	-0.010	0.771	Experience (Years in a FD) => Information Quality	-0.004	0.879
Command Level => Information Satisfaction	0.001	0.983	Experience (Years in a FD) => Information Satisfaction	-0.026	0.411
Command Level => System Quality	-0.027	0.479	Experience (Years in a FD) => System Quality	0.051	0.145
Command Level => System Satisfaction	-0.015	0.671	Experience (Years in a FD) => System Satisfaction	0.004	0.895
Command Level => Performance Expectancy	-0.002	0.996	Experience (Years in a FD) => Performance Expectancy	0.031	0.541
Command Level => Effort Expectancy	-0.037	0.500	Experience (Years in a FD) => Effort Expectancy	0.013	0.810
Command Level => Behavioral Intention	-0.038	0.314	Experience (Years in a FD) => Behavioral Intention	0.001	0.962
Command Level => Use	-0.075	0.348	Experience (Years in a FD) => Use	-0.061	0.371

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9 Paper VIII: Ethnographical Insights into ERIS Adoption – Preliminary Results

Table 9.1 Fact sheet paper VIII

Fact	Description
Title	Which Factors Govern the Use of Emergency Response Information Systems? Insights from an Ethnographical Study of a Voluntary Fire Department
Authors	Julian Weidinger[1] julian.weidinger@uni-bamberg.de Sebastian Schlauderer[1] sebastian.schlauderer@uni-bamberg.de Sven Overhage[1] sven.overhage@uni-bamberg.de [1]University of Bamberg An der Weberei 5 96047 Bamberg, Germany
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Which Factors Govern the Use of Emergency Response Information Systems? Insights from an Ethnographical Study of a Voluntary Fire Department

Abstract. *To realize the digitalization potential of emergency response processes, several information technologies have been proposed that shall support firefighters in their operations. In the incident command process, especially emergency response information systems (ERIS) are supposed to raise the situation awareness and overall efficacy. Despite their theoretical potential, these technologies only slowly disseminate in practice, however. While extant acceptance models can basically explain firefighters' intention to use them, the actual usage so far remained unexplored. To gain an in-depth understanding of the specific domain and its influence on the usage of technologies, we ethnographically observed a voluntary fire department over several years. During its digitalization of command processes, we identified operational specialties like flexibility, organizational requirements like error culture, and social aspects like perceived importance that influence the introduction of an ERIS. These factors shall enrich existing acceptance models and help to better consider the special characteristics of the firefighter domain.*

Keywords: Disaster Information, Resilience, for Emergency and Crisis Technologies, emergency management, ethnography, firefighter information technologies, incident command, process digitalization.

9.1 Introduction

Improving the efficacy of emergency responders such as firefighters with information technologies is receiving increasing attention in academia and practice. In recent years, significant efforts have been made to digitalize and improve emergency response processes [35, 41]. Despite their significant potential, however, novel information technologies such as emergency response information systems (ERIS), intelligent clothing, or digital maps oftentimes disseminate only slowly in the firefighter domain [39].

This observation seems to apply particularly for the activity fields of incident commanders (ICs), who constantly need to assess the encountered emergency situation and make context-dependent decisions to coordinate the operation [1]. Information technologies reportedly have a significant potential to support the command processes, because the situation awareness – i.e., the perception of the environmental elements, the comprehension of their meaning, and the projection of their development – is a critical determinant for the quality of such decisions [1, 2, 10]. However, extant studies have shown that there exists a significant discrepancy between firefighters' intention to use supporting information technologies and the actual usage of such technologies in command processes [40]. The findings suggest that firefighters are willing to use supporting information technologies if they fulfill domain-specific requirements. Nevertheless, the actual use of such technologies in daily routine remains low.

Next to the acceptance of information technologies, it is hence also necessary to examine their introduction and use to fully understand the constraints prevalent in the firefighter domain. To help achieving this goal, we present the results of a study, in which we observed the introduction of an ERIS to support the command processes of an exemplary fire department. Thereby, we focus on the following research question: "*Which factors influence the introduction and practical usage of information technologies in the firefighter domain?*"

To obtain rich insights into this mostly unexplored field of study and be able to comprehend the background of our observations, we adopted an ethnographical approach. Thereby, one of the authors accompanied the introduction of an ERIS at his voluntary fire department, which resembles a "typical" organizational unit. While the observed fire department is located in Germany, there exist comparably organized departments around the globe. The obtained results contribute to the body of knowledge on the adoption of information technology in the emergency response domain. Our findings particularly suggest that the introduction and actual use of information technology is not only influenced by domain-specific user requirements (which determine the intention to use such technologies), but also by additional team-related and organizational factors, which so far have not been considered adequately.

The remainder of the paper is organized as follows: in the next section, we describe the background of our study and discuss related work. In section 9.3, we provide details of the ethnographical research methodology. The insights gained during our study are discussed in section 9.4. Section 9.5 concludes the paper by highlighting the implications and limitations of our study and providing an outlook on future research directions.

9.2 Background and related work

To establish a basic understanding of the study's background, we briefly describe the firefighter domain and discuss related research.

9.2.1 Fire departments and their digitalization

Around the world, fire departments are assembled as specialized emergency response organizations. They provide services in non-fault-tolerant, often time-critical situations, which largely dictate the characteristics of their special domain. With respect to the widely applied disaster management cycle [15], fire departments are typically concerned with two phases: preparation and response. Preparation comprises the provisioning of equipment, training the personnel, and defining operation procedures. In the response phase, fire departments provide help in a variety of emergencies. Typical areas of operation are firefighting, technical rescue, and hazardous materials operations [1, 6]. Also, fire departments play a key role in many scenarios of large-scale disasters [15]. Both phases go hand in hand since a successful response particularly depends on good preparation like the concrete design of local processes based on general regulations. Such regulations typically provide basic guidelines for the most important procedures. One of them is the incident command process, since it is crucial for the outcome of the whole operation [1, 2].

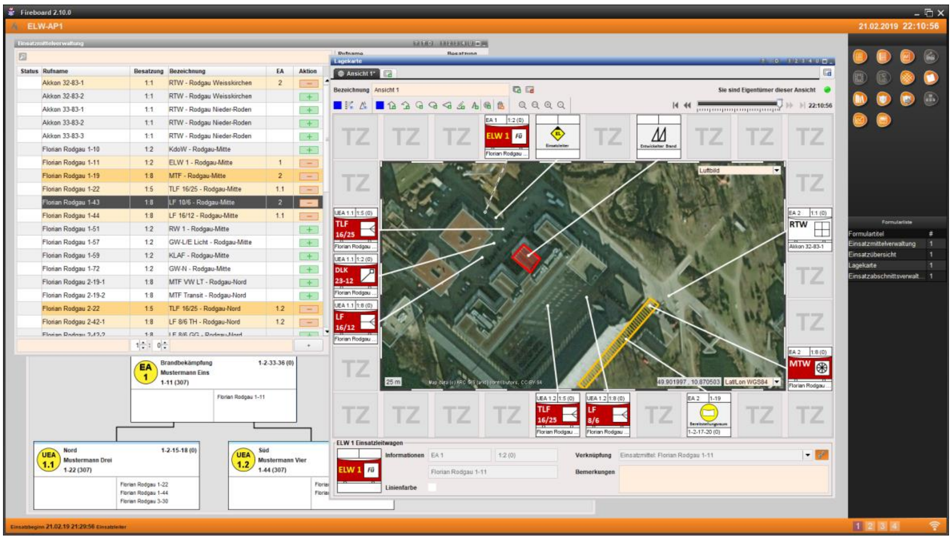


Figure 9.1 Exemplary ERIS "Fireboard" [11]

Over the last years, several novel technologies have been proposed to digitalize parts of the firefighter work and raise the situation awareness of firefighters. Among them are unmanned aerial or ground vehicles [18, 19], smart protective clothing [4, 30], and many others. A technology to specifically support command processes can be seen in ERIS. They provide a platform to gather, process, and share relevant operational information. As shown in Figure 9.1, they typically comprise an overview of responding units, the hierarchical command structure, and a situation map of the incident area. From a technological point of view, they can be divided in three evolutionary stages. Basic ERIS require the manual input of data by the user [11, 14]. Advanced systems partly automate this data input and capture real-time information from different sensors like GPS-positions of units or water tank levels [24, 29]. ERIS of the highest stage even automate parts of the decision-making by calculating recommendations and proposing them to the commander [3, 33]. A comprehensive overview of these systems can be found in literature [39, 40].

9.2.2 Acceptance and use of technologies

The acceptance and use of novel technologies have been extensively researched in the IS literature. The most prominent theories aim to explain it based on the users' attitudes and beliefs toward the technology. A recent examples of this approach is the *Unified Theory of Acceptance and Use of Technology* [37]. It postulates that the users' *Performance Expectancy*, *Effort Expectancy*, *Social Influence* and *Facilitating Conditions* will determine their *Behavioral Intention* and ultimately the *Use Behavior*. These constructs unify findings described in the *Innovation Diffusion Theory, Technology Acceptance Model*, and other established theories. Meanwhile, these models have been adapted and applied in several business and consumer domains [38, 40]. Amongst others, they can explain individual and organizational use decisions, utilitarian and hedonic scenarios, and mandatory and voluntary use cases. All these aspects can be further detailed. For example, voluntariness can be divided in several categories [34].

9.2.3 Related work

To identify related work concerning the acceptance of information technologies in fire departments, we used the results of a broad literature review that we conducted for a prior study. It considered EBSCOhost, ScienceDirect, SpringerLink, AISeL, ACM DL, and IEEE Comp. Soc. DL with search terms like *firefighter* and *fire department*. For ERIS just like most other technologies, we mainly identified studies with a technology-centered point of view. Only a few authors take the user's perspective or specifically address their acceptance of technologies. Multiple works analyzed command processes to design suitable interfaces and implement them in a system architecture [26, 27]. The capabilities of fire departments to adopt information technologies has been researched as well [32]. Multiple works have identified factors for the acceptance of ERIS by firefighters [39]. The integration of these factors into an acceptance model, however, illustrated that there remain certain blind spots to fully understand under which circumstances fire departments use novel technologies like ERIS [40]. While the intention to use can be reasonably well predicted, the factors governing actual usage still can be explained only weakly.

To examine such unexplored and often social phenomena, ethnography has been proven to be a suitable method. In the field of sociology, there exist several ethnographies examining the specialties of emergency responders. Van Maanen, for example, exhibits ethnographic research about police officers [36]. Regarding firefighters, there has been a special focus on wildland firefighting [7, 9] and the role of gender [13, 25]. In Information Systems and Computer Science research, ethnographic methods have been applied to understand firefighter interactions during structure fires to derive design implications [8, 20, 28]. Other areas of application were the temporal effects of information technology in emergency operations [22], the interplay between emergency planning and response [16], and general interactions of first responders with information technology [31]. What comes closest to the focus of the work at hand is an ethnographic study about introducing digital plans in Swedish fire departments [23]. While ethnography therefore seems to be a widely applied and established research method in this domain, we could not identify studies examining the command processes of fire departments. It hence remains unclear how emerging technologies such as ERIS can digitally support the command processes of firefighters.

9.3 Methodology

To help closing this literature gap, we pursued an ethnographical approach that allowed us to gain in-depth insights into the reality of a fire department and the digitalization potentials of its command processes.

9.3.1 Research approach

Following Van Maanen's seminal guidelines [36], our goal was to capture first-hand experiences from the firefighter domain. As shown before, such input seems necessary to enhance existing acceptance models that insufficiently explain firefighters' use of technologies. Participatory observations, as included in ethnographic approaches, are especially suited to gain such in-depth insights [36]. For several reasons, we decided to observe the digitalization of command processes in a voluntary fire department. First, despite the publicity of some professional departments (like the FDNY), in many countries most firefighters are volunteers (e.g., 67% in the US, 96% in Germany). Second, one of the authors has been a long-year member of a voluntary department, thus being able to conduct participatory observations. Third, the observed department started a project to digitalize its command processes in 2018. Since command is vital for the overall success of an operation, these processes are of specific interest [1, 2].

The recommendations of Klein & Myers served as another guideline to ensure the rigor of our observation and analysis [21]. For *contextualization*, we described the general domain in section 9.2, details about the case are given in the next section. The *interaction between researcher and subjects* was collegial. One of the authors is a trained firefighter and has been member of the department prior to this study. Therefore, he could directly participate in all official and social activities. From our point of view, this is the only realistic way to obtain in-depth insights and be able to capture *multiple interpretations* from a voluntary fire department. Main reasons are that the operations occur extremely spontaneously, and most other things happen outside normal office hours of a researcher. However, to rule out biases (*suspicion*), the observations were documented in a diary and frequently discussed with the non-firefighter co-authors. For *abstraction and generalization*, the gathered data was coded, grouped based on common themes, and labeled accordingly. The resulting insights presented in section 9.4 were linked to theoretical concept wherever possible. Nevertheless, we tried to make our observations unprejudiced and linked them to theory afterward, to also identify contradictions to or gaps in existing theory (*dialogical reasoning*).

