Improving emergency and disaster response management through bidirectional communication between citizens and decision-makers – A field test on the coordination of spontaneous volunteers

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ABSTRACT

Cooperation between different stakeholders plays an important role in managing crises and disasters. The software tools used must also support cooperation and the mutual exchange of information. The bidirectional exchange of information between the population and official agencies poses a particular challenge. In this paper, we present a software demonstrator for the coordination of spontaneous volunteers and its evaluation as part of an overarching research project to gain design knowledge for the development of interconnected systems in disaster management. We describe how the system demonstrator was instantiated on the basis of our existing design knowledge from technical requirements and reference architecture and show the respective interfaces for the stakeholders involved. As the main contribution of the paper, we describe the implementation of a field test to evaluate the demonstrator and present the results in terms of usability and perceived usefulness, which we obtained using a methodologically sound questionnaire.

Keywords

Volunteer Coordination, Field Test, Interconnected Systems, Population, Bidirectional Communication

INTRODUCTION

Good crisis and disaster management depends on how well different stakeholders cooperate (Grolinger et al., 2013). Due to the possible large number of stakeholders involved, there is also a large number of information and communication systems involved. These are usually specialized in storing and processing the data relevant to their user group. To ensure good cooperation, however, it is necessary for the stakeholders to share their information in order to develop a common picture of the situation and determine the best courses of action (Sakurai & Murayama, 2019). This requires systems that enable a digital exchange between stakeholders that is not based on centralized data but is organized in a decentralized manner.

The civilian population plays a special role as a stakeholder in disaster management (DM). On the one hand, they are directly exposed to the risks and consequences of a crisis or disaster scenario and are therefore dependent on comprehensive and reliable information from authorities in order to protect themselves in the best possible way.

(Nikolai et al., 2015). On the other hand, citizens themselves can also be a very extensive source of information to support official DM (Schimak et al., 2015). Bidirectional communication supports the process, as it increases the validity of the information shared, which is essential for making decisions in DM.(Moshtari & Gonçalves, 2017). Kaufhold (2021) conducted a literature review on communication needs from authorities to citizens (A2C) and citizens to authorities (C2A) in crises. The literature review revealed bidirectional communication requirements in crises, thus motivating the need for bidirectional crisis communication tools. A key benefit seen by authorities resp. emergency services workers is better situational awareness through citizen-generated content, such as situational updates, photos, videos or information on the public mood (Reuter & Spielhofer, 2017). Citizens, on the other hand, benefit from information about threats and possible damages, the duration and the area affected by a crisis as well as recommendations about how to cope with the crisis (Reuter, 2014). In general, authorities help to reduce the information deficit of the citizens in times of crises with bidirectional communication solutions (Reuter, 2014).

Studies show that DM authorities and organizations are open to using data from citizens in operations and also to providing information to citizens via bidirectional communication apps (Holzhüter et al., 2023). In the past, therefore, there have already been some research efforts in this area. One specific branch of research that has already been investigated in the past is the coordination of spontaneous or informal volunteers (Whittaker et al., 2015) using bidirectional information systems (Betke et al., 2023; Poblet, 2013). However, although there are already some approaches that address the design and implementation of such systems, e.g. (Batard et al., 2019; Fuchs-Kittowski et al., 2017; Gerstmann et al., 2019), their evaluation is difficult because the systems do not find their way into application and the exercises or experiments required for evaluation are associated with very high effort. As only a few papers have so far focused on evaluating the practical suitability of the approaches, there is a need for further research in this area. In past crises, it has been shown that the use of ad-hoc applications/platforms, such as social networks, e.g. in (Albris, 2018), has enabled spontaneous volunteers to coordinate themselves with all the associated disadvantages, such as unsolicited voluntary actions, data inaccuracies, data overload and even misleading information (Reuter et al., 2015). For better guidance of spontaneous volunteers by DM authorities and organizations for support in coordinated operations, editorial systems are needed that can address end applications, such as volunteer or warn apps. Instead of relying on centralized systems, the use and networking of ad-hoc applications seems promising to harmonize heterogeneous system landscapes and not end at artificial boundaries (federal states, countries, organizations).

In order to extend the knowledge about the practical applicability of such systems, we present the demonstration and field test-based evaluation of a related software artifact. The results of this paper are part of a larger design science research project in which we want to generate design knowledge about the development of interconnected systems in disaster and crisis management. We want to investigate, if the developed architecture, which allows for the use and networking of other ad-hoc applications, is a valid method for providing technologies for various purposes in crises. In the final step of the current research cycle, we have used the design knowledge gathered so far to develop a software demonstrator using the example of a spontaneous volunteer coordination system (SVCS). We chose the example of coordinating spontaneous volunteers (SVs) because an initial comprehensive acceptance study yielded mixed results: without having used such systems themselves, half of the experts were in favor of using such systems, while the other half were either neutral or had a negative opinion (Holzhüter et al., 2023). Taking into account established methods such as UTAUT (Venkatesh et al., 2003), we want to gain insights into the user experience of SVCS, as well as to gain general insights into the suitability of our current design knowledge, in the form of a requirements catalog and a reference architecture, for the development of practicable software. The collected feedback serves as a foundation for targeted improvements aimed at increasing acceptance in crisis situations. Our current efforts are directed towards ensuring that the systems not only provide utility and user-friendliness but also align with user expectations. With the results presented here, we want to facilitate the future development of interconnected systems and especially SVCS for scientists and practitioners, as well as to show a possibility for the methodical evaluation of corresponding systems with regard to perceived usefulness and usability. For this purpose, we want to examine two research questions in this paper:

(Research question I) *To what extent is our existing design knowledge suitable for the development of application-ready systems?*

(Research question II) *How do the two user groups disaster managers and spontaneous volunteers evaluate a special coordination software in terms of usability and usefulness under practice-oriented conditions*?

This paper is structured as follows: In Section 2, we explain our approach based on a design science research method, and then in Section 3, we describe our instantiated software demonstrator based on our previous gathered design knowledge. In section 4 we describe the experimental setup of our field test to evaluate the software demonstrator In Section 5, we present and discuss our evaluation results. Section 6 contains a brief discussion of related work, particularly in relation to the evaluation of similar software artifacts. Finally, in Section 7 we give an outlook on further research so that our proposal for a reference architecture can be implemented in practice.

RESEARCH METHODOLOGY

It is our superordinate objective to create a theorical IS artifact that helps developers, disaster response experts and researchers to create interconnected systems for DM. Designing such an artifact is a demanding task, requiring innovative approaches, particularly in domains where existing theories fall short (Hevner et al., 2004). To accomplish this goal, we have initiated a design science research (DSR) project, following Hevner et al. (2004). DSR, as defined by Iivari and Venable (2009), involves "[…] a research activity that invents or builds new, innovative artifacts for solving problems or achieving improvements […]" (Iivari & Venable, 2009). By combining scientific principles with practical relevance, we aim to provide valuable design knowledge for the development of ICT in DM (Hevner et al., 2004). Our approach, therefore is based on the design science research methodology by Peffers et al. (2007). In this section we describe how we instantiated the method of Peffers et al. (2007) as our IS research framework to structure the iterative process to design and evaluate a suitable IS addressing our research question (see Figure 1). By employing this framework, we ensure the incorporation of continuous improvement throughout the artifacts development process. As our framework starts with the identification of a problem and motivation, we follow Peffers et al.'s (2007) problem-centered approach to guide our investigation, driven by both practical and scientific demand.

	Identify Problem & Motivate	**Define Objectives of a Solution**	**Design & Development**	**Demonstration**	**Evaluation**
Instantiation of Research Steps following Peffers et al. 2007	**Method:** Survey on the need for and acceptance of information and communication systems for the exchange between disaster response officers (n = 354) and the public (n = 504). **Result:** Both user groups have a fundamental need and willingness for information exchange in different use cases using an IT system, including a system for coordinating spontaneous voluntary tasks. *(Holzhüter et al., 2023)*	**Method:** Literature analysis and expert survey (n = 49) to derive requirements for a decentralized multi-stakeholder information and communication system in disaster management **Result**: 40 requirements identified (38 functional, 2 non-functional) *(Holzhüter & Meissen, 2021)*	**Method:** Conceptual description of a solution based on the derived requirements **Result**: Service-oriented reference architecture for a decentralized multi-stakeholder information and communication system in disaster management *(Holzhüter & Meissen, 2021)* -------------------------------- **Method:** Implementation of a software artifact based on the reference architecture using the example of a coordination system for spontaneous volunteers **Result:** Web-based dashboards with widgets for the integration of various situation information and a module for coordinating spontaneous volunteer work. iOS & Android app for registration, alerting and coordination of spontaneous volunteers	**Method:** Application of the software artifact (dashboard & app) in a realistic use case with both user groups **Result**: Planning and execution of a disaster response exercise for the reception of refugees with the participation of disaster management employees (n = 13) and spontaneous volunteers (n =32)	**Method:** Survey among the use case participants to evaluate the usefulness and usability of the software artifact using UTAUT-methodology (Venkatesh et al.(2003)) **Result**: Evaluation results for 22 items per user group plus comments from participants show a consistently positive perception of the software artifact.

