An Information System for Predicting the Influx of Spontaneous Volunteers at Operating Sites in Natural Disasters

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Summary

Past natural disasters showed that disaster management is no longer conceivable without considering civil participation. The characterization of so-called spontaneous volunteers is their immediate help in the disaster area in response to a disaster event and regardless of disaster management requirements. Without affiliations to civil protection or disaster management organizations, they tend to be untrained in disaster response activities.

It is particularly noteworthy that spontaneous volunteers predominantly organize and coordinate their help efforts on their own and usually via social media. Such self-organization led to their influx at operating sites, that did not always appropriately meet official disaster management's demands for help. In this regard, spontaneous volunteers led to massive overloads of operating sites, causing on-site staff to be hampered in their actual work by this additional challenge. Spontaneous volunteers were turned away from operating sites despite their willingness to help. Rejections sustainably weakened their motivation to help or resulted in self-organized relief efforts, some of which even counteracted the goals of disaster management. Contrarily, there were also operating sites with a high demand for help, but where the influx of spontaneous volunteers was absent.

Nevertheless, the overall utility of spontaneous volunteers for disaster response in coping with disasters and reducing their extents was conceived as valuable for disaster management. The problems caused by their influx at operating sites were primarily due to the unpredictable nature of spontaneous volunteers and a lack of disaster management tools to plan and train for such scenarios.

Consequently, the research project in the dissertation aims to design, develop, and evaluate an information system for predicting the influx of spontaneous volunteers at

operating sites. The prototype, as the result of the design and development process, is called IS2SAVE. It intends to enable disaster management planning and training with dynamic spontaneous volunteer scenarios.

In order to achieve the goal, the research project follows a Design Science Research (DSR) approach as it seeks a tangible software-technical solution to the lack of training and planning tools in the organizational context of disaster management. The project is structured through a multi-cyclical DSR process to facilitate a continuous evaluation of the prototype with subject-matter experts, particularly for providing utility for practice. DSR was further chosen as a suitable research framework because it documents the process of solving an organizational problem and simultaneously promotes contributing design knowledge to academia.

The design process was conducted in three consecutive design cycles as new research questions emerged from each evaluation, leading to the development of new artifacts. First, the design requirements for the system were elicited from the perspectives of domain experts in a focus group, from which initial design principles were derived. These design principles resulted in the development of mockups and a system architecture. Considerations about their specific instantiations triggered another design cycle.

In the second design cycle, the research project first outlined the context of dynamic spontaneous volunteer scenarios in a conceptual scenario language. The scenario language served, on the one hand, to understand the characteristics of dynamic disaster scenarios with spontaneous volunteers and, on the other hand, to deliver a machine-processable format of dynamic scenarios for the IS2SAVE system. Additionally, the behavior of spontaneous volunteers was conceptualized in a model to gain a general understanding of their behavior and actions in these disaster scenarios. The evaluation posed questions about the plausibility of the predictions of IS2SAVE, which led to further investigation of the behavior of spontaneous volunteers in a third design cycle.

The first part analyzed influencing factors and their effects on spontaneous volunteers' willingness to help, whereby the analysis concerned flood disaster scenarios in Germany to alleviate complexity. The second part addressed the prediction of operating site choices with machine learning. Besides the artifacts derived from the development process of IS2SAVE, the gained design knowledge was summarized in evaluated design principles and a design theory to add value for academia. Furthermore, the IS2SAVE prototype was presented to domain experts to evaluate its utility for disaster management and to demonstrate the plausibility and predictive validity of the spontaneous volunteer influx predictions.

The focus on flood scenarios in Germany in IS2SAVE offers a sound starting point for future research work. The artifacts constituting IS2SAVE and IS2SAVE itself may be adapted to other types of disasters and other countries. Moreover, the derived design knowledge promotes future instantiation of an information system for planning and training beyond solely predicting the spontaneous volunteer influx and incorporating technological advantages and new findings. The system can further extend existing approaches that build upon knowledge of the impending influx, such as spontaneous volunteer coordination systems or on-site task assignment approaches.

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List of Abbreviations

ABS Agent-based Simulation.

API Application Programming Interface.

CON Concisenes.

DC Design Cycle.

DITAK Digitales Trainingssystem für die Aus- und Weiterbildung von Krisenstäben (*Eng. Digital training system for the education and training of disaster management teams*).

DM Disaster Management.

DP Design Principle.

DR Design Requirement.

DSR Design Science Research.

DT Design Theory.

EE Effort Excpectancy.

EXP Explananatory Power.

EXT Extensibility.

FC Facilitating Conditions.

IEEE Institute of Electrical and Electronics Engineers.

ILAS IT-gestütztes Lageübungs-System für Aus- und Weiterbildung in der Stabsarbeit (*Eng. IT-supported situational training system for education and professional development in disaster management*).

IS Information System.

ISR Information System Research.

IT Information Technology.

IS2SAVE Software artifact for the prediction of the spontaneous volunteer influx.

JSON JavaScript Object Notation.

KUBAS Koordination ungebundener vor-Ort-Helfer zur Abwendung von Schadenslagen (*eng. Coordination of spontaneous volunteers to overcome disaster situations*).

KatHelferPro Koordination von Spontanhelfenden im Krisen- und Katastrophenfall (*Eng. Coordination of spontaneous volunteers in the event of crisis and disaster*).

MAE Mean Absolute Error.

OS Operating Site.

PE Performance Expectancy.

PES Pruned Entity Structure.

REST Representational State Transfer.

RMSE Root Mean Squared Error.

PU Perceived Usefulness.

RQ Research Question.

SES System Entity Structure.

SI Scale Item.

SiK Simulationen im Katastrophenmanagement (*Eng. Simulations in disaster management*).

SMA Simple Moving Average.

SRQ Sub Research Question.

SSD Simulation Scenario Development.

SV Spontaneous Volunteer.

SVCSDL Spontaneous Volunteer Coordination Scenario Definition Language.

UML Unified Modeling Language.

URL Uniform Resource Locator.

UTAUT Unified Theory of Acceptance and Use of Technology.

XML Extensible Markup Language.

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List of Symbols

$\overline{X}$ mean

σ standard deviation

m total number of expert predictions

MAE mean absolute error

n total number of examined data

x_i simulated prediction for examined item i

y_{ij} expert prediction j for examined item i

N_{all} total number of participants

N_{high} number of participants who voted for *high*

N_{low} number of participants who voted for *low*

N_{medium} number of participants who voted for *medium*

List of Equations

Introduction

1.1 Motivation

Natural disasters are an unavoidable part of our lives. We are regularly confronted with news about extreme weather events with disastrous extents that cost the lives of thousands of people every year [1] and cause billions of dollars in economic losses [2]. In addition, the number of natural disasters increased significantly in recent decades (see Figure 1.1). At the same time, it can be observed that the intensity of these disasters has risen considerably [2]. Natural disasters are no longer just an international phenomenon; also, Germany is regularly affected by such events. In particular, the flood disaster in the Ahr valley in 2021, the flood of the century in 2013, and storm Kyrill in 2007 highlight that Germany had and will have to cope with numerous natural disasters with severe economic damages [3].

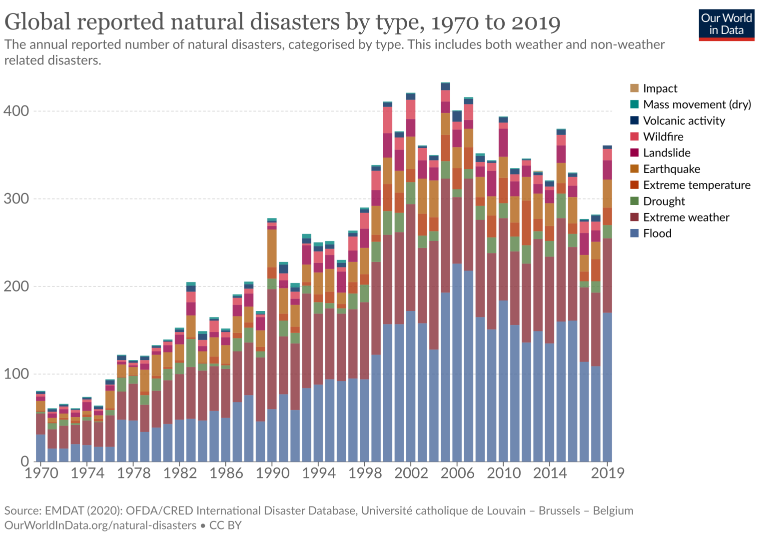

Figure 1.1: Global reported natural disasters by type (1970 to 2019) [1]

Although we cannot prevent natural disasters, it is even more important to respond appropriately to and prepare for such events, as well as to learn from past disasters. Civil communities are therefore required to gain an awareness of natural disasters and an augmentation of resilience, which is supported by official disaster management [4].

Disaster management is characterized by the preparation of authorities for potential hazards and the education of civil society [5]. In addition, disaster management is responsible for protecting human life and assets before and during an impending disaster [5]. The recovery of the original state in the aftermath of a disaster, e.g., through clean-up tasks, is another critical duty [5]. Volunteer relief organizations usually support official disaster management and state an important pillar in disaster response. However, disaster management is the primary responsibility of official civil protection and disaster management authorities and, at least in Germany, they are in charge of command and control in disaster events [6]. Consequently, volunteer relief organizations constitute an integrated part of official disaster response activities and are coordinated accordingly.

Nevertheless, several recent disasters revealed that, in addition to official and voluntary disaster relief, more and more citizens spontaneously offer their help and donate resources to tackle the disaster scales on-site [7]. These citizens are usually not trained for disaster response activities and provide their assistance immediately after a disaster occurs and until the original condition is restored [8, 9, 10, 11]. Research refers to this type of volunteers as *spontaneous volunteers* (SV) [8]. In response to recent disasters, spontaneous volunteers converged to operating sites to assist first responders in, e.g., filling sandbags, or forming human supply chains to transport sandbags to designated locations [9]. According to reports from disaster managers, the extent of some disasters would have been much more severe without their help [12, 13]. They were further conceived as valuable, as they partially counteract the decline of memberships in volunteer relief organizations, which is caused by a lack of interest in binding to organizations and demographic change [14, 15, 16].

Irrespective, spontaneous volunteers have not only had a positive impact on disaster response. Since spontaneous volunteers mainly organize themselves independently and via social media [17], rather than being coordinated by authorities, the goals of the two helping parties are sometimes at odds with each other [10]. E.g., spontaneous volunteers tended to help at centralized and already overcrowded operating sites rather than at peripheral operating sites that urgently needed help [18, 10]. As a result, on-site disaster staff were overwhelmed by the sheer number of spontaneous volunteers [19], and in some cases, spontaneous volunteers even impeded them from carrying out their assigned tasks [18]. In response, spontaneous volunteers were oftentimes turned away at operating sites [20]. The massive influx of spontaneous volunteers further led to traffic jams and congested emergency routes, which caused difficulties for responders to reach their deployment sites [21, 22, 18]. Similarly, on the one hand, rejections by on-site staff led to crowds of volunteers searching for locations to help and further congesting emergency routes [18] and, on the other hand, to frustration among the spontaneous volunteers due to being turned away from their assistance [16]. Some disappointment caused by the rejections was so intense that future help was ruled out by the volunteers [9, 23].

Since spontaneous volunteers have become an inevitable part of disaster response, disaster managers have increasingly questioned how to cope with assistance from the public [15, 24]. One aspect of this was a lack of knowledge about why and when the population would participate [10]. The 2013 flood of the century in Germany, for example, took place in summer with high temperatures [25] and occasionally a "party atmosphere" [26]. Disaster managers consequently wondered how the support would have turned out under different conditions, e.g., in winter or with heavy rain [16]. Moreover, it was utterly unclear to disaster managers why people helped at crowded operating sites when, by contrast, operating sites urgently needed help elsewhere [10].

Due to this, it was challenging or even impossible for the disaster management to respond, as the imminent influx of spontaneous volunteers remained widely unknown [27]. The unpredictability, both in terms of their arrival and their numbers on-site, was highlighted as a major challenge for disaster management [28, 27, 29, 22, 12].

Aside from the unpredictability of their influx, disaster management lacks tools to plan or train for such scenarios, which is critical to address the problems mentioned before [24, 30, 31, 10]. Planning, before and in a disaster, enables disaster management to prepare for the impending influx of spontaneous volunteers. If disaster management, e.g., anticipates overcrowding and understaffing of operating sites, as well as potential congestion caused by masses of volunteers, it can take corresponding actions. Moreover, planning allows for "what if"-analysis [28], e.g., to evaluate the effects of weather changes on the citizen participation. And, even though disasters are unique [10], a continuous training for versatile spontaneous volunteer scenarios promotes improving the overall spontaneous volunteer management. Thereby, disaster managers can test and practice strategies for scenarios to react faster and better to the impending influx in the future.

1.2 Research Goal

Therefore, the research project aims at designing, developing, and evaluating an information system that facilitates predictions about the influx of spontaneous volunteers at operating sites. Information systems generally promote effectiveness and efficiency in organizations [32]. The resulting prototype, referred to as IS2SAVE, targets utility for disaster management training and planning by enabling predictions about the spontaneous volunteer influx at operating sites in dynamic scenarios.

The research project in the dissertation sets out to answer the overall research question (RQ):

How to design an information system for predicting the influx of spontaneous volunteers at operating sites?

IS2SAVE intends to enable disaster managers to plan for the impending arrival or absence of spontaneous volunteers in disaster situations, e.g., to derive management plans, as well as to present volunteer movements to identify congested or crowded routes. It further promotes regular training and exercising to respond faster and better to future disasters. The research contributions of the dissertation were developed and applied within the framework of several government-funded research projects (*KUBAS, SiK, ILAS*) and form the basis for further research projects currently applied for (*DITAK, KatHelferPro*). The relevance of the topic and the targeted information system is thus particularly underlined.

1.3 Research Method

Fundamentally, two paradigms exist for information systems research: *behavioral science*, which involves the creation and measurement of theories that predict organizational or human behavior [33, 34], and *design science*, which seeks to expand the boundaries of organizational and human capabilities through the creation of new artifacts (e.g., *models, methods, constructs, design principles*) as well as the development of new *design theories* [35, 36, 37]. In particular, Hevner et al. (2004) highlight that the goal of behavioral science is truth, whereas the purpose of *design science research* (DSR) is utility [38].

Regardless of their opposing alignments, the approaches should instead complement each other [34]. Research findings on organizational or social phenomena, such as the behavior of spontaneous volunteers, may form the basis for designing artifacts. However, since the sole knowledge about spontaneous volunteer behaviors does not promote the training and planning, behavioral science is only concerned with the artifacts of the system and not guiding the overall research process. Moreover, the objective is to solve the practical problem of planning and training with spontaneous volunteer scenarios due to their unpredictable influx by developing innovative IT artifacts. In regards, Venable and Baskerville (2012) particularly define DSR as *"Research that invents a new purposeful artefact to address a generalized type of problem and evaluates its utility for solving problems of that type"* [39, p. 142].

The research project is oriented toward the research paradigm of *design science research* due to its particular focus on problem-solving, thereby framing a suitable approach. It stimulates theory and practice by guiding the development of innovative IT artifacts that provide utility to practice and deriving design knowledge that contributes to the knowledge base in academia. Moreover, the approach addresses the demand for design knowledge in the research domain of information systems in natural disaster management, as pronounced by Schryen and Wex [40].

Design Science Research is more of a research strategy or a plan for conducting a research study, instead of precisely specifying the methods to solve the problem. The precise research approach is unique to each research project and must be adapted to the researcher's specific requirements. The information system development in this research project follows a multi-cyclic DSR process, with each cycle aiming at answering research questions that emerged in the design process. The articles contributed to the cumulative dissertation address these research questions, and their findings constitute the core artifacts of IS2SAVE. Chapter 3 describes the applied research process in more detail (see p. 24).

1.4 Dissertation Structure

The structure of the dissertation orients toward the approach of structuring DSR projects for dissertations proposed by van der Merwe et al. (2017) [41]. The introduction thereby stated the problem. Chapter 2 explains disaster management concepts, spontaneous volunteers, and current research. Furthermore, the chapter presents a literature review focusing on the spontaneous volunteer influx to identify and discuss related works. Chapter 3 introduces the general concept of design science research and the documentation about the process followed in the research project. The subsequent Chapter 4 presents the developed core artifacts and articles within the frame of the cumulative dissertation. Chapter 5 outlines the instantiation of the prototype IS2SAVE.

Following Venable et al. [42], Chapter 6 introduces the framework for evaluating design science projects. As the contributed artifacts were evaluated in the design process, the focus of Chapter 6 is on the summative evaluation of IS2SAVE. Chapter 7 concludes the research project with a discussion of the findings, implications for academia and practice, the limitations of the work, and a general conclusion.

Foundations and State-of-the-Art

2.1 The Role of Spontaneous Volunteers in Disaster Management

2.1.1 Disaster Management

Even though there is a lack of universal definitions of *"disasters"* [43], they commonly describe a sudden situation that causes loss of property and lives that cannot be tackled with the standard emergency staff and measures [43]. In comparison, an *"emergency"* describes an unexpected and severe but local situation requiring immediate action, usually restricted to fewer affected people [43]. The term *"crisis"* is often confused with *"disaster"* in the literature. However, a crisis refers to an indefinite period of great difficulty and uncertainty and differs from disasters in that these occur only temporarily [43]. Further, in comparison, a crisis can lead to the disruption of whole systems [43, 17]. Disasters can generally be distinguished as *man-made*, i.e., oil spills, terror attacks, and *natural disasters*, i.e., earthquakes, floods, or hurricanes [43].

Whereas disasters are temporary, disaster managers think of disasters as recurring events and their management as a continuous process [44]. Formal and time-based disaster and disaster management structures have been investigated for many years [45]. One commonly referenced approach is thereby the so-called disaster management cycle to defining disaster management by Khan et al. (2008) [44]. The well-established and traceable process consists of the four phases [44]: *Mitigation, Preparedness, Response, and Recovery*.

The *mitigation phase* targets measures to reduce the causes, effects, and damages of disasters to people and property, such as vulnerability assessments or public education to raise awareness [44].

The *preparedness phase* is characterized by actions taken to prepare for an impending disaster. Typical tasks include developing plans (e.g., hazard maps), establishing early warning systems, and training disaster management staff [44, 46].

The subsequent *response phase* is reacting to a disaster event, in which disaster management aims to reduce hazards and immediate threats, including search and rescue and emergency response activities [44, 46, 47]. During this phase, spontaneous volunteers commonly gather and converge to disaster sites to provide resources and help [19, 24]. This convergence leads to an increasing influx of spontaneous volunteers at the operating sites, which creates additional challenges for disaster management beyond their primary duties [19].

Once the immediate threat of a disaster subsided, the recovery follows. The *recovery phase* can last from days to weeks or even longer, depending on the extent and nature of the disaster [46]. It involves restoring pre-disaster conditions by repairing physical, social, and psychological damages [46].

Bussell and Forbes (2002) highlight that spontaneous volunteers affect disaster operations mainly in the response phase [47]. During this phase, disaster managers are concerned with an influx of volunteers at operating sites and take the necessary steps to regain control [19].

Nevertheless, the aforementioned problems with spontaneous volunteers motivated researchers and practitioners to incorporate them also into training and planning [24, 30, 31, 10], which usually takes place in the mitigation and preparedness phases. Several articles found in literature reviews for identifying related works in the research process demonstrate that researchers propose plans and strategies for managing spontaneous volunteers (e.g., [48, 49, 50, 28, 51]).

These plans and strategies are, however, often at a high level of abstraction and rather imply strategic aspects instead of specific tools for planning with spontaneous volunteer scenarios, such as:

- the proposition of guidelines for selecting qualified volunteers (e.g., [52]),
- the pronounced requirement for volunteer registration (e.g., [28]),
- the option of establishing of volunteer reception centers (e.g., [53]),
- or binding spontaneous volunteers to organizations (e.g., [24]).

Additionally, training disaster management is rather concerned with the previously mentioned plans, focusing on their inclusion in disaster management exercises and education [53, 54, 50, 55]. However, no software tools addressing disaster management training with spontaneous volunteer scenarios were identified in the research process.

Strategic implications lack operational tool support for the impending volunteer influx for disaster management planning and training, which is particularly addressed with IS2SAVE. Particularly, it aims to anticipate the spontaneous volunteer influx under different circumstances, which promotes understanding effects of parameters on the influx and a preparation for overloads, understaffing, or congested roads. Based on a raised understanding of spontaneous volunteer behaviors, IS2SAVE enables disaster managers to tackle situations and execute measures in relation to their influx to overcome the mentioned problems. Moreover, the tool-support for influx predictions enables continuous trainings for different scenarios to increase the effectiveness of disaster management for the advent of real disasters, e.g., by faster reactions to situations due to learnings from exercises.

Disaster management is a complex process that involves myriad variables, tasks, and decisions that go far beyond managing spontaneous volunteers. In this context, Rogstadius et al. (2013) highlight software solutions to be particularly valuable for management training and planning with spontaneous volunteers [31].

In particular, information systems help to reduce cognitive efforts for users [56, 57], which in the context of disaster management can lead to additional relief for disaster managers and an overall improvement of the management of spontaneous volunteers.

2.1.2 Spontaneous Volunteers

Citizen participation in response to emergencies and disasters is natural due to human situational altruism [58] and also not a new phenomenon. Disaster researchers have observed the role of volunteer citizens since the early 1950s [59, 60] and especially since the 1985 Mexico City Earthquake, when over 2 million citizens were estimated to volunteer in the aftermath [61].