9.3.2 The Haßfurt Voluntary Fire Department

As in many other countries, fire departments are organized on the municipal level in Germany. We studied the Haßfurt Voluntary Fire Department, a fire department that provides emergency services for the 13,500 inhabitants of Haßfurt. Located in Bavaria, Germany, the city is the largest municipality in the rural district Haßberge. On an area of 53 km^2, it is structured into the city center and nine separate city districts.

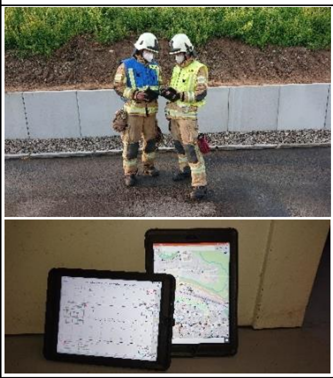
Although the pure numbers might seem quite small, there are several characteristics that make the city an interesting and challenging area from a firefighter's point of view. Haßfurt is linked to all kinds of traffic infrastructure. The river Main and its adjacent streams flow right through the city. A federal freeway and other busy roads cross its boundaries. The city's regional airport processes more than 10,000 annual aircraft movements. Those traffic routes provide the potential of ship, car, or aircraft accidents, as well as floods and other scenarios. Moreover, the city has several special facilities itself. The historic city center comprises many culturally significant buildings packed closely together. Several schools and retirement homes, as well as the hospital have regional catchment areas. There are multiple buildings near the high-rise threshold as well as industrial plants and warehouses. Large forests and agricultural areas complete the highly diverse cityscape. All these characteristics combined make Haßfurt a rather interesting environment with quite challenging conditions in relation to the small size of the city.

To cope with these challenges, Haßfurt maintains a well-equipped and trained voluntary fire department. Its main fields of duty are firefighting, technical rescue, and hazardous materials operations. The members are volunteers, as it is common in Germany. This means that training and other predictable activities are done in their leisure time, mostly in the evenings. For emergency operations, the firefighters get alerted by pagers or sirens and head to their station to staff the needed vehicles. Over the last years, the department responded to an average of 180 annual incidents with a peak at 300. The 373 volunteers are supported by two fulltime employees in administrative and maintenance issues. The department headquarter houses a command center, several workshops, and a broad spectrum of specialized equipment. Eight smaller fire stations are distributed around the city districts. The department operates 22 vehicles, including engines, ladders, and boats.

9.3.3 Digitalization of command processes

Starting in fall 2018, the fire department has begun to continuously improve its incident command (IC) and adjacent command support processes. The introduction of novel IT solutions has been a key aspect of this still ongoing project. Three specific subdomains have been iteratively addressed by now (see Table 9.2). In the first iteration, the vehicles were equipped with tablets. On these devices, the IC and the squad leaders can access relevant information like building plans and operation guidelines. Besides that, several apps can be used to distribute information amongst the command staff. For example, pictures from different angles of the operation site, situation maps, and so on can be easily shared.

Table 9.2 Iterations of the observed project

Iteration	Tablets for command staff	Command center	Command vehicle
Focus	Single unit + communication	Large-scale disasters	All mobile operations
Kick-off	Fall 2018	Winter 2018	Spring 2020
Sample images			

In the second iteration, starting in December 2018, the command center processes were addressed. The command center in the headquarters is staffed in large-scale disasters like blackouts, thunderstorms, or floods. Apart from these special occasions, a regional control center alerts departments and coordinates operations. To support the commanding of large-scale disasters, the command center in Haßfurt was equipped with five PCs and the ERIS Fireboard – a basic system with respect to the categorization of section 9.2.1. A command support unit (CSU) was formed that is responsible to operate the command center. In multiple training sessions, a standard staffing of six functions was established: Two CSU members answer incoming calls or faxes and generate prioritized tasks based on the information. The IC and the command assistant allocate the available units to these tasks. Finally, two CSU members manage and document communications with responding units, the regional control center, and other institutions.

The most impactful iteration started in March 2020 and concerned the command structures on the site of the operations. A new command vehicle was procured and configured according to the new, digitalized command processes. Amongst others, it contains three computers running the ERIS Fireboard and an exterior display for situation reports. The vehicle responds to any operation of the department. The default staffing was defined with three functions: The IC coordinates the operation. The command assistant supports the IC in the field. He acts as an advisor or gets assigned to command a separate sector in larger operations. One CSU member operates the vehicle and establishes a command post with it. His tasks are to look up relevant information, to maintain overviews of responding units and a situation map in the ERIS, and to manage and document the communication on site, with the control center, and other institutions.

9.4 Key observations

During our study, we gained the following insights why and how the observed fire department introduced an ERIS and integrated it into its command processes. While some results seem to apply to all kinds of fire departments, others seem specific for voluntary ones.

9.4.1 Emergency management needs flexible guidelines instead of rigid processes.

Amongst firefighters it is widely acknowledged that no incident is like the other and unexpected events can occur in virtually any situation. Over the last years, we observed countless examples for this in Haßfurt: a car standing vertically on its front after an accident, multiple gas containers in what appeared to be a normal vehicle fire, exotic scorpions in a burning apartment, etc. The same applies to the command of an operation. It is hardly possible to estimate the needed means and processes of command at the beginning of an operation. Imagining a BPMN of emergency command processes, there would be endless branching gateways and ad-hoc structures needed to come near a realistic illustration.

Due to this level of uncertainty, fire departments need flexibility in their work. As Denef et al. [8] framed it: the structures of firefighter operations are rigid, but the units acting within these structures are largely independent. This also is the case in Haßfurt, where firefighters organize in teams, squads, and platoons. For some operation types, these units' initial measures are given in standard operating procedures. All measures beyond the initial phase, however, are dependent of the specific situation. Instead of fixed processes, firefighters rely on guidelines like mnemonics, checklists, and regulations. The regulation for command, for example, structures an emergency command process into a circle with three phases: reconnaissance, planning, and issuing of orders [1]. The command staff iterates through this circle multiple times during an operation. Each officer applies it for his/her current situation, the unit(s) under command, and the orders from higher command levels.

This quite basic circle has also proofed to be a solid base to deduce functions and tasks in the digitalized command processes of the observed department. The tablets help squad leaders in their reconnaissance. In the command center, capturing information from telephone and fax supports reconnaissance, the allocation of units is a planning task, and communication supports the issuing of orders. In the command vehicle, all three phases are supported by a single operator. Precise processes are defined in neither of the three areas. Only checklists are provided for certain tasks like launch of the respective devices, available systems including their features, etc. Priority lists define specific tasks that must be executed in any case, for example ensuring communication with the control center. Other tasks are defined as optional and are executed ad-hoc in idle times or on request. Posters provide overviews of the most important tasks that can be requested from the CSU.

The described degree of flexibility in the process must consequently be representable in the used systems, as well. This assessment also corresponds with other studies, in which flexibility has been shown as a major factor for the intention to use an ERIS [40]. We could observe such flexibility in many regards in the ERIS used in Haßfurt. The main functionalities are grouped in freely accessible modules like *resources* to organize units and *operation logs* to protocol important events. There is no defined order in which the modules must be used. While often-used data like properties of local units can be predefined, the user can always add new elements at runtime. In the multi-user mode, the tasks can be freely distributed among the users. What requires flexibility of the user, however, is that the system can crash, which we observed a couple of times. In that case, the user will switch to pen and paper as a backup and – if there is time – they will try to solve the problem.

9.4.2 Command structures must be able to grow and adapt with the operation structures.

From a firefighter perspective, a burning fire has many factors in common with a living creature. It needs air to breath, it consumes flammable materials as food, and it grows. Generally, diffusion or spread is seen as one of the major dangers in any type of emergency operation. Diffusion needs to be prevented or, if it is inevitable, the responding units need to adjust their response according to it. For this reason, emergency operations grow like fires do. Growing operations imply increasing numbers of units. For these additional units, the command structures must be able to grow in an equivalent way. Therefore, German fire departments think in four levels of command. They range from level A, where the squad leader of a single unit commands without support, to level D, where an executive staff acts with numerous support personnel and consultants. Within these levels, the operation can be divided in areal or thematical sectors and sub-sectors. As a rule of thumb, each officer shall have at least two and at most five units or sectors under their command.

The focus on command levels was evident in the observed case, as well. The tablets for the squad leaders support level A, the command vehicle the levels B-C, and the command center the levels C-D. While the levels as such seemed quite clear from the beginning, it was the transition from one level to another that caused problems. In the command center, a Thunderstorm in 2019 showed that the standard staffing of six functions cannot be realized right from the beginning. The voluntary members of the CSU arrive at the station one by one, while the telephones start ringing in the first minute. As a reaction, a preliminary stage was defined, in which the most important tasks are divided among only three functions. In the command vehicle, the suspected emission of explosive gases in an industrial plant in September 2020 demonstrated how fast the standard staffing of three functions can be overwhelmed with a growing operation. At that time, there was no real concept on how to grow. Especially the operator of the vehicle was unable to fulfill all the given tasks (communicate with IC and control center, research the dangers from the emitted gas, define staging areas for approaching units, etc.). Meanwhile, the vehicle gets staffed with four functions for certain types of emergencies. If further growing is needed, additional CSU members from other units get assigned to man functions 5 and 6. Responses to fires in a hospital (2020) and a dormitory (2021) showed a clear improvement.

This ability to grow, which might be referred to as scalability, could in parts be observed in the used ERIS, as well. In the system, the operation can be easily divided into sectors and units can be assigned to them. The numbers of personnel are automatically summed up for the whole operation. Most importantly, there is a multi-user functionality that, however, only works for local networks by default. Looking at the literature, the growing of operations and scalability of used systems has not been of great interest, so far. Most authors do concentrate on specific levels of command, i.e. single units [8], normal-size operations [41], or large-scale disasters [35]. However, the transition from one level to the other is hardly discussed in the literature. Also in practitioner outlets, most of the work seems to be only concerned with the separate levels [1, 2]. The same applies for the acceptance of ERIS, for which scalability has by now not been examined as a relevant factor.

9.4.3 Lack of error culture is one possible root for a perceived resistance to change.

In operations, trainings, and interactions with other departments, we observed a significant resistance to change among firefighters. While this finding is in line with other studies and practitioner outlets [12, 39], we could also observe some possible roots for this phenomenon. Generally, there seems to be an attitude to never change a running system. Changes might risk the reliability of usual habits and making them right is a time-consuming task. More specific for fire departments is that they feel a strong pressure to appear as competent and infallible in the eyes of the public. It is essential that, in an emergency with lives at stake, people blindly trust their fire department. Therefore, it is quite common among fire departments that mistakes are not discussed in public or in front of outsiders. While this may still appear plausible and reasonable, many departments overdo it. They often do not even internally talk about errors and possible consequences. It appears to us that they confuse the outwardly presented infallibility with an actual one – which can, realistically, not be reached.

This situation can be described as a lack of error culture that is, of course, not a black or white situation. Many departments try to introduce a more open handling of errors. In this regard, the observed case is a pleasant example. The adaption of command processes in Haßfurt was informed by identified and analyzed errors. During the iterative process of improvement, feedback was frequently gathered and openly discussed. Of course, there remained skeptics in the department and even within the CSU that considered the project to be exaggerated for the size of the department or a waste of time. However, with each training or operation, in which improvements over the former status quo got visible, these voices fell silent. Meanwhile, the new processes have become firmly established within the department. The major drawback remains that they are still quite unique in the surrounding area. Most of the neighboring departments observed this "revolution" rather suspiciously than openly interested.

Summing up, the widespread lack of error culture amongst fire departments seems to decline only slowly. The small steps toward a more open attitude seem to be depending on the will and perseverance of individuals. To better understand the interrelationships between error culture and resistance to change as well as their impact on the acceptance and use of technologies, further research is necessary.

9.4.4 Unveiling experiences or due investments trigger major progress.

Apart from the general existence of an error culture, we could observe two triggers that seem to be needed for substantial progress in a fire department. First and foremost, a firefighter relies on his own experiences. Be it at fighting fires or using hydraulic rescue tools – firefighters seem to learn things best by doing them. This focus on personal experiences often transfers to decision making. Progress like fundamental process adaptions is often triggered by events that illustrate need for action. Another, more external trigger can be due investments. Typically, publicly funded equipment of a fire department gets replaced on a regular basis. In a voluntary department the replacement cycle of a vehicle can be more than 25 years. On the one hand, whenever the replacement of a vehicle is pending, it triggers the department to get informed about the current state of the art. On the other hand, internally desired progress must often wait for such a due investment, because old equipment cannot be adjusted for the new requirements or there is simply no financial support.