Figure 1. Design science research methodology process model by Peffers et al. (2007)

As part of the first step, **problem identification and motivation**, we conducted a broad-based survey among the public (n = 504) and DM professionals (n = 354) to identify specific challenges in the area of information systems for information exchange. In summary, the results showed that participants from both DM and the public were overwhelmingly positive about and in favor of information exchange in various use cases (Holzhüter et al., 2023). The survey showed that there is a need on both sides to provide and receive different types of information. Interconnected systems are a promising approach for bringing together a wealth of information from different sources and processing it in a user-friendly way.

To **define the objectives of a solution**, we drew up a catalog of requirements. This is based on an extensive literature analysis and a survey of experts in the field of interconnected systems development and experience in DM (n=49). As the focus of the survey was on functional requirements, we were able to identify significantly more, resulting in 38 functional and 2 non-functional requirements (Holzhüter & Meissen, 2020). The concrete identification and consideration of the undoubtedly existing non-functional requirements represent a good approach for the processing of a further research cycle.

The **design & development** of a suitable solution consists of a general theoretical part and a use case-related software development. We have designed and described a reference architecture as a general theoretical basis for the implementation of interconnected systems in DM (Holzhüter & Meissen, 2020). This shows how stakeholders with different applications and technical requirements can exchange information with the help of a decentralized information exchange adapter.

Up to this point the results were generated in previous papers, all following steps are the core contributions of this paper. To further concretize the solution approach, we have developed a software demonstrator considering the requirements and reference architecture. As our acceptance study showed that users are generally positive about a SV coordination system, but that there is also a lot of skepticism, we decided to develop a software demonstrator in this problem area to investigate user acceptance of a specific system. The resulting demonstrator is SVCS, consisting of an iOS & Android app for the registration and alerting of SVs, as well as a web-based dashboard for the creation and monitoring of SV missions. The system is described further in the following chapter.

For the **demonstration**, we carried out a disaster response exercise in a medium-sized German city (approx. 99,500 inhabitants) with the participation of SVs (n = 32) and local DM staff (n = 12). In the exercise context of a mass arrival of refugees, both groups of participants used their respective subsystems of the VCS to manage and process multiple missions. The exercise demonstrated that the processes and tasks in the application area can be supported by an appropriate system.

The **evaluation** was carried out in connection with the demonstration. The exercise participants were asked afterwards to complete a questionnaire on their experience of using and perceived usefulness of the VCS used. The questionnaire was methodologically based on the UTAUT model by Venkatesh et al. (2003). UTAUT, as one of the most common methods for evaluating software artifacts, takes into account other approaches such as the Technology Acceptance Model (TAM), the Theory of Reasoned Action (TRA) and the Theory of Planned Behaviour (TDB). Hence, it offers a comprehensive perspective on the various factors that influence the acceptance and use of technology. The items surveyed by UTAUT are familiar to many scientists and increase the comprehensibility and comparability of the evaluation results in this paper. The results showed a high acceptance of both user groups when using the system. A detailed description of the demonstration and evaluation results can be found in sections 4 & 5.

INSTANTIATION OF THE SOFTWARE DEMONSTRATOR

The objective of the solution is derived from a reference architecture, which was created on the basis of a requirements analysis (Holzhüter & Meissen, 2020). The requirements were derived from a user survey and existing solutions (Holzhüter et al., 2023) in a larger acceptance study. For this purpose, various use cases were created that can better involve the population in disasters. The use cases include the feedback of warning messages (work in progress), the inclusion of data from the population, e.g. private weather stations (Holzhüter et al., 2021) the coordination of SVs (evaluation in this paper) and a feedback function for the population in the warning process (not part of the paper).

The demonstrator focused mainly on interfaces and, for the demonstration in the research project, on visualization using dashboards and widgets for data visualization. In addition, a volunteer component was added to the KatRetter app and a feedback function was added to the KatWarn app as value-added services. The KatRetter app, with the actual aim of coordinating first responders for cardiological emergencies, was extended by an independent KatHelfer component. The KatHelfer component is a value-added service that takes over the coordination of SVs. The following requirements in Table 1 from the reference architecture (Holzhüter & Meissen, 2020) were implemented as described.

Table 1. Mapping of requirements to developed services

ID	Requirement	Description	Realization in the demonstrator
R01	Authentication	Authentication should be state-of-the-art and support multiple authentication methods.	State of the art Authentification-Service implemented.
R02	Multi-client capability	The system must be multi-client capable. It must be possible to configure role-based data display and transfer.	A roles and rights model has been created. This allows different roles to have different views of widgets, for example to create assignments or approve assignments as a decision-maker.

ID	Requirement	Description	Realization in the demonstrator
R03	Filter option	Filter options should be offered; the focus should be on the relevant data.	Data can be freely filtered. When configuring the widgets, filters can be applied to certain regions, certain radiuses, certain deviation criteria or even certain alerts, for example, to create the optimum focus for the user.
R04	Validation of information	A transaction check is to take place. The data must be unchangeable and usable in court.	"Deviation criteria" have been developed for various widgets so that "incorrect" data does not distort calculations. Correct information is to be validated using a blockchain, which is still in the concept phase.
R05	Data exchange	Data should be usable not only in the event of a crisis but also during normal operation to generate synergy effects.	Some data is stored in a local database as an OLAP cube to efficiently access data outside of events, for example for follow-up. To improve data exchange, care was taken to ensure data anonymity when designing the interfaces so that no additional data protection requirements had to be implemented.
R06	Event orientation	It should also be possible to view the data under less-than-optimal conditions, for example when information systems have failed. The system must act event oriented.	The high level of interface orientation means that other connected systems can continue to operate in the event of system failures. In addition, work can continue the existing "old data" until the interface is available again. The user is visually informed when data falls out of the update rhythm.
R07	Data actuality	The system should be able to update information automatically.	The interval at which data should be updated can be set in the dashboard.
R08	System boundary	The system should also be applicable in federal states.	The system design knows no municipal or national borders.
R09	Automation	The system should be fully automated and should not require manual operations.	No further input is required for widgets created by the user.
R10	Prioritization of data transmission	The system must offer the possibility to prioritize certain transactions to certain participants.	Implemented by an ETL service.
R11	Geoinformation system	The system must offer the possibility to transfer data from geographic information systems.	Map service is implemented and can be used as a form of visualization for most widgets.
R12	Interfaces	Standards like OGC (Open Geospatial Consortium), STANAG (NATO contracting parties' Standardization Agreement) should be usable. The exchange format should be easy to design. The interface should be compatible with as many media as possible in terms of hardware and software. The data network should be uniform, and services usable across systems. It should also be possible to establish permanent connections to check availability.	Standardized interfaces were implemented. The requirements have been fully implemented. Interfaces can also be used by other value-added services so that the application can be used not only with the KatRetter or KatWarn apps. However, the app developers are responsible for implementing the interfaces on their side.
R13	Control over connections	The system must be able to give the user full control over the data connections.	Is controlled via the rights and roles system.