However, as technology advanced and the population became more interconnected, their role shifted dramatically [7, 10]. Social media significantly contributes to this context [62]. Nowadays, personal on-site reports, photos, and videos are shared immediately in response to a disaster, which led to a new form of involvement beyond the borders of the disaster scene. The availability of on-site reports empowers a strong connection and interaction between affected citizens and the general population, which leads to moral support or monetary donations, as well as requests or supplies for assistance [10, 63, 25]. In fact, spontaneous volunteers primarily acted in response to requests for assistance on social media [63, 18]. The broadly unrestricted ability to obtain and disseminate information about disasters also led to a new form of volunteers, so-called *digital volunteers* [64, 9, 7]. In response to the flood of disaster-related news and help requests, social media users felt compelled to filter, collect, and disseminate information, particularly on help requests [64].

In contrast to spontaneous volunteers, these digital volunteers operate solely online and are not always physically present in disaster areas. As with social networks in general, the information gained and shared was frequently biased, subjective, or even false [65, 66, 18].

At the very least, they were usually not consistent with the requirements of official disaster management [67]. In this regard, the role of digital volunteers and social media constitute a large part of spontaneous volunteer-related research. Reuter et al. (2018) provide an exhaustive overview of social media approaches in disasters regarding digital volunteers [68]. However, neither of the studies investigates the influx of spontaneous volunteers at operating sites.

Compared to the actions of digital volunteers, and despite the undeniable influence of social media, studies only partially investigated spontaneous volunteer behaviors to gain a broader understanding ([16, 69, 70, 15, 71]). Studies that are particularly addressing the behavior of spontaneous volunteer as their main research objective tend to focus on psychological for helping ([16, 69]).

The problems associated with the influx of spontaneous volunteers originate primarily in their self-coordination [21, 22]. Despite their unprecedented willingness to help, spontaneous volunteers typically pursue goals that are not always in line with official disaster management requirements, resulting in significant obstacles to disaster staff and overcrowded operating sites [21, 22].

In this regard, coordinating spontaneous volunteers is encouraged in disaster research and directly addressed in many research approaches (e.g., [72, 18, 73, 74, 75, 22]). Their specific goal is to match the supply of help with the demands of disaster management while avoiding overcrowded and understaffed operating sites. It is either achieved by improving the self-coordination of spontaneous volunteers (e.g., through public displays [10]) or by integrating them into official command and control structures (e.g., [75, 18, 72]). For example, some approaches target app-based solutions for coordinating spontaneous volunteers through disaster management. Karl et al. (2015) provide a detailed overview of such approaches [76]. However, these approaches rely on technological infrastructures and technology acceptance.

A failure of the cellular network or technology, as occurred in the past [10], would cause spontaneous volunteers to act as if these coordination approaches did not exist.

While some research approaches address aspects of influx-related problems, none of the existing approaches aims at predictions or tools for training and planning with their influx from the perspective of disaster management. Existing concepts, however, were used to the maximum extent to achieve the goal of IS2SAVE. IS2SAVE, in general, complements rather than competes with existing approaches. As a result, IS2SAVE and existing approaches can benefit from each other.

2.2 Literature Review and Related Works

In contrast to the previous section, which focused on a general assessment of spontaneous volunteers in disaster management, this section presents a systematic literature review on the influx of spontaneous volunteers at operating sites. The primary goal of the literature review is to present related works and highlight the research gap. A sound literature review relies on using a conceptual framework to help focus it [77]. Therefore, the literature review followed the well-known approach of vom Brocke et al. [78].

In general, five scientific databases (*IEEE Xplore*[1], *ScienceDirect*[2], *SpringerLink* [3], *ACM Digital Library*[4], *Wiley Online Library*[5]) were searched with the following search string:

((“spontaneous volunteer” OR “emergent group”) AND (“disaster” OR “crisis” OR “crises” OR “catastrophe”) AND (“convergence” OR “influx”)

[1]https://ieeexplore.ieee.org
[2]https://www.sciencedirect.com
[3]https://link.springer.com
[4]https://dl.acm.org
[5]https://onlinelibrary.wiley.com

In academia, the terms *"spontaneous volunteer"* and *"disaster"* are frequently replaced by synonyms. In addition, *"influx"* is sometimes also referred to as *"convergence"*, but the implication is the same. As a result, the search term included common alternatives to retrieve a diverse range of topic-related literature. The articles considered for the review satisfied the following **inclusion criteria**:

- The focus was on the on-site help of spontaneous volunteers.
- The influx or convergence at operating sites was addressed.
- The focus was mainly on natural disasters.

If the article satisfied any of the following **exclusion criteria**, it was discarded:

- The focus was either on online or off-site help (e.g., digital volunteers).
- The focus was on affiliated volunteers (i.e., volunteers bounded to an organization).
- The primary focus was not on natural disasters.

The search yielded 170 articles (see Figure 2.1). Before assessing the articles, duplicates were removed from the review. The resulting articles were investigated according to the titles and abstracts, whereas articles from different research domains and/or addressing the exclusion criteria were sorted out. The 27 resulting articles were fully read, and only articles that satisfied the inclusion and not satisfied the exclusion criteria (six articles) were considered as relevant for examination. Based on the resulting articles, a forward search (i.e., *reviewing literature that references the article*) and backward search (i.e., *reviewing literature referenced from within the article*) was conducted following the previously mentioned criteria. The forward and backward search resulted in one more article for analysis.

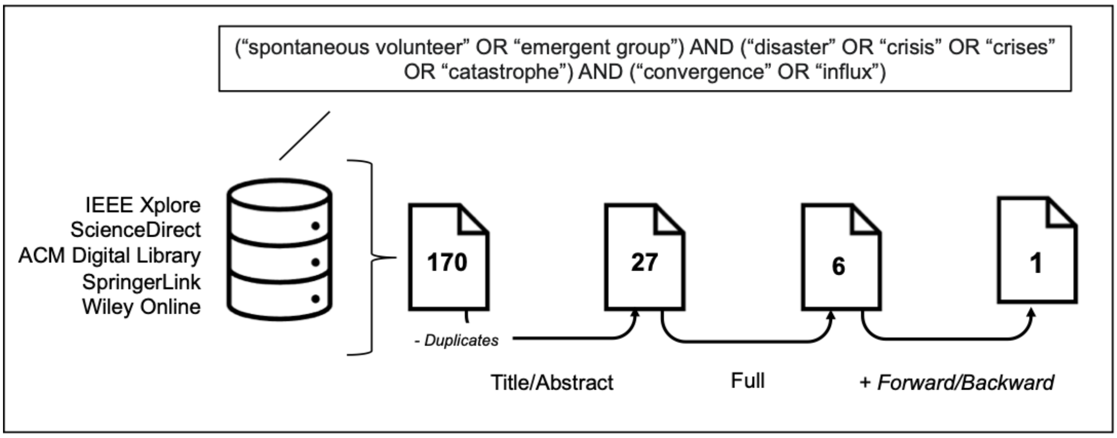

Figure 2.1: Literature search and selection process

In contrast to the previous section, these findings address the convergence or influx of spontaneous volunteers directly or indirectly. The results were assigned to the main concepts of the research project in a concept matrix to differentiate examined studies from the research project [79]. The main concepts represent the artifacts that form IS2SAVE, wherein *(agent-based) simulation* (ABS) is the applied method to simulate the spontaneous volunteer behavior regarding their operating site choice in dynamic disaster scenarios. IS2SAVE can further predict the influx at any number of operating sites (1 to n). The artifacts will be explained in Chapter 4 in more detail.

The literature review confirmed that none of the existing research efforts addresses all concepts of this research project (see Table 2.1), highlighting the research gap. However, the influx of spontaneous volunteers was addressed at least indirectly in all studied articles, e.g., as a prerequisite for achieving their goals. As shown in Table 2.1, all articles incorporate more than one concept of the research project.

	CONCEPT					OPERATING SITES	
	SIMULATION	DYNAMIC SCENARIOS	SPONTANEOUS VOLUNTEER BEHAVIOR	OPERATING SITE CHOICE	INFLUX	1	N
Mayorga et al. (2017)	X				I	X	
Lodree and Davis (2016)	X				I	X	
Zayas-Caban et al. (2020)					I	X	
Sperling and Schryen (2022)	X	X			I		X
Paret et al. (2020)	X				I	X	
Rauchecker and Schryen (2018)		X			I		X
Paret (2020)	X		X	X	X		X
DISSERTATION	X	X	X	X	X	X	X

X = directly addressed; I = indirectly addressed

Table 2.1: Concept matrix of related works

To provide more comprehensibility, the articles were categorized according to their defined objectives instead of the involved concepts. The objectives of the reviewed articles can be summarized as: *Task assignments*, which focus on assigning tasks to on-site volunteers, *Coordination support*, which focus on decision support for disaster management regarding the spontaneous volunteer coordination, and *Influx prediction*, which particularly focus on predicting the influx of spontaneous volunteers at operating sites.

2.2.1 Task assignments

On-site task assignment approaches evaluate strategies, e.g., to reduce waiting times and bottlenecks at operating sites and, thus, can promote a reduction of volunteer rejections [80]. These approaches necessitate information about the arrival of spontaneous volunteers [80, 81, 27, 82]. Therefore, the task assignments are simulated based on probabilistic arrival rates of spontaneous volunteers at operating sites either by empirical data [81, 27] from real disasters or assessed by plausible assumptions [80, 82]. However, the utilized empirical data in the approaches did not fully distinguish between affiliated and spontaneous volunteers.

Among all studied articles, they concern static situations without changing parameters in the progression of the disasters. Further, some task assignment approaches analyze only single operating sites. Hence, a holistic view of the influx prediction is not addressed. Moreover, the approaches particularly mention some unaddressed concepts directly or indirectly in their limitations and future work, in particular the unpredictable influx [80, 82, 81, 27], the number of operating sites [81, 27], dynamic scenarios [27], and operating site preferences [80, 82].

Nevertheless, both this research project and task assignment approaches can mutually benefit. First, IS2SAVE does not consider on-site task assignment strategies or policies. Therefore, existing models could be incorporated for on-site task assignment decisions to provide even more realistic predictions about the influx and enable disaster managers to plan task assignment strategies for various disaster situations. Second, these approaches highlight the unpredictable influx to provide realistic task assignments in their limitations. Therefore, the research project promotes more realistic predictions and can enhance the task assignment results by providing data on the arrival of spontaneous volunteers at operating sites. Additionally, since the approaches particularly focus on on-site decisions, the general behavior of spontaneous volunteers is not addressed.

2.2.2 Coordination support

Compared to the aforementioned IT coordination solutions, the examined coordination support approaches here focus on management decisions for the optimal deployment of spontaneous volunteers to operating sites [83, 84]. Hence, the coordination tools can be used to implement the deployment strategies derived from the support approaches. They distinguish from task assignment approaches by incorporating a more holistic view of a disaster scenario and more than one operating site. Their objective is on how spontaneous volunteers can optimally be distributed to operating sites to avoid volunteer shortfalls or overloads, thereby focusing on decision support for disaster managers [83, 84].

These approaches adopt concepts that were also considered in the research project, e.g., dynamic scenarios and more than one operating site. Nevertheless, their focus is on the decision support instead of predicting the actual influx. The optimal deployment of spontaneous volunteers is thereby derived from probability assumptions concerning their impending influx at operating sites derived from expert knowledge, and due to the lack of empirical data [83, 84]. The decisions of spontaneous volunteers at which operating site they would actually help remains unclear.

This distinction rather encourages a complementation of both the decision support and the findings from the research project. The aspired influx predictions can enhance the decision support as they deliver a more realistic result of operating site choices and, therefore, may advance practical implications for coordination decisions.

2.2.3 Influx prediction

The literature review revealed only one publication addressing the influx prediction directly, thereby incorporating most concepts utilized in this research project. Therefore, a comprehensive discussion must take place to provide scientific rigor and to distinguish the approaches. Paret [85] follows a similar approach in his dissertation. The overall goal was an improved management of spontaneous volunteers from the disaster management perspective [85]. Paret examined the on-site assignment of tasks and the prediction of the spontaneous volunteer influx. Both are achieved with models instead of the information system-based approach applied here [85]. The distinction concentrates on the latter, where Paret also utilizes agent-based simulations to simulate the influx of spontaneous volunteers. It is particularly mentioned, that the *"[. . .] work was inspired by Lindner et al. [. . .]"* [85, p. 70].

The conceptual representation of spontaneous volunteer behaviors in Paret's simulations is derived from Lindner et al. (2017) [86] and Lindner et al. (2018) [87].

Paret also implemented the conceptual model to simulate spontaneous volunteers in agent-based simulations. The approach he uses is akin to Lindner et al. (2018) [87], which particularly emphasizes the relevance of the conceptual model for academia. While both approaches build upon the same foundations, they distinguish particularly in the investigated level of detail for simulating spontaneous volunteer behaviors and partly in their application context.

Hence, Paret rather focuses on evaluating strategies and policy implications for spontaneous volunteer management, such as establishing volunteer receptions centers [85], instead of providing an actual tool to enable planning and training with spontaneous volunteer scenarios. This becomes even more apparent when looking at the time period of the predictions. Instead of providing predictions on a precise (hourly) basis, like in IS2SAVE, the influx is predicted on a weekly basis, which, in conclusion, lacks details for anticipating volunteers on specific days. The level of detail is also concerned by the motivations to help, which is exclusively evaluated in the morning and only once a day [85]. Thus, the dynamics of disaster scenarios according to parameter changes during the day and decisions to help at night are not considered. In general, dynamic scenarios are not covered in Paret's work. Instead, the model predictions rely on an initial and fixed setting of operating sites and one particular operating site-choice strategy.

Paret assessed the evaluation of the spontaneous volunteer influx by calibrating the model to existing data from disasters [85]. However, the data that Paret used did not fully distinguish between affiliated and spontaneous volunteers; thus, the prediction results are likely to be biased. The decision grounded in a lack of empirical data for the influx of spontaneous volunteers, which Paret noted accordingly [85]. Paret further evaluated the model and according influx predictions with subject-matter experts (face validation) [85]. The evaluation process is only sparsely reported, both in terms of the number and selection of experts and the results, which precludes adaptation or comparability with IS2SAVE.

Paret's work was inspired by the design and developments of the IS2SAVE artifacts, which highlights the importance of the general topic and the particular concepts he adapted. Nevertheless, the approaches distinct in their goals and implementations after the common instantiation of the conceptual behavior of spontaneous volunteers.

Even Paret addresses similar concepts, the operating site choice applied here is based on empirical data from real spontaneous volunteers, which was denoted as future work to improve his model in his dissertation [85]. Moreover, the IS2SAVE prototype is generally more detailed in both terms, the dynamics of disaster scenarios with changing parameters and the spontaneous volunteer decision to opt-in for working at nights. Apart from the fact that it is not available as an executable model, these two aspects underline the lack of comparability with IS2SAVE.

Research Approach

The aspired IS2SAVE is a sociotechnical system that focuses on solving the organizational problem of lacking tools for training and planning with the unpredictable spontaneous volunteer influx in dynamic natural disaster scenarios. The research method known as design science research is commonly utilized in information systems research and is further becoming increasingly important in disaster research. This chapter provides an overview of common DSR frameworks, and specifically the design process followed in the dissertation with its according design cycles, artifacts, and contributions.

3.1 Design Science Research

Design science research emerged in the early 1990s as a research method [88]. According to Hevner et al. [38] and March and Storey [89] design science originates in the work of Simon *"The Sciences of the Artificial"* [90], who firstly distinguished *"artificial"* phenomena from the classical perception of how things are, referred to as *"natural"* phenomena. In contrast to understanding or describing phenomena, DSR aims to solve problems [38], and a designer should answer questions and contribute new knowledge by creating innovative artifacts [32].

One purpose of DSR is the development of design knowledge that represents a more generalized knowledge to solve a class of problems, rather than a specific solution to a particular problem [38, 91]. Design knowledge can be represented in various ways and at different levels of abstraction and is referred to as *"artifacts"* derived from the design process.

Artifacts can be in the form of *constructs* (vocabulary and symbols), *models* (abstractions and representations), *methods* (algorithms and practices), *instantiations* (implemented and prototype systems), *design principles*, or general *design theories* [38, 32, 92]. The purpose of artifacts is either to improve existing solutions to a problem, or to provide the first solution to an important problem [32].

Design science became the foundation for methodologies and frameworks in several fields of research, including *information system research* (ISR), where it got recognized by the ISR community, mainly due to the publication of Hevner et al. (2004) [38]. Nowadays, DSR is broadly applied in ISR and information science, yet, not limited to this. Information systems are also essential in disaster research to overcome organizational problems and support disaster managers in charge. Nonetheless, the DSR approach is still not commonly applied in disaster research, resulting in a lack and a pronounced interest in design knowledge in this research field [40, 93]. This requirement is of particular importance for the interdisciplinary nature of this research project and supports DSR as the chosen research approach.

3.2 Design Science Research Frameworks

Research on DSR led to the development of several frameworks to guide researchers through the DSR project, wherein the approaches proposed by Peffers et al. [88], Vaishnavi and Kuechler [94], and Sein et al.[91] are broadly applied. Whereas Sein et al. combine *design science* with *action research* [91], the process of Peffers et al. [88], and Vaishnavi and Kuechler [94] offer similar approaches. However, Vaishnavi and Kuechler have a reduced process model.

Action design research aims at solving practical problems of a particular organization with a predefined team of practitioners [91].

Since in this research project, the design of the information system is not limited to the particular problem of a single organization and does not involve a predefined team of practitioners, *action design research* is discarded as a guiding research framework.

Peffers et al., in comparison to Vaishnavi and Kuechler, provide a process guideline for conducting DSR projects [88], however, they *"[...] do not provide explicit prescriptions how to achieve theoretical abstraction from an IT artefact in a structured way [...]"* [95, p. 12].

For this reason, this research project follows the approach of Vaishnavi and Kuechler [94] to provide structure for the research project and to ensure scientific rigor in the design and development. Compared to Peffers et al., the approach of Vaishnavi and Kuechler was mainly chosen due to their focus on designing artifacts and obtaining design knowledge [94, 96], and therefore to comply with the request for design knowledge for information systems in the natural disaster management domain [40]. The developed artifacts make a knowledge contribution of the type *"exaptation"* [97], which means that they are adapting known solutions to new problems. The general steps of a DSR project, according to Vaishnavi and Kuechler [98], are presented in Figure 3.1.

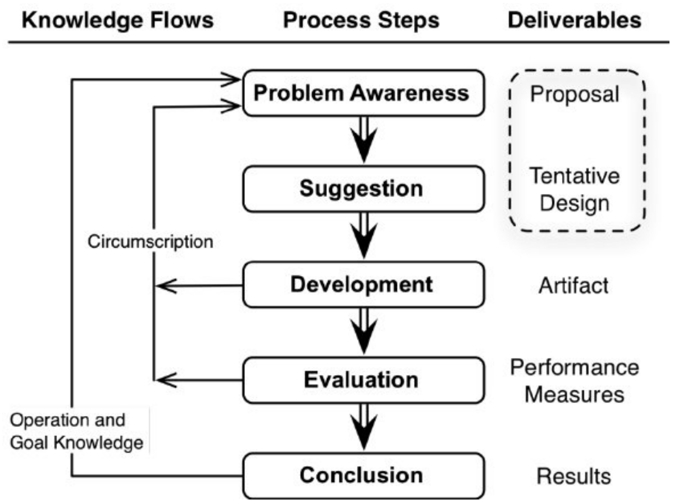

Figure 3.1: General steps of design science research [98]

According to Vaishnavi and Kuechler [98], each design cycle starts with a problem awareness phase, in which the justification of the project or design cycle should become apparent. It involves the clarification of problems to be solved within the design cycle, e.g., in the form of research questions. The subsequent suggestion phase is rather creative, aiming at the proposition of design ideas, e.g., in the form of design principles. The development phase includes developing and implementing the design ideas as artifacts, e.g., in an instantiated prototype. Afterward, the artifact can be evaluated, noting that the general evaluation of DSR projects should follow a consistent evaluation strategy, such as Venable et al. [42]. The conclusion phase ends the research cycle or, depending on the designer's impression of *"how good"* the developed artifact addresses the problem, also the research project. However, the evaluations can update the problem awareness and initiate another design cycle.

3.3 Research Process

The DSR project in this dissertation consists of three consecutive cycles, since reflecting the experiences of each cycle concluded in the formulation of new research questions informing the problem awareness of a subsequent design cycle. The DSR project finished in cycle three with two summative evaluations. Figure 3.2 shows the applied design process, whereas each step of the design cycle presents either the trigger for the cycle (*Problem Awareness*), the resulting artifacts (*Suggestion*), the instantiation of the artifacts (*Development*), the applied evaluation approach (*Evaluation*), and the evaluation results (*Conclusion*).

The remainder of this chapter describes the process of each cycle, followed by a brief description of the developed artifacts. The artifacts further constitute the IS2SAVE prototype and can be considered as the dissertation's main contribution. Hence, they will be described in a more detailed manner in the subsequent chapter. Furthermore, the applied evaluation strategy and results will be presented in Chapter 6.