For the command center in Haßfurt, the triggering event was a thunderstorm in 2015, which confronted the department with more than 100 incidents in less than an hour. Until then the command center coordinated large operations for many years, most prominently floods of the river Main. There has always been a long lead time and the situation changed only sporadically. In the 2015 thunderstorm, however, the untrained personnel with their usual paper forms and Excel sheets were totally overwhelmed. Based on this event, the CSU was established, and the command center got its digital upgrade. For the command vehicle, there was an unveiling event, as well. At a structure fire in 2017 with two fatalities the IC could not contact the control center with his handheld radio. For the stronger vehicle radio, he had to run a hundred meters away from the incident area several times. At that time, command support was completely missing in mobile operations. However, in this case the desired technologies could not be integrated into the existing equipment. The command vehicle at that time was an SUV without sufficient space for any computer workstations. Consequently, it needed the procurement of a new command vehicle, that was planned for some years later, as an additional trigger.

Summing up, we observed two triggers to introduce novel technologies in a fire department. First, users must be convinced by own experiences. It seems reasonable to intentionally evoke such experiences in trainings instead of real operations to avoid dangers and not depend on chance. This way, technologies and processes can also be better standardized across the departments. While we observed such approaches in practitioner seminars, technology acceptance literature has not taken this topic into focus. Neither has the second trigger of due investments been researched.

9.4.5 Personnel is biggest strength and biggest weakness of a voluntary fire department.

On first sight, it appears clear that qualified personnel is scarce in fire departments – just like in most other professions. In voluntary fire departments, however, personnel matters are of a quite unique, two-fold nature. On the one hand, voluntary firefighters do their service as a (very special) hobby besides their actual job. Due to this fact, the members can come from all social groups. They may comprise highly educated and specialized experts of virtually any profession. In that regard, they may even have higher educated personnel than professional departments in certain areas. The experts can be used to address highly complex topics and problems. On the other hand, especially these higher qualified members tend to commute to other cities or are engaged in their actual job during office hours. They are hence less available for emergency operations in these times. Consequently, especially the most important tasks in the initial phase of an emergency response must be comprehensible for any ordinary firefighter and not only a few experts.

The fact that the adaption of command processes in Haßfurt went hand in hand with the introduction of novel information technologies was only possible because the department had multiple IT experts. They implemented specific solutions in the command center and vehicle and the used systems. One example is the administration of continuous VPN connections between the ERIS workstations for remote multi-user access. In Operations, all

CSU members take turns on the vehicle. For the less experienced users, there are checklists provided for the most common tasks as well as the handling of the most frequent errors. Besides that, certain routine activities like the transfer of unit status and alarm data from the control center into the ERIS were automated. These are just some of the measures taken to facilitate the work in the command vehicle and in similar form in the command center.

Regarding the used ERIS, most users acknowledge that it is quite intuitive to use but still requires some routine. Especially for the firefighters that do not regularly work with computers in their job, we could observe a noticeable insecurity. However, only by including this group, the staffing of command vehicle and center in Haßfurt can be ensured throughout the day. This demonstrates why processes and technologies in emergency management must be generally designed for the easiest possible handling in operations. This is in line with existing literature, in which ease of use is seen as a major acceptance factor for ERIS and other systems [40]. The question of personnel availability, however, is rarely raised in the literature. One reason might be that voluntary departments are much more affected by this problem than the more often studied professional ones. Nevertheless, voluntary departments are the vast majority in many countries and not all professional departments do have IT experts. Hence, future research must consider the availability of qualified personnel as a non-trivial requirement for digitalization, especially in fire departments.

9.4.6 Command work must be perceived as important and can be perceived as fun.

As we observed, the common firefighter seems to be a craftsman. He/She likes manual work and to see the results of the actions right away: splash water and the fire goes out, kick in the door and the way is free. In contrast to manual actions, command work is of a more theoretical nature and its results are less visible. The command staff itself may have the power of decision-making as a kind of compensation. The command support staff, however, has theoretical work to do without any apparent benefit. While this applies for all kinds of fire departments, the problem is further increased for the voluntary ones. First, there are very limited options for disciplinary consequences since a volunteer is much less dependent than an employee. Second, the members do the service as a hobby and typically seek a change from their everyday work routine. Especially the ones working with computers all day do not necessarily want to continue this activity in their hobby, while the others do “the real work”. It is these people, however, who are best suited for the command support. All in all, motivating firefighters for this kind of work appears to be a difficult task.

One key factor of success in the observed case was to establish an overall understanding of the importance of command and especially command support. The commanders tried to keep the events triggering the process adaption and the expected improvements in the minds of their firefighters. They did so with personal conversation, by mentioning them in meetings and press releases. The establishing of the CSU as a special task force illustrated the topic's significance as well. CSU members obtain incentives like specialized trainings or seminars and the option to "reserve" the command vehicle in an online calendar. In that time, they can assume the operator position despite the common first-come-first-served staffing principle. What might seem like negligible trifles does work much better than monetary incentives in this special domain, since the firefighters work out of conviction. Another motivator we could observe was fun. Especially for younger members, the use of an ERIS can be framed as playing a video game. Amongst some of this group the term of "playing Fireboard" has meanwhile become established.

Be it perceived importance or just fun – especially for voluntary fire departments it is important that the members are motivated and show the desired behavior as result of their own will. While we know of several practitioner publications about motivating firefighters, research has so far largely omitted the topic. In most cases, firefighter information technologies are examined from a technological point of view and human factors are left out. In the literature of technology acceptance in general, however, there are several constructs that might help to map the observed phenomenon. *Job relevance* [5] and *Perceived enjoyment* [17] might be suitable concepts for what we called perceived importance and fun. *Hedonic motivation* [38], *Intrinsic motivation* [37] or various aspects of *Voluntariness* [34] might capture the overall topic. Such human or social factors should receive more attention in future research of firefighters' use of technologies. Our observation indicates that they are essential for the success of such projects.

9.5 Concluding Remarks

During our ethnography, we could gain in-depth insights into factors influencing the digitalization of command processes in a voluntary fire department. The study has implications for academia and practice alike.

9.5.1 Implications

From the academic point of view, we elaborated on many specific aspects that characterize the firefighter domain. This complements existing literature that does acknowledge the domain's high specialty but insufficiently explains exactly why it is so special. Our study constitutes a detailed domain characterization with specific focus on the highly important command process. At the same time, we answered our initial research question and identified several factors that influence the introduction and practical usage of new information technologies in the firefighter domain. These add several new perspectives, which enrich extant models explaining the acceptance of / intention to use technologies like ERIS [40]. The first perspective concerns specificities of the command process itself with a high degree of flexibility and scalability in processes, personnel, and systems as important factors. As a second perspective, we found organizational requirements for progress like the introduction of novel technologies, namely an existing error culture, the presence of a triggering event, and due investments. Finally, we identified human or motivational aspects such as personnel availability, perceived importance, and fun. Exactly these soft factors might resemble some of the blind spots of extant acceptance models. Including them may lead to a more holistic understanding of the topic. Next to the firefighter domain, our insights are transferable to other emergency management domains, especially those with comparable volunteer structures. Some findings like the unexpected importance of soft factors for the use of technologies are also relevant for business or private contexts. The gained insights did, however, not only deliver answers but created just as many open questions that may serve as starting points for future research. Some of our own plans will be described in section 9.5.3.

For practice, we shed light on the phenomena and mechanisms in voluntary fire departments that so far might even have remained hidden for those involved. On the one hand, this concerns the firefighters themselves. The awareness for their own needs and ability to articulate them may be strengthened by our insights. Furthermore, uncovered aspects like the lack of error culture may initiate a rethinking in departments. On the other hand, the vendors of technologies can use our findings to better match their products to the users' needs. Products that better support firefighters during their operations will ultimately raise their efficacy and may save lives in the long run.

9.5.2 Limitations

When interpreting our results, several limitations should be considered. First of all, we observed a single case (i.e., one fire department). Although our contacts to other departments confirmed most of our assessments, there might still be undiscovered differences. Moreover, our research object was a voluntary department in Germany. While our insights into operational processes will be transferable to professional departments as well, other findings are rather specific for voluntary ones. Also, the insights may only be transferable to countries like the US, where comparable volunteer structures exist. The specific focus on command processes only partly allows for statements about other processes in a department, as well. Also, our approach to provide a broad overview of several aspects prevented a deeper discussion of each aspect on its own.

General limitations associated with the method of ethnography are the lack of quantifiability and the challenge of objectivity. In particular, the researcher was deeply involved as a long-year firefighter. This appeared to be the only realistic way for ethnographic work in a voluntary fire department with spontaneous operations and most other activities in the leisure time. However, to control the rigor of our study, we followed established rules [21]. Frequent discussions with the less involved co-authors were moreover conducted to prevent biased interpretations. The pandemic situation leads to an additional limitation, since there were restricted training conditions and lower incident numbers at times during our study.

9.5.3 Future Research

As mentioned before, the project of digitalizing the command processes in the Haßfurt Fire Department is still ongoing. We want to continue our observation and try to gather additional insights. With the end of the Corona pandemic, more trainings and an increasing number of incidents can be expected. We also plan to conduct semi-structured interviews with the involved actors. This way, our observations can be complemented with firefighters' subjective perceptions. Another plan is to interview experts from other departments. Our experience makes us assume that the identified insights will largely apply to most fire departments, at least in Germany. Nevertheless, there might be additional factors or alternative interpretations that should be considered. The ethnographical insights may be used to enhance existing models to describe the acceptance and use of information technologies by firefighters. Finally, the long-term appropriation of ERIS after the initial acceptance is of interest. For these endeavors, we hope to provide a suitable starting point with the results of our study.

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10 Paper IX: Ethnographical Insights into ERIS Adoption – Final Results

Table 10.1 Fact sheet paper IX

Fact	**Description**
Title	Determinants for the Acceptance of Emergency Response Information Systems: Ethnographical Insights into the Digitalisation of a Voluntary Fire Department
Authors	Julian Weidinger[1] julian.weidinger@uni-bamberg.de Sebastian Schlauderer[1] sebastian.schlauderer@uni-bamberg.de Sven Overhage[1] sven.overhage@uni-bamberg.de [1]University of Bamberg An der Weberei 5 96047 Bamberg, Germany
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Determinants for the Acceptance of Emergency Response Information Systems: Ethnographical Insights into the Digitalization of a Voluntary Fire Department

Abstract. *Fire departments are one of the most versatile and widespread emergency management organizations. To support their digitalization, innovative firefighter information technologies such as emergency response information systems (ERIS) are suggested. Despite theoretical potentials like raised situation awareness, however, these technologies seem to disseminate only slowly in practice. As existing acceptance models cannot sufficiently explain the acceptance of novel technologies in this special domain, literature calls for increased contextualization. To get insights into the domain-specific acceptance factors, we conducted an ethnography and observed a voluntary fire department's multi-year project to introduce an ERIS. We identified seven factors, like revealing events and error management culture, which acted as triggers for different adoption stages. From overarching characteristics of a voluntary fire department, we derived six additional acceptance factors, like situational adaptability and self-determination. The identified factors can help firefighters in conducting successful digitalization projects, and policy makers in supporting voluntary emergency management organizations. Moreover, the results provide numerous avenues for future research, can be linked to various research fields and contextualize existing acceptance models. Beyond fire departments, the results may be transferred to similar high-reliability organizations.*

Keywords: emergency management, ethnography, firefighter information technologies, incident command, process digitalization.

10.1 Introduction

To better cope with increasingly occurring human-made and natural disasters, significant efforts are made to improve emergency response processes and to provide a better infrastructure for first responders such as firefighters [1]. Digitalization, that is the use of digital technologies to provide new efficacy-increasing opportunities, seems to have a particularly promising potential since the success of emergency responses considerably depends on the ability of first responders to understand and adapt to the encountered situation with context-dependent decisions. In such circumstances, information technologies and systems can help firefighters to improve their *situation awareness*. This comprises the perception of relevant environmental elements, the comprehension of their meaning, and the projection of their future status [2]. To improve the situation awareness, several innovative technologies for firefighters have been suggested, including digital maps, smart protective equipment, unmanned vehicles, and emergency response information systems (ERIS). While most of these technologies are meant to provide a rather specific support, ERIS introduce a generic platform that supports the gathering, analysis, and communication of mission-critical information in incident command processes. They hence appear to be particularly suited to enhance the overall situation awareness on site.