ID	Requirement	Description	Realization in the demonstrator
R14	Use of own software, transformation of data	The system must be able to transform data so that users can use their own systems.	Not implemented in the use case. In this case, the company's own dashboard was developed. As part of SPELL, data is also to be made usable in third-party software via interfaces.
R15	Data visualization	The system must be able to prepare data in such a way that it can be displayed within the system if the data is not transferred to another system by the user.	Dashboard with widgets was implemented for this use case.
R16	Central storage of information	The system must also be able to store data centrally so that the user can analyze them even without his own software.	Backend of the dashboard holds the data in OLAP cubes.
R17	Trusted connections	The system must be able to easily establish communication connections to other users.	This use case has been implemented. Additional portals from private weather stations can be easily integrated, as well as additional value-added services such as apps for warning messages or the coordination of SVs.
R18	Digital data transfer	The system must be able to support many different formats and interfaces so that data can be transmitted digitally.	This was the focus of the implementation, so that there were no media disruptions.
R19	Real-time transmission	The system must be able to transmit data in near real-time (e.g. video streams)	This was not necessary for the application.
R20	Filter options	See R03	See R03
R21	Interfaces	The system must be able to create, adapt or delete interfaces	See R12
R22	Decentralized system architecture	The system must be decentralized to increase the availability of information.	The system is designed to be decentralized. The aim is for each user to use their own system, as shown in Figure 2, or to use the dashboard with their own local storage. This means that the architecture is not dependent on any central data or systems.
R23	Open-Source	The system must be open source so that other providers can make extensions (including interfaces, value-added services) quickly available. In addition, a reference architecture should make it possible for different service providers to develop the system.	During system development, care was taken to ensure that free libraries were used.
R24	Validation of information	See R04	See R04

From the continuous evaluation of user feedback and results from previous surveys, on which the requirements analysis is based, and a consideration of the advantages and disadvantages of various architectural models, the following non-functional requirements emerged. When introducing applications, not only the non-functional requirements of end users (such as reliability, user-friendliness, simplicity, intuitive operations, understandability) must be satisfied, but also those of administrators (such as scalability, traceability, interfaces, innovative capability, maintenance) or management (such as it-security, data security and privacy, auditability, costs). These were also evaluated by stakeholders as part of the reference architecture (Holzhüter & Meissen, 2020).

Figure 2 shows the reference architecture from (Holzhüter & Meissen, 2020). The grayed-out areas are the components that were not implemented. For the demonstrator, the part in which the data was processed via the web browser was implemented. In addition, the reference architecture was extended by the stakeholders for value-added services.

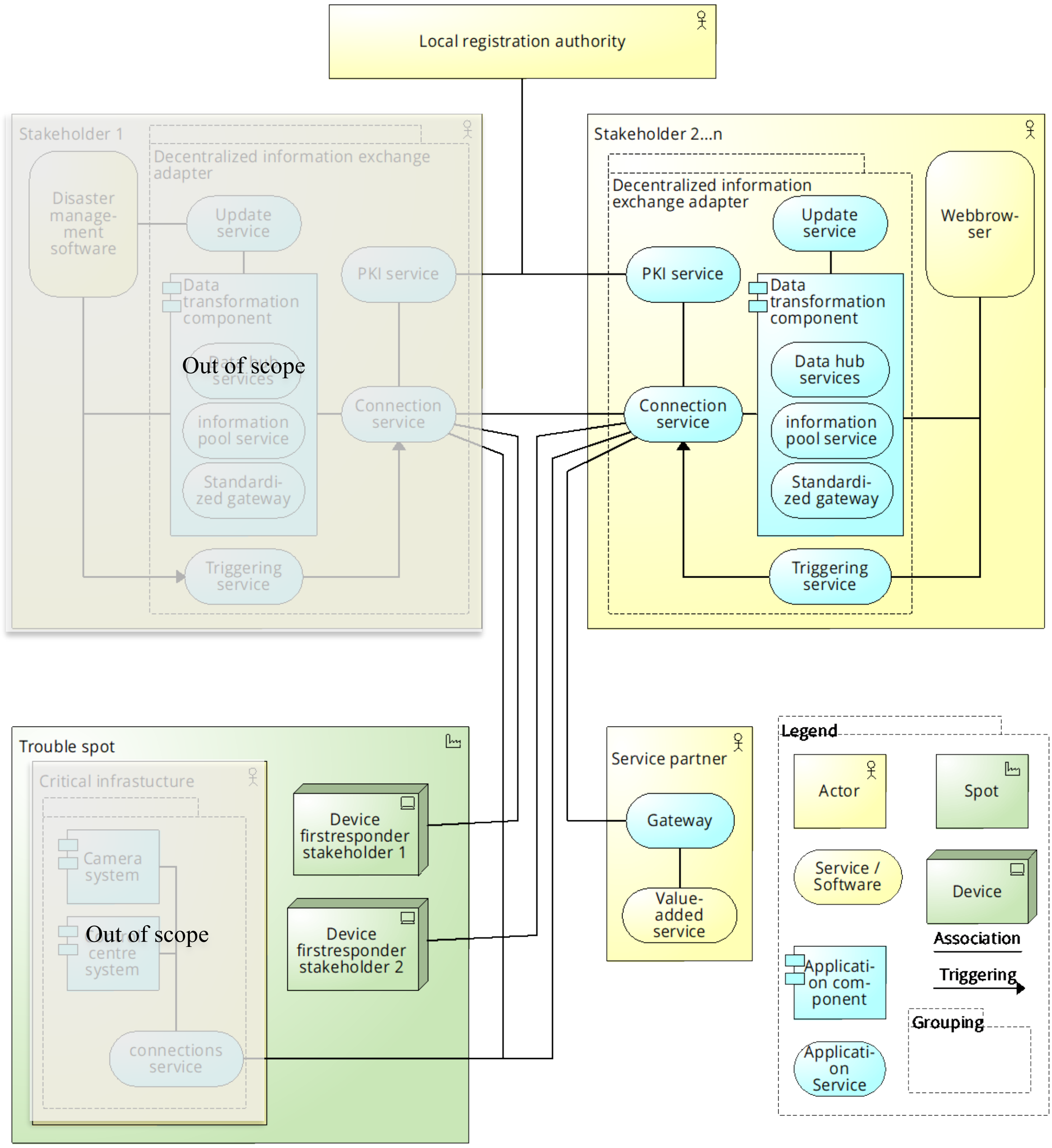

Figure 2. Adapter for decentralized information exchange with value-added services

The components for displaying information were developed in the form of an easy-to-configure dashboard with widgets (see Figure 3). On the left side, new dashboards can be created to have different views for various situations, for example. Each user can create their own dashboards and customize the widgets in the grid differently. This allows most widgets to be displayed as statistics, key figures, maps, or even heatmaps.

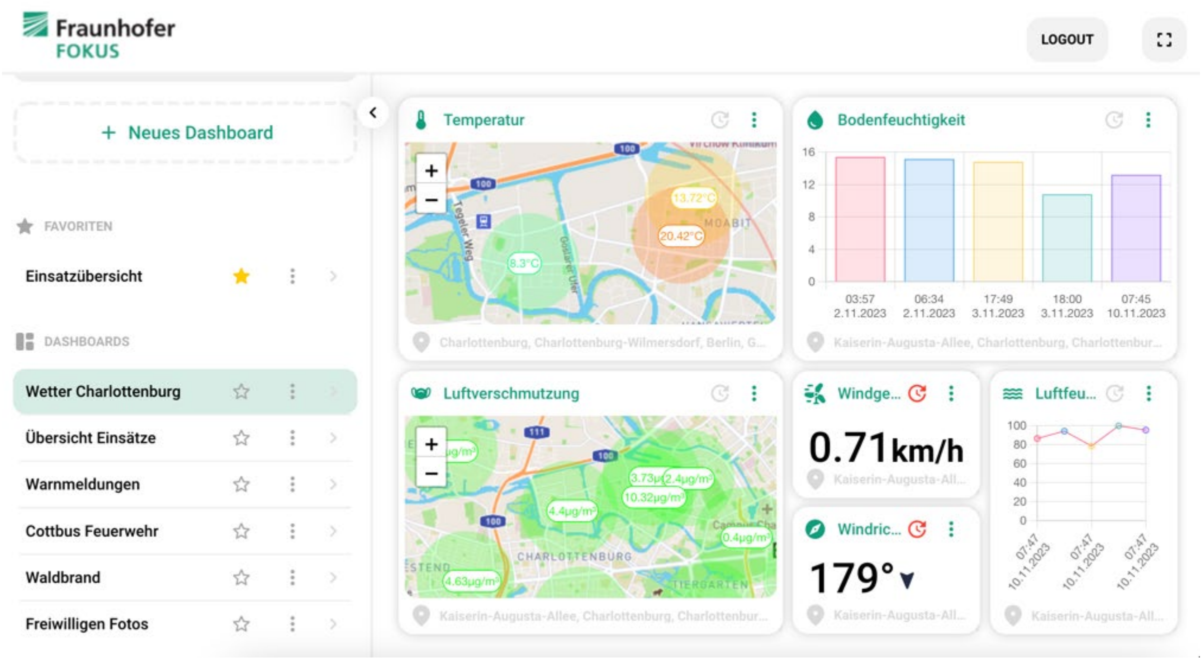

Figure 3. Example of a configured dashboard with widgets for displaying weather data from private weather stations

Figure 4 shows the implementation for displaying the evaluation of warning messages (not the use case of this paper). This shows that the demonstrator also works for other applications of bidirectional communication. In this scenario, the user is presented with information pertaining to an alert notification within a specified area. The user receives an overview, including the number of users who received the alert in the designated area, the quantity of individuals who provided feedback on the alert, and the timeframe during which the feedback was received. This feature will not be discussed further because it was not part of the exercise.