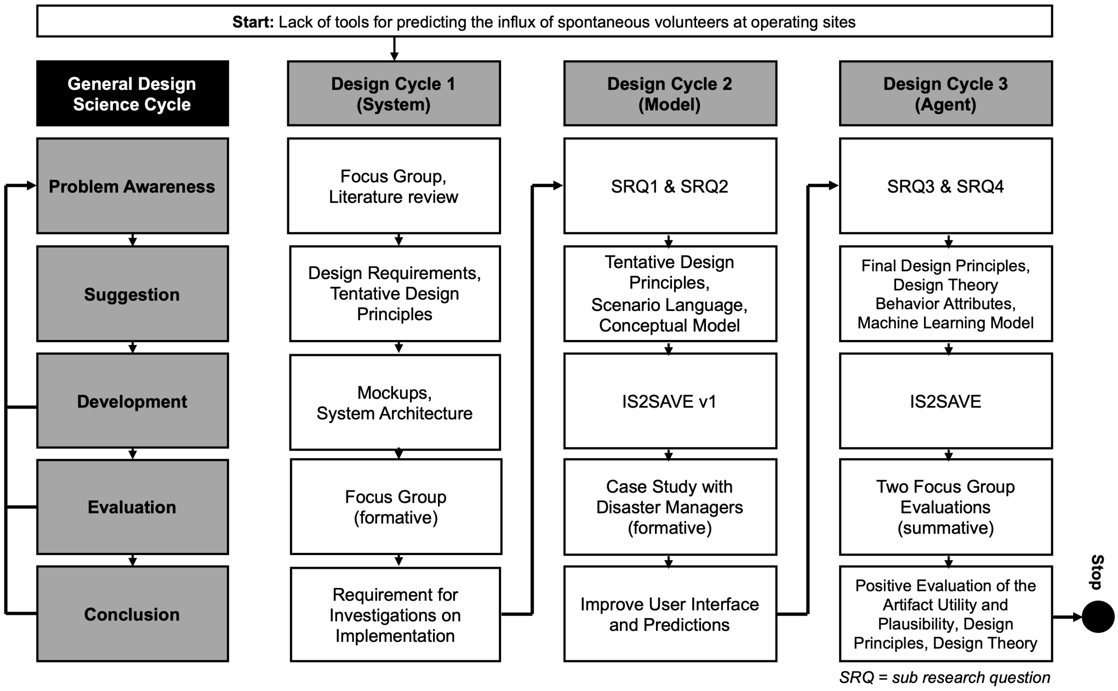

Figure 3.2: Research cycles of the DSR project (following [94])

The lack of tools for planning and training with spontaneous volunteers poses a significant challenge for disaster management [24, 30]. Lacking understanding of their behaviors (e.g., weather influences) further limits the ability of disaster management to plan with spontaneous volunteer scenarios [99, 25].

Accordingly, the unpredictable influx at operating sites caused problems in past disasters and necessitated scientific investigation. However, knowledge about the influx is only beneficial for disaster managers if the information is meaningfully presented and if the use of the system provides utility to users without causing additional effort. To establish a tool for planning and training, this DSR project investigates the design of an information system for predicting the influx of spontaneous volunteers at operating sites.

Design Cycle 1: Focus on the system level Based on the problem-solving nature of DSR and ensuring user utility, the first design cycle was started by identifying the design requirements for the system from a user's perspective to provide maximum utility for planning and training with spontaneous volunteers regarding their influx. Therefore, a moderated focus group with practitioners from the disaster management domain was conducted to retrieve *design requirements* (DR) for IS2SAVE.

From a disaster management perspective, the design requirements concisely represent what an information system must accomplish in order to encourage training and planning with spontaneous volunteer scenarios. The adequate addressing of the design requirements with a prototype represents the stop criterion of the research project. It should only be stopped when the utility of the system is confirmed from the perspective of the users.

Considerations about addressing the DRs with a prototype led to the derivation of five initial *design principles* (DP) [100]. Design principles can be described as *"prescriptive statements that show how to do something to achieve a goal"* [101, p. 2]. An additional systematic literature review [100] was performed to retrieve two more DPs to comply with DSR on building upon existing design knowledge. The design principles were prescriptive and tentative since, at this point, they were neither instantiated in a prototype nor evaluated.

Therefore, the first design cycle focused on conceptual considerations on how the design requirements can be addressed with an information system. Besides the design principles, the system architecture and initial mockups of IS2SAVE were developed, discussed, and evaluated with a focus group of researchers from the IS domain. The evaluation was formative and artificial [42], since the evaluation was with researchers instead of real users.

Particularly, the dynamic aspect of disaster scenarios was extensively discussed. Disaster scenarios are not static snapshots of a situation. Instead, changes in the environment or other parameters happen or can happen. E.g., the demand for spontaneous volunteers may change, the weather may change, and operating sites may be established or closed depending on the requirements of disaster management. The discussion concerned questions about the characteristics and a formal constitution of dynamic disaster scenarios with spontaneous volunteers.

Moreover, simulations of the spontaneous volunteers were proposed in the derived design principles in order to predict their influx. However, the discussion concluded on how their behavior can be defined for simulations. A lack of formal representations of their behavior could be delineated in response.

Design Cycle 2: Focus on the model level The previous two valuable considerations resulted in two *sub research questions* (SRQ) to be addressed for the overall goal of IS2SAVE. Compared to the more system-oriented approach of Design Cycle 1, Design Cycle 2 explicitly focuses on model knowledge by making concrete suggestions for instantiable artifacts based on answering the following research questions.

SRQ1: How can dynamic disaster scenarios with spontaneous volunteers be represented in a formal and machine-processable format?

In order to simulate spontaneous volunteers in disaster scenarios in IS2SAVE and appropriately address the design principles, the development of a machine-processable, structured, and exchangeable representation of dynamic disaster scenarios was aspired. Therefore, the scope of spontaneous volunteer scenarios in disasters was first explored, leading to a conceptual understanding of relevant scenario elements [102].

Subsequently, it was investigated how this scenario knowledge can be decomposed and represented in a machine-processable format [102]. These two considerations were used to derive the contextual and conceptual scenario language, or more precisely, a *system entity structure* (SES) [102]. The scenario language adds to the objective of planning and training by establishing a scientifically grounded knowledge for formally representing dynamic disaster scenarios with spontaneous volunteers. It constitutes an intelligible model for disaster management to create dynamic scenarios. Additionally, the knowledge about dynamic spontaneous volunteer scenarios contributes to academia for building upon or adapting it for new research approaches.

SRQ2: How can spontaneous volunteer behaviors be conceptually modeled for simulations?

It turned out that the requirements of the information system for predicting the influx at operating sites can best be achieved with *agent-based simulations* (ABS) [87, 86]. The spontaneous volunteer influx emerges from numerous individual decisions and behaviors. ABS particularly address emergent phenomena and, therefore, particularly fit the objective.

Based on the previous analysis of dynamic spontaneous volunteer scenarios, two agent types of interest were identified: *operating sites* and *spontaneous volunteers*. Operating sites represent the locations where spontaneous volunteers help.

For the sake of IS2SAVE, these agents consist of a location, a demand for volunteers, and a variable number of active on-site volunteers. In contrast, spontaneous volunteers make multiple decisions in the course of a disaster and, technically speaking, may have multiple states.

To represent spontaneous volunteers in the simulation, it was indispensable to identify their decisions and states within the progress of a disaster, which resulted in the development of a conceptual model in the UML statechart representation [87]. On the one hand, the conceptual model approach pursues a general understanding of spontaneous volunteer behaviors that serve academia and practice. On the other hand, the choice of UML statecharts as their representation allowed for an effortless implementation in the agent-based simulation model for IS2SAVE.

Based on the findings and the developed models, the first prototype of IS2SAVE was instantiated (*IS2SAVE v1*), whereby assumptions and probability distributions drove the simulated volunteer agents. It was presented to disaster managers in a formative case study evaluation. Since the evaluation considered real users and a real problem (case study) and was conducted with an instantiated prototype, it was more naturalistic according to Venable et al. (2016) [42].

Due to the focus on establishing a running simulation model and proofing agent-based simulations to be an appropriate approach for the goal of influx predictions, the prototype heavily relied on assumptions regarding the spontaneous volunteers state changes. Thus, the participants perceived the predictions to be hardly realistic, and the poor usability and visualization of the information system was further considered improvable.

Design Cycle 3: Focus on the agent level The conclusions of Design Cycle 2 led to an additional two SRQs examining the agent level of the system. The focus was on individual volunteers to design IS2SAVE with improved realism. The experiences further led to a refinement of the design principles [100]. Design Cycle 2 concluded with the requirement for empirical investigations on why, when, and where people help, along with the need for improved usability, which initiated Design Cycle 3.

Accordingly, the third cycle focused on individual decisions of whether a spontaneous volunteer helps and, if so, at which operating site. The first research question therefore aims to understand whether a spontaneous volunteer helps in a specific scenario situation, what aspects affect his or her decision, and how they influence it.

The second question focuses on the prediction of where a spontaneous volunteer helps. It is worth mentioning that compared to the broadly applicable findings from Design Cycle 1 and Design Cycle 2, the results of Design Cycle 3 mainly focus on the behavior and decisions of spontaneous volunteers in flood disaster scenarios in Germany. This limitation is due to the complexity of human behavior and the effort required to collect an adequate amount of data to appropriately reflect all behavior-related aspects.

Consequently, the predictions of the influx in IS2SAVE are limited to flood disasters in Germany. Nevertheless, the process is comprehensively documented in the related articles and can therefore be easily adopted to other countries or disaster types in future works. For the prototypical instantiation, particularly flood disasters were chosen, since these are likely events with the most severe economic damages in Germany [103] and usually involve the participation of spontaneous volunteers [25].

SRQ3: What are influences and their effects on the willingness of spontaneous volunteers to help?

This research question partly captures the general motivation of a spontaneous volunteer to help in a specific disaster situation. Thus, it is a prerequisite for the later predictions of where a spontaneous volunteer helps. The goal was to identify attributes and their effects on the decision to help [99]. For example, the results showed that individuals' decisions to help are positively influenced when friends are already helping. This discovery was critical for IS2SAVE, as connections between spontaneous volunteers were not considered up to this point. The analysis promoted IS2SAVE as a valuable finding about why spontaneous volunteers make certain decisions.

Both practice and academia can benefit from understanding spontaneous volunteers' willingness to help. Furthermore, it was shown that the applied *discrete choice experiment* (DCE) approach can be used for disaster research, especially to elicit spontaneous volunteer preferences. The chosen approach and its documentation in the related article may support future studies from an academic point of view in conducting similar experiments.

Besides the connection with friends, the identified attributes refined the implemented scenario language, since the adopted scenario language for IS2SAVE only requires representing attributes that affect the decision to help. However, the extendible format of the scenario language allows for easy adoption to any other kind of disasters.

SRQ4: What is an accurate model for predicting the decision where a spontaneous volunteer will help?

Whereas SRQ3 identifies the influences of the willingness to help that promotes an understanding on a general level, SRQ4 aims at an accurate model specifically for predicting operating site choices in a disaster situation.

The dynamic scenarios in IS2SAVE require a prediction model that captures the operating site preference of spontaneous volunteers when more than one operating site is available.

Additionally, the prediction model builds upon the behavior-influencing attributes and extends them with new findings in regard to the operating site choice. Since the focus was on accurate predictions of the operating site choice instead of understanding the attributes and their relations, machine learning was chosen as the approach.

Based on a broad study, data was collected for training several machine learning algorithms and consequently evaluating, among others, their prediction accuracy [104]. The most accurate model on average, based on a *Random Forest* algorithm, was integrated in IS2SAVE with a *TensorFlow* instantiation for spontaneous voluntary choice of the operation area.

The machine learning model for predicting operating site choices can be used in other projects beyond the application of IS2SAVE, and thus, both practice and academia can benefit from it. Furthermore, the well-documented process of gathering data from surveys, comparing algorithms, and the training of the model allows for further adaptations to other kinds of disasters or other countries. Moreover, IS2SAVE can benefit from new models to extend its applicability.

In addition to integrating the findings from SRQ4, further adjustments were made to IS2SAVE (e.g., improving the user experience) to address the usability issues from Design Cycle 2 mentioned above. The final simulation model, incorporating all recent findings, was implemented in the second prototype of IS2SAVE, which successfully generated predictions for the influx of spontaneous volunteers in flood disasters.

The development of IS2SAVE led to new design knowledge in the form of design principles and to a new design theory for an information system for predicting the influx of spontaneous volunteers at operating sites.

Design Cycle 3 was evaluated in two summative evaluations. The first evaluation focused on the utility of the examined design theory for academia. The evaluation was therefore conducted with IS researchers to prove the relevance of the design theory and design principles for IS research in the domain of natural disaster management [100].

The second evaluation covered the user perspective and two main aspects of IS2SAVE. On the one hand, the focus was on examining the plausibility and predictive validity of the predictions generated in the system. Validating the predictions from IS2SAVE was required to provide meaningful results for the users to promote training and planning with spontaneous volunteer scenarios. On the other hand, the focus was on the utility of the system for the users and, thus, if it addresses the organizational problem of lacking knowledge about the spontaneous volunteer influx and an according tool for planning and training. In response to the positive summative evaluations, the research project stopped after Design Cycle 3.

Figure 3.3 shows the research questions of each design cycle and the contributed articles of the dissertation. The developed artifacts result from answering the research questions and constitute IS2SAVE.

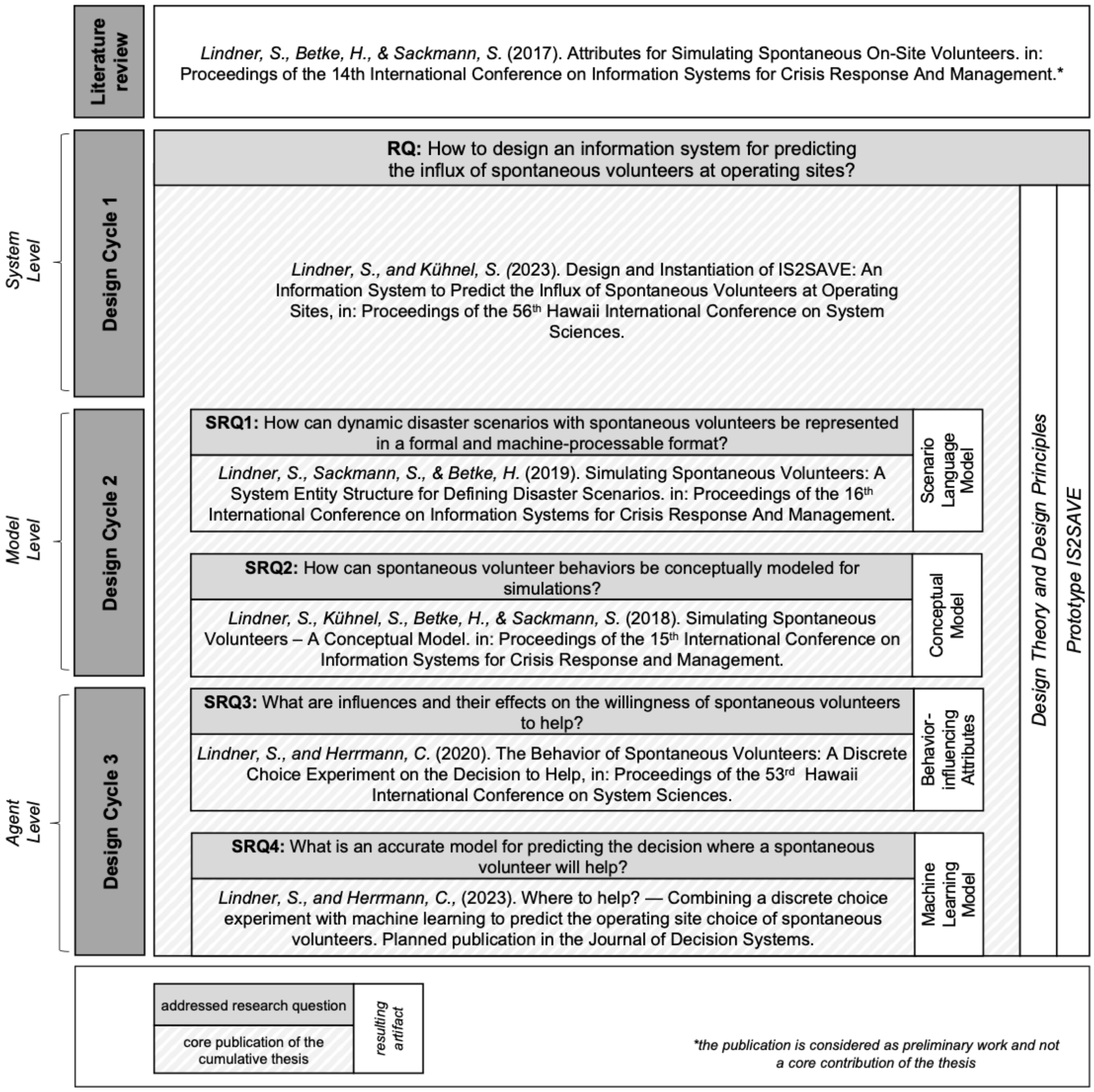

Figure 3.3: Positioning of the contributed articles

Development of the Artifacts

This chapter summarizes the contributions of the cumulative dissertation in the form of artifacts resulting from conducting a design science research project for designing an information system to predict the spontaneous volunteer influx at operating sites.

4.1 Design Theory and Design Principles

The contribution of this article is artifacts in the form of a design theory, evaluated design principles and an instantiated prototype. The findings are published in Lindner and Kühnel (2023) [100] and include both the initiation and result of the multi-cyclic research process, thereby addressing the overall RQ of how to design an information system for predicting the influx of spontaneous volunteers at operating sites.

The design process started with conducting experienced disaster managers to identify design requirements for IS2SAVE. Overall, the focus group identified three design requirements that were required to be addressed by IS2SAVE to predict the spontaneous volunteer influx in an information system and to provide utility for planning and training. The design requirements for IS2SAVE were defined as follows [100]:

- **DR1:** *The information system should provide a comprehensive dashboard of data about the spontaneous volunteer influx at operating sites.*
- **DR2:** *The information system should enable the evaluation and comparison of the spontaneous volunteer influx at operating sites in different scenarios.*
- **DR3:** *The information system should show the movement of spontaneous volunteers on a map, and highlight frequently used paths.*

In addition to the focus group, the design requirements were confirmed by findings from the literature to reduce bias in the sample selection and to ensure scientific rigor in providing a more general solution for practice. Conceptual considerations of the requirements led to the derivation of five initial design principles (see Table 4.1. These design principles can be understood as prescriptive knowledge [101] to *"[. . .] define the structure, organization, and functioning of the design product or design method"* [105, p. 325]. Consequently, the purpose of design principles is to guide the design and evaluation of artifacts [91], and the communication of design knowledge that can be reused for new applications [106].

After deriving design principles and, to comply with the DSR objective to build upon existing design knowledge [38], a systematic literature review following vom Brocke et al. [78] was performed to find and adopt other design principles for the information system. Two more DPs could thereby be derived. An additional three design principles were explored within the course of the DSR project, leading to a total of ten design principles (see Table 4.1). Due to the versatile interpretations of DPs, the DPs are formulated following Gregor et al. (2020) [101].

All DPs were instantiated and addressed in the prototype IS2SAVE. A more detailed explanation of the instantiation will be given in Chapter 5. The DPs provide designers and developers with precise and evaluated guidelines to facilitate predictions about the influx with an information system. However, the specific instantiation is related to the designer's goal and may vary for different applications.

The evaluation of the design principles was the first of two summative evaluations. The evaluation is important to address the lack of validated DPs [107] and to meet the requirement to add design knowledge to the knowledge base for academia, particularly for information systems in natural disaster management [40].

	Initial DPs
DP1: Principle of Influx Simulation	To predict the influx of spontaneous volunteers, reproduce the spontaneous volunteer behavior with a suitable simulation.
DP2: Principle of Scenario Customization	To predict the influx in different disaster scenarios, provide a computational representation of scenarios and a front-end editor to customize scenario parameters.
DP3: Principle of Path Traceability	To detect congested and highly utilized roads, highlight spontaneous volunteer paths on a map.
DP4: Principle of Movement Visualization	To trace time-dependent paths, provide the visual representation of individual spontaneous volunteer locations at a certain time on a map.
DP5: Principle of Influx Analytics	To draw actionable conclusions about the influx of spontaneous volunteers at operating sites, provide visualizations (e.g., in the form of charts) and metrics on different levels of abstraction about the influx on a comprehensive dashboard.
	DPs from literature
DP6: Principle of Ubiquity	To allow for time- and location-independent system use and predictions, provide internet accessibility.
DP7: Principle of User Experience	To guarantee ease of use and reduce complexity, use modern design frameworks and follow contemporary UI/UX guidelines.
	DPs from experiences and evaluations
DP8: Principle of Error Proofing and Scenario Validation	To focus on creating disaster scenarios and, to avoid user mistakes, provide an error checking mechanism in the form of validating scenarios against schemas and user errors.
DP9: Principle of Exchangeability and Reproducibility	To enable exchanging and reusing scenarios, provide an exchangeable scenario file format, validation, and fixed simulation seeds.
DP10: Principle of Comparability	To compare the effect of actions or scenario-dependent variations, establish a side-by-side comparison of different prediction results and an opportunity to store the results.

Table 4.1: Design Principles of an Information System to Predict the Influx of Spontaneous Volunteers at Operating Sites [100]

For the evaluation, a focus group with knowledgeable IS researchers was convened to investigate the: *perceived usefulness* (PU), *conciseness* (CON), *extensibility* (EXT), and *explanatory power* (EXP) of the design theory and design principles. The focus of the first summative evaluation was on the usefulness of the design knowledge mainly for academia, instead of the utility of IS2SAVE for practice, which was assessed in the second summative evaluation (see p. 69).