Despite the potential to improve the situation awareness, however, the digitalization of firefighter processes and the dissemination of the proposed information technologies in particular appear to be progressing only slowly [3]. As one reason for this observation, literature emphasizes that digitalization approaches and technologies have been suggested mainly based on their theoretical potential. Such technology-driven approaches ignore that information technologies are delicate artifacts for emergency responders because several tight usage constraints exist during emergency responses. To explore the factors that impact the acceptance of information technologies and systems in the emergency response domain, research has only recently begun to develop specific acceptance models that reflect domain-specific requirements such as reliability, mobility, or simplicity [4]. While these models explain the intention to use better than generic acceptance models, they still seem to miss relevant factors. Especially actual usage remains poorly predicted and appears to be contingent on other, so far unexplored factors.

To provide insights into the conditions that facilitate digitalization approaches and the acceptance of information technologies in the firefighter domain, we present the findings of an ethnography, in which we closely observed a multi-year project to introduce digital support for the command processes in a typical voluntary fire department in Germany. A core element of this project was the introduction of an ERIS, which allowed us to examine the following research questions: *"Which determinants guide the digitalization of a voluntary fire department? Which factors determine the acceptance of ERIS by firefighters?"* During our observation, we identified several triggers for different stages of technology acceptance. Beyond that, we found characteristics of voluntary fire departments that influence digitalization projects. While the results are closely related to the observed fire department, we deem them to be transferrable to other fire departments in Germany and around the globe, because they are often organized as voluntary service units with comparable structures and constraints.

To put our results into perspective, we integrate the identified factors into an acceptance model that is based on the Unified Theory of Acceptance and Use of Technology

(UTAUT) as well as the User Satisfaction literature [5, 6]. The model was developed to describe the usage constraints of ERIS and was hence felt appropriate as a theoretical framework to classify our results. With the identified acceptance factors, we also answer a call to contextualize the UTAUT [7]. We hence complement existing acceptance theories such as the UTAUT with a domain-specific perspective that might also be able to explain the usage of other firefighter information technologies as well as technologies in other high reliability organizations with similar structures and constraints. From a practical perspective, our insights can help firefighters in conducting successful digitalization projects, vendors in designing suitable technologies, and policy makers in strengthening voluntary emergency response organizations.

We proceed as follows: next, we describe the concept of ERIS, existing acceptance theories, and related works in detail. In section 10.3, we discuss the chosen ethnographic research approach and describe the study object. The key insights are presented and discussed in section 10.4. In section 10.5, we link the identified factors to existing acceptance models, discuss implications and limitations. Section 10.6 concludes the paper.

10.2 Background and related work

10.2.1 Firefighter information technologies

All over the world and for centuries, fire departments have been assembled as highly available emergency response organizations. According to the widely applied disaster management cycle, firefighters are typically engaged in the phases of preparation and response [1]. Preparation comprises all activities to establish, equip, and train a fire department. Firefighter responses typically include firefighting, technical rescue, and hazardous material operations [8]. Beyond that, fire departments often play a key role in dealing with large-scale disasters [1, 9]. To ensure positive outcomes, both phases must go hand in hand. Amongst others, departments should prepare concrete, local processes to guide their responses. For the most important topics, such processes can build upon general regulations that provide basic guidelines. One of these topics is incident command and command support, which is crucial for the outcome of the whole operation [9, 10].

A quite unique feature of fire departments are their mostly voluntary structures in many countries, which fundamentally distinguish them from other agencies like police or emergency medical service. Some examples include China with 98%, the United States with 65%, and Germany with 97% volunteers [8]. Such structures appear necessary to achieve a sufficient density of departments and ensure quick response times especially outside major cities. In contrast to career firefighters, volunteers receive no or only minimal payment for their service. They are firefighters as a hobby besides their regular jobs. In case of an emergency response, they must first rush to their stations to gear up and staff the needed vehicles. Apart from this evident difference, voluntary firefighters typically have the same rights and duties as their paid colleagues [11]. They undergo similar trainings, use the same equipment, and respond to the same types of emergencies.

To stay safe and make correct decisions within an operation, firefighters must gain situation awareness [2]. As a means to achieve this, literature proposes several firefighter information technologies. A recent review gives an overview of the different technology types and remaining literature gaps [12]. The technologies range from data-driven approaches for forecasting and detection, over unmanned aerial and ground vehicles, to personal firefighter augmentation with smart protective equipment and augmented reality. Remaining gaps in the domain include the support beyond the reconnaissance phase and merely firefighting missions as well as user-centered aspects like technology acceptance.

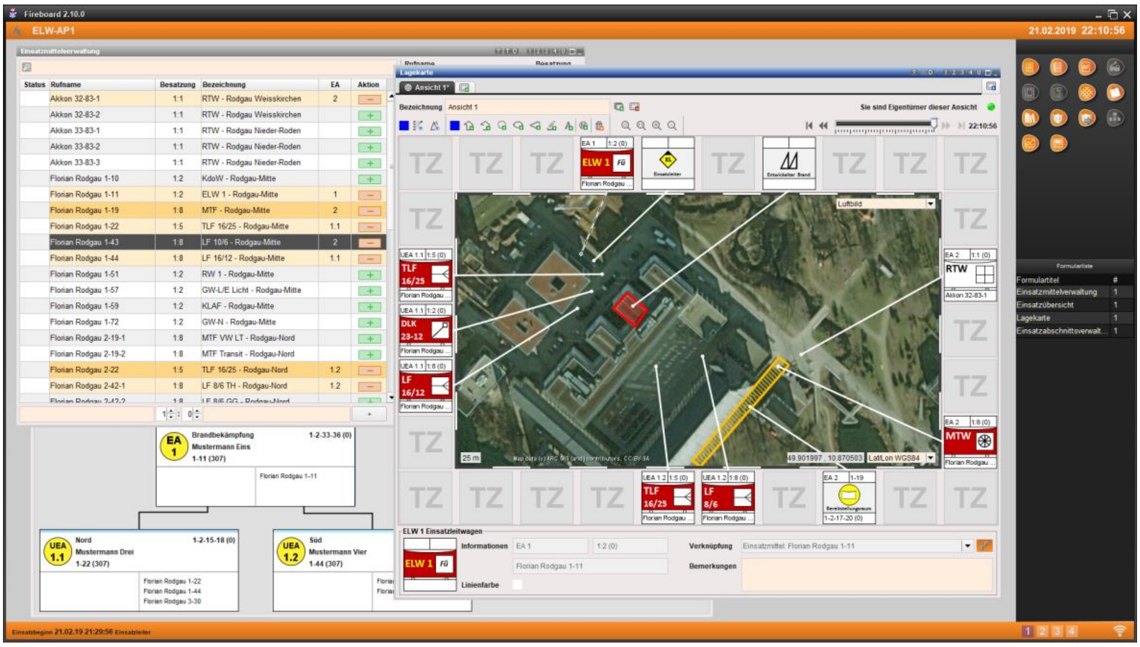

Figure 10.1 Exemplary ERIS "Fireboard"

Among the firefighter information technologies, ERIS appear especially promising. They are designed to holistically support the incident command process across all phases and for all operation types, which addresses two major literature gaps [12]. ERIS provide a platform to gather, process, and share relevant information about an emergency operation. As displayed in Figure 10.1, typical elements of an ERIS include an operation log, an overview of responding units, a representation of the command structure, and a situation map. ERIS can be further divided into three evolutionary stages regarding their degree of automation. Most currently available systems require the manual input of data [13, 14]. Advanced systems, which are so far mostly discussed in research, can capture automatic sensor inputs for unit positions, water tank capacities, and others [15, 16]. ERIS of the highest stage can use the available data to derive suggestions for commands and actions, which categorizes them as decision support system [17, 18].

10.2.2 Digitalization of fire departments

Digitalization and the acceptance of novel technologies has been extensively researched in the past. Amongst others, the UTAUT and its predecessors (Technology Acceptance Model, Diffusion of Innovations Theory, etc.) have been successfully applied in several contexts [5]. Recent contributions, however, indicated numerous potentials for further development [7]. Amongst them are the need for new conceptions of technology use and the identification of new endogenous, exogenous, or moderating mechanisms. The proposed areas of research are summarized in Figure 10.2. Most prominently, Venkatesh, et al. [7] call for an increased contextualization of UTAUT, considering context-specific factors. Following this call for research, our study examines digitalization and technology acceptance in the special context of firefighters.

Technology acceptance by firefighters is not well understood by now, as the previously mentioned review shows [12]. For most technologies, including ERIS, the study found a clear focus on technology-driven works. Only few works take a user-driven perspective or specifically examine technology acceptance in this domain. A couple of papers analyzed command processes to derive appropriate interfaces and integrate them in a system architecture [17, 19]. Another study identified general capabilities a fire department must have to be able to adopt information technologies [20]. The review found only one study that explicitly took the identification of acceptance factors for firefighter information technologies into focus [21].

A subsequent study integrated such factors into a model explaining the acceptance of ERIS, which is summarized in Figure 10.2 [4]. Based on the ideas of Wixom and Todd [6], the authors interpreted information and system satisfaction as antecedents of the core UTAUT constructs. Regarding the contextualization call of Venkatesh, et al. [7], they resemble *technology attributes*. The resulting model revealed important information and system characteristics. With a coefficient of determination (R^2) above 0.75, it could reasonably well predict a firefighter's intention to use an ERIS [4]. The predictive power for actual usage, however, remained weak ($R^2 < 0.5$). To fill the remaining blind spots, an increased contextual understanding appears necessary.

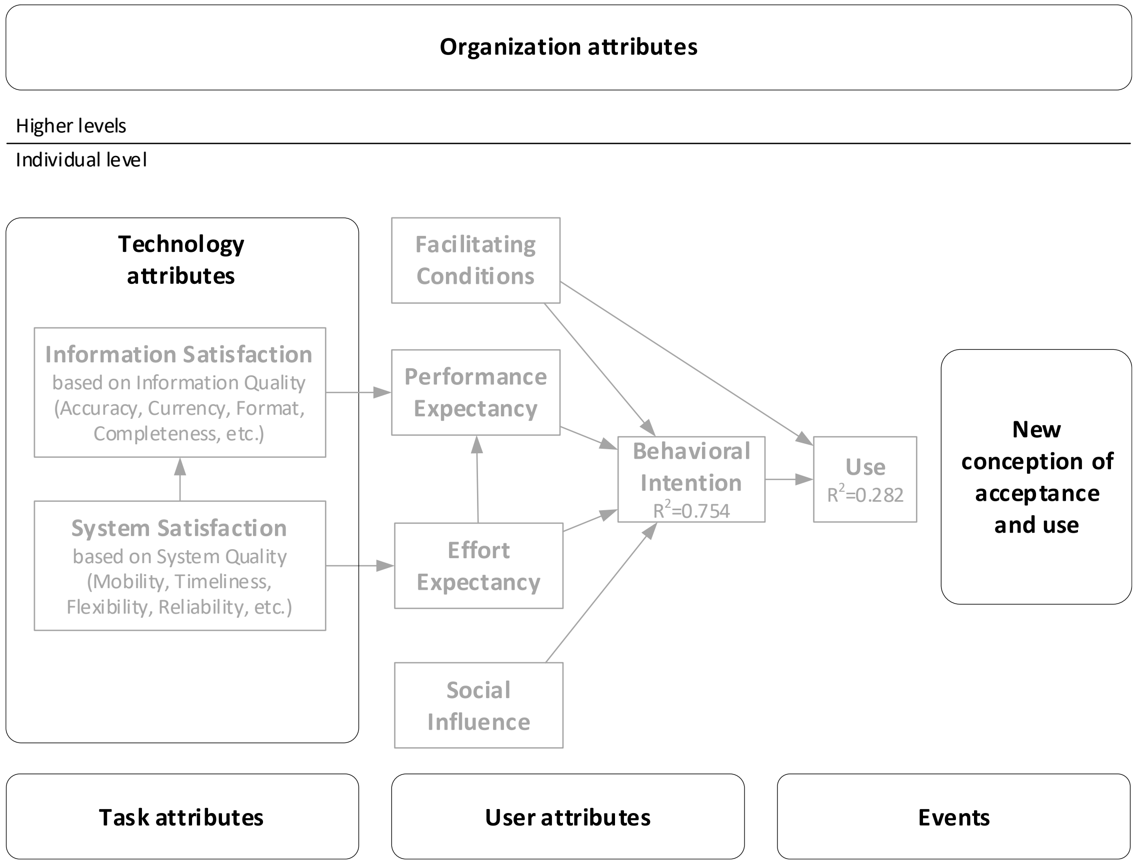

Figure 10.2 Summary of extant literature
Legend: UTAUT-based acceptance model for ERIS based on Weidinger, et al. [4] in faded grey with calls for contextualization based on Venkatesh, et al. [7] in solid black

10.2.3 Ethnographic research about firefighters

Despite initial insights, the digitalization of fire departments remains a rather unexplored phenomenon. To explain such phenomena in special organizational contexts, literature suggests conducting ethnographic research to gain deep insights [22]. For the emergency responder domain, ethnographic studies can especially be found in the field of sociology. The seminal work of Van Maanen [23], for example, exhibits insights into the routine of police officers. With the specific focus on firefighters, multiple studies examined wildland firefighting [24, 25] and the role of gender [26, 27]. Other recent works focused on learning in fire departments [28], the coping with temporal boundaries [29], and the impact of life-death decisions [30].