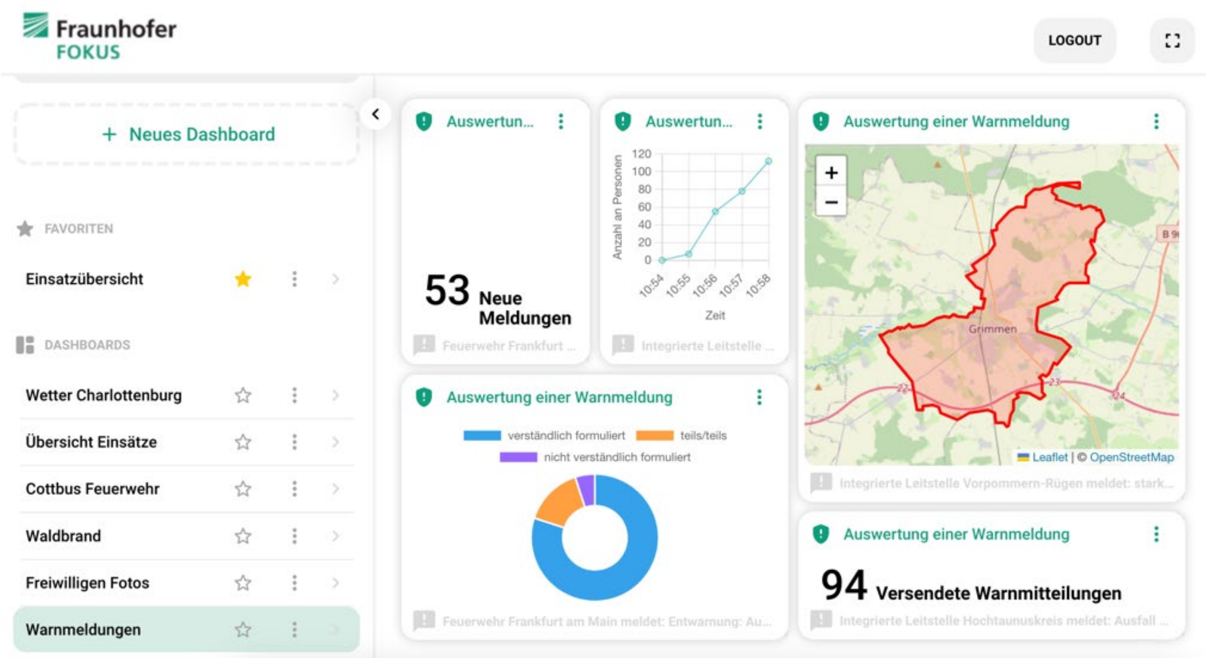

Figure 4. Example of a configured dashboard with widgets for evaluating feedback from alerts

Value-added services, as used in this exercise, represent additional services that cannot be mapped in the adapter. The KatHelfer component designates/ allocates tasks to the right registered volunteers. The component can use the KatRetter app for this, but other services for SVs can also be used. The adapter for decentralized information exchange handles communication with the KatHelfer component. The dashboard is used to create deployments. Figure 5 shows the option of creating assignments for SVs in the dashboard. Specify when the operation starts and ends, what type of operation it is (this becomes crucial for the app settings in Figure 7), what the operation should be named, provide a description of the operation, indicate the number of SVs needed, specify the meeting point, and identify the geographical area in which the operation is located.

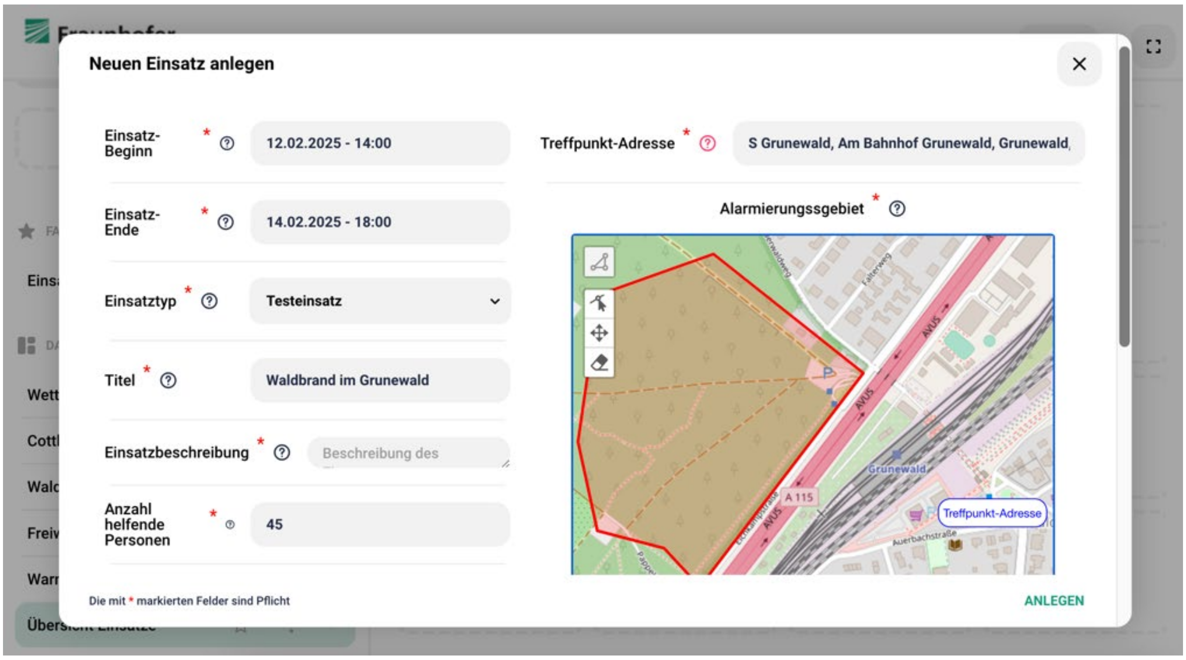

Figure 5. Example of creating an operation in the dashboard

Once the assignment has been created in the dashboard, the assignments are displayed in an overview (see Figure 6). A description, the status and the number of activated volunteers is displayed. The assignment can also be ended via a shortcut.