Perceived usefulness is not a directly measurable construct, whereas the six scale items (SI) *speed* (SI1), *performance* (SI2), *productivity* (SI3), *effectiveness* (SI4), *simplicity* (SI5), and *overall usefulness* (SI6)) were used, as proposed by Davis (1989) [108]. Following the so-called *"10 ± 2 rule"* [109] for choosing the sample size, which states that 8 to 12 respondents are sufficient for evaluating the usefulness, a total of 12 IS researchers and experts were chosen for conducting the focus group.

The focus group was introduced with the general problem to be addressed with the design principles, followed by the presentation of the developed design theory and design principles. Afterward, the participants were asked to fill a questionnaire including sociodemographic questions and the rating of statements for each item on a 5-point verbal numeric rating scale (1 = *strongly disagree*, ..., 3 = *neither agree nor disagree*, ..., 5 = *strongly agree*).

The participants had an average working proficiency of 7 years (σ = 4.37) as researchers (58%), project leads (17%), software engineers (17%), and no specifications (8%) [100].

The initial factor analysis showed that SI1 and SI5 had loadings less than 0.4 (SI1: 0.171 and SI5: 0.087) and, therefore, were dropped as they provided little explanatory power [110].

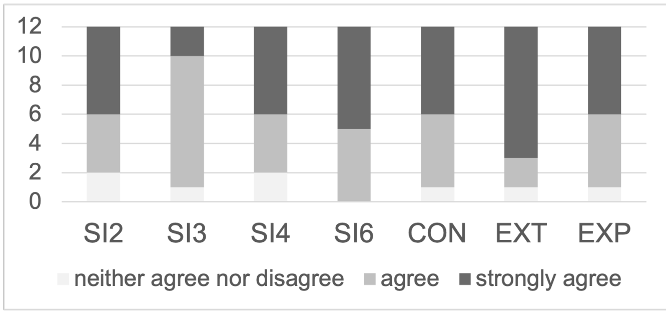

Figure 4.1: Evaluation results for the perceived usefulness, conciseness, extendibility, explanatory power of the design principles [100]

Figure 4.1 shows the evaluation results for the examined items regarding the experts' statements on their agreement. Generally, the design principles received high levels of agreement for all examined items, primarily because neither of the statements was strongly disagreed or disagreed. Moreover, the high rating of SI6 about the general usefulness with $\bar{x} = 5$ (strongly agree) can be inferred as confirmation of the overarching usefulness of the DPs. The median sum score of the examined items was 53 and, thus, close to the maximum value of 60. The results reflect and emphasize the utility of the DPs for designing and developing an information system to predict the spontaneous volunteer influx at operating sites.

On top of the summative evaluation, the developed design theory was formally assessed with the framework proposed by Gregor and Jones (2007) [105]. The formal evaluation serves to clarify whether the developed design theory fully covers all required elements of an academic representation of design knowledge [105]. Figure 4.2 presents the components and corresponding explanations of the framework, and further shows that the design theory addresses all components accordingly. The design theory is nascent since it has not yet become a well-known and broadly applied theory and, hence, is a level 2 artifact according to Gregor and Jones (2007) [97].

Component	Description
Purpose and scope	The goal of an information system to predict the spontaneous volunteer influx at operating sites in disasters is: (DR1) to provide a comprehensive dashboard of data about the spontaneous volunteer influx at operating sites; (DR2) to enable the evaluation and comparison of the spontaneous volunteer influx at operating sites in different scenarios; (DR3) to show the movement of spontaneous volunteers on a map and highlight frequently used paths.
Constructs	Information System, Disaster Manager, Spontaneous Volunteer, Developer, Operating Site, Disaster Scenario Language, Scenario Editor, Influx Statistics, Simulation Model, Dashboard, Movement Map
Principles of form and function	DP1: Principle of Influx Simulation, DP2: Principle of Scenario Customization, DP3: Principle of Path Traceability, DP4: Principle of Movement Visualization, DP5: Principle of Influx Analytics, DP6: Principle of Ubiquity, DP7: Principle of User Experience, DP8: Principle of Error Proofing and Scenario Validation, DP9: Principle of Exchangeability and Reproducibility, DP10: Principle of Comparability
Artifact mutability	IS2SAVE is developed for the application in flood disasters. However, it can easily adapt for different disaster types, since the applied Design Science Research approach rigorously suggests and documents the required design principles on a general level. IS2SAVE can further be adapted to different application contexts, such as evaluating spontaneous volunteer coordination or deployment strategies and their effectiveness in different scenarios. The prediction model of when and where a spontaneous volunteer helps, as well as the disaster-scenario language, can be implemented in other research approaches following a different research goal.
Testable propositions	The information system itself provides valuable new insights that promote the management of spontaneous volunteers. The design knowledge in form of design principles enables designers and developers to easily adapt and implement such a system. The prediction model of when and where a spontaneous volunteer helps provides new knowledge about their decision-making process.
Justifactory knowledge	Across three design cycles, the approach presented builds on an analysis of background literature and theories (disaster management, design science, spontaneous volunteers), expert knowledge from focus group, and case study findings
Expository instantiation	Development of a prototype encompassing: an AnyLogic agent-based simulation method for simulating the spontaneous volunteer influx at operating sites; a TensorFlow model for predicting the individual decision to help; a PostgreSQL database for storing influx data from the simulation; a ReactJS web application powered by a NodeJS server for the purpose of creating (and exporting/importing) disaster scenarios, triggering simulation runs, presenting influx predictions on a Grafana-powered dashboard, exporting/importing prediction analytics for comparison

Figure 4.2: Components of the design theory for IS2SAVE [100]

The design knowledge obtained in the design process of IS2SAVE addresses the lack of design knowledge and the pronounced request for design artifacts in the domain of IS in natural disaster management [40]. The design principles serve developers and researchers in designing an information system to predict the influx of spontaneous volunteers at operating sites beyond the prototypical instantiation in IS2SAVE. The design knowledge is independent of implementations and promotes developing new software artifacts with technological improvements.

Table 4.2 serves as an overview of the contributed article and the developed artifacts. The full article can be found in the appendix (p. xlvi).

Title	Design and Instantiation of IS2SAVE: An Information System to Predict the Influx of Spontaneous Volunteers at Operating Sites
Authors	Lindner, S., Kühnel, S.
Year	2023
Published in	Proceedings of the 56th Hawaii International Conference on System Sciences
Abstract	Disaster managers are in charge of encountering natural disasters, yet, more often supported by citizens, so-called spontaneous volunteers. Their help has repeatedly been reported to be valuable for reducing disaster scales, regarding an increase in natural disasters occurrences with devastating effects. However, their characteristic to emerge in large groups has led to an unpredictable influx at operating sites from the perspective of disaster management. Finally, this led to problems such as congestions and blocked emergency routes, overcrowded operating sites and hampering officials in doing their work. To address this unpredictability, we apply a design science research approach to design and develop an information system to predict the influx of spontaneous volunteers at operating sites. We examine three design requirements and ten design principles, that we instantiate in a prototype. We finally validate our design theory empirically with experts, who positively highlight its perceived usefulness, conciseness, extendibility, explanatory power.
Keywords	design science, design principles, spontaneous volunteer, disaster management, influx prediction
Artifact	Design Theory, Design Principles
Evaluation	Focus Group
Contribution	design knowledge for an information system to predict the influx of spontaneous volunteers at operating sites, instantiated prototype IS2SAVE

Table 4.2: Meta-data of the article by Lindner and Kühnel (2023)

4.2 Scenario Language

The evaluation results of Design Cycle 1 led to the requirement for a specification of dynamic spontaneous volunteer scenarios. Based on that, SRQ 1 was derived and addressed in Lindner et al. 2019 [102]. The goal was thereby an instantiation-independent representation of dynamic disaster scenarios. In this regard, the artifact in the form of a scenario language can deliberately be adapted for other applications in the context of spontaneous volunteer scenarios.

The literature review for the article revealed that scenario languages are mainly used in the context of military applications [102]. Nevertheless, valuable concepts were identified and adopted for the context of spontaneous volunteers. Precisely, the process followed the *simulation scenario development* (SSD) approach proposed by the *IEEE* to identify *entities*, *behaviors*, and *events* that characterize dynamic spontaneous volunteer scenarios [111]. The process allowed inferring the context of disaster scenarios with spontaneous volunteers and its features, but did not provide a solution to the goal of a machine-processable representation.

Therefore, *system entity structure* (SES) was identified as a methodical framework for instantiable scenario languages. SES reflects the system-engineering concepts of hierarchical decomposition and specialization [112] and is based on a limited set of elements (*entity, aspect, specialization, variables, and multi-aspect*). It is commonly used for the automatic creation of exhaustive XML schemas, which can be considered as proof of concept for instantiable scenarios. Thus, SES was suitable for providing a broadly applicable and conceptual representation of disaster scenarios that can further be translated into machine-processable formats such as XML, but not limited to that. Following the SSD approach to identify scenario elements by consulting experts and the literature, the concept of the scenario language was implemented in the format of SES, as shown in Figure 4.3.

The model includes the elements of interest and their relations to represent a spontaneous volunteer scenario. It was deliberately developed at a high level of abstraction to be independent of the instantiation for achieving a particular goal. In particular, variables were only exemplarily mentioned in the model but remained unspecified to promote a general understanding beyond the instantiation in IS2SAVE.

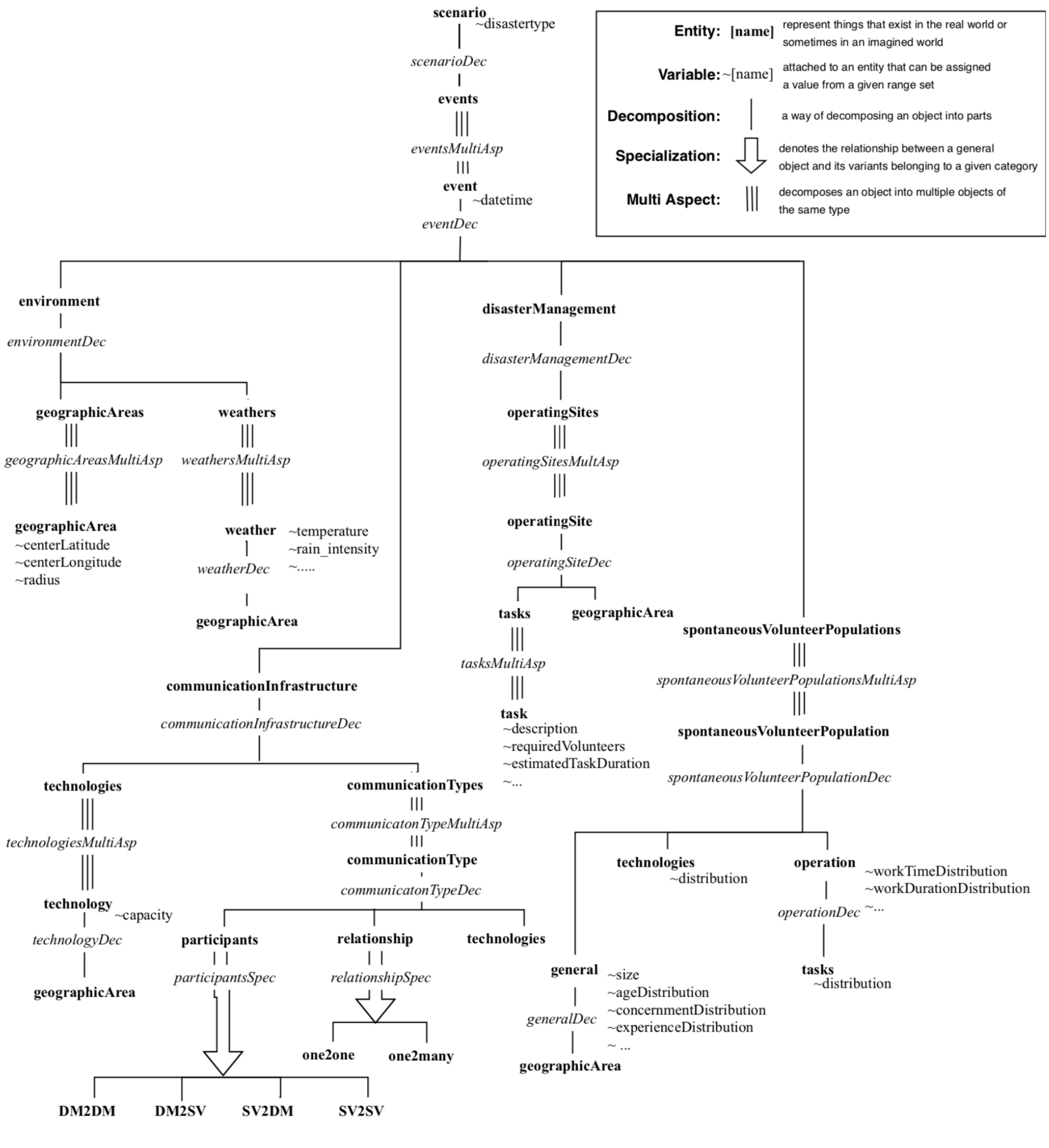

Figure 4.3: System entity structure for defining disaster scenarios [102].

The applicability of the SES for representing realistic scenarios was demonstrated in a case study. The study was conducted in collaboration with local disaster managers to develop a real-life spontaneous volunteer scenario observed in the past. Applying a real scenario onto the conceptual SES representation results in a so-called *Pruned Entity Structure* (PES).

Resolving the elements in the real-world scenario led to a selection-free tree [113] (see Figure 4.4) without raising errors or revealing new elements that were not considered in the scenario language. Hence, it was demonstrated that the scenario language captures all aspects of the studied real-world scenario without adjustments to the scenario language model. The applied real-world scenario indicates the usability of the scenario language for representing dynamic scenarios with spontaneous volunteers. However, since only one scenario was assessed for evaluating the scenario language model, the final assessment of its applicability to a broader range of spontaneous volunteer scenarios requires findings of further applications.

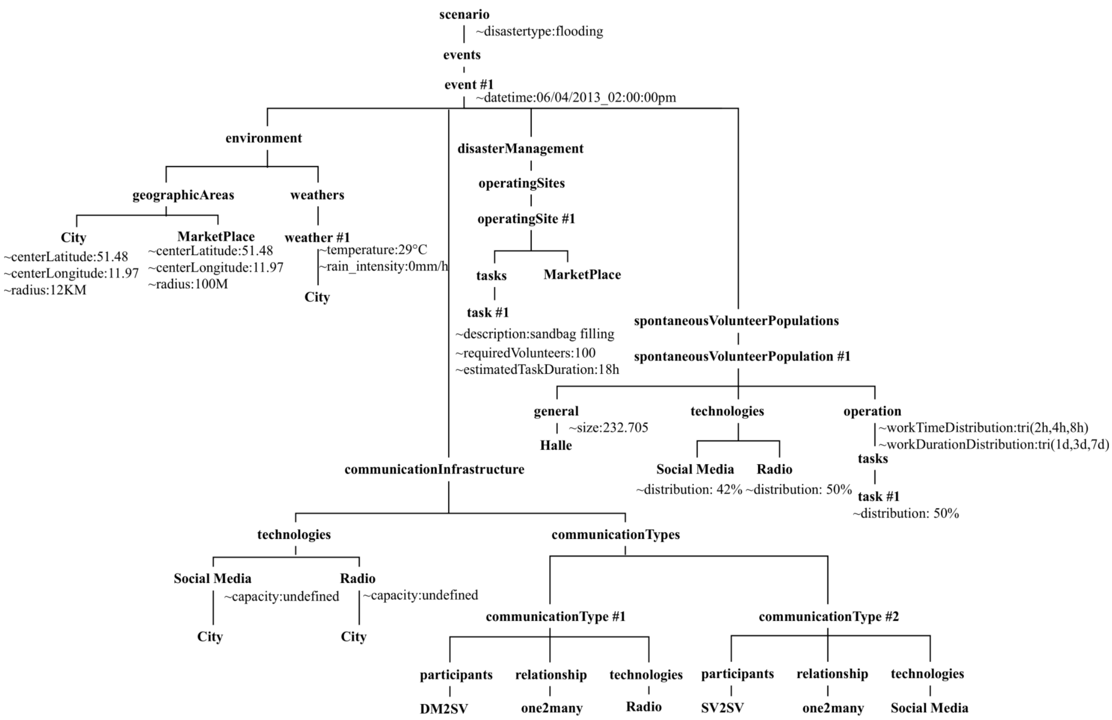

Figure 4.4: Pruned entity structure for an example scenario [102].

The high level of abstraction of the scenario language proved to be particularly valuable for the design process of IS2SAVE in two aspects: 1) The original prototype of IS2SAVE was based on an XML-based instantiation of the SES. However, due to implementation decisions, the XML version was discarded in favor of a JSON representation of the adopted scenario language. Deriving a corresponding JSON schema based on the SES could feasibly be accomplished without additional methodological effort. 2) Since the exact variables were not determined at the time of development, the instantiation of the scenario language was continuously revised by newly gained knowledge, e.g., by identifying behavior-influencing attributes.

The conceptual scenario language contributes to both disaster research and practice. It presents the characteristics of dynamic disaster scenarios on a conceptual level and, therefore, serves as an orientation for scenario development in the context of spontaneous volunteers while extending the application context beyond predictions.

The comprehensive methodological approach serves academia in achieving similar goals, e.g., scenario languages in other domains. Moreover, the high-level conceptual representation allows an extension of existing or an integration into new research approaches.

Table 4.3 serves as an overview of the contributed article and the developed artifacts. The full article can be found in the appendix (p. lvii).

Title	Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios
Authors	Lindner, S., Sackmann, S., Betke, H.
Year	2019
Published in	Proceedings of the 16th International Conference on Information Systems for Crisis Response And Management
Abstract	Fast and easy communication, e.g. via Twitter or Facebook, encourages self-coordination between spontaneous volunteers in disasters. Unfortunately, this is more and more challenging official disaster management. The need for the directed coordination of spontaneous volunteers triggered researchers to develop effective coordination approaches. However, evaluating and comparing such approaches as well as their exercising are lacking a standardized way to describe repeatable disaster scenarios, e.g. for simulations. Therefore, we present a novel System Entity Structure (SES) for describing disaster scenarios considering the disaster environment, communication infrastructure, disaster management, and population of spontaneous volunteers. The SES is discussed as a promising scheme for including spontaneous volunteers in disaster scenarios on a general level. Its applicability is demonstrated by a Pruned Entity Structure derived from a real disaster scenario. Based on the results, we give an outlook on our subsequent research, the XML-based Spontaneous Volunteer Coordination Scenario Definition Language (SVCSDL).
Keywords	agent-based simulation, spontaneous volunteers, spontaneous volunteer coordination scenario definition language (SVCSDL), system entity structure (SES), disaster scenario
Artifact	Scenario Language
Evaluation	Case Study
Contribution	system entity structure for defining dynamic spontaneous volunteer scenarios in disasters

Table 4.3: Meta-data of the article by Lindner et al. (2019)

4.3 Conceptual Model

The requirement for conceptualized behavioral representations arose in the evaluation of Design Cycle 1 from the consideration of how to implement and reproduce the behavior of spontaneous volunteers in a simulation. The resulting SRQ2 was addressed in Lindner et al. 2018 [87] with a conceptual model to be considered as the artifact.

Generally speaking, conceptual models represent new theories or phenomena through domain-specific elements, and their associations [36]. They can be constructed based on domain knowledge focusing on utility and not on the universal truth [36]. Therefore, the conceptual representation of spontaneous volunteer behaviors promotes an understanding on a general level and further helps to implement their behavior in software beyond the context of IS2SAVE.

Countless types of conceptualization methods and models exist [87]. With the goal of simulations in mind, an analysis of related works targeting the simulation of behaviors revealed the UML statechart modeling notation as a common approach. UML statecharts consist of: - *states* that are considered as a period in which a particular condition holds or activity is performed, - *events* that trigger state changes, and - *transitions* that connect and change states under certain conditions [114]. A literature review was conducted to identify states and their interrelations in regard to spontaneous volunteer behaviors [87]. The identified characteristics of spontaneous volunteers led to the derivation of states and, finally, to the development of the conceptual behavior model, as shown in Figure 4.6.

For example, the literature revealed that spontaneous volunteers decide after being rejected at an operating site [18, 30]. Either they continue their process and look for another operating site to help, or they decide to go home.

Moreover, the steady decline in citizen participation in past disasters [85] suggests that spontaneous volunteers are either temporarily unwilling to help or finally not motivated to help anymore. The latter may have caused participation to decline as the disaster progresses. Further, it was observed that spontaneous volunteers discontinue providing help when they were turned away too often, since this repeatedly resulted in their frustration [16].