There are examples of ethnographic research in the fields of information systems and computer science research, as well. Most prominently, it was employed to derive design implications from firefighter interactions during structure fires [31, 32]. Other studies concentrated on the preparation phase. They examined the interrelations of emergency planning and emergency response [33] and the projection of structure fires to enable proactive responses [34]. We also identified two studies in the command context. One illuminated the interaction of first responders with information technology on the multi-agency level [35] and the other examined technological challenges of digital plans in Swedish fire departments [36]. Overall, ethnography seems to be an established research method in the firefighter domain. However, we could not identify any study examining digitalization of the incident command processes in fire departments. It hence remains unclear under which specific circumstances novel technologies like ERIS can be integrated in the command processes of firefighters.

10.3 Methodology

To bring light into the dark, we aimed to directly observe and experience the adoption of an ERIS in a fire department. We had the chance to ethnographically accompany a voluntary fire department over multiple years to gain in-depth insights [23, 37]. In the following, we describe the observation site, the observed project, the data collection, and analysis of our study.

10.3.1 The Haßfurt Fire Department

Our observation site was the Haßfurt Voluntary Fire Department, which provides emergency services for the 13,500 inhabitants of Haßfurt in Bavaria, Germany. While this pure number might seem small, there are several characteristics that make the city a quite interesting area of firefighter operation. As the largest municipality and administrative seat of the county, it is home to several facilities with regional catchment areas. Among them are schools, dormitories, authorities, retirement homes, and a hospital. The historic city center with its narrow alleys includes numerous churches and other culturally significant buildings. It is contrasted by large commercial areas, industrial plants, and several buildings near the high-rise threshold. The nine separate city districts distributed over 53 km^2 complete the highly diverse picture with extensive forests and agricultural areas. Regarding traffic infrastructure, Haßfurt is linked to a federal freeway and other busy roads. The city’s regional airport processes 10,000 aircraft movements per year. The river Main flowing through the city is a federal waterway and used for passenger and freight traffic. Summing up, the city combines a variety of special characteristics packed into a quite small area. For a firefighter this means an interesting and challenging mix of potential dangers. They range from structure, industrial, and wildland fires, over car, aircraft, and ship accidents, up to floodings and many other scenarios.

To cope with these dangers, the city of Haßfurt maintains a highly trained and well-equipped fire department. Like 97% of German firefighters, the 328 members are volunteers who work in regular full-day jobs as well. Therefore, predictable activities like trainings are typically held in the evenings or on weekends. For the unpredictable emergency operations, the firefighters get alerted via pagers or sirens. They rush to their fire station, equip themselves and staff the needed vehicles. On average, the department responds to about 200 emergencies per year. To support the volunteers in maintenance and administrative issues, the department has two fulltime employees. Nevertheless, most work including the observed command processes are done fully by volunteers. Of the nine fire stations, eight smaller ones are distributed across the city districts. Several workshops and specialized equipment are centralized in the headquarters. Overall, the department has 24 vehicles as well as several trailers and roll-off containers. Among them are engines, an aerial ladder, a water tender, a heavy rescue vehicle, and boats.

10.3.2 Command support facilities

Figure 10.3 Command center impressions

Our observation focused the digitalization of the department's two major command support facilities and the surrounding processes. The command center in the department headquarters (see Figure 10.3) gets staffed only in large-scale or long-lasting disasters like thunderstorms, floodings, or blackouts. On such occasions, the regional control and dispatch center will just forward all incident data to the municipal fire departments where the further coordination is managed. Besides that, citizens will also directly contact the fire departments. During the observed digitalization project, the command center got equipped with five PC workstations and the ERIS Fireboard. More importantly, a command support process including pre-defined functions was established. As displayed in Figure 10.4, it is based on the three-phase command circle [10]. For reconnaissance, two functions answer incoming emergency calls and transfer them into prioritized tasks. For planning, the incident commander and the command assistant evaluate these tasks and decide which units to dispatch. Finally, the transmission of information gets managed by two functions for incoming and outgoing communications via radio, telephone, and email. To staff the newly established functions, a command support unit (CSU) was founded. This special task force recruits its members from ordinary firefighters which frequently train the new command support processes.

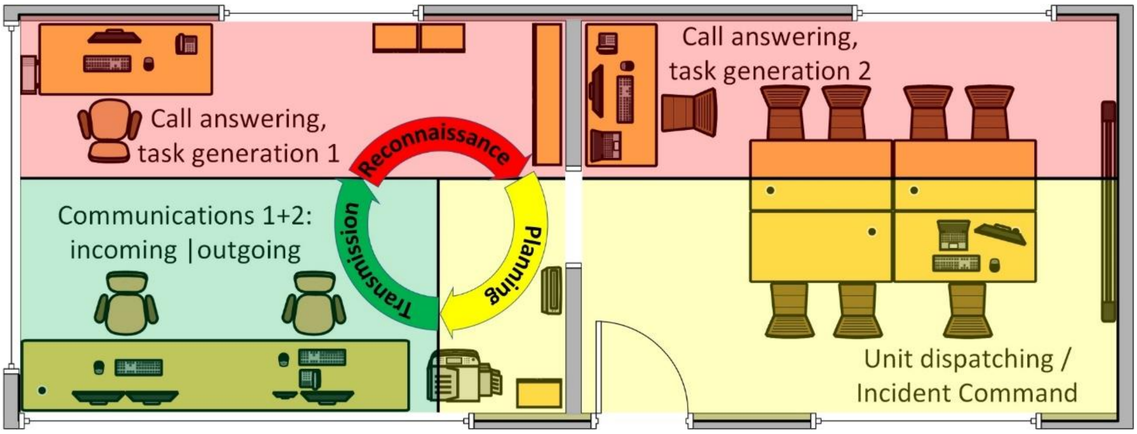

Figure 10.4 Current command center setup (excerpt, translated from original resource)

The other major facility is a newly procured command vehicle for mobile operations and command support on the operation site (see Figure 10.5). It carries three PC workstations, the identical ERIS as the command center, extensive office equipment, and many more accessories. Like the command center, it is staffed by the CSU. The standard crew comprises three functions. The incident commander leads the department's response. The command assistant supports him/her in the field. As an officer at special disposal, the assistant may, for example, take command of an operation sector. One CSU member operates the vehicle and establishes a command post with it. This includes information gathering, holding radio contact to the regional control and dispatch center, and documenting important events in the operation log. On special occasions, like large-scale operations, the standard crew can be extended up to six functions. Figure 10.6 displays this highest expansion level and summarizes the task areas covered by the command vehicle.

Figure 10.5 Command vehicle impressions

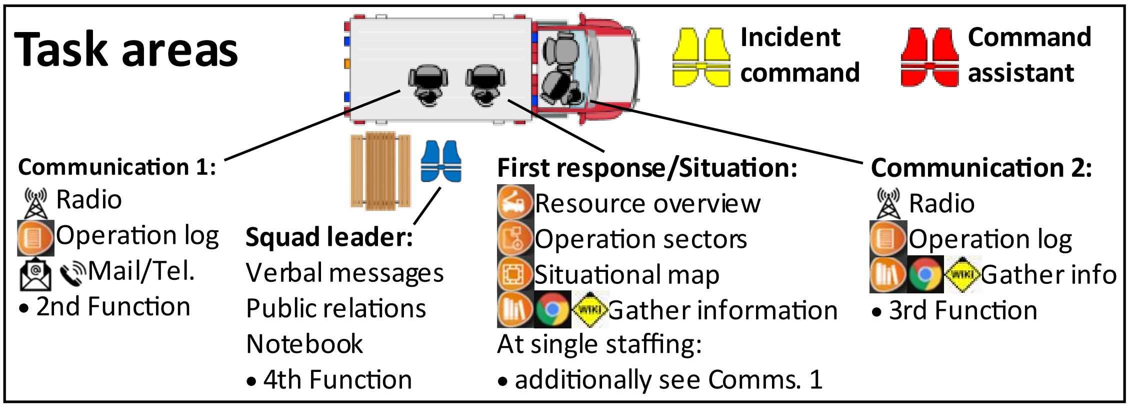

Figure 10.6 Current command vehicle setup (excerpt, translated from original resource)

10.3.3 Data collection

The observed digitalization project extended over a period of multiple years. Its official beginning is marked by the foundation of the CSU in September 2018. From then on, we consciously observed and documented the developments. Significant events from previous years have already been witnessed but not explicitly observed. Major milestones were the command center digitalization in December 2018, the command vehicle test operation from March 2020, and its active operation from September 2020 on. These marked usage decisions in terms of technology acceptance and the completion of the digitalization project from the fire department perspective. However, we continued the still ongoing observation to cover long-term aspects. This paper describes the insights up to the year 2024.

The extensive observation was conducted by the first author, who is a trained firefighter and has been a member of the Haßfurt Fire Department since 2004. Besides rich firefighter experience, he also has a background in the IT sector and holds a master's degree in information systems. The observation took place in the context of his PhD studies about the acceptance of firefighter information technologies. At the observation beginning in 2018, he had the position of a squad leader and signed up for the newly founded CSU. In May 2021, he was elected assistant chief of the department. From then on, he could not only experience the perspective of a firefighter and CSU member, but also of a command assistant and incident commander as described in the section before. The decisions of digitalization itself, the use of an ERIS, the software selection, and the command support processes have been made prior to this. Therefore, these new perspectives mainly account for the long-term usage observation and the better interpretation of prior events.

The observation itself as well as the later data analysis were informed by the established principles of Klein and Myers [22], which are italicized in the following paragraphs. The *interaction between the researcher and the subjects* can be described as companionable

[22]. The first author actively engaged in form of a participant observation [38]. Since 2018, he participated in several trainings (17 explicitly for the CSU), more than 400 emergency responses, countless surrounding talks, and social activities of the department. Such deep involvement might be the only realistic way to capture *multiple interpretations* and gain a holistic insight from a voluntary fire department [22]. Their emergency operations occur extremely spontaneously, and planned activities typically happen outside normal working hours of a researcher. The observation focus was on the digitalization project including related problems, solutions, opinions, facilities, processes, etc. Despite theoretical knowledge of extant acceptance models, we did not aim to verify certain factors or adoption phases. Instead, we aimed for an unprejudiced observation to identify novel aspects and enable *dialogical reasoning* based on our data [22].

Our observations were documented in multiple ways. The observer frequently took fieldnotes of project-related and otherwise relevant events, observations, talk impressions, etc. and collected them in a diary [38]. Due to the nature of a voluntary fire department with spontaneous responses and sporadic "office hours" in the evenings, notes could not be taken daily but on a rather scattered timeline. Besides his own notes, the observer had access to all training and organizational resources of the department. These included, for example, the intended command setups displayed in Figure 10.4 and Figure 10.6 as well as official reports of trainings and responses. Finally, we also collected audio-visual resources in form of pictures and videos.

10.3.4 Data analysis

The goal of our research was to identify aspects influencing the digitalization of a voluntary fire department and, more precisely, the introduction of a new technology. For this, we aimed to tell a *Realist Tale* as categorized by Van Maanen [23]. To inductively derive insights from our data, we applied open coding techniques [39]. Related observations and resources were grouped to common concepts and labeled with speaking names. For example, the concept *revealing events* in section 10.4.1 combines multiple aspects. First, the observer personally witnessed the hectical situations and stressed impression of the involved firefighters in the referred events. Second, the decision-makers themselves told that these events *"made problems evident"* and *"opened our eyes"*. Third, official reports of the operations state the experienced problems and later training resources name them as the motivators for change. Like this, the identified concepts are based on combinations of the different resources and inductively identified.

To rule out possible biases resulting from the observer's deep involvement (*suspicion*), the observations and derived concepts were frequently discussed with the non-firefighter co-authors [22]. In our analysis and the insights described in section 10.4, we focused on novel concepts that have not yet been described in related research. For example, the significance of *information format* and *system reliability* in the acceptance of ERIS have already been proven and were omitted [4]. The identified concepts could be further organized in the two overarching themes of *stages and triggers for technology acceptance* (section 10.4.1) and *characteristics of voluntary fire departments* (section 10.4.2).