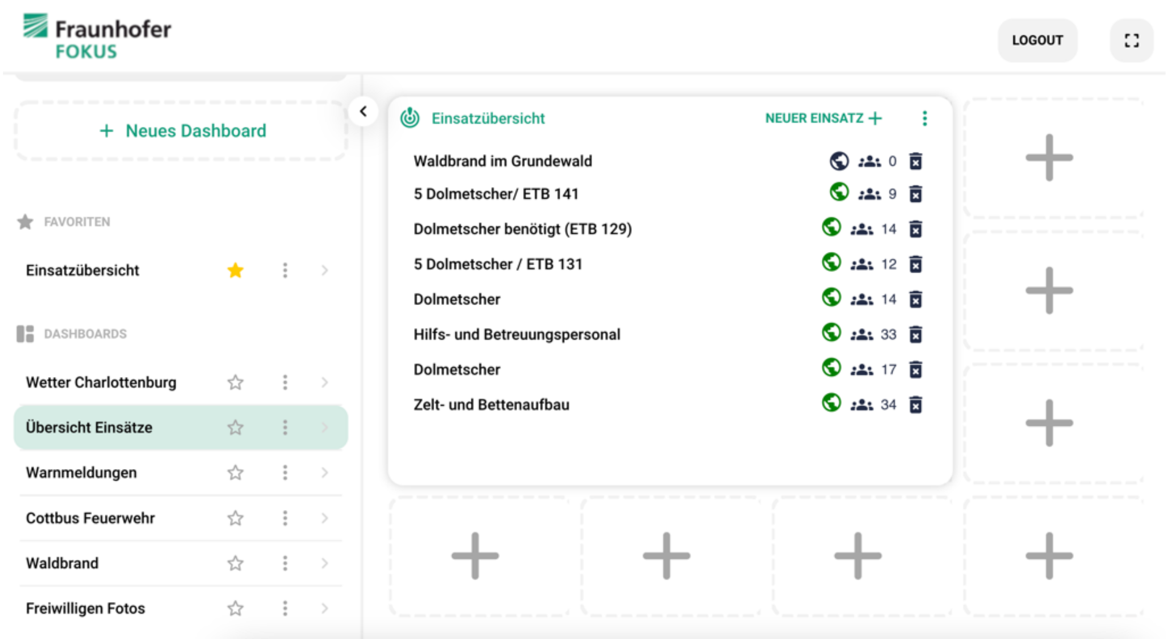

Figure 6. Overview of operations

Value-added services, as used in this exercise, represent additional services that cannot be mapped in the adapter. The adapter for decentralized information exchange handles communication with the KatHelfer component. The dashboard is used to create missions.

To utilize the KatHelfer component within the app, users must configure certain settings, as illustrated in Figure 7. This enables users to specify their availability as a volunteer (named "Mithelfer" in the picture on the left) during disasters. Subsequently, users can select the types of missions for which they wish to receive notifications (in the picture on the right), such as those related to catering support or missions requiring more physical involvement.

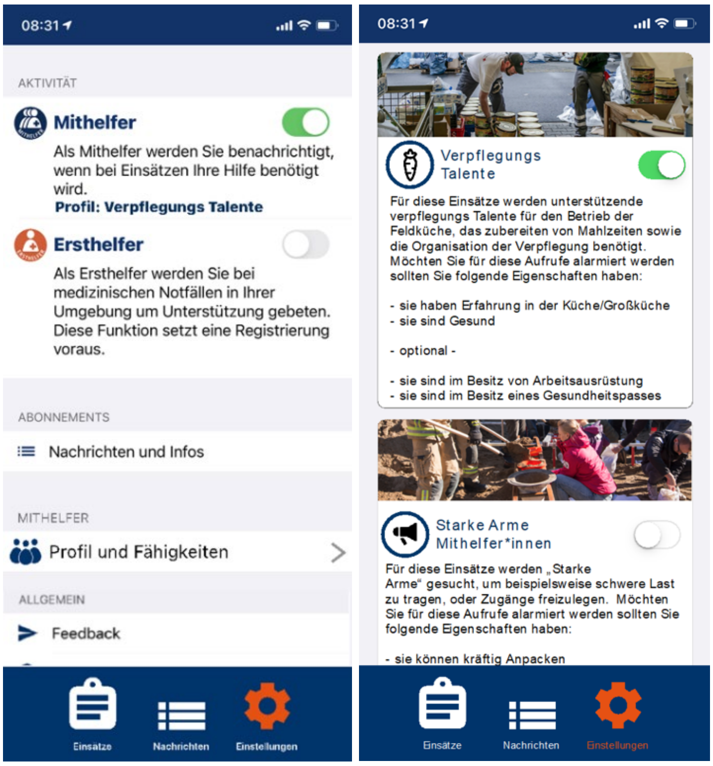

Figure 7. Settings

If volunteer assistance is needed, an operation is created and sent to volunteers, as depicted in the dashboard above. Volunteers can now view the operation details, as shown in Figure 8 (on the left side). Users can review the operation details and decide whether they wish to support the operation (as shown in the middle image). If they opt to do so, they can proceed to the operation site, confirm their on-site presence, or choose to cancel their participation in the operation (as shown in the image on the right).

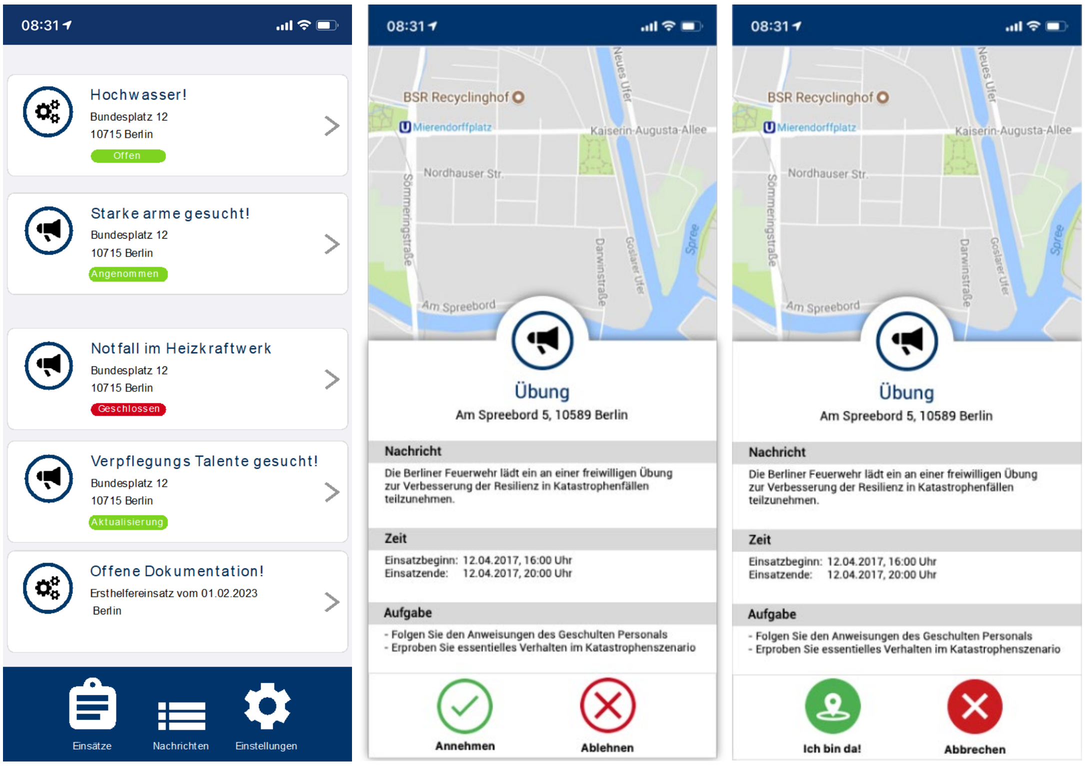

Figure 8. Mission Screens (Mission List, Accept/Decline Mission, Arrived/Mission Aborted).

The acceptance study (Holzhüter et al., 2023) revealed that there is a desire for technological support for spontaneous interventions by voluntary volunteers from both the general population and emergency response forces. However, a crucial aspect is the need for coordination of SVs. To address this, a tool has now been provided to both stakeholders, which needs to be evaluated in use before it can be employed in actual operations.

With the development and presentation of the SVCS in this chapter, we can make initial statements regarding our first research question: We have shown that it is possible to instantiate a software based on our current design knowledge using a concrete application domain. We have shown how the technical requirements can be addressed and how the reference architecture is used, thus providing starting points for the instantiation of further systems. In the following chapter, we show how we demonstrate the suitability of the software for the application and how we have set up the evaluation to answer the research question II.

FIELD TEST & QUESTIONNAIRE DESIGN

For demonstration and evaluation of our solution we conducted a disaster response exercise with both user groups. The exercise was set in Cottbus, a middle-sized city (99.500 residents) in Germany. Aim of the exercise was testing the capabilities of the city's rapid intervention unit and evaluation of the KatHelfer component. A new organizational aspect of this exercise was the involvement of SVs. The exercise was based on a scenario where a large group of refugees arrived from Ukraine. The DM was expected to set up care facilities for the refugees, provide them with medical care and food, register them and look after them until their onward journey, as well as coordinate that journey. Thus, various tasks needed to be completed in order to manage the situation. These tasks included setting up tents and camp beds, providing language mediation for Russian, Ukrainian, Polish and English at various locations, setting up a supportive IT structure and offering nursing and non-acute medical care for the refugees. The tasks were to be accomplished with the help of SVs from the civil population. Throughout the course of the exercise, it was therefore necessary to register, activate and coordinate SVs via the KatHelfer component to manage the situation.