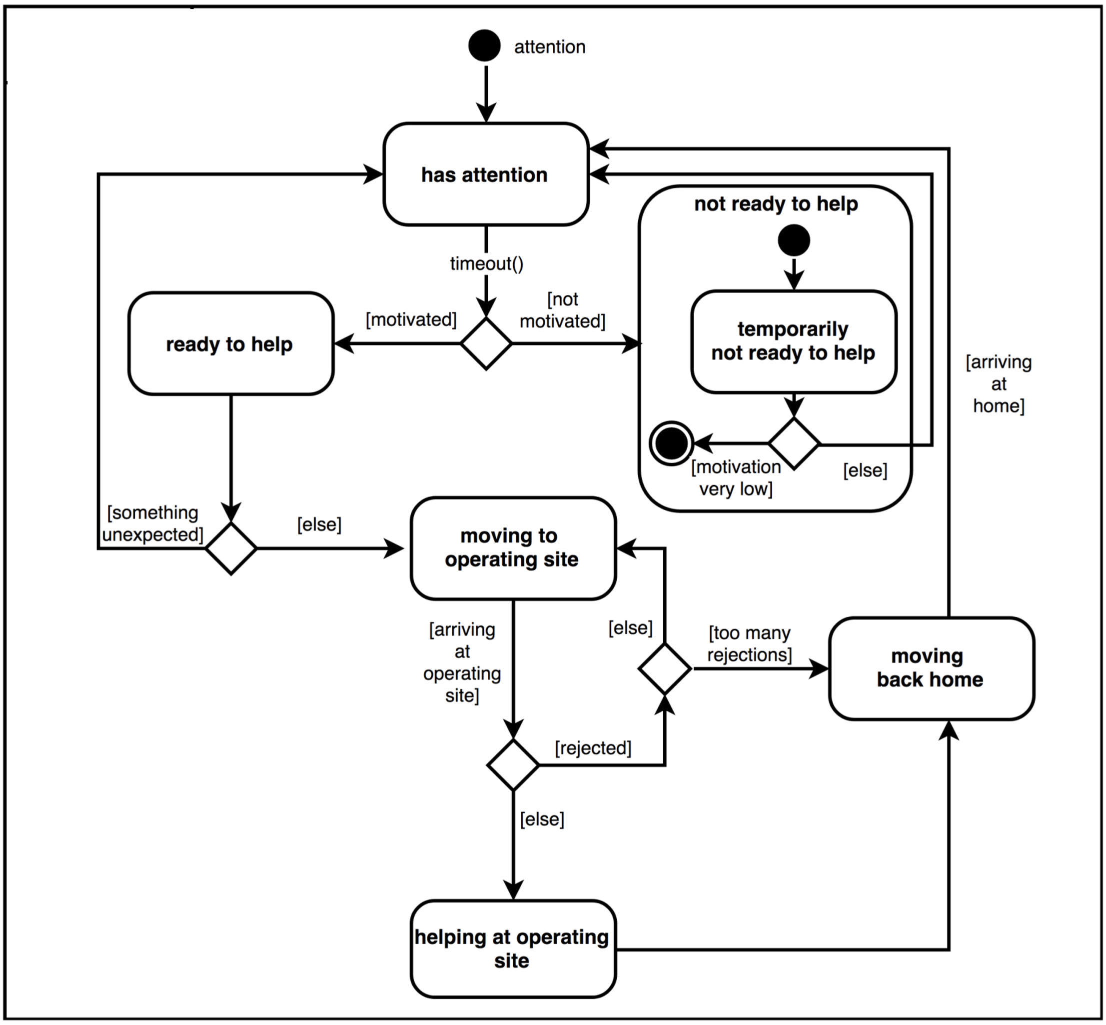

Figure 4.5: Conceptual model of spontaneous volunteer behavior [87]

Since agent-based simulations were chosen as the approach for simulating the influx of spontaneous volunteers in IS2SAVE [86], the conceptual model was instantiated in the AnyLogic simulation software (see Figure 4.6). The evaluation took place in the form of a case study with disaster managers to validate the expected behaviors, such as people converging to operating sites and wandering around after being rejected.

Based on expert opinions, this behavior reflected observations from real disasters [87]. Additionally, the instantiation was further supplemented by integrating the scenario language in a first version prototype of IS2SAVE and presented to disaster managers in the form of a formative evaluation of Design Cycle 2. However, the instantiation of the conceptual model in software agents and, in particular, their state changes were based on probability functions and assumptions, so that a meaningful interpretation of the influx at operating sites was questioned by the experts.

The instantiation of the conceptual model was complemented by new findings from the research project, e.g., empirically grounded state changes from the results of the subsequent cycle (see p. 54).

The paper's main finding constitutes the conceptual representation of spontaneous volunteer behaviors. Both academia and practitioners can benefit from this model alike. On the one hand, the model provides a general understanding of how spontaneous volunteers behave in disasters. On the other hand, precisely documenting their behavior in a model that can easily be instantiated in software promotes further research with different goals and applications.

Figure 4.6: Instantiation of the conceptual model in IS2SAVE v1 in AnyLogic [87]

Table 4.4 serves as an overview of the contributed article and the developed artifacts. The full article can be found in the appendix (p. lxx).

Title	Simulating Spontaneous Volunteers – A Conceptual Model
Authors	Lindner, S., Kühnel, S., Betke, H., Sackmann, S.
Year	2018
Published in	Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management
Abstract	Recent disasters have revealed growing numbers of citizens who participate in responses to disasters. These so called spontaneous unaffiliated on-site volunteers (SUVs) have become valuable resources for mitigating disaster scales. However, their self-coordination has also led to harm or putting themselves in danger. The necessity to coordinate SUVs has encouraged researchers to develop coordination approaches, yet testing, evaluating, and validating these approaches has been challenging, as doing so requires either real disasters or field tests. In practice, this is usually expensive, elaborate, and/or impossible, in part, to conduct. Simulating SUVs' behaviors using agent-based simulations seems promising to address this challenge. Therefore, this contribution presents a conceptual model that provides the basis for implementing SUV agents in simulation software to perform suitable simulations and to forecast citizens' behaviors under a given set of circumstances. To achieve adequate simulations, the conceptual model is based on the identification of 25 behavior-affecting attributes.
Keywords	spontaneous volunteers, disaster management, agent-based simulation, conceptual model, citizen behavior
Artifact	Conceptual Model
Evaluation	Case Study
Contribution	conceptual representation of spontaneous volunteer behaviors, instantiation as simulation model in AnyLogic

Table 4.4: Meta-data of the article by Lindner et al. (2018)

4.4 Behavior-influencing Attributes

The evaluation of IS2SAVE in Design Cycle 2 resulted in the requirement for investigations of influences on whether a citizen is willing to help, and an accurate prediction of their operating site choices in a disaster situation. The former was subject to Lindner and Herrmann (2020) [99]. The goal was to analyze influences and their effects on the willingness to help in flood disaster scenarios, forming the contributed artifact. Therefore, the paper addressed SRQ3. As described before, for the sake of this research project, the focus was on flood scenarios in Germany.

Behavior influences on the willingness to help in real disasters are both barely observable, and hardly to conduct. To gather relevant data, the sheer mass of volunteers would require numerous researchers for interviews on-site and heavily relies on the commitment of volunteers to report to them in such situations, which is questionable due to their aspiration to help. Therefore, *discrete choice experiments* (DCE) were identified as an appropriate approach to elicit the preferences of spontaneous volunteers regarding their willingness to help in a disaster [99].

In a preliminary work [86], 25 attributes that feature spontaneous volunteers were identified based on theoretical findings from a literature review. These included attributes whose influences were heavily discussed by practitioners, e.g., the influence of the weather. Further features were considered influential to their decision to help and important for spontaneous volunteering in general (e.g., bringing shovels and tools).

While grounded on theoretical considerations, the attributes were neither empirically proven nor was their influence on the behavior analyzed. Through discussion with experts, the number of attributes was reduced to a reasonable number for analysis. The consideration included the most likely influencing attributes based on the experts' opinions and were defined as scenario-specific, and individual-specific variables [99].

attribute	levels	description
impact	small/big	How is the scale of the disaster?
friends	no/yes	Do friends already help?
exp.time	short/long	What is the expenditure of time to get to the operating site?
daytime	night/day	The daytime of the present scenario.
temp	extreme/normal	The temperature of the present scenario.
media	low/high	How is the media coverage?
rain	no/yes	Is it raining?

Table 4.5: Selected scenario-specific attributes [99]

The scenario-specific variables were used in the DCE with according levels (see Table 4.5), and the individual-specific variables served as control variables.

Two samples (sample1 = 170, sample2 = 311) were conducted from students in two introductory statistic courses leading to 2488 ternary choices that resulted in 7464 observations after reviewing the data [99].

The results of the experiment indicated that the *impact* of the disaster had the most considerable effect on the willingness to help, followed by *media coverage*. It was further observed that spontaneous volunteers are rather willing to help, if their *friends* are already helping. Additionally, the results indicated a preference for helping during the day. Thus, the probability of helping in a specific situation decreases during the night. Average *temperatures*, and high *media coverage* about the disaster, positively influence the willingness to help. Only two variables negatively influenced the willingness to help: the *time to get to the disaster site* and *rain*. Besides that, there was no indication that *gender* influences the willingness to help either way, and the results indicate that people who helped before are more willing to help again.

Overall, the findings promote an understanding of the willingness to help as spontaneous volunteers in flood disasters. It was demonstrated that the applied DCE approach can be used to elicit preferences in the domain of disaster management and particularly in the context of spontaneous volunteers.

Table 4.6 serves as an overview of the contributed article and the developed artifacts. The full article can be found in the appendix (p. lxxxii).

Title	The Behavior of Spontaneous Volunteers: A Discrete Choice Experiment on the Decision to Help
Authors	Lindner, S., Herrmann, C.
Year	2020
Published in	Proceedings of the 53rd Hawaii International Conference on System Sciences
Abstract	Modern communication technology has enabled new ways to exchange information and is one of the main drivers for citizens participation in disaster response.During the last decades, so-called spontaneous volunteers have become an important resource in coping with disasters. However, their unpredictable behavior has also led to several problems. Disaster managers urgently need insights into volunteers behavior to effectively use the offered potential. To gain and provide these insights into explaining what drives the decision to help, we performed a discrete choice experiment based on previously identified behavior-affecting attributes. Our results indicate that attributes like the scale of the disaster and the media coverage are among the most important factors in the decision to help. The model correctly predicts volunteer's scenario-specific decisions with an accuracy of 65%. Hence, the experiment offers valuable insights into volunteers behaviors for disaster research and is a sound foundation for decision support for disaster management.
Keywords	agent-based simulation, decision support, discrete choice experiment, spontaneous volunteer, volunteer behavior
Artifact	Behavior Influences
Evaluation	Model Performance
Contribution	analysis of influences and according effects on the willingness to help, discrete choice experiments as methodological approach for spontaneous volunteer behaviors in disaster research

Table 4.6: Meta-data of the article by Lindner and Herrmann (2020)

4.5 Machine Learning Model

The previous contribution delivered valuable insights on behavior influences on the general willingness to help. Compared to the focus of the DCE, the objective of SR4 was on prediction instead of understanding. In Lindner and Herrmann (2023) [104], the goal was therefore an accurate model to predict the choice of at which operating site spontaneous volunteers will help in a specific situation, which forms the artifact of the contribution.

Since DCE was proven to be a sound approach for data collection and to elicit preferences [99], it was applied again. This time, however, the data were used to make predictions with machine learning models rather than to be analyzed in depth. For acceptable prediction accuracy, more observations were considered valuable. In addition, in conversations with disaster researchers and in discourse with conference participants, it was anticipated that further variables may influence the decision of where to help. As a result, a focus group with researchers and experts was convened in preparation for the study to discuss an exhaustive collection of attributes for the operating site choice. These findings resulted in more scenario-specific (see Figure 4.7) and additional individual-specific attributes (e.g., *age, empathy, social network, fitness*).

The decision was on machine learning, which is a common approach when the goal is prediction instead of inferring about the variable relationships with *"classical"* statistical methods.

attribute	levels	description
impact	low/medium/severe	The impact of the disaster at the operating site
friends	no/yes	Describes if friends already help at the operating site
exp.time	less than 15 minutes/between 15 and 30 minutes/more than 30 minutes	The expenditure of time to get to the operating site
daytime	morning/afternoon/night	The daytime at the operating site
temp	cold/moderate/hot	The temperature at the operating site
media	low/middle/high	The media coverage about the operating site
precipitation	none/low/heavy	the precipitation at the operating site
threat	none/low/high	the risk for the own life at the operating site
information	no/a bit/a lot	the information about if help is needed at the operating site

Figure 4.7: Selected scenario-specific attributes and levels [104]

Based on the presumed attributes, the resulting questionnaire began with sociodemographic questions and questions about former experiences as spontaneous volunteer, followed by the DCE. The DCE consisted of 48 choice sets divided into six blocks of eight choice sets per questionnaire (see Figure 4.8) to reduce the cognitive load on participants. The development of the machine learning model, again, addressed flood scenarios. The survey completed 472 of 567 questionnaires (completion rate = 83%). A total of 3,746 ternary decisions were made, yielding 11,238 observations. Since the sample included 174 men, 293 women, and five unspecified, and the average age was 28.99 years (σ = 10.92), the sample is younger and more female than the German population, which can be considered as a limitation for the predictions.

Scenario 1	Scenario 2
There is a **moderate** temperature.	There is an **extreme hot** temperature.
There is **no** precipitation.	There is **low** precipitation.
It is **morning** (7 a.m. to 1 p.m.).	It is **afternoon** (2 p.m. to 7 p.m.).
There is an **low impact** of the disaster.	There is an **low impact** of the disaster.
There is a **large extent** of media coverage.	There is a **medium extent** of media coverage.
There is **no** risk for my own life.	There is **high** risk for my own life.
I **do not know** other volunteers.	I **do not know** other volunteers.
There is **a lot of information** about the operating sites.	There is **a bit of information** about the operating sites.
I need **more than 30 minutes** to the disaster area.	I need **between 15 and 30 minutes** to the disaster area.

❓ In case of a natural disaster, which of the following alternatives would you choose?

- I would help in scenario 1.
- I would help in scenario 2.
- I would not help at all.

Figure 4.8: Example choice set (translated from German) [104]

The model was intended to predict whether a person helps at an operating site, which represents a binary classification problem. In order to select the best model for predicting if a person helps at an operating site, several machine learning algorithms were evaluated and mutually compared with several performance metrics (e.g., *accuracy*, *precision*, *specificity*, . . .). Whereas all parameters were required for the paper to document the process rigorously, *accuracy* was of particular importance to correctly predict the operating site choice in IS2SAVE. *Accuracy* is hereby defined as the ratio of the correct predictions and the number of all observations.

The following algorithms were evaluated: *Logistic Regression*, *Random forest*, *Gradient boosting*, *Neural network*, *Naïve Bayes classifier*. More details and configurations can be found in Lindner and Herrmann (2023) (see p. 54).

After training and validating the models, the evaluation revealed *Random forest* and *Gradient boosting* outperforming the other algorithms in all examined performance metrics. A feature selection was performed to reduce the model and improve the accuracy of these two algorithms.

The most important variable for all two algorithms was *friends*, followed by *temperature*. Further, the *impact*, *daytime*, *threat*, and *expenditure of time* were also impacting the decision to help at a specific operating site. New models were then trained with the reduced variable set for both algorithms. Their performance was comparable, and the median accuracy was between 0.69 and 0.70, whereas *Random forest* achieved the best median accuracy. The best examined *Random forest* model predicted the decision to help at an operating site with an accuracy of 71% and was therefore chosen. For the use in IS2SAVE, the model was implemented with *TensorFlow* (see p. 59).

Apart from being implemented in IS2SAVE, the well-documented approach and the resulting model contribute to academia and practice, both to be implemented in other contexts beyond influx predictions and to be adapted for other scenarios, e.g., other countries and other types of disasters.

Concerning the findings of the article, the instantiated scenario language was revised according to the decision-influencing features from the machine learning model. In IS2SAVE, the prediction is triggered whenever a spontaneous volunteer is in the state of being *"ready to help"*.Based on the current scenario situation, the model predicts the probabilities of the available operating sites for the volunteer agent. Afterward, the agent selects the operating site with the highest utility/probability. Thus, the individual operating site choices from the model directly influence the influx of spontaneous volunteers at operating sites. However, the influx does not solely rely on the operating site prediction. Apart from the discussed machine learning model in the article, the conducted study further improved IS2SAVE concerning:

- the number of hours a volunteer would be willing to help per day,
- the total number of days a volunteer would help in a disaster,
- the number of rejections a volunteer would accept, and
- whether a volunteer would help again if rejected.

Probability distributions were then approximated from this data and integrated into the simulation model accordingly.

Table 4.7 serves as an overview of the contributed article and the developed artifacts. The full article can be found in the appendix (p. xciii).

Title	Where to help? — Combining a discrete choice experiment with machine learning algorithms to predict the operating site choice of spontaneous volunteers
Authors	Lindner, S., Herrmann, C.
Year	2023
Published in	Journal of Decision Systems *(planned)*
Abstract	In recent disaster, particularly, citizen participation has become imminent. The unforeseen convergence to disaster sites of so-called spontaneous volunteers challenged disaster managers and caused various problems on-site. Nevertheless, reports about stronger disaster scales without their help along with an increasing number of natural disasters have made spontaneous volunteers become undeniably important for disaster management. Predicting the decision where spontaneous volunteers help at operating sites can promote disaster manager's ability to take action by providing unexplored information. Hence, the paper proposes a model for predicting the operating site choice of spontaneous volunteers by combining a discrete choice experiment with machine learning algorithms. Gradient boosting and random forest turn out to be the two algorithms with the best prediction performance. The model is able to predict the site choice with an accuracy of 71%.
Keywords	spontaneous volunteers, disaster management, machine learning, discrete choice experiment, information system
Artifact	Machine Learning Model
Evaluation	Model Performance
Contribution	machine learning model for predicting the operating site choice for spontaneous volunteers

Table 4.7: Meta-data of the article by Lindner and Herrmann (2023)

Instantiation of IS2SAVE

This chapter briefly overviews the implementation decisions and the IS2SAVE prototype. The source code and the documentation are available on GitHub (`https://github.com/sebsebli/is2save`). The functionality is demonstrated with a *screencast*[1] (German).

5.1 System Architecture of IS2SAVE

Figure 5.1 presents the architecture of the final prototype of IS2SAVE in a UML component diagram. The UML component diagram is developed in conformance with *UML version 2.5.1* [115] and presents the following elements:

- *component*: represent modules, (sub) systems, and views
- *provided interface*: represent the services and obligations a component offers
- *requested interface*: represent the service/interface that a component requires to perform its function
- *dependency*: represent the dependence on a component to operate
- *(SYSTEM)*: represent the realization or implementation in IS2SAVE

[1]https://lindner.me/is2save/IS2SAVE.mp4

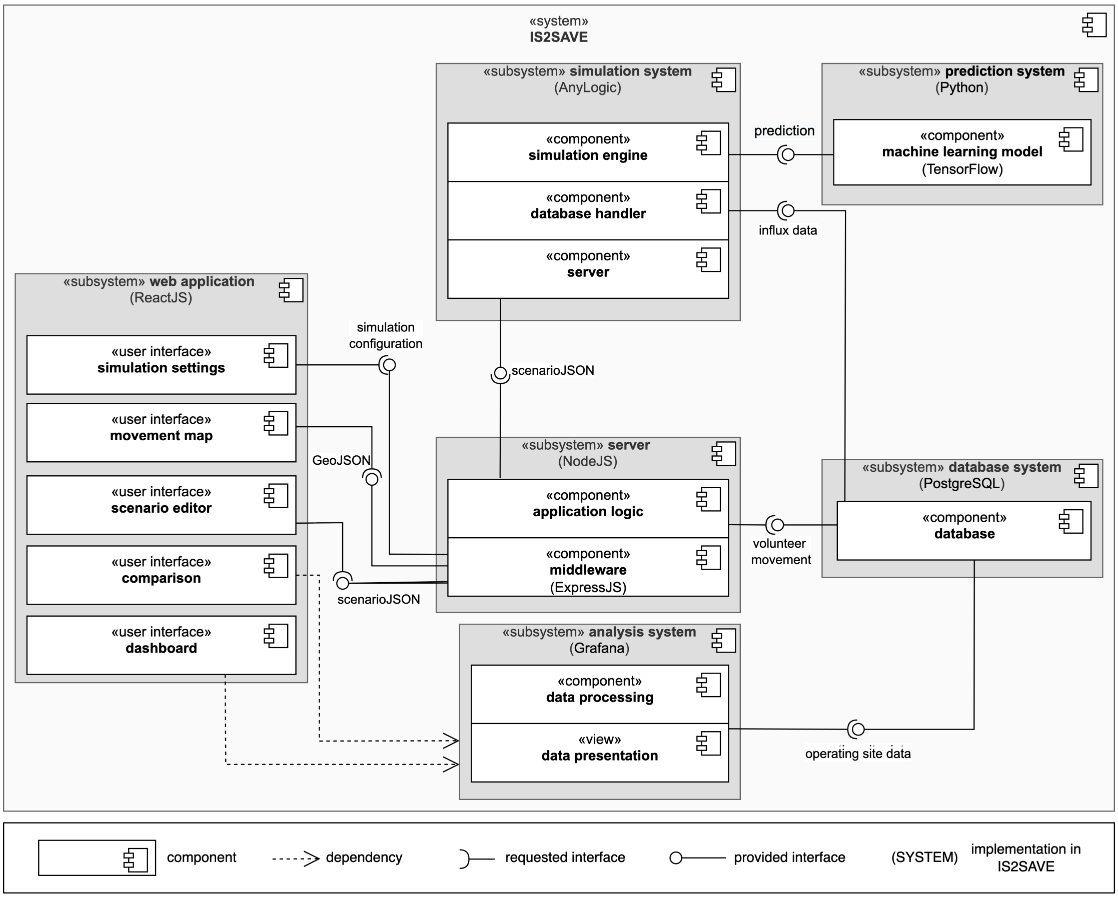

Figure 5.1: Architecture of the IS2SAVE prototype as UML component diagram

Simulation system The core component for the simulation of spontaneous volunteers in IS2SAVE in order to simulate their influx at operating sites is the agent-based simulation model implemented in the Java-based simulation software *AnyLogic*. The simulation model integrates the conceptual model (p. 47) as well as the scenario language (p. 42). The simulation system, consists of a simple web server offering an interface to start simulations whenever a new scenario in JSON representation (*scenarioJSON*) is submitted. The simulation engine then executes the scenario (see Chapter 5.2 for the workflow).