To interpret the identified concepts, we built on several *contextualization* information [22]. Section 10.2.1 described the firefighter domain and firefighter information technologies in general. Sections 10.3.1 and 10.3.2 explained the observed department and its command support facilities in particular. For *abstraction and generalization* purposes, we tried to link our identified concepts to existing theory where possible [22]. To explain them, we integrated findings of various research disciplines. They illustrate the generalizability beyond the observed project and fire department. For the overall interpretation presented in section 10.5, we integrated the identified concept into an extant acceptance model [4]. The causal relationships between the newly added concepts and the existing constructs were derived via axial coding [39]. This procedure illustrates how the inductively identified concepts uncovered gaps in or contradictions to existing theory, which is in line with the principle of *dialogical reasoning* [22].

10.4 Key Insights

During our observation of the Haßfurt Fire Department, we drew several insights from the command support digitalization project. On the one hand, they can explain certain stages and triggers of technology acceptance within a fire department. On the other hand, they comprise general characteristics of voluntary fire departments that may have an overall influence on their digitalization potentials. In the following, we describe our observations and discuss them in relation to existing literature.

10.4.1 Stages and triggers of technology acceptance

The adoption of information technologies can be seen as a process of multiple stages. Technology acceptance literature refers to the intention to use and the decision of actual usage as the main stages. Beyond this, the long-term use can be seen as the final stage of adoption. For all three stages, we observed specific triggers that were needed to reach the respective stage in the Haßfurt Fire Department. These are summarized in Figure 10.7 and described in the following sections.

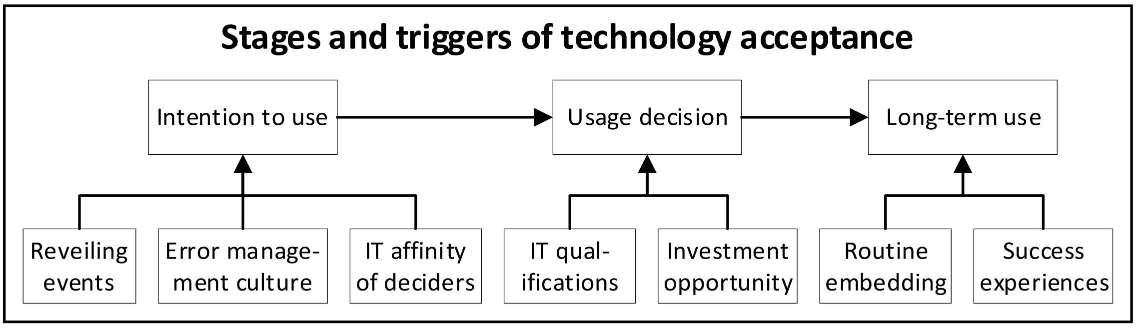

Figure 10.7 Stages and triggers of technology acceptance

10.4.1.1 Revealing events

To trigger a fire department's intention to use an ERIS, many incidences must convene. Typically, firefighters feel a rather strong resistance to change. They work in hectical, sometimes life-threatening situations and demand reliable technologies to support them. Therefore, many firefighters resemble true incarnations of the term *never change a running system* – unless it appears necessary. To illustrate such necessity, the personal experience of revealing events can serve as a major trigger. In the Haßfurt Fire Department, two such revealing events occurred. The first one took place on July 5th, 2015, when a heavy thunderstorm hit the city. Within an hour, the fire department got confronted with 107 simultaneous incidents. Without any dedicated command support structures and using paper or excel sheets, the department was completely overwhelmed by the situation. The second revealing event occurred on October 14th, 2017, at an apartment fire with two fatalities. During the operation, the incident commander had communication problems with his handheld radio. Without any on-site command support, he had to run from the incident area to his command vehicle several times to communicate important information with the control center.

These observations can add to a more holistic view of the intension to use technologies. The trigger of revealing events implies that firefighters learn best from their own experiences. This is in line with the educational theory of experimental learning [40]. Especially in safety critical domains like firefighting or police, extreme events revealing a need for change could be systematically provoked in trainings. On the one hand, this could trigger intentions in more departments and help disseminate innovative technologies. On the other hand, this could avoid revealing events during real operations where affected people could be harmed. We know of practical approaches to deliberately stress command staff during trainings. However, its interpretation as a trigger of intention to use technologies might add a valuable perspective. In terms of Venkatesh, et al. [7], it would resemble an *event*.

10.4.1.2 Error management culture

To trigger the intention to use an ERIS, such revealing events must at the same time fall on the fertile ground of an existing error management culture. This is not given in every department, by far. Most departments are quite considerate about maintaining a nimbus of infallibility, especially in the eyes of the public. Therefore, mistakes will rarely be discussed or even mentioned in any public context. This appears insofar comprehensible that civilians must be able to blindly trust the firefighters in life-threatening situations of an emergency. However, many firefighters confuse this nimbus of infallibility with actual infallibility. They believe their own tale of doing all that is humanly possible to avert harm from the community and of negative developments always resulting from the situation itself – never from their own mistakes or misjudgments. This perceived infallibility is not only unrealistic. It is often an impediment to a working error management culture where mistakes can be admitted, analyzed, and conclusions can be drawn. In this respect, the Haßfurt Fire Department was a pleasant example. Those responsible did acknowledge own mistakes revealed by the before-mentioned events. They analyzed them and tried to bring about improvements.

A lack of error management culture can be an explanation for the frequently reported resistance to change in fire departments [21, 41]. In psychology, error management culture stands in contrast to error aversion culture and is supposed to improve overall performance [42]. Also, error management culture on organizational level will promote innovativeness on organizational as well as individual level [43]. In the firefighter domain, error management culture was shown to be related to lower accident occurrence rates while error aversion culture relates to a higher one [44]. Despite this evidence from psychology and safety science, we could not identify any study that examined error management culture in the context of technology acceptance. It may be integrated as an *organization attribute* and, due to the generalizable nature, enrich acceptance models in many different contexts [7].

10.4.1.3 IT affinity of deciders

The fact that the improvements of command support in Haßfurt included the intention to use an ERIS required a third trigger: a certain IT affinity of the deciders. Fire departments typically follow a rather strict hierarchy. Therefore, strategic decisions largely depend on the opinions of the respective chief and perhaps his/her assistants. Besides that, fire departments are organized at the communal level in many countries, which provides the individual chiefs with a certain freedom in decision-making for their respective municipality. In that sense, the organizational level and the individual level of technology acceptance will often become blurred in a fire department. In the observed case, the chief was used to working with IT from his job and aware of its potentials. Therefore, his intention was not only to modernize command support and assemble the CSU as a task force. He also wanted to digitalize command support with a modern ERIS at the same time.

Such IT affinity of deciders appears to be closely related to the already established construct of computer self-efficacy [45]. The more interesting point here is the blurring of individual and organizational level effects. Due to the hierarchical structure of a fire department, many aspects heavily depend on few individuals. One could argue that this also applies to the before-mentioned error management culture, which is an organizational characteristic. Such culture must be wanted and exemplified by the command staff individuals to introduce and maintain it. While a fire department with its strict hierarchy may be an extreme case, mitigated forms of the described aspects can be found in business and other contexts, as well. As a construct, IT affinity resembles a *user attribute* but points toward the importance of cross-level effects [7].

10.4.1.4 IT qualifications

Once the fire department committed to the intention of using an ERIS, additional triggers seem necessary for the decision to actually use it. The department's team must have certain IT qualifications for the introduction of such a system. On the one hand, IT experts are needed to enable full-fledged operation. Luckily, the observed department does have such experts. They administrate all the necessary hard- and software in the command facilities and realized custom solutions like a VPN for remote data exchange. On the other hand, the prospective users of the ERIS should bring at least basic IT skills. With the typical firefighter rather being a craftsman than a theorist, this is anything but self-evident. In Haßfurt, most CSU members are familiar with computers from their everyday jobs. Only with these two team qualifications fulfilled, the observed fire department could decide to realistically integrate an ERIS into its command support.

The above observations can help understand firefighters' actual technology usage, which is rather unclear by now [4]. The necessity of certain IT qualifications includes multiple facets. First, a firefighter's confidence in using an ERIS may be described by established constructs like computer anxiety [46], computer literacy [47], and computer self-efficacy [45]. These might introduce factors that go beyond *effort expectation* or *ease of use*, which are typically considered in technology acceptance literature and precede usage intention. From our observation, they could rather be interpreted as specific *facilitating conditions* in terms of the UTAUT [5] or *user attributes* [7]. Second, needed team qualifications constitute a special challenge for volunteer organizations. They are typically not free to choose their personnel or retrain them from scratch. The overall voluntariness aspect will be explained in detail in sections 10.4.2.5 and 10.4.2.6.

10.4.1.5 Investment opportunity

Another potential trigger for the usage decision typically lies outside the departments. In most countries, fire departments are financed by public means. Investments therefore require the approval of the relevant bodies. An ERIS comes with significant one-time and running costs. That alone was not a problem in Haßfurt. In the command center, it was only the ERIS itself and two computers that had to be added to the existing infrastructure. These manageable investments could be quickly implemented. However, in mobile operations, the ERIS could not straightforwardly be integrated in the existing infrastructure. The command vehicle at that time was an SUV without sufficient space for a computer workstation. The necessary procurement of a larger command vehicle could not be spontaneously implemented. In Germany, like most other countries, emergency vehicles are normally replaced at regular intervals. In Haßfurt this interval is between 15 and 25 years. Consequently, the integration of the ERIS into mobile operations was on hold until the end of the replacement interval. Only the investment opportunity for a new command vehicle enabled the usage of the ERIS here.

An investment opportunity as a usage trigger is another aspect that may complement existing literature. There are several approaches to integrate monetary views into acceptance models. They range from actual *cost* [48] to perceived constructs like *price value* [49]. However, we observed investment opportunities to go way beyond a mere amount of money. It can rather be interpreted as an external trigger that is a basic prerequisite for the technology usage. As such, it constitutes an *event* according to Venkatesh, et al. [7]. Besides fire departments, this trigger may also be relevant for other public institutions and business contexts, where innovation must wait for predefined replacement intervals.

10.4.1.6 Routine embedding

Even if a fire department has purchased an ERIS, it is not yet a given that it will keep using it in the long-term. Two triggers may have enabled this in the Haßfurt Fire Department. Long-term use typically needs the technology's integration into user activities. However, users in a voluntary fire department have way less opportunities to use a new technology than typical fulltime employees. To still provide as many points of contact, it seems important to embed the technology in as many routines as possible. For this reason, in Haßfurt the ERIS is supposed to get used in every single emergency operation – even smaller ones where command support is not necessarily needed. Only this way and with frequent trainings, the CSU staff could get used to the system and gain experience with it. Over time, several process adjustments and change requests toward the vendor were identified by the team. Meanwhile, the team, the technology, and the process have quite well adjusted to each other.

While the factors leading to the punctual decision of technology adoption are well understood, the long-term interaction between users and technology has been researched far less extensively. One existing concept that could represent our observations is technology appropriation. It can be interpreted as part of a multilevel cycle. Following the adoption, a newly designed technology may be *explored*, *evaluated*, and *adapted* by its users. This appropriation can, in turn, deliver input for another design process [50]. By now, the decision if and how a technology gets appropriated, has mainly been addressed in a philosophical way. For example, the appropriation decision itself may be explained by Marx's dichotomy of human nature and his concepts of *perception*, *orientation*, and *appropriation* [51]. Technology appropriation strategies may be derived from cultural appropriation in the new world, including *baroquization*, *creolization*, and *cannibalism* [52]. The above-described, deliberate embedding of the ERIS into working routines may indeed be a factor fostering its appropriation. As such, it can be interpreted as an *organization attribute* and may be transferable to other contexts of technology usage, as well [7].

10.4.1.7 Success experiences

Besides routine embedding, a certain sense of achievement may be another potential trigger. Best suited seem personal success experiences. They can be interpreted as counterparts to the before mentioned revealing events. While the ones trigger the initial intention to use an ERIS, the others are needed to confirm the usage decision and motivate long-term use. In Haßfurt, several such success experiences occurred over time. One was a thunderstorm on June 22nd, 2019. The newly introduced ERIS and the adapted processes led to a much calmer and more structured working style compared to the revealing thunderstorm in 2015. For mobile command support, larger operations impressively demonstrated improvements, as well. A gas leakage in an industrial plant and a compartment fire in a hospital in 2020, fires in a dormitory and a production hall in 2021, and a barn fire in 2022 are just some examples. In all these cases, command support as well as command staff could experience the positive effects of the digitalization project first hand. This way, they stayed convinced and motivated to keep using the introduced ERIS on the long-term.