The members of the rapid invention unit served as the coordinating disaster managers (n = 13) while the SVs were people who had already been active as volunteers in previous disaster situations (n = 32). The disaster managers had an average age of 36 years, with a range of 17-61 years. 5 identified as male, 3 as female, 5 did not specify their gender. The majority had a German high school diploma or a comparable qualification. The SVs were on average 44 years old; the youngest participant was 20 years old and the oldest 65 years old. 14 of them were male, 8 female, 10 did not specify. 61% of the volunteers have a German high school diploma or comparable. The exercise began at 9 a.m. with the alert that 600 refugees, in various states of health, would arrive at 10 a.m. in Cottbus and ended at 12 p.m., with the dismantling and the announcement via the KatHelfer component that the exercise was now over. At 12:45 p.m., the units were then moved back to their original locations. Afterwards, the exercise was evaluated with the help of our questionnaire. In addition, short interviews were conducted with some of those involved and observations were made and noted during the exercise, both in DM and on site.

The aim of the evaluation was to gain insights into the perceived usefulness and user-friendliness of the KatHelfer system demonstrator for both user groups (SVs, disaster managers). For this reason, we based the questionnaire on items and constructs from the established UTAUT (Unified Theory of Acceptance and Use of Technology) (Venkatesh et al., 2003). One problem with using the UTAUT, however, is that not all items fit the context of our specific application. For example, the item "If I use the system, I will increase my chances of getting a raise" was not applicable to our scenario since the dashboard and app are not intended to provide an economical benefit for the users. For the same reason of transferability to our specific scenario the item groups that measure the factors "social influence" and "facilitating conditions" were not used, as well as the two items, "It scares me to think that I could lose a lot of information using the system by hitting the wrong key" and "I could complete a job task using the system if I had just the built-in help facility for assistance". In the end, we were left with 14 items of the UTAUT, measuring Performance Expectancy, Attitude towards using technology, effort expectancy, self-efficacy, anxiety, and behavioral intent. To gain further information on how our design is perceived and about user satisfaction, we additionally added 8 items from a questionnaire from (Sindhuja & Dastidar, 2009), which is derived by the Purdue Usability Testing Questionnaire (PUTQ) by (Lin et al., 1997). In conclusion our questionnaire contained 22 items, measuring user acceptance of our dashboard and app with main emphasis on usefulness and ease of use/design. We translated these items to German and developed two versions, one for the members of the rapid intervention unit to rate the dashboard and one for the SVs to rate their experiences with the app. In addition, we added demographical items about age, gender, level of education and profession, taken from the recommendation for demographical standards from the German Federal office of Statistics.

EVALUATION RESULTS

Of the 13 DM experts using the dashboard, 10 completed the questionnaire in full, we consider. Even if this number of participants is too small for a comprehensive statistical evaluation, this number of experts already provides useful results regarding the usability of software artifacts, as described by (Hwang & Salvendy, 2010) in their 10 +-2 rule. Of the SVs, all 32 participants completed the questionnaire. Of the SVs, all 32 participants completed the questionnaire. This difference in the number of participants should be considered when examining the results presented below as a percentage. The results are presented and briefly summarized in the following based on the dimensions surveyed and the associated items for both user groups responsible frontends (dashboard/ app).

Performance Expectancy: Both user groups rate the usefulness of the system used as predominantly positive (Figure 9). Usefulness in work as SV is rated considerably higher for the app than for the dashboard, going in line with the results of the acceptance study in our earlier research steps.

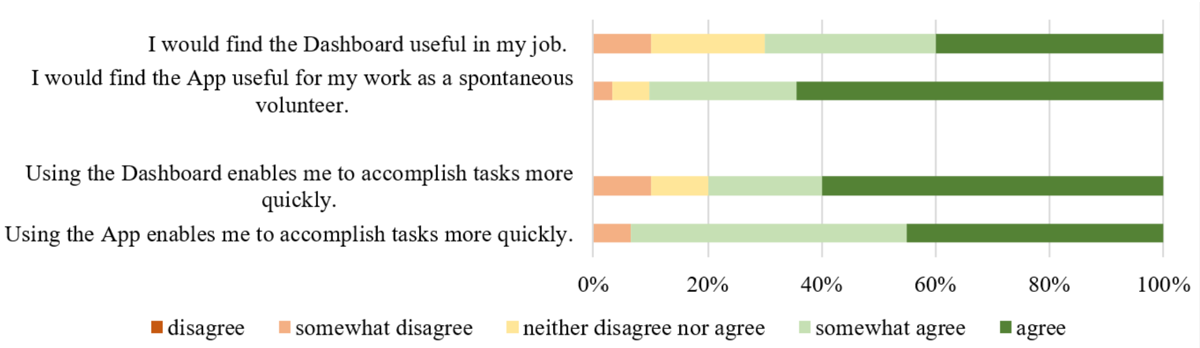

Figure 9. Performance Expectancy

Attitude Towards Technology: The results of this dimension show that both user groups enjoyed interacting with the system by a large majority (Figure 10). The negatively polarized item generates responses with a wider range of agreement to disagreement for the app. However, this pattern is repeated for the other negatively polarized items from other dimensions. Perhaps a percentage of SVs also missed the polarity reversal (however, this does not explain all "Agree" and "Somewhat Agree" responses, because the percentage is lower for the other reversed items). The results of the reversed items show that, overall, the items were read and answered carefully.

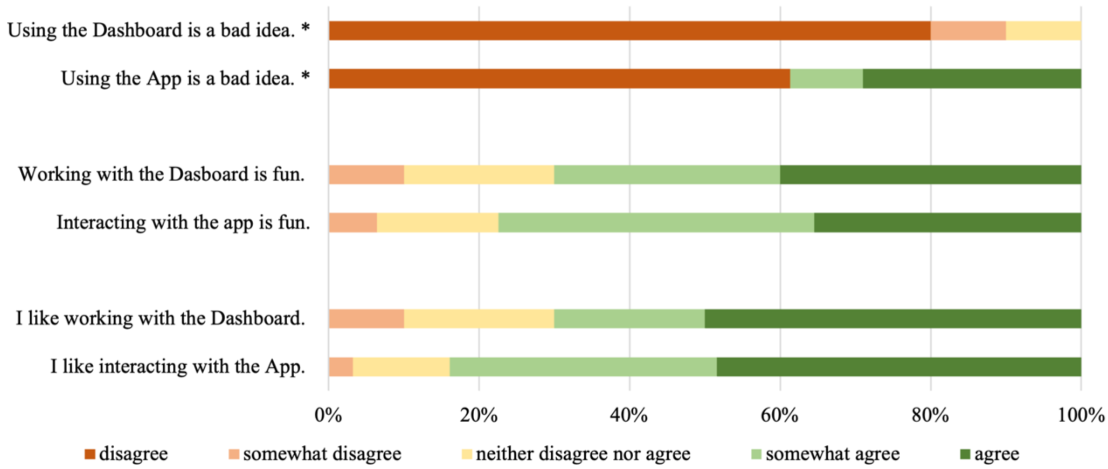

Figure 10. Attitude Towards Using the Technology (* negative polarized items)

Anxiety: The results show that both user groups have few reservations about using the system (Figure 11). However, it is evident that the SVs are more skeptical about using the app. One possible explanation could be that some of the SVs who have so far coordinated via existing communication channels see no need to introduce further systems and are fundamentally skeptical about unknown applications.

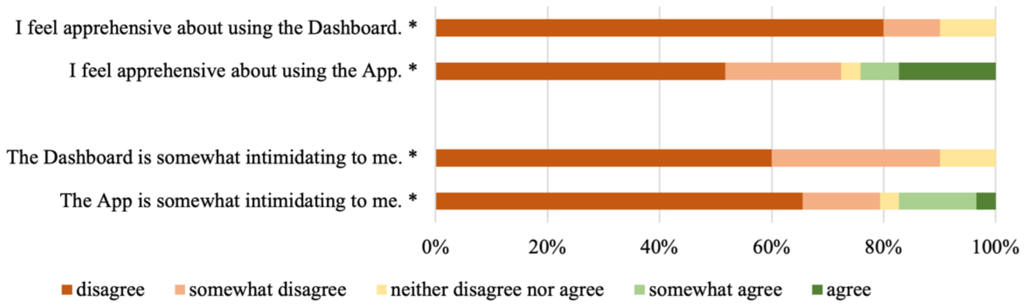

Figure 11. Anxiety (* negative polarized items)

Behavioral Intent: While most respondents in both user groups also had a positive attitude towards the system in the case of behavioral intent, a slightly higher level of rejection was found among SVs (Figure 12). However, the fact that some completely reject the use of the system is consistent with the results of some other dimensions (e.g. satisfaction, anxiety), which show a clearly negative attitude among a small subset of SVs.