Prediction system The prediction system serves the simulation system to predict the probability of that a spontaneous volunteer will help at any operating sites. During the simulation, the probabilities are predicted for every volunteer agent and every time it enters the *"ready to help"* state (p. 47) or whenever an event happens (p. 42). The prediction system offers therefore an interface that accepts the current perception of the volunteer agent and returns the *prediction* for the probability to help at any operating site. The prediction system is based on *Python* and the probabilities to help are predicted from a *TensorFlow* implementation of the introduced machine learning model (p. 54).

Database system The influx-related data from the simulation is stored in certain intervals in a *PostgreSQL* database (with *PostGIS* extension to support geolocations). The data is required to present meaningful results of the influx to the users. This data includes, e.g., the current operating site utilization (*operating site data)* and each spontaneous volunteer location (*volunteer movement*).

Web application Comments about the poor usability (p. 27) and addressing the derived DP7 (*Principle of User Experience*, p. 36) led to the development of a *ReactJS* web application as front-end for IS2SAVE. It provides users functionalities to *configure simulation settings, create/edit/upload/save scenarios* (Figure 5.3), *monitor ongoing simulations,* and *compare the results of several influx predictions* (Figure 5.8). *BlueprintJS* was chosen as a user interface toolkit to adhere to current design guidelines and to rely on established components (i.e., buttons, inputs, forms, …). A custom map component for the visualization of spontaneous volunteer movements (Figure 5.10) and highly frequented paths (Figure 5.9) builds upon *MapBox*, which can process and present *GeoJSON* data.

Server The web application is powered by the *ExpressJS* web application framework running in a *NodeJS* environment. *ExpressJS* is further used as REST API (provided interface) to exchange data with the web application, such as the created scenarios in the JSON form (*scenarioJSON*), simulation settings (*simulation configuration*), or spontaneous volunteers movements in *GeoJSON* format. Additionally, the application logic, such as preprocessing data (e.g., *GeoJSON* generation), and scenario validation, is implemented in *NodeJS*.

Analysis system *Grafana* was used as a data analysis system component to provide meaningful visualizations of the influx for the simulated scenarios on a dashboard. Even though the analysis system is seperated from the web application, the dashboard is natively integrated with the web application to provide an engaging user experience. *Grafana* is connected to the database and allows intuitive modification of dashboard components, such as charts, according to the needs of the users.

5.2 Workflow of IS2SAVE

Figure 5.2 presents a simplified version of the workflow in IS2SAVE from user inputs to influx predictions.

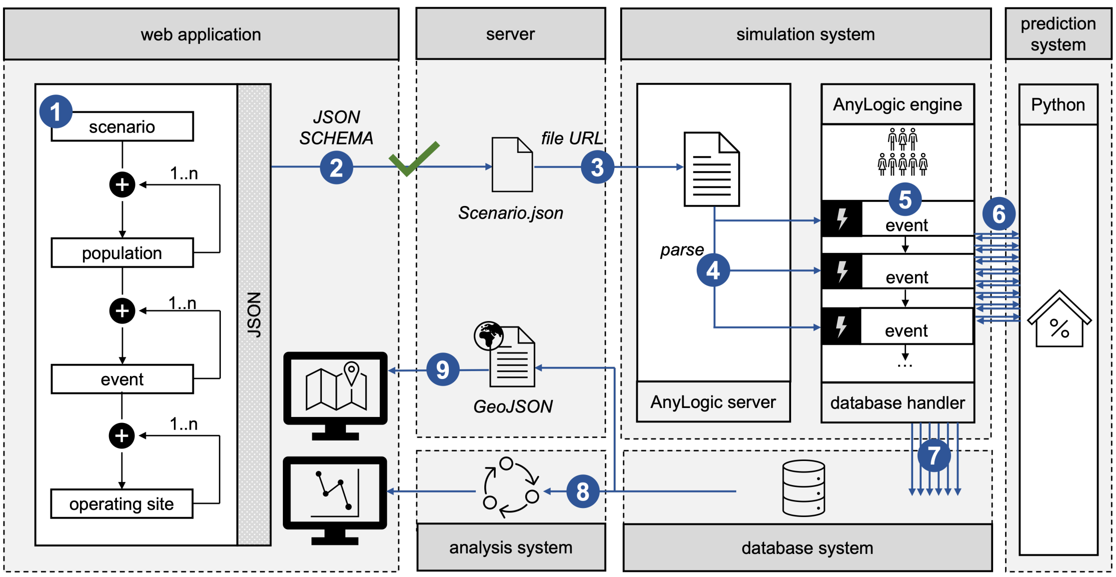

Figure 5.2: Simplified workflow of IS2SAVE

The process starts with creating the desired scenario **(1)** and setting the duration and general data of the scenario (Figure 5.3).

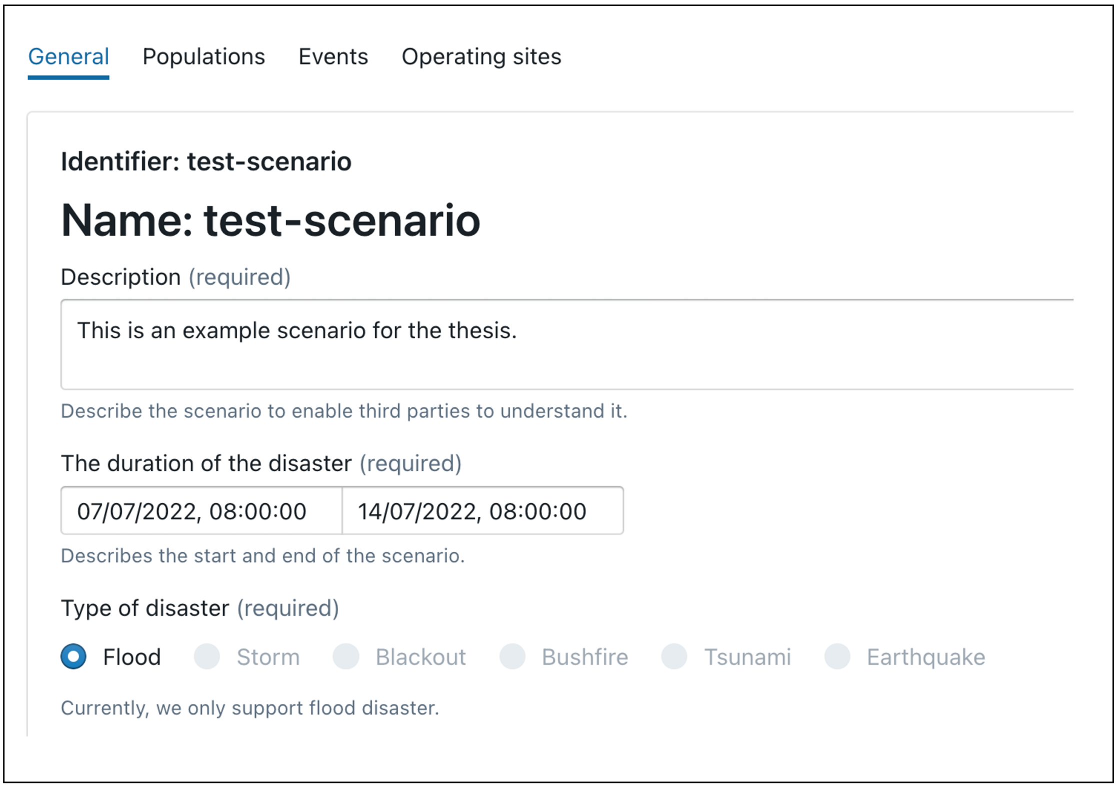

Figure 5.3: Screenshots of the IS2SAVE prototype – general scenario settings

The web application guides the users through the scenario creation process, which orients toward the components of the scenario language (p. 42). According to that, a scenario exists of a minimum of one spontaneous volunteer population (Figure 5.4), a minimum of one event (Figure 5.5), and a minimum of one operating site (Figure 5.6).

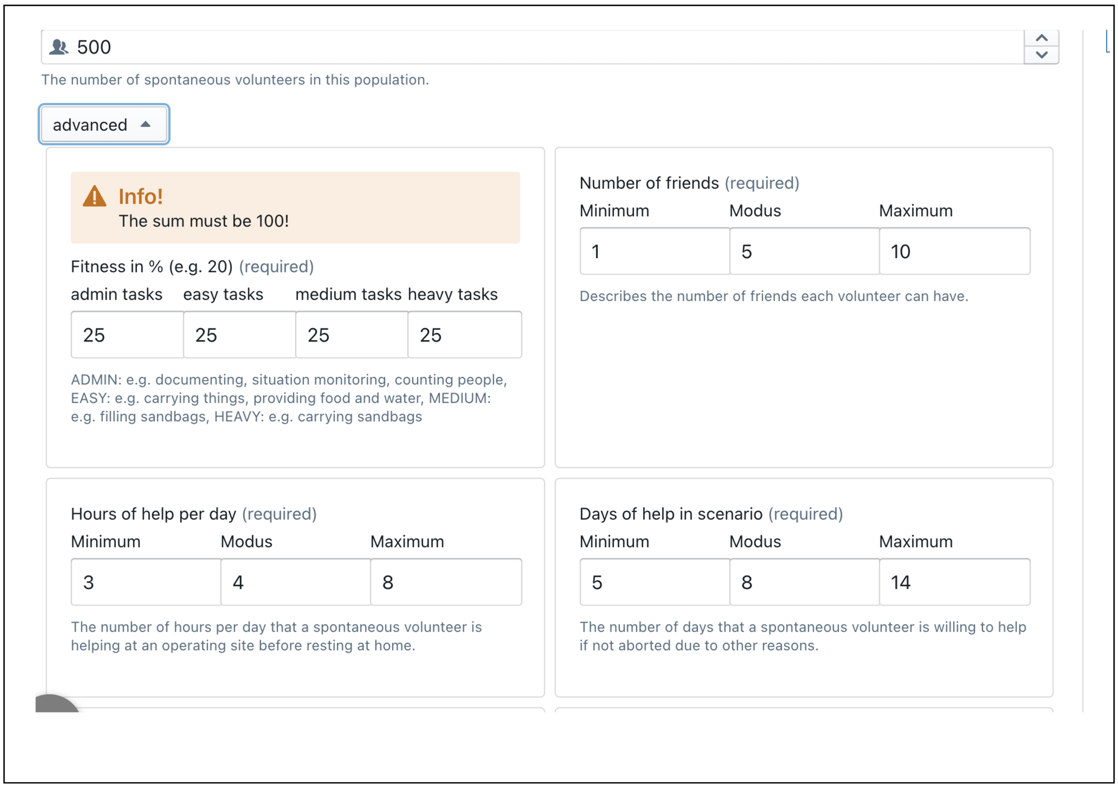

Figure 5.4: Screenshots of the IS2SAVE prototype – editing populations

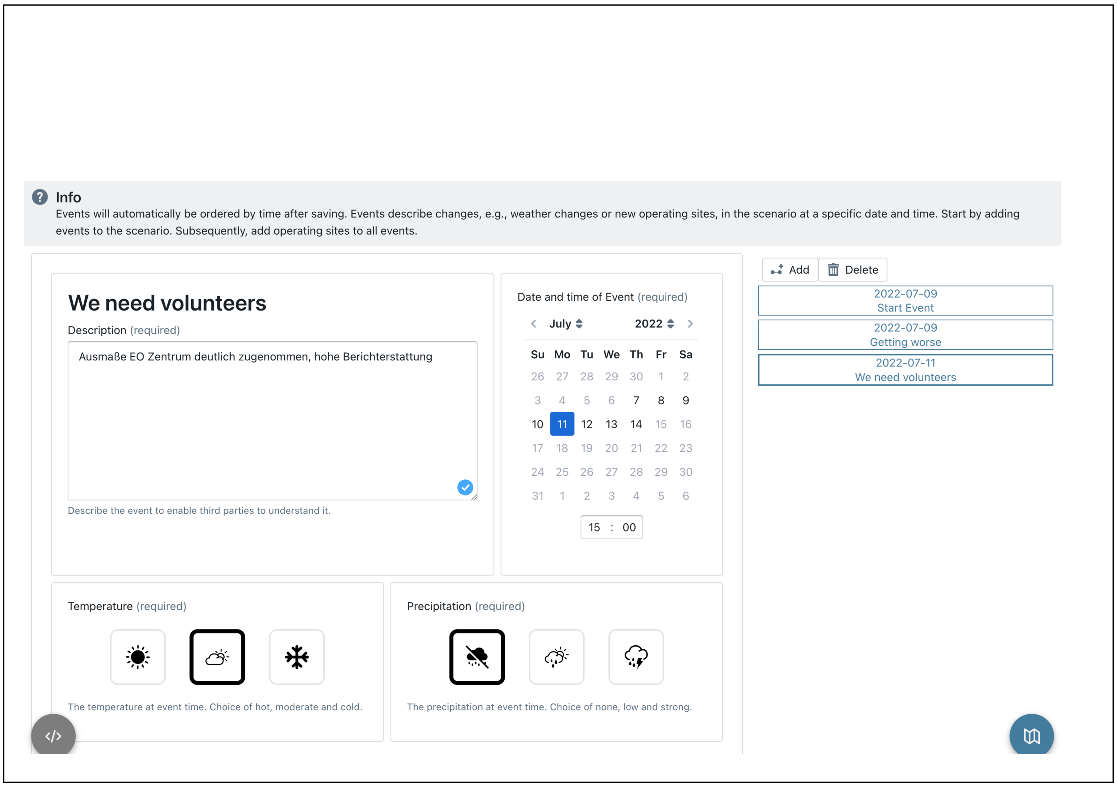

Figure 5.5: Screenshots of the IS2SAVE prototype – editing events

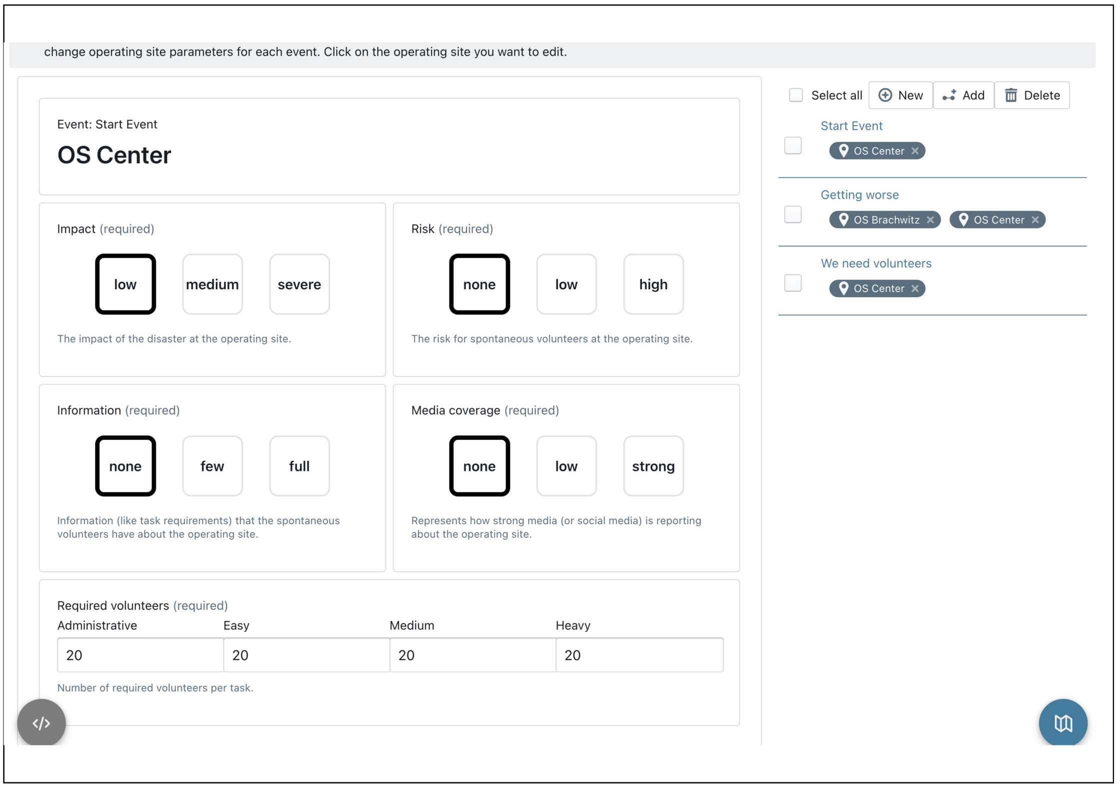

Figure 5.6: Screenshots of the IS2SAVE prototype – editing operating sites

Users can further import scenarios from a file or the server. Either way, the scenario must comply with the JSON schema retrieved from the scenario language and is therefore validated against the JSON schema before the process continues **(2)**. If it is not compliant, IS2SAVE will throw an error; otherwise, the JSON file (Figure 5.7) is stored on the server.

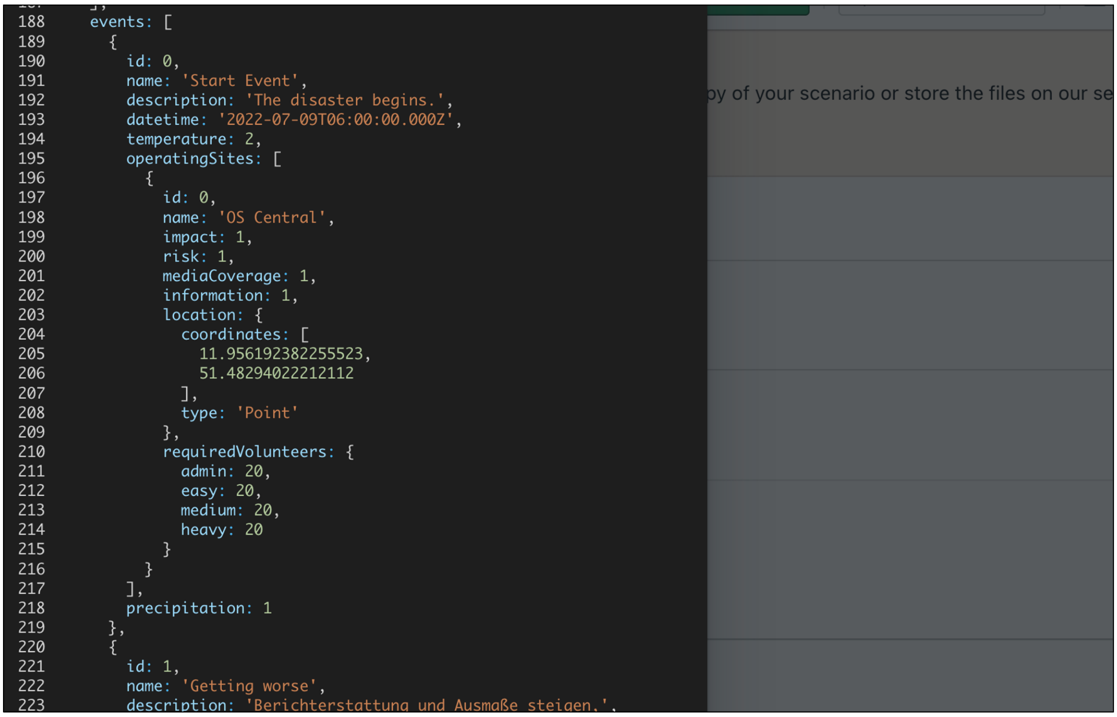

Figure 5.7: Excerpt of the JSON-based scenario language in IS2SAVE

Then, the file location is immediately sent to the simulation server **(3)** via an *HTTP POST* request, which further initiates the simulation. The simulation engine loads, parses, and preprocesses the scenario **(4)**.

Afterward, the spontaneous volunteer population(s) are initialized in the *AnyLogic* simulation engine according to the data of the scenario. Further, the events are decomposed and translated to the *AnyLogic* representation for time-related events **(5)**, and the simulation run starts.

In the simulation, the probability of helping at an operating site is predicted for each volunteer and every operating site **(6)**. Therefore, *internal volunteer states*, *observations of the environment*, and *the friend connections* among the volunteers are evaluated and sent to the *Python* script whenever an agent enters the *"ready to help"* state (p. 47) or an event happens (p. 42).

The *Python* script predicts the probabilities of the operating sites with an *TensorFlow* implementation of the machine learning model (p. 54).
The predictions are returned to the simulation, at which point the volunteer agent chooses the operating site with the highest probability if a certain threshold is exceeded; otherwise, it does not help.

Simultaneously and within a pre-defined interval, the simulation data, i.e., *current volunteer agent locations* and *the number of volunteers at each operating site*, is stored in the database **(7)**.

Once the simulation is complete, the influx prediction data is processed in the *analysis system* and can be accessed on the dashboard component of the web application **(8)**. The results in form of graphs can further be compared with influx prediction results of other scenarios (Figure 5.8).