The observed success experiences can be interpreted as the demonstration of digitalization results. Such *result demonstrability* has been observed as an acceptance factor for other technologies or innovations, as well [53]. Even if expectations from the adoption get negatively disconfirmed over time, success experiences may still facilitate technology appropriation. The basic prerequisite seems to be that identified benefits must exceed experienced restrictions [54]. Despite some obstacles during the integration of the ERIS in Haßfurt, the success experiences frequently demonstrated the benefits. It was somewhat fortunate that there were emergency scenarios suitable to demonstrate the ERIS's benefits. As a compensation, success experiences could also be intentionally provoked in training situations. Nevertheless, experiences from real operations will be much more impressive for a firefighter. This might imply that larger fire departments with more frequent operations have a larger chance of result demonstration and can more easily appropriate new technologies. Success experiences can be interpreted as *events* [7].

10.4.2 Characteristics of a voluntary fire department

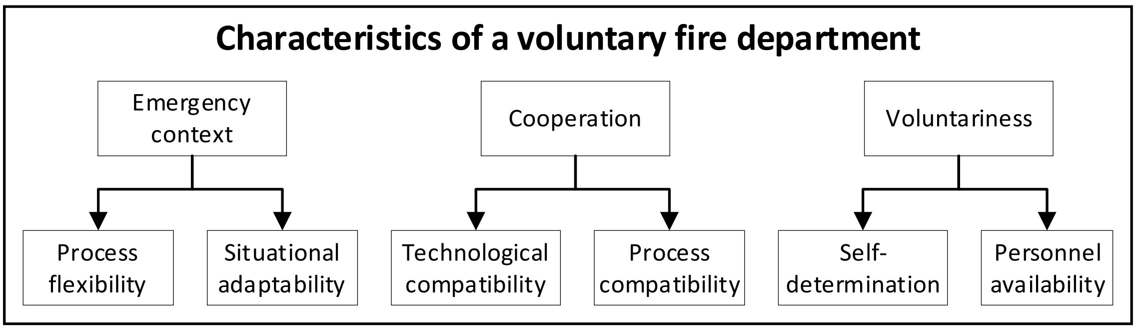

Figure 10.8 Characteristics of a voluntary fire department

Besides the stages and triggers of technology acceptance, we observed some general characteristics of a voluntary fire department. These fundamental aspects significantly influenced the whole adoption process as well as the way the Haßfurt Fire Department uses the newly introduced ERIS. As summarized in Figure 10.8, they include specialties of the emergency context, necessary cooperation scenarios, and aspects of voluntary structures. The factors resulting from these three are explained in the following sections.

10.4.2.1 Process flexibility

The context of emergency management comes with fundamental implications for the way fire departments can employ information technologies. It is important to understand that firefighters can rarely follow rigid processes. As many of them put it, no operation is like the other and deviations from the plan are the standard. Like the operation itself, the scope and type of command support can vary heavily and change spontaneously. Therefore, the Haßfurt Fire Department rather relies on flexible guidelines and checklists to integrate the ERIS in their operations. There are predefined positions in the command center and command vehicle, each initially assigned to one or more approximate task areas. Exemplary areas are *operation log documentation*, *resource overview*, *situational map*, *radio communications*, and *information gathering*. Depending on the operational situation, the task areas can be added, prioritized, skipped, or transferred between the positions. This enables the incident commanders to flexibly compile the command support they need and the CSU to flexibly react to the requests. The same applies to command structures that will be flexibly adapted to the respective operation by dividing it in sectors, assigning sector commanders and units to them.

Observing this flexible approach toward command support, we noticed analogies between emergency management and agile project management. As for example, emergency management follows an iterative approach. The command cycle of reconnaissance, planning, and issue of orders can be interpreted as a sprint known from scrum [55]. Each officer will repeat this cycle until the end of the operation. Frequent situation reports among commanding officers resemble daily meetings or sprint retrospectives. Moreover, an incremental approach can be seen in the prioritizing of tasks and the division of large operations in different sectors [55]. Another example are the visualization techniques that are comparable to a kanban board [56]. All commanding officers will detect, prioritize, and combat dangers using their assigned units. An ERIS can provide a visual overview of such dangers, their status, and assigned units. Given all these similarities, it is surprising that we could not identify studies that systematically compare the aspects of emergency management and agile project management. Such comparisons might potentially unveil new beneficial patterns that could be introduced into emergency response processes. As for example, Scrum Retrospectives typically encompass the questions „What went well? What could be improved? What did we learn? How should the next iteration look like?“.

Adding such a structure might not only target potential threats such as perceived infallibility, but it would also help structuring and harmonizing meetings. Additionally, existing templates and/or tools from the agile project management domain could be introduced to document, visualize, and summarize the results of meetings. Following Venkatesh, et al. [7], process flexibility resembles a *task attribute*.

10.4.2.2 Situational adaptability

Besides the usage behavior, the technologies themselves must provide a certain adaptability for emergency management. An old saying among firefighter is that *technology must follow tactics – not the other way around*. The ERIS employed by the Haßfurt Fire Department indeed offers many degrees of freedom. All functions are grouped in independent modules that can be used in any order and combination. Default values for units etc. can be pre-set but also overwritten at runtime. An important factor we could witness was the system's ability to situationally adapt with growing up operation structures. Even large-scale operations, of which some were mentioned in section 10.4.1.7, typically started with few units on site an evolved from this initial state. On the one hand, the scope of command support will grow. Therefore, the ERIS must support the transition from single-user to multi-user operation. On the other hand, the number of responding units will grow and they will get organized in sectors and subsectors. The ERIS must be able to digitally map this actual command structure. In both aspects, only minor optimization potentials were identified in Haßfurt.

The described requirements can be interpreted as direct consequences of the established situation awareness theory [2]. Incident commanders must comprehend the situation and act according to it. Therefore, ERIS supporting them must be adaptable to the situation, as well. Modern ERIS can indeed follow tactics in the sense that highly diverse situations can be mapped in them. Strictly following tactics, however, they cannot prevent tactical fails. For instance, we observed that the transition between different levels of command is a special challenge. The incident commander must recognize the right moment to expand the command support while simultaneously commanding an escalating operation itself. An ERIS automatically suggesting a higher command level or the distribution in sectors based on parameters like the number of responding units might effectively increase situation awareness. Thereby, it would not only follow tactics but support it. Such decision support systems have already been proposed by literature [17, 18]. While the practitioners seem to be more and more open toward such approaches, they still fear too excessive interference in their work. Therefore, automation in incident command remains a delicate subject. As a system characteristic, situational adaptability resembles a *technology attribute* [7].

10.4.2.3 Technological compatibility

Firefighting is always teamwork. In smaller operations, the team is limited to a single fire department. In larger operations, multiple departments, as well as other emergency organizations, must cooperate to ensure overall success. Despite that, state or federal standards ensure the compatibility of tactics and technologies only in certain areas. Regarding means of command support, the German service regulation on incident command merely lists exemplary solutions. Since fire departments are organized at the communal level, each municipality can decide for itself, if and which ERIS gets used. Due to missing interface definitions, no data can be exchanged between the ERIS of different providers. This particularly affects the creation of situation awareness at a higher level. In Haßfurt, the CSU of the county luckily uses the same ERIS as the Haßfurt Fire Department. This at least enables data exchange between these two levels. However, to pass it on toward the state level, data must be manually transferred into another software. Also, data exchange with the regional control and dispatch center takes place almost exclusively via e-mail. Around Haßfurt, most other municipalities employ paper-based solutions for command support, which excludes data exchange from the start. Summing up, fire departments only occasionally benefit from easy data exchange and aggregation as major advantages of IT solutions like ERIS.

There are various aspects to be drawn from these observations. First, emergency organizations must be able to employ information technologies, at all. To assess their maturity in this area, literature defined several metrics [20]. Second, being able to adopt an ERIS, the departments must actually do so. Factors deciding usage intention and actual use have been described in section 10.4.1 and in related work [4]. Among them, easy data exchange can be interpreted as a significant advantage compared to paper-based solutions. Finally, interfaces and exchange formats must ensure compatibility of the used systems. Even for this, there are already some suggestions in the literature [57, 58]. Exemplary studies demonstrate the potentials of compatible systems in emergency organizations [15]. Overall, most problems and solutions regarding technical compatibility appear theoretically well understood. What is still largely missing is the practical implementation of existing knowledge. As a construct, it resembles a *technology attribute* [7].

10.4.2.4 Process compatibility

Even assuming technological compatibility, there remain cooperation obstacles. To effectively work together, a common process or at least understanding of the ERIS usage should exist among all stakeholders. As pointed out, the Haßfurt Fire Department defined and frequently trains a basic framework of task areas. While such guidelines are far less structured than a fully defined process, they still ensure a common understanding. As a contrast, a neighboring department's CSU works without any guidelines and solely relies on the ERIS's intuitive operability. This works well with single users. In multi-user scenarios, especially when cooperating with users from other departments, the individual intuitions will collide. The common understanding must then be established at runtime during the emergency operation. Beyond that, the before-mentioned data exchange is not only a technological but also an organizational challenge. For example, remote data exchange in the ERIS used in Haßfurt only works offline or within a VPN. The technologically possible exchange between different departments would require the organizational measure of introducing a unified VPN on county or even state level. Without it, the current form of exchange is to punctually export the incident data in one command vehicle to an USB drive and import it in the other command vehicle.

Regarding the process compatibility of different departments and organizations, we already elaborated on the analogies between emergency management and agile project management in section 10.4.2.1. Like in agile projects, contents develop iteratively and incrementally, but every team member must know and acknowledge the employed frameworks. However, frameworks in emergency management are often abstract and only briefly mention the use of modern IT [10]. More detailed organizational standards for information processing and sharing would be needed to achieve process compatibility. Additional enablers of interorganizational data exchange proposed in related work include incentive mechanisms, fair benefit distribution, understanding of the other organizations, ease of use, and the integration in daily routines [59]. Overall, the interoperability of ERIS is seen as a mainly organizational rather than a technological challenge [60]. This organizational challenge should be tackled at the highest possible instance to achieve state-wide or even federal compatibility. A starting point could be to identify the needed scope and quality of information from and for each involved organization [61]. Our German example showed highly diverse organization levels (fire departments on communal, emergency medical service on county, police on state level). This alone appears to be a huge problem, resembling an *organization attribute* [7].

10.4.2.5 Self-determination

Among the different emergency services, fire departments have an even more special position in many countries due to their voluntary structures. This significantly influences if and how a fire department can adopt technologies like an ERIS. On the one hand, voluntariness holds the great opportunity to gain expert knowledge of various domains at zero cost. For example, the Haßfurt Fire Department has several IT and electronics graduates in its ranks. With their help, parts of the ERIS, the surrounding infrastructure and processes could be customized according to the department's needs. On the other hand, it is all the more important to awaken and maintain the firefighters' motivation. In a voluntary fire department, opposed to business contexts, extrinsic regulations like money or sanction threats are unsuitable for motivation purposes. The firefighters do their service as a hobby and typically seek fun, team spirit, and self-realization with it. These are consequently the much better motivators in this domain. The Haßfurt Fire Department tries a playful approach by emphasizing the analogies between using an ERIS and playing a video game. Furthermore, it tries to promote a feeling of perceived importance regarding the newly shaped command support. The CSU is referred to as a special task force and the achievements of the new processes get frequently presented to the entire team.

An established psychological concept to explain different forms of motivations can be found in Self-Determination Theory [62]. Following its taxonomy, voluntary fire departments constitute prime examples for the need of intrinsic motivation. This accounts to the described aspects of fun and joy. The aspects of perceived importance and team-spirit can be interpreted as extrinsic motivators. However, in contrast to salary, Ryan and Deci [62] still see the source of these motivators as internal. The resulting high degree of self-determination can foster engaged use of technologies [63]. Of course, a fire department with entirely voluntary structures may be an extreme case. But to a certain degree, the aspects of motivation and self-determination are transferable to any other domain, also in business contexts. According to DeLone and McLean [64], "no system use is totally mandatory." Users will typically be able to find workarounds or, in sectors with labor shortage, simply refuse or quit. Therefore, paid users should also get motivated and not forced to use the intended technologies. Regarding ways of motivation, all kinds of organizations can draw inspiration from our exemplary voluntary fire department. We interpret self-determination as an *organizational attribute* according to Venkatesh, et al. [7].

10.4.2.6 Personnel availability

Voluntary structures typically come with a set of natural limitations like limited personnel availability. With the firefighter service being a hobby, the firefighters will be engaged with their main occupations during the office hours. Plannable activities like trainings or the before-mentioned ERIS-customizations must be done during free time in the evenings or weekends. This alone limits available times in a voluntary department compared to professional departments or any ordinary business context. Even for emergency operations, it is anything but certain that every needed firefighter can leave their workplace to respond to the call. Especially the above-mentioned experts often commute to neighboring cities or are engaged in management obligations. Consequently, employed technologies and processes must be manageable for ordinary firefighters, or in this case any CSU member, with limited time of training. The Haßfurt Fire Department considered this in two ways. First, intuitive handling was an important selection criterion when purchasing the ERIS. Second, the guideline-based usage with prioritizable task areas can help keeping complexity low. Certain task areas are defined as necessary, and any CSU-member must be able to manage them on their own. Others are defined as optional and can be omitted if necessary.