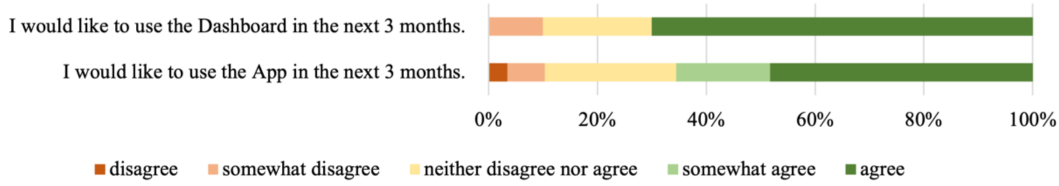

Figure 12. Behavioral Intent

Effort Expectancy: Both user groups rate the simplicity of using the system as overwhelmingly positive (Figure 13). The second item shows that the app appears to be a little easier to use than the dashboard.

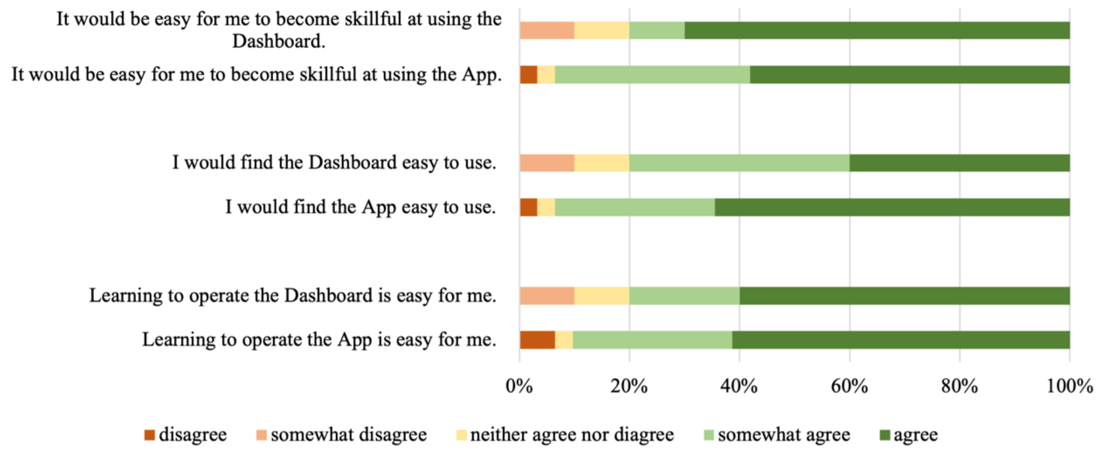

Figure 13. Effort Expectancy

Self-efficacy: Although the results for self-efficacy for both user groups are also largely positive in favor of ease of learning how to use the system, this dimension performs the weakest overall (Figure 14). It is notable that the availability of assistance would not appear to significantly improve the perception of handling the system.

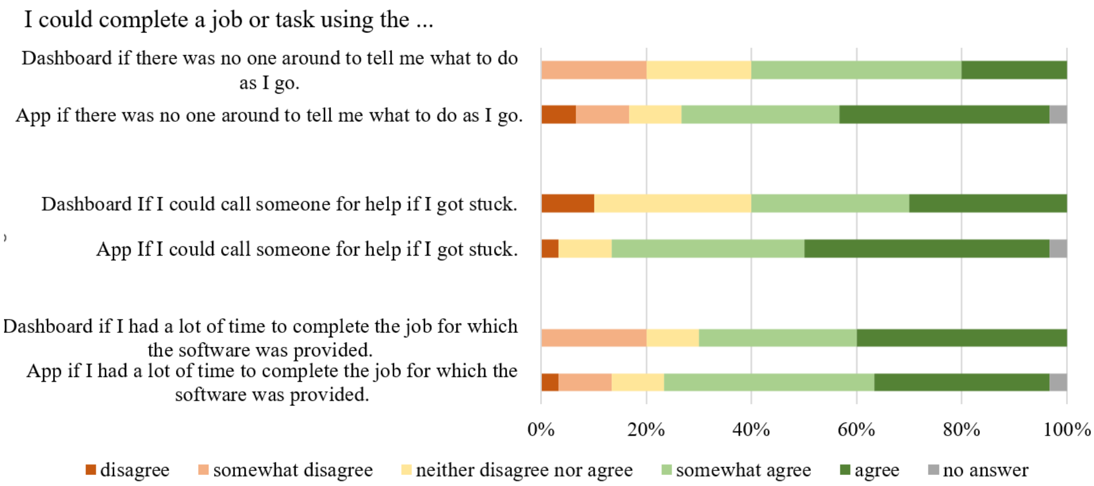

Figure 14. Self-efficacy

Satisfaction: The results indicate that both user groups are highly satisfied with the system overall (Figure 15). With a more hypothetical and less concrete formulation, the difference between app and dashboard is smaller.

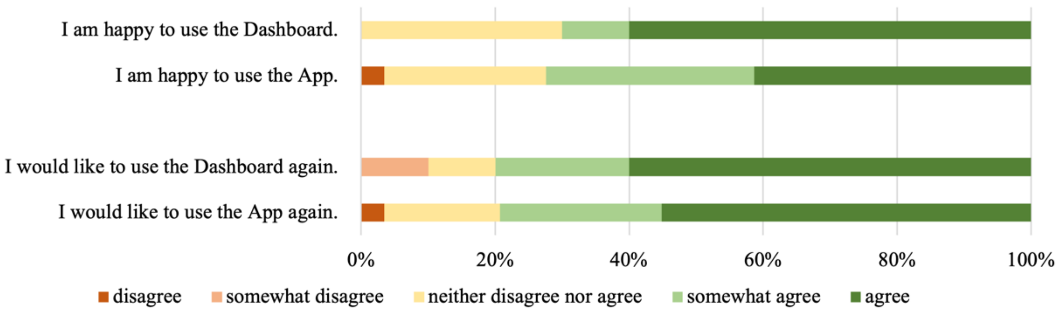

Figure 15. Satisfaction

Design: Both user groups also rated the design of their respective front ends as predominantly positive (Figure 16). The design of the app seems to be more intuitive. Still our software could be improved especially with the color codes used and in clarity and consistency of the wording.