Figure 5.8: Screenshots of the IS2SAVE prototype – scenario comparison on dashboard

Besides that, the spontaneous volunteer location history is processed to the *GeoJSON* format on the server and represented on the map component **(9)**. The map component allows for both tracking volunteer movements over time (Figure 5.10) and presenting the aggregated volunteer movement paths to highlight frequently used routes (Figure 5.9).

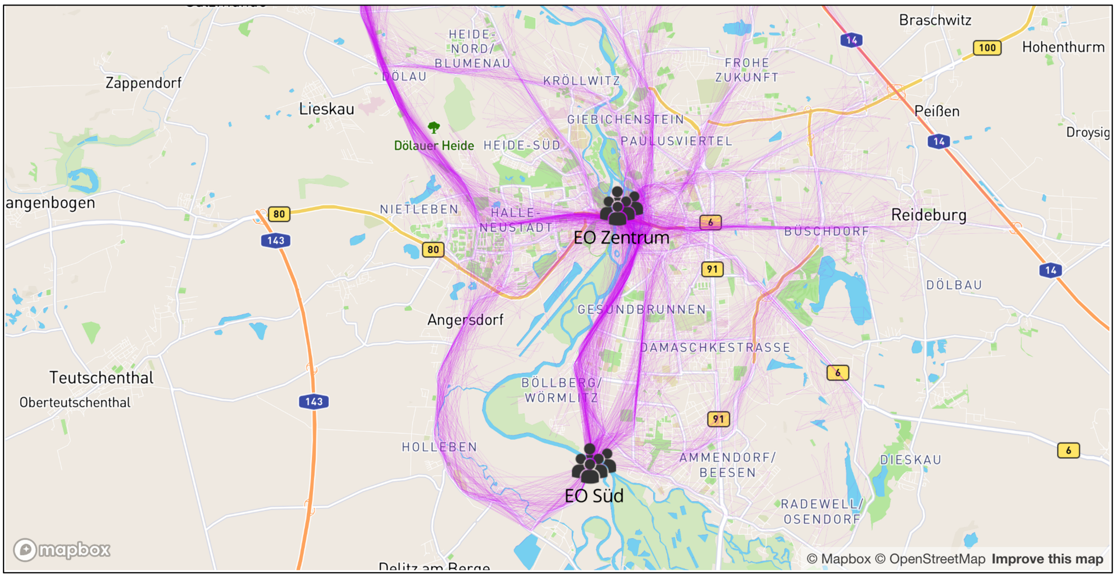

Figure 5.9: Screenshots of the IS2SAVE prototype – aggregated paths

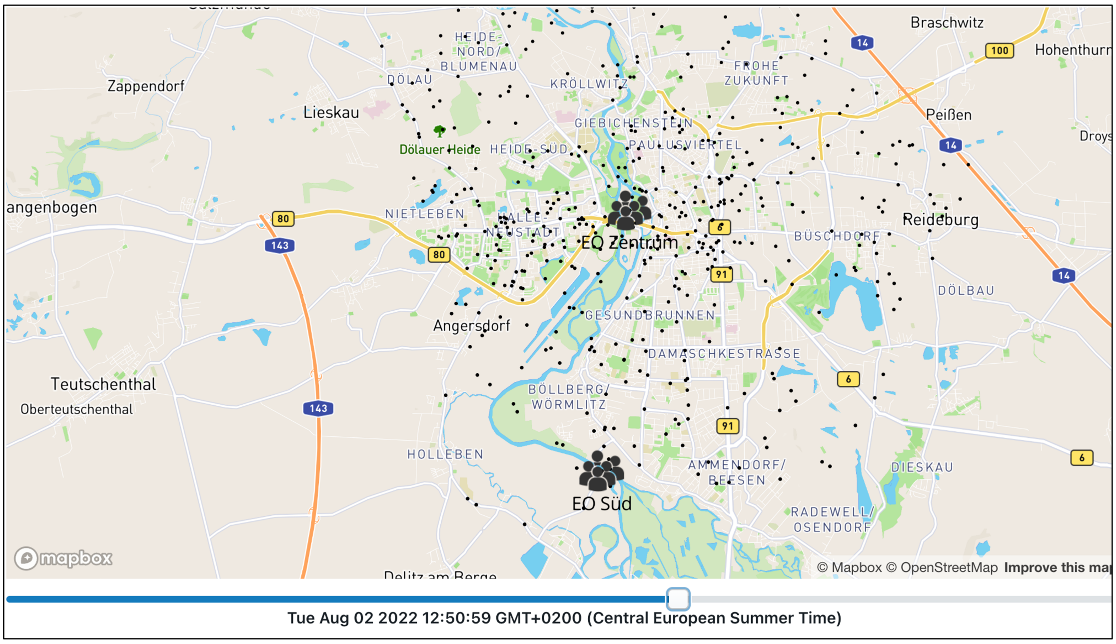

Figure 5.10: Screenshots of the IS2SAVE prototype – volunteer movements

Evaluation of IS2SAVE

6.1 Evaluation Strategy

The design science research project follows the well-known evaluation framework of Venable et al. (2016) [42]. The design of IS2SAVE heavily depends on user requirements and the utility for disaster managers, who are primarily, yet not exclusively, intended to use the system to predict spontaneous volunteer influx.

Venable et al. particularly suggest a strategy named *"Human Risk & Effectiveness"*, when the goal of the artifact is on user utility and the integration of users into the evaluation process is possible [42]. The user utility is addressed with the particular objective to provide a tool for planning and training with spontaneous volunteer scenarios for practice. Due to profound connections with the local fire department, involving real users in the evaluation process was possible and naturalistic evaluations could be achieved.

The research was conducted in three consecutive iterations (p. 26). Both Design Cycle 1 and Design Cycle 2 finished with a formative evaluation. Two summative evaluations were conducted for Design Cycle 3 to a) evaluate the gained design knowledge, as well as b) to demonstrate the utility of IS2SAVE for practice (more details on p. 30).

The first evaluation was conducted by discussing a conceptual prototype (*mockups, system architecture, tentative design principles*) with researchers from the IS domain (p. 26). The evaluation was formative and artificial, and the discussion was with researchers instead of real users [42]. The goal was a first opinion on the suggested DPs and how well they address the DRs in an instantiation with mockups and the system architecture.

	Episode	Purpose	Paradigm	Focus	Method	Result
Design Cycle 1	1	formative	artificial	design requirements, design principles	ex-ante literature review, discussion with subject-matter experts	tentative design theory, feedback on instantiation considerations
Design Cycle 2	2	formative	naturalistic	IS2SAVE v1, scenario language, conceptual model	prototyping, case study	tentative prototype, evaluated scenario language and conceptual model, improvement of usability and plausibility
Design Cycle 3	3	summative	naturalistic	design principles, design theory	focus group and survey with IS experts, formal assessment following Gregor and Jones (2007)	perceived usefulness, conciseness, extendibility, explanatory power of the design theory
	3	summative	naturalistic	IS2SAVE	focus group with subject-matter experts, (online) survey	performance expectancy, effort expectancy, plausibility, predictive validity

Table 6.1: Evaluation episodes of IS2SAVE

The second evaluation was based on a first version instantiated prototype of IS2SAVE in AnyLogic. This second evaluation was again formative because the discussion led to the requirement for improvements (p. 27). The second evaluation involved real users, a real problem (case study), and an instantiated prototype, and was thereby naturalistic [42].

According to Venable et al. (2016), evaluating design science research projects must assure both qualities of the artifact utility and of the knowledge outcomes [42]. Additionally, they propose having more than one summative evaluation for more robust evidence.

Therefore, two summative evaluations were conducted. On the one hand, to provide evidence that the examined design theory and design principles contribute to the knowledge base and, on the other hand, that the information system plausibly predicts the influx and delivers utility for the users. Evaluated design knowledge is of particular importance to comply with the DSR methodology to add design knowledge to the knowledge base, particularly for IS in natural disaster management [40] and addresses the lack of validated DPs [107].

The first summative evaluation was addressed in Lindner and Kühnel (2023, see p. 35). The second summative evaluation will be described in the remainder of this chapter.

In addition to the evaluations described above, each developed artifact was independently evaluated according to the methodology used (see Chapter 4).

The summative evaluation addresses two aspects of the prototype that are of importance. The goal of IS2SAVE is to predict the influx of spontaneous volunteers at operating sites. Therefore, the first part addresses the plausibility of the influx predictions and the predictive validity of IS2SAVE. The second part addresses the general utility of IS2SAVE for the users. Thereby, it can be shown that the information system can solve real organizational problems [38].

6.2 Evaluation of IS2SAVE

6.2.1 Foundations

In accordance to Hevner et al.[38], the goal of the developed artifact IS2SAVE is on utility instead of truth. Nevertheless, it only adds value for users if the predictions in IS2SAVE are some kind of *"realistic"* [116]. Thus, disaster managers expect a certain amount of realism to utilize the system in their training and planning with and for spontaneous volunteers [117].

However, human behavior relies on uncountable variables beyond the examined influences, and models cannot guarantee general realism. Therefore, particularly for human behaviors, the term plausibility is rather appropriate [118, 119]. Plausibility describes if a model closely reproduces a phenomenon observed in reality [120]. The human behavior is hereby simulated with an *agent-based simulation* (ABS), whereas the plausibility assessment should concern related evaluation methods.

In the world of ABS, the evaluation process is rather referred to as verification and validation [121, 122, 123].

Verification focuses on the technical operability [122] proven by the fact that the simulation did not cause errors [122]. Validation addresses *" [. . .] how well the model approximates the real world system and meets the original objectives"* [117, p. 181].

There exist numerous validation techniques for ABS, whereas comparing simulation outcomes with empirical data is common among many ABS approaches [121]. However, the lack of empirical data on the influx of spontaneous volunteers in disasters [83, 85] leads to different validation techniques.

Therefore, comparing the simulation outcomes with other models is recommended [121]. Even though one similar approach was identified (p. 18), it was not possible to compare the models. The model by Paret is neither available, nor practically useful for comparison due to the lack of dynamic aspects of spontaneous volunteer scenarios [85]. The decision to help is only taken once a day, and the model is calibrated to data that does not distinguish between affiliated (bonded to an organization) and spontaneous volunteers [85]. Hence, a comparison, if possible, would likely lead to distorted results.

If the previous validation techniques cannot be applied, *face validation* through subject-matter experts is commonly proposed to assess the plausibility of simulation models [121, 122]. Face validity is, e.g., achieved by presenting a model to experts, who assess plausibility based on their knowledge and experiences [124]. It can be assessed by either monitoring the behavior of a single agent and evaluating if its decisions seem plausible, by monitoring the progression of a population of agents in a simulation and their obtained emergent behaviors, or by evaluating simulation results, e.g., with meaningful charts [124, 122]. Even though face validity is often applied, there is a lack of scientifically-proven approaches and methodologies, and conducting face validity relies on the researcher's interpretation of the expert's opinions [121, 125].

Additionally, disasters are, more or less, unique and unpredictable situations [10], and thus, the influx might be unique, too. A validation on empirical data would demonstrate that the model can reproduce the past, yet, there would be no evidence that it can predict the future [117].

According to Zeigler et al. (2000), the goal is instead on predictive instead of replicative validation [126]. *Predictive validity* therefore indicates, that the model *"[...] matches data before data are acquired from the real system [...]"* [127].

In this regard, Berk (2008) suggests the examination of the *"[...] overall correspondence between the model output and ground truth [...]"* [128, p. 302]. Therefore, drawing on the knowledge and experience of subject-matter experts is advocated [129, 116, 130]. Their knowledge can be considered the ground truth [131], according to which the simulation results should be compared.

The plausibility and predictive validity of the system was assessed by a combination of: a) face validation in the form of a focus group to obtain a general impression of IS2SAVE, and b) the collection of ground truth data from the subject-matter expert predictions for the influx of spontaneous volunteers.

To sum up, the objective of the evaluation was both to show that the predictions are plausible in an expert's opinion and to provide predictive validity by comparing the influx simulation with the ground truth gained from expert predictions.

The validity of the study, which denotes the trustworthiness of the results [132], is ensured with four test quality criteria commonly applied in the software engineering domain.

Construct validity indicates the extent to which the right things were measured [132]. A common problem is a gap between what the researchers try to examine with a question and how the interviewed persons understand it [132].

The use of standardized and validated questions for the performance and effort expectancy, and extensive discussions with a team of researchers to avoid measurement errors satisfy the construct validity criterion.

Since the study examines no causal relationships between constructs or variables, *internal validity* [132] is generally given. However, there is still a risk that an examined variable is dependent on factors that were not considered within the study. Further, there was no control group to maintain unexplored influences, and thus, the single group threat [132] on the study's internal validity remains. However, the risk could partly be addressed by surveying the job experience of the participants to demonstrate professional expertise in the studied domain.

The *external validity* describes the generalization of the evaluation results and their utility beyond the studied domain [132]. The evaluation results indicate the utility of IS2SAVE for disaster management in general and may promote the usage of the software. Nevertheless, a more significant number of participants of different accountabilities in disaster management may promote the generalization of the evaluation results.

The *reliability* of a study concerns the dependence of study results on the researcher [132]. Thus, the results should be the same if another researcher does the study at a later point in time [132]. Reliability was primarily addressed by using established standard questions unrelated to the study's researcher.

6.2.2 Study preparation

In order to assess correspondence of simulated and expert predictions, three scenarios were developed. The baseline scenario was the same for all scenarios. It consisted of three operating sites (*OS Brachwitz, OS South, OS Center*) in Halle (Saale), all with the same demand for spontaneous volunteers. The demand was set to be equal for reducing the cognitive load on experts for assessing the effects on the citizen participation. Each scenario had one start and two consecutive events. In advance of the expert assessment, the scenarios were simulated in IS2SAVE. The citizen participation in response to an event was analyzed according to the three aspects:

- The overall participation of spontaneous volunteers.
- The utilization of each operating site.
- The order of the operating sites regarding their utilization to identity very crowded or less crowded operating sites.

The utilization of the operating sites over time was determined to represent the spontaneous volunteer influx at operating sites. Thereby, utilization defines the ratio of spontaneous volunteers on-site and the demand for help at the operating site.

The influx at operating sites regarding the volunteer movements and travel to operating sites is simulated based on realistic routes from a routing provider in the simulation software. It can be assumed that the routes are calculated realistically and, hence, the movement was not evaluated with the experts. Moreover, the overall participation of spontaneous volunteers does not directly represent the influx at operating sites. Yet, it represents the total number of available volunteers potentially helping, wherefore it was evaluated, too.

For the overall participation of spontaneous volunteers, the *simple moving average* (SMA) (period of 300 data points) was calculated for the average utilization of all operating sites in the scenario and presented on a line chart (see Figure 6.1). The SMA was chosen to smooth the data and better interpret the general trend of influx.

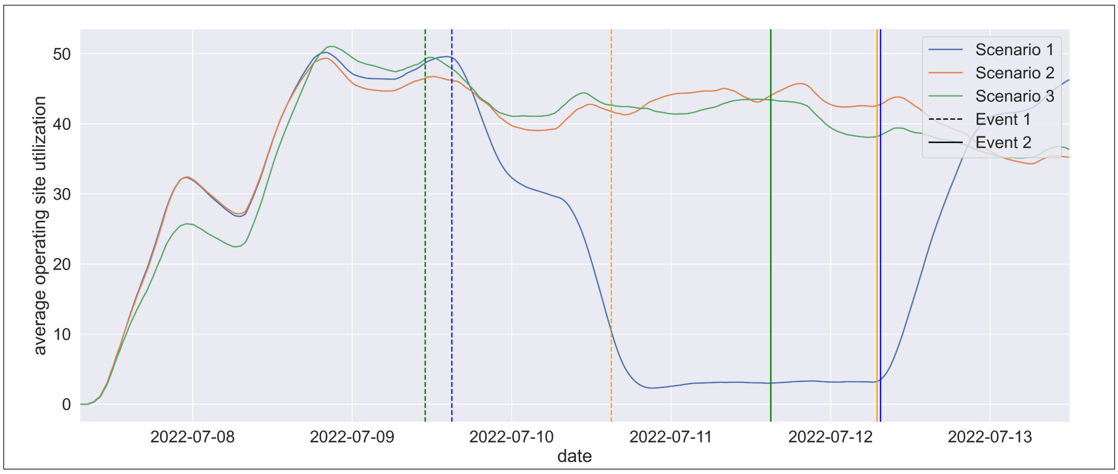

Figure 6.1: Total average utilization for all scenarios

The SMA was also applied for the utilization of each operating site in every scenario (Figure 6.2). The results were interpreted and noted as follows: If the general participation of spontaneous volunteers in response to an event *increased*, *decreased*, or *remained steady* was coded to match a verbal numeric rating scale: 1 = *strong decrease*, 2 = *decrease*, 3 = *steady*, 4 = *increase*, 5 = *strong increase*. Due to the absence of standardized approaches to assess the influx, a 5-point scale was chosen to represent a trend in response to an event instead of precise changes, e.g., in percentages. Therefore, a loss of detail was accepted to achieve a general assessment of predictive validity.

The same approach was followed for the operating site utilization in response to an event. Their order was addressed by ranking each site with 1 = *least utilized*, 2 = *medium utilized*, 3 = *most utilized*. Equally, utilized operating sites were coded as both 1 or 3 depending on the remaining operating site, or all 2, if no (or very small) differences were observed.

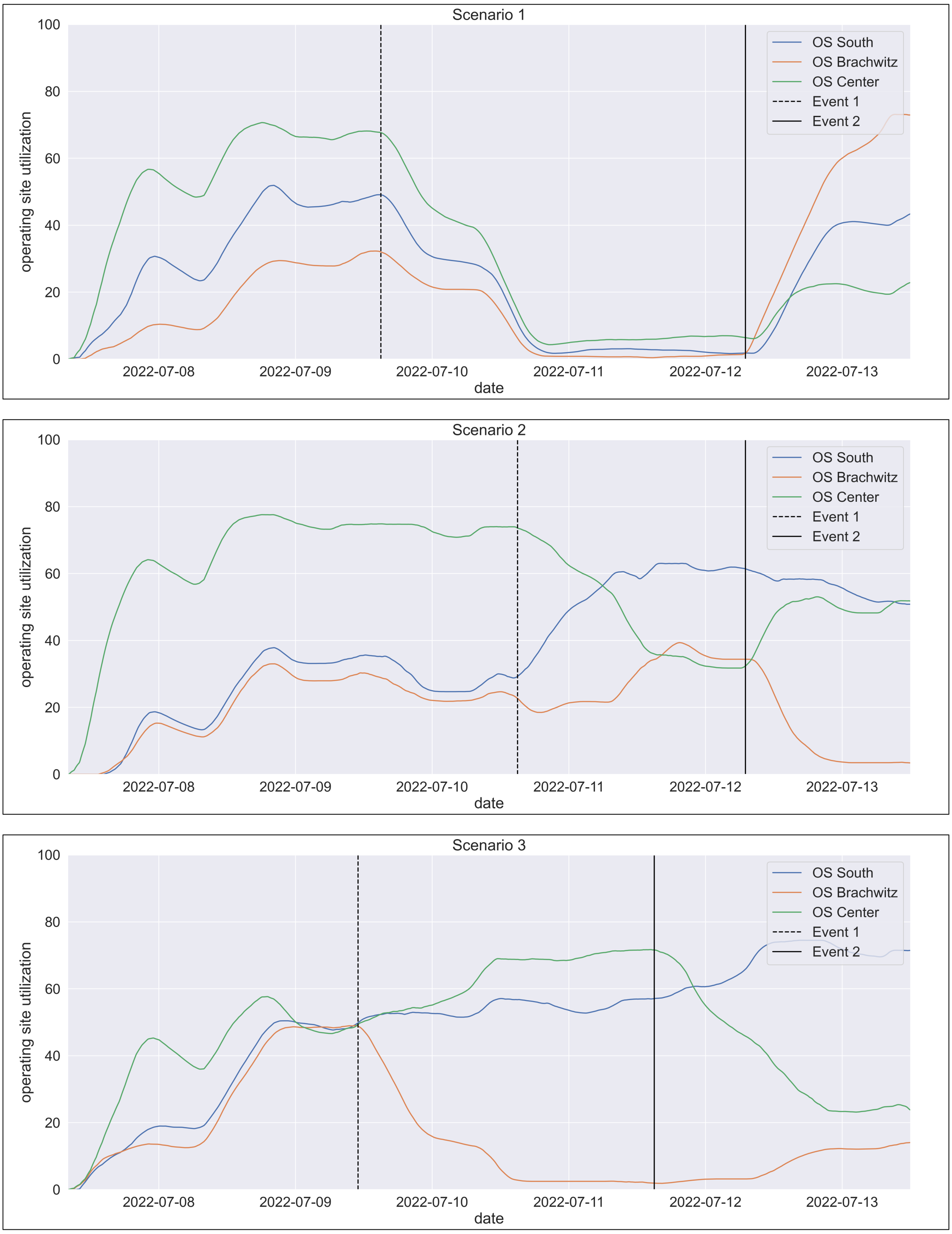

Figure 6.2: Operating site utilization for all scenarios

In order to obtain the desired ground truth data from experts, a three-part questionnaire was designed. Part one examined their job experience in years as well as their current job role. Part two focused on the evaluation of the performance and effort expectancy, which will be described later. Part three concerned the plausibility and predictive validity of IS2SAVE. Here, the emphasis is initially on the third part of the questionnaire.

Part three first introduced the task and the baseline scenarios. Subsequently, the three scenarios were introduced. Each scenario started with a description of the initial scenario conditions in text form (see Figure 6.3). The description of the initial situation was thereby in correspondence with the observations from the simulations.

Initial situation		
On 07/07/2022, 08:00 am, the three previously mentioned operation sites are set up. The temperature is moderate and there is no rain. The extent of the disaster is visible at all operating sites, but not extreme, and the risk to spontaneous volunteers is low. Due to the low level of media coverage, there is little information available to spontaneous volunteers about the operating sites. In the first few hours after the operating sites become apparent, spontaneous volunteers quickly arrive at the operating sites. Due to its central location, *OS Center* is initially preferred. However, the large number of volunteers means that some spontaneous volunteers are turned away at this location. Nevertheless, the general willingness to help is very high. The spontaneous volunteers offer their help at the nearby *OS South*. The demand at *OS South and OS Center* can be met by spontaneous volunteers. Furthermore, these two locations are preferred over the *OS Brachwitz*, which is located considerably further away. Compared to the more central locations, significantly fewer spontaneous volunteers help at the *Brachwitz EO*. There is a clear decline in the participation of volunteers at night at all operating sites.		
SF1	Could this scenario take place or have taken place in reality?	☐ Yes ☐ No
S1FP	<u>If so,</u> how plausible do you think is the influx or participation of spontaneous volunteers at the operating sites described above? ☐ low ☐ medium ☐ high	
	Explanation *(optional):*	

Figure 6.3: Description of the initial scenario condition for Scenario 1 (translated from German)

The description included the scenario setting (i.e., *the weather, media coverage, . . .*), and the initial influx at all operating sites. The description put the experts in a particular situation to evaluate the effects of the subsequent events, but also allowed for assessing a general perceived plausibility of the simulated outcomes. The participants were therefore asked to evaluate if the scenario could have happened in reality, and if so, how they would rate its plausibility as *low*, *medium*, or *high* [133] (see Figure 6.3). Thereby, the experts were allowed to take notes on their decision.

Afterward, the event was presented to the experts (i.e., *a weather change*, see Figure 6.4). They were asked to predict the effects of the event on the overall participation of spontaneous volunteers and the change in the influx at each operating site. The assessment should be performed regardless of whether the baseline scenario appeared plausible to them or not.

Event 1
09.07.2022, 03:00 pm: Heavy precipitation sets in
Description
The temperature is still moderate, but suddenly a heavy rain shower starts.

Figure 6.4: Survey example for Event 1 in Scenario 1 (translated from German)

For the correspondence between simulated and expert predictions [128] to assess predictive validity, the experts were asked to rate the change in the general participation and the influx at operating sites on a 5-point scale as introduced before (1 = *strong decrease*, . . . , 3 = *steady*, . . . , 5 = *strong increase*. The process was repeated for each event and every scenario.

The developed approach provides valuable results on the prediction quality of IS2SAVE by comparing the predictions of knowledgeable experts with simulated predictions of the system. This is particularly meaningful due to the lack of empirical data and the uniqueness of disaster events.

In doing so, the approach demonstrates not only that IS2SAVE provides realistic results, but also that it is capable of predicting outcomes for events that have not yet occurred in the real world. The presented approach is novel, and its positive application may encourage the use and adaptation for other researchers in other contexts.

The study was conducted in August 2022 at the local fire department in Halle (Saale) with a focus group of subject-matter experts from the disaster management domain. The focus group started with a presentation of the general motivation for the research topic, followed by a demonstration of the IS2SAVE prototype. Subsequently, the experts were asked to discuss the research outcomes, which led to valuable considerations for future research (see p. 90). Afterward, the experts were asked to fill out the previously described questionnaire.

Due to the limited number of participants (n = 7), the study was extended to an online survey. The study was introduced with the topic and the motivation. The prototype demonstration was accomplished with a *screencast*[1] of IS2SAVE (German), which was presented accordingly. Afterward, the previously described questionnaire was developed in *Limesurvey* and shared within a network of disaster management experts. After one month of conducting the online study, nine additional responses were received, of which three were completed, leading to a total of 10 completed responses (completion rate = 62.5%). The original questionnaire (in German) can be found in the appendix (p. cxxxix).

[1] https://lindner.me/is2save/IS2SAVE.mp4

6.2.3 Evaluating the Plausibility and Predictive Validity

According to Norman (2010) [134], there is no generally applicable minimum of samples to perform statistical analysis. Instead, the sample should represent a valuable group for the subject of investigation [134]. Since the respondents had an average job experience of 16.7 years (σ = 14.13) and consisted of seven senior disaster managers, one disaster researcher, one engineer, and one not specified, the sample represents an experienced group of practitioners. Their experiences in the studied domain seem adequate for the assessment of the plausibility, predictive validity, and the examination of the performance and effort expectancy introduced in the next section. It is also presumed that the pronounced knowledge of the experts in terms of job experience in disaster management can be considered the ground truth [131].

For the overall plausibility, the statements on whether the presented scenarios could have happened in reality were evaluated, whereby 96% of the responses were *"yes"* and 4% were *"no"*. The participants had an option to explain their decision. However, no explanations were given on why an expert voted for "no". For the question of how they rate the plausibility of a scenario, a plausibility score was calculated according to the following formula [135]:

$$PlausibilityScore = \frac{(1*N_{low}) + (2*N_{medium}) + (3*N_{high})}{N_{all}} \tag{6.1}$$

Where N_{low}, N_{medium}, N_{high} represent the total number of participants who voted for *low, medium, or high*, and N_{all} represents the total number of examined responses. The plausibility score can take any value between 0 and 3. The values close to 0 represent a very low plausibility for the scenario, and 3 represents a very high plausibility.

The average Plausibility Score for all examined scenarios is 2.73, which indicates a generally high plausibility of the scenarios simulated in IS2SAVE.

	Scenario 1	Scenario 2	Scenario 3
low	0	0	1
medium	0	2	4
high	10	8	5
Plausibility Score	**3**	**2,8**	**2,4**

Table 6.2: Plausibility scores for the examined scenarios

However, there were differences in the perceived plausibility for the scenarios, as indicated by the plausibility score (see Table 6.2). Whereas Scenario 1 was rated as very plausible, Scenario 2 and Scenario 3 were evaluated as less plausible, even though their plausibility scores were still high. Only one respondent voted for a low plausibility for Scenario 3, explaining his decision that the overall participation should have been less in this scenario according to the represented parameters. Nevertheless, the high plausibility scores reflect an overall plausible perception of the simulated scenario by the experts.

The subsequent evaluation was on the predictive validity of IS2SAVE, wherefore the correspondence between the predictions of IS2SAVE and the experts were examined [128]. The first step was an examination of the experts' opinions to identify how close the predictions were among them. Therefore, the standard deviation of all responses was examined to assess the predictions among the experts. The average standard deviation of all responses was 0.63, which means that the experts' predictions were generally very consistent.

Several measures exist for indicating the correspondence between predictions and observations, whereas Santos et al. [136] and Berk [128] suggest the *mean absolute error* (MAE) and the *root mean squared error* (RMSE). According to Chai and Draxler [137], the RMSE should only be assessed for sample sizes larger than 100. Therefore, the MAE was chosen as an indicator for the correspondence. The MAE calculates the average difference between the simulated and expert predicted values, whereas the direction of this difference is not considered [136].

Therefore, the MAE is suitable to represent the general prediction performance of IS2SAVE [137]. It should be noted that an accurate interpretation of the effects of the differences on the influx is not possible due to the chosen scale. However, the MAE value indicates the level of correspondence and thus how close the simulated predictions of IS2SAVE are to the ground truth. The MAE is calculated as follows:

$$MAE = (\frac{1}{n \times m}) \sum_{i=1}^{n} \sum_{j=1}^{m} \left| x_i - y_{ij} \right|$$

(6.2)

where: MAE = mean absolute error

n = total number of examined data

m = total number of expert predictions

x_i = simulated prediction for examined item *i*

y_{ij} = expert prediction *j* for examined item *i*

The examined items thereby represent the influx rating for each operating site and for the overall participation, as well the ranking of each operating site. The MAE was calculated on different levels of abstraction to understand the general predictive validity and identify differences for scenarios or operating site levels. The closer the MAE is to 0, the better the simulated predictions matched the expert predictions (i.e., *MAE of 0 means that every expert prediction matched the simulated prediction*). In contrast, an MAE of 4 would mean that all experts predicted completely opposite to the simulation.

Example:

To give an example, the process of calculating the MAE will be demonstrated for one examined aspect. The example will assess the MAE of the overall participation in response to the introduced Event 1 (Fig. 6.4, p. 79) for Scenario 1 (Fig. 6.3, p. 78). In the event, a heavy rain certainly starts in the scenario. The simulated response to the event was therefore a *strong decline* in the overall participation (see Fig. 6.1), which interprets as **1** (x_1 = 1). Further, n is 1, since only one aspect of interest is examined in the example, the total number of expert predictions is 10 (m = 10), and the expert predictions (y_{1j}) are presented in Table 6.3.

j	y_{1j}	$\lvert 1 - y_{1j} \rvert$
1	2	1
2	1	0
3	2	1
4	2	1
5	2	1
6	1	0
7	2	1
8	1	0
9	2	1
10	3	2

Table 6.3: Expert predictions and absolute errors for Event 1, Scenario 1

The calculation of the MAE for the overall participation in the example is as follows:

$$MAE = (\frac{1}{1 \times 10}) \sum_{i=1}^{1} \sum_{j=1}^{10} \left|1 - y_{1j}\right|$$

$$= (\frac{1}{1 \times 10}) \times (1+0+1+1+1+0+1+0+1+2)$$

$$= 0.1 \times 8$$

$$= \underline{\mathbf{0.8}}$$

The MAE for the overall participation in response to Event 1 in Scenario 1 is 0.8. It can be interpreted, that a correspondence between expert and simulated predictions is given (close to zero), and the expert data deviates by 0.8 on average in either direction. The results for all examined MAEs are presented in Table 6.4. The entire dataset is presented in the appendix (p. xxxv).

				Mean Absolute Error (MAE)			
Overall Participation	S1	E1		1.0000		1.1167	0.6881
		E2					
	S2	E1		0.9500			
		E2					
	S3	E1		1.4000			
		E2					
Operating Site Influx	S1	E1	OS Brachwitz	0.8333	0.9667	0.8667	
			OS Center				
			OS South				
		E2	OS Brachwitz	1.1000			
			OS Center				
			OS South				
	S2	E1	OS Brachwitz	0.7000	0.9833		
			OS Center				
			OS South				
		E2	OS Brachwitz	1.2667			
			OS Center				
			OS South				
	S3	E1	OS Brachwitz	0.6333	0.6500		
			OS Center				
			OS South				
		E2	OS Brachwitz	0.6667			
			OS Center				
			OS South				
Operating Site Order	S1	E1	OS Brachwitz	0.3000	0.4167	0.3667	
			OS Center				
			OS South				
		E2	OS Brachwitz	0.5333			
			OS Center				
			OS South				
	S2	E1	OS Brachwitz	0.4000	0.3667		
			OS Center				
			OS South				
		E2	OS Brachwitz	0.3330			
			OS Center				
			OS South				
	S3	E1	OS Brachwitz	0.1667	0.3167		
			OS Center				
			OS South				
		E2	OS Brachwitz	0.4667			
			OS Center				
			OS South				

S = Scenario; E = Event; OS = Operating Site

Table 6.4: Mean absolute errors for all events and scenarios

The overall MAE for all predictions is 0.6881, which indicates that the simulated predictions generally correspond reasonably well with the predictions of the experts. Therefore, it can be deduced that a predictive validity is given for IS2SAVE.

Nevertheless, there are differences in the operating site order (0.3667), the operating site influx (0.8667), and the overall participation (1.1167). The predicted operating site orders for IS2SAVE and the experts correspond more in comparison, which indicates that IS2SAVE performs moderately better in predicting the operating site order than in predicting the actual influx or the overall participation.

There is a relatively high MAE of 1.400 for Scenario 3 in the overall participation. In the simulation, the response to Event 2 was a decline, whereas, in comparison, the experts predicted an incline of the overall participation on average. The poor correspondence between expert and simulated predictions may be due to the experts focusing on the operating site influx without considering a general decline of the help in the progression of a disaster. Moreover, *"obvious"* environmental effects (e.g., weather changes) were not explained in Scenario 3, wherefore the decline might not be apparent from the experts' perspectives.

In addition, the correlation between the job experiences in years and the MAE of the expert predictions was investigated. Therefore, the Pearson correlation coefficient for the MAE of expert predictions and the job experience was calculated. The result was a modest negative correlation of -0.3681. Even though the effect is low, it indicates that the higher the job experience of the participant, the lower the MAE. This means the higher the job experience of the experts, the closer their predictions were to the predictions of IS2SAVE. Conversely, it means that the predictions of IS2SAVE were closer to the experts with a more pronounced job experience. Thus, when accounting for professional experience, the correspondence may be a little higher.

The results show that the influx predictions of IS2SAVE correspond to the predictions from experienced experts for the examined scenarios, and the simulated scenarios were generally perceived as plausible. Even if this indicates a predictive validity of IS2SAVE, there are limitation to the approach and results: a) more scenarios should be considered for a more holistic assessment, b) more experts should be consulted, and c) the interpretation of the simulated outcomes should be conducted with more than one researcher to reduce bias. The limitations of the applied approach will be discussed in Chapter 7 in more detail. Apart from these results, the focus was on an assessment of the general utility of IS2SAVE for disaster management.

6.2.4 Evaluating the Performance Expectancy and Effort Expectancy

Researchers examined the acceptance and behaviors towards different technologies and provided several formal models to understand the usage behavior [138, 139]. Meechang et al. (2020) particularly analyzed how the acceptance of using IT for disaster management was conducted in the disaster research domain [140]. Their results indicate that the perceived usefulness of software solutions had the biggest influence on using software in the disaster management context, and its assessment was applied in the majority of software approaches [140]. Based on this and the DSR requirement for evaluated artifacts [42], another part of the summative evaluation of the DSR project was an assessment of the utility for the system users, disaster managers in particular.

For this purpose, Venkatech et al. [138] analyzed eight established models (among others, the well-known Technology Acceptance Model [108]), and proposed the Unified Theory of Acceptance and Use of Technology (UTAUT) derived from prominent aspects of the investigated models. Their integrated model overcomes critics of other models, such as the simplification of usage behavior [141].

UTAUT consists of the four constructs 1) *performance expectancy*, 2) *effort expectancy*, 3) *social influence*, and 4) *facilitating conditions* [138].

Performance expectancy (PE) is a construct that concerns the usefulness of technology for different (job-related) activities, and *effort expectancy* (EE) represents the belief of the users about the ease of use or the effort associated with usage of a technology [138].

Social influence (SI) analyzes the degree to which an individual perceives that (important) others believe s/he should use a technology [138].

Facilitating conditions (FC) investigates the degree to which a user believes that the technological foundations for using the technology exist in their organization [138].

A main critique of UTAUT is its focus on users' individual perceptions or expectancies without considering technological, organizational, and social components [141]. Since the study particularly focuses on the user perspective, these points of criticism are negligible. The study investigates the PE construct since it is closely related to the perceived usefulness proposed to analyze disaster-related software [140] and due to the particular interest in the utility of IS2SAVE for disaster managers. In this context, a positive evaluation indicates a valuable artifact for practice.

Moreover, evaluating the EE reflects the usability of the information system. Due to the poor usability results in the evaluation of Design Cycle 2 (p. 27), EE can indicate a potential improvement. Implementing IS2SAVE in an organizational context is out of the scope of this study, and therefore FC is not examined. Furthermore, social influences were not examined due to the particular focus on utility for users. It is worth mentioning that the study was on explaining PE and EE with established and commonly applied items rather than measuring their influences on the behavioral intention to use a technology, which states the original purpose of UTAUT [138]. The item statements were translated and adapted to the use case of IS2SAVE [142]. For rating the according statements, there is no consensus on the use of 5- or 7-point scales [143].

To obtain a more detailed understanding of the items under study, the statements for the constructs were rated on a 7-point verbal numeric rating scale with ratings from 1 = *totally disagree*, ..., 4 = *neutral*, ..., 7 = *totally agree* for both constructs.

The sample of respondents was described in the previous section. For the constructs PE and EE, ten completed questionnaires were examined. The sample size particularly meets the requirement of 8 to 12 respondents for the assessment of the usability of software products [109]. The results of the quantitative expert survey can be found in Table 6.5. The table presents the relative frequencies of the evaluated aspect for all items and the according statements (translated from German).

		Statement	Relative Frequency						
			1	2	3	4	5	6	7
Performance Expectancy	PE1	IS2SAVE helps me increase productivity in my job.	0%	0%	0%	30%	10%	50%	10%
	PE2	IS2SAVE helps me respond faster to disasters with spontaneous volunteers.	0%	0%	0%	10%	20%	30%	40%
	PE3	IS2SAVE helps me to better respond to disaster situations with spontaneous volunteers	0%	0%	0%	0%	20%	50%	30%
	PE4	In general, I find IS2SAVE useful for disaster management	0%	0%	0%	10%	20%	30%	40%
Effort Expectancy	EE1	I find it easy to learn how to use IS2SAVE.	0%	0%	0%	0%	60%	20%	20%
	EE2	The handling of IS2SAVE is clear and understandable for me.	0%	0%	0%	0%	30%	60%	10%
	EE3	I find IS2SAVE easy to use.	0%	0%	0%	10%	30%	60%	0%
	EE4	I find it easy to become skilled in the use of IS2SAVE.	0%	0%	0%	20%	40%	20%	20%
1 = totally disagree; 2 = do not agree; 3 = rather do not agree; 4 = neutral; 5 = rather agree; 6 = agree; 7 = totally agree									

Table 6.5: Relative frequencies per evaluation aspect and statement

In general, the level of agreement of all examined items was very high. Especially, PE4 partly captures a high degree of the general utility of IS2SAVE for disaster management. Figure 6.5 depicts the distributions of answers according to the examined item. The diagram reflects a generally positive perception of IS2SAVE towards all aspects of the PE and EE constructs. Not a single statement about IS2SAVE was disagreed with as a result of the survey, which is a positive indication for IS2SAVE to deliver utility for disaster management.

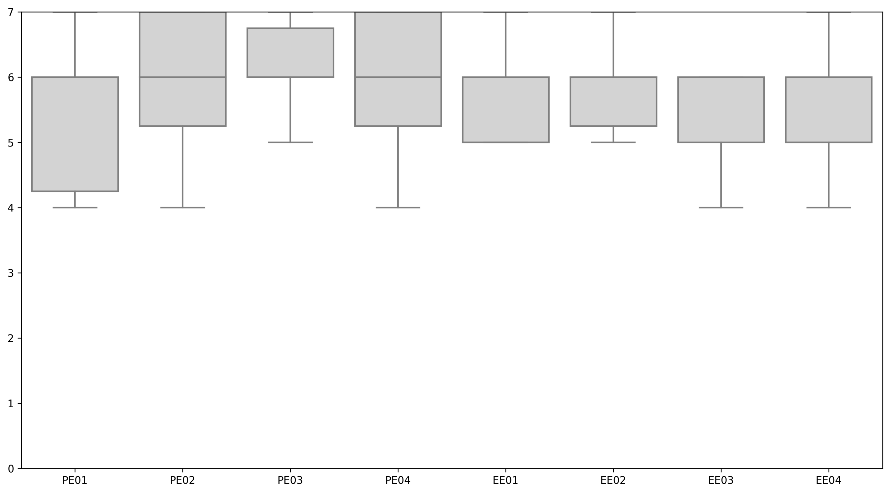

Figure 6.5: Box plots of the evaluation results per statement

The discussion of the prototype with the experts led to more valuable considerations for future work. One participant, e.g., mentioned the integration of road closures in the simulation to evaluate the effects on the influx of spontaneous volunteers and to account for potentially resulting congestions. It was further pointed out that the application domain could be extended to other types of disasters. Another participant proposed the calculation of resource requirements (e.g., food and beverages) against an allocation formula based on the predicted influx at operating sites.

Discussion

7.1 Contributions and Research Desiderata

The willingness of citizens to help in disasters is indispensable to counteract an increasing number of disasters, however, remains a significant challenge for disaster management [10, 15, 18]. Spontaneous volunteers, hence, represent a considerable resource for disaster management. In order for disaster management to benefit as thoroughly as possible without being impaired in its primary activities, both practitioners and researchers are encouraged to explore solutions to the problems related with spontaneous volunteers. In the past, it was repeatedly shown that their unpredictable influx at operating sites led to wide-ranging problems [17, 22, 12, 28]. It was shown that there is a lack of tools and solutions to cope with this unpredictable influx by promoting disaster management planning and training for such scenarios [28, 12, 24, 30]. Therefore, the goal of the research project was to design, implement, and evaluate an information system for predicting the influx of spontaneous volunteers at operating sites.

A total of three design cycles were conducted in this research project, following the DSR research approach of Vaishnavi and Kuechler [94]. The developed artifacts for answering emerged research questions in the design process resulted in five core contributions for the sake of the cumulative dissertation.

The design principles and design theory that emerged from the research project preserve the evaluated design considerations of IS2SAVE to guide researchers and practitioners in developing information systems for disaster management planning and training with spontaneous volunteers beyond the context of influx predictions.

The design theory and design principles particularly address