Several studies examined the voluntary use of technologies on the individual level. Technology acceptance in wholly voluntary organizations, however, has seen little research. Existing literature emphasizes the special characteristics of voluntary organizations [65, 66] and describes reasons for their failure in technology appropriation [67]. The researched organizations (churches, historical societies, etc.) have certain aspects in common, like limited time or heterogeneity of volunteers. What distinguishes a voluntary fire department from other voluntary organizations is the spontaneity of emergency operations. This circumstance intensifies certain issues like personnel availability. However, we could not identify any study researching the specific aspects of a voluntary emergency organization in technology acceptance. The observed focus on technologies' ease of use in fire departments is in line with existing literature [4]. The before-mentioned agility in the command process can be seen as another measure to ensure ability to act even with limited personnel availability. Several other limitations and solutions of voluntary organizations combined with the emergency context could be identified by specialized studies in the future. Like personnel availability, they will resemble *organization attributes* [7].

10.5 Interpretation of results

The paper at hand raised the question which determinants guide the digitalization of a voluntary fire department and which factors determine the acceptance of ERIS by firefighters. We described several observations gained during an extensive ethnography and discussed each of them in the context of existing literature. In this section, we interpret the contribution of our results to answering the initial research questions. We also elaborate on their implications and describe remaining limitations.

10.5.1 Determinants guiding the digitalization of a voluntary fire department

Our study took the digitalization of command support in the Haßfurt Voluntary Fire Department as an example. This project’s key element was the adoption of an ERIS as a novel technology and its integration into the command process. We identified three stages of adoption. For each stage, we found specific triggers of which some appear completely unexplored in the context of technology acceptance. We observed that usage intention may be triggered by revealing events as firefighters’ personal experiences. At the same time, there should be an organizational error management culture and individual IT affinity of few deciders in place. The decision to actually use an ERIS seems dependent on appropriate IT qualifications among the department members and the external event of an investment opportunity. Finally, the long-term use of an ERIS may be consciously facilitated by organizationally embedding it in routines and affirmed by occurring success experience events.

Beyond the mere adoption triggers, we identified overarching characteristics of a fire department that must be considered in their digitalization. First, fire departments work in the context of emergency management. The task calls for highly flexible or agile processes and employed technologies must be able to situationally adapt to these processes. Second, firefighters frequently cooperate with other fire departments or emergency organizations. Therefore, the used technologies themselves, as well as the organizational process of how to use them, should be compatible among departments. Third, fire departments are a special case even within the emergency domain, due to their mostly voluntary structures on the organizational level. This calls for a high degree of self-determination as a key motivator but also comes with specific limitations, especially regarding personnel availability.

Overall, our study identified 13 novel aspects that can complement extant literature. As pointed out in section 10.2.2, one of the few related works tried to explain technology acceptance by firefighters with an UTAUT-based acceptance model [4]. The model integrated several technology attributes as antecedents of the UTAUT constructs, based on the ideas of Wixom and Todd [6]. It could reasonably well predict a firefighter's intention to use an ERIS. However, actual usage was measured as a punctual decision and could be predicted only weakly. Beyond technological antecedents, there is a call to complement the UTAUT with new conceptions of technology use and a higher degree of contextualization [7]. This state of the literature has been summarized in Figure 10.2 before. Based on this, Figure 10.9 adds our insights in the different areas of contextualization. Following the interpretations of section 10.4, they added several contextual factors regarding events, organization, technology, task, and user attributes. As a new conception of acceptance and use, we identified determinants for appropriation.

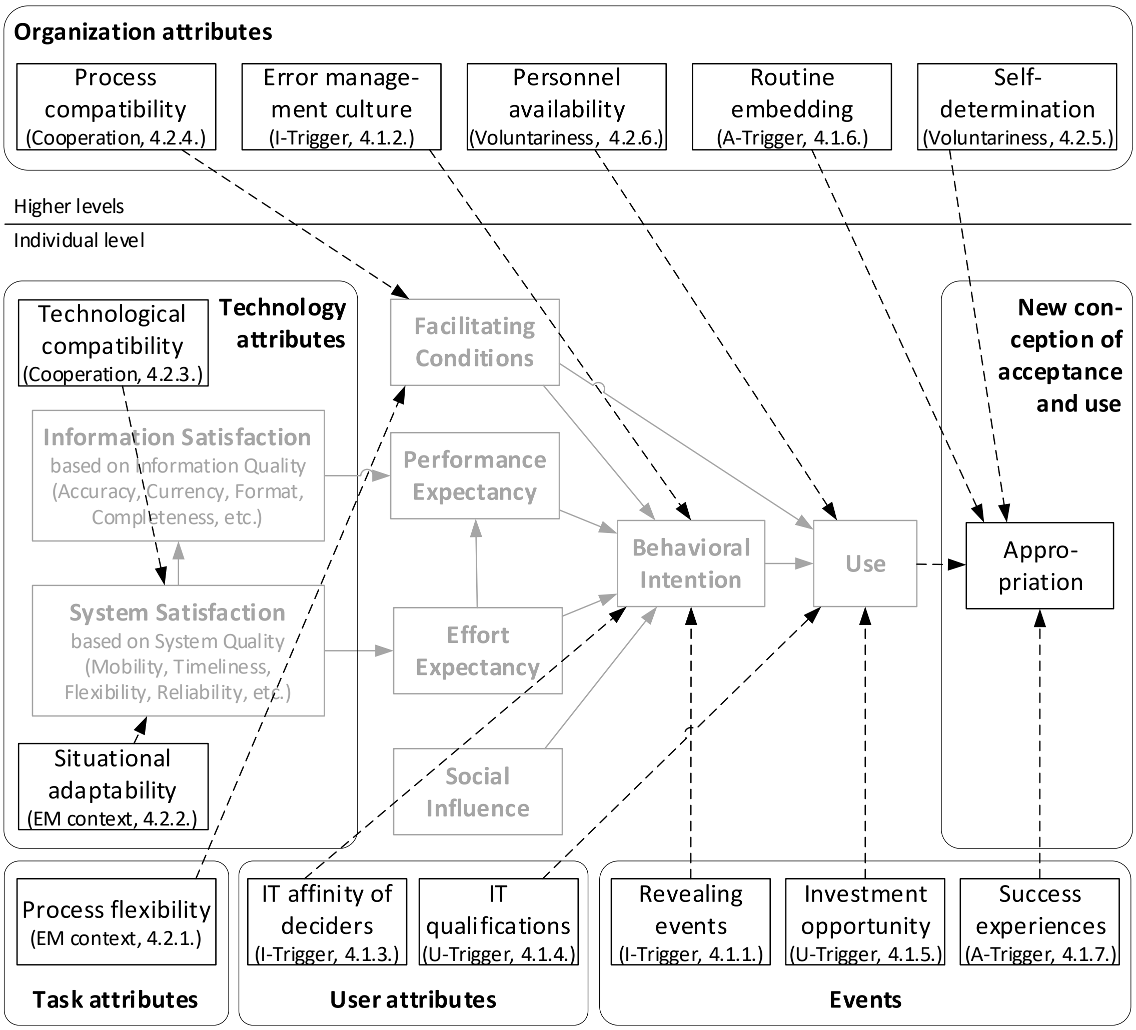

Figure 10.9 Allocation of results in extant literature
I-Trigger = Intention trigger; U-Trigger = Use trigger; A-Trigger = Appropriation trigger; EM context = Emergency context

Besides ERIS as a specific technology, many of our insights may also be transferred to other technologies that are intended for the use in emergency operations, like unmanned aerial vehicles or smart protective equipment. Especially the overarching characteristics of a voluntary fire department have a generalizable nature and may be transferred to virtually any kind of digitalization in this specific domain. Taken together, the discovered aspects provide a comprehensive overall picture. They cover several perspectives of technology, process, and personnel.

10.5.2 Implications for practice, policy, and academia

This study holds direct implications for several practical areas. For the fire departments, the implications can be described in the context of their old saying that *tactics without technology are helpless, technology without tactics is pointless*. On the one hand, digitalization provides fire departments with new technologies that support them in their tactics. We described how an exemplary department adopted a novel ERIS to improve their command support. The observed and explained practices can act as an inspiration for other departments facing similar challenges. On the other hand, novel technologies can only be effective, if they get suitably integrated into an organization and its processes. Therefore, we derived several triggers of technology adoption as well as general characteristics of a voluntary fire department. Both must be considered if a novel technology like an ERIS is supposed to be used in a voluntary fire department. Besides fire departments, the provided insights can also be relevant for the vendors of digital technologies. They can use our study to better understand the firefighter domain and its special characteristics to provide better-matching technologies. Beyond voluntary fire departments, the findings may, to varying degrees, also be transferred to professional fire departments, other emergency organizations, and institutions of critical infrastructure. Several aspects, like situational adaptability, error management culture, and routine embedding appear applicable to a wide range of high reliability organizations.

Politically, our study can provide implications for the digitalization and overall strengthening of voluntary fire departments. Decision-makers can consciously pull the triggers of technology acceptance that our study identified. For example, they can install training programs to actively provoke revealing events and awaken intentions to use novel technologies. To accelerate their diffusion, they can promote acquisitions apart of anyway existing investment opportunities. Such measures may foster the digitalization of fire departments. We also identified starting points to increase the efficacy of used technologies. Amongst them is the necessity to define universal interfaces for technologies like ERIS on the state, federal, or international level. This would ensure interoperability of different systems and allow data aggregation for situation awareness on higher command levels. While all these aspects account for all kinds of fire departments, our study also provides insights specific for voluntary ones. Policy may use them to help mitigate the natural limitations of voluntary emergency structures. They especially call for improved personnel availability and increased research of the topic. Again, many of these implications can be partly transferred to other emergency organizations and voluntary associations.

As academical implications, we complemented existing research on digitalization, technology acceptance, and firefighter information technologies. Up to now, there remained many uncertainties regarding the usage of novel technologies in fire departments [4]. The study at hand addressed this literature gap by conducting an extensive ethnography within this special domain. We could exploratively identify several additional determinants of digitalization and provide rich insights into their respective backgrounds and roots. In the interdisciplinary tradition of information systems research, we could explain many of our observations using knowledge from other disciplines. Among them were educational theory (experimental learning), safety science (error management), sociology (appropriation), project management (agile methods), and psychology (self-determination). However, despite their prominence in other fields of research, many of the identified aspects have not yet been considered in the context of digitalization and technology acceptance. On the one hand, these newly gained insights may complement existing acceptance theories and raise the understanding about why firefighter do or do not employ novel technologies [4]. This also answers existing calls for research regarding the increased contextualization of UTAUT and the identification of novel acceptance factors [7]. Despite context-specificity, some of the discovered factors may also be transferred to other domains. Examples include public institutions (investment opportunities), voluntary organizations (personnel availability), high reliability organizations (situational adaptability), and arbitrary business contexts (revealing events). On the other hand, our results provide several starting points for future research. Within the firefighter domain, the similarities between agile project management and emergency management call for more detailed research to identify interdisciplinary insights. Outside the examined domain, error management culture may be examined as an acceptance factor in virtually any other context. These are but two of the many literature gaps identified by this study and waiting to be filled.

10.5.3 Limitations

Despite valuable insights, the results of our study should be considered in the light of certain limitations. Our observation covered multiple years but was mostly focused on a singular voluntary fire department in Germany. This can be seen as a natural drawback of ethnography as a methodology, which is especially suited to derive in-depth insights but lacks breadth [38]. While we also had limited insights in neighboring departments, the study cannot account for international variations. While many other countries like the United States and China at least have comparable voluntary firefighting structures, our insights might be less transferrable to countries that build primarily on career structures. Additional insights are needed to verify our results in such contexts. As another limitation, we took command support and ERIS as an exemplary process and technology. Our results might not be straightforwardly transferrable to arbitrary processes or technologies within a fire department. Finally, one of the authors was deeply involved in the observed department and its processes. This was the only realistic way to enable in-depth observations but held the dangers of subjectivity and influencing. We tried to ensure objectivity by following established rules of ethnographical research.

10.6 Conclusion

Digitalization and technology acceptance in the firefighter domain remains a rather unexplored, yet relevant field. The ethnographic insight provided by the paper at hand can help illuminate it and establish an increased contextualization of existing acceptance theories. With 13 novel aspects, we identified approaches to explain under which circumstances firefighters will adopt an ERIS and which determinants will guide digitalization in the domain. The results hold several theoretical and practical implications and can serve as starting points for various future research endeavors.

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