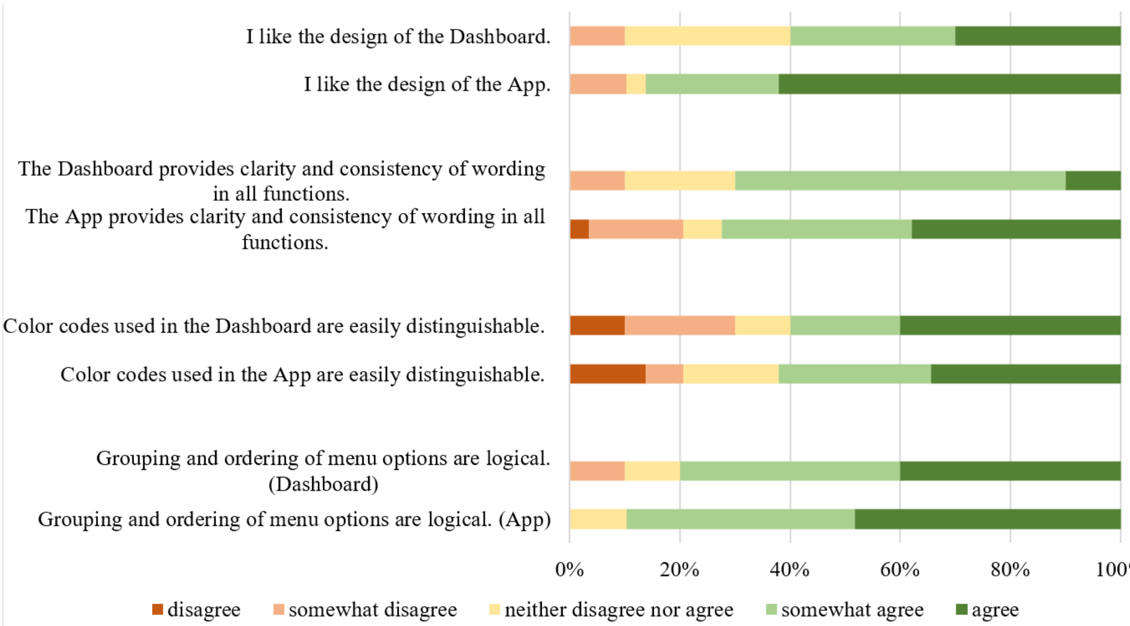

Figure 16. Design

Easiness of Use: While both user groups can easily find the information and functions, they are looking for, SVs believe that the app needs to be used regularly to be fully utilized (Figure 17). Since the answers to other dimensions, in particular effort expectancy, do not indicate that using the app is considered difficult, we assume that the users answered this question more regarding organizational aspects such as community building and gaining experience in disaster response activities and less regarding system design.

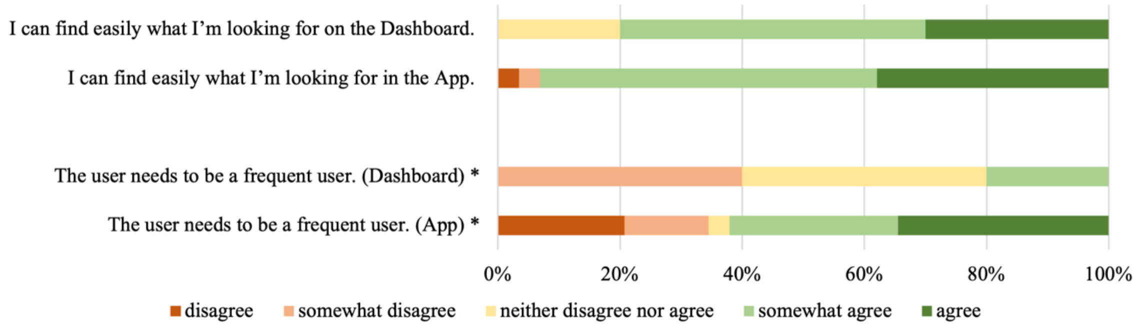

Figure 17. Easiness of Use

In summary, the results presented in relation to our second research question allow the following statements to be made: the results of the questionnaire show that most participants in both user groups have a mostly positive attitude towards the system demonstrator. Compared to the previous acceptance study (Holzhüter et al., 2023), it is clear that users appear to be much more likely to accept a real system. It is notable that the results of the SVs are more polarized and that a small group of participants is very skeptical about the system. Measured in terms of complete agreement (answers with "agree"), there is still room for improvement, particularly in terms of interface design. The good results regarding the perceived usefulness and usability of the system give us an initial indication that the theoretical results we have developed (catalog of requirements, reference architecture) can support the development of suitable systems. Due to the positive perception of the interviewees, we also assume with regard to the first research question that the development of suitable systems is possible on the basis of our design knowledge.

RELATED WORK ON FIELD TESTS OF BIDIRECTIONAL COMMUNICATION TECHNOLOGY FOR CRISES

Since we see the implementation and presentation of the evaluation of the software demonstration as the main contribution of our paper, we would like to briefly discuss the evaluation approaches of related research projects in this chapter. Although some practical studies have already been carried out in the field of volunteer coordination using social media (e.g. Batard et al.,2019; Reuter et al. 2015, Starbird 2013), the related work in relation to specific SVCS is limited. Previous field tests of bidirectional crisis communication apps either focused on an assessment of the overall importance of bidirectional communication between citizens and authorities in crises (Reuter & Kaufhold, 2018) or had a strong focus on the usability aspect of said apps (Jendreck et al., 2016).

Kaufhold et al. 2018 tested the application '112.Social', an application that allows citizens to forward alerts or report an incident to emergency services. '112.Social' then allows authorities to request additional information or disseminate behavioral tips, either via broadcasts or direct reply. Most test users evaluated the citizen to authority component positively (15 out of 21 respondents), and the same applies for the communication from authorities to citizens (14 out of 21). Furthermore, the individual app functions such as sending and receiving messages, assigning categories to messages, adding a description or a multimedia file were positively evaluated by most test persons. The only exception was the GPS tracking functionality, which was negatively evaluated, but this can be explained by the fact that the exercise took place in a building. While Kaufhold et al.'s research shows that the overall assessment of bidirectional communication in crises / disaster exercises is positive, their studies do not provide an in-depth analysis of different aspects of technology acceptance as provided by the UTAUT approach used in this paper.

The research group around the CrowdTasker system has published several papers on their approach (Auferbauer et al., 2016; Havlik et al., 2016; Middlehoff et al., 2016), each of which presents evaluation results from various experiments, although these are not mostly the focus of the paper. A significant evaluation section can be found in Auferbauer & Tellioğlu (2017), in which a field test with 12 participants, which has already been taken up in previous papers (Auferbauer et al., 2016), is discussed to a greater extent. Qualitative observations are discussed here using four categories. In Middelhoff et al. (2016), the results of a larger field test with an unknown number of participants are presented in detail. In addition to qualitative observations, a questionnaire is also used here to have users evaluate two different tools. No reference to the use of established evaluation methodology can be found in the papers.

Jendreck et al. (2016), on the other hand, conducted a live-drill exercise with potential volunteer responders using a preliminary version of the application described in this paper. Their analysis focused on a usability assessment using the System Usability Scale (SUS). They were able to show that the application tested did have a good overall usability. Furthermore, test users positively evaluated the reliability and availability of the system tested as well as its perceived security and efficiency. The presentation of the evaluation results in (Betke et al., 2024) is similar. In this paper, the field test-based evaluation of the SVCS presented is discussed in detail, whereby the evaluation of the SVs (n = 70) was carried out quantitatively using a questionnaire and that of the disaster managers qualitatively through interviews and observations. While these studies provide important insights in technology acceptance, these studies also did not follow a holistic assessment in line with the UTAUT approach. The additional benefit provided by this paper is that it provides an overall assessment of a bidirectional crisis communication tool in a field test in line with the Unified Theory of Acceptance and Use of Technology.

CONCLUSION

In this paper we have gone through a complete design science process for the development of interconnected systems in DM. Having already conducted a requirements analysis and acceptance study and developed a reference architecture in previous work, in this paper we have focused on the implementation of a concrete software artifact in the context of the coordination of SVs and presented the demonstration and evaluation in the context of a disaster prevention exercise. We were able to show how our software demonstrator addresses the previously collected technical requirements and how its components are designed according to the reference architecture. The demonstrator was used in an exercise involving both user groups (DM, SVs) in the case of providing for large numbers of incoming refugees. The methodical evaluation based on the UTAUT approach showed that both user groups see a great benefit in the demonstrated system and perceive the implementation as very user-friendly. The results provide an initial indication that the requirements and reference architecture also provide suitable design knowledge for developing useful systems in the domain. It also indicated that a system for coordinating SVs that mees the requirements would be accepted by the majority of both user groups.

However, this is also a limitation of the approach, as the assessment based on a single use case with a small user group is only meaningful to a limited extent. However, the results are encouraging for continuing the research in further design sciences cycles. We are currently working on the implementation of an information crowdsourcing system for collecting and analyzing information from the population, which is also based on the design knowledge of our approach. Jurgens & Helsloot (2018) and Starbird (2013) have already outlined this by using social media for collective intelligence. With the evaluation of this system, we want to show that our results can be usefully applied to various interconnected systems in DM. In connection with the design of our demonstrator systems, we also collect further information to enrich our design knowledge and adapt it if necessary. The final goal of the approach is to create an overall design theory with requirements, principles, and features, which is further substantiated by an associated software architecture reference model. A final step in our approach will be to have the design knowledge evaluated by experts in the field of software development and DM to be able to make general statements about its suitability. In addition, further desiderata in the field of SVCS appear promising, so an analysis of existing approaches could synthesize the previous design knowledge into a superordinate design theory for SVCS.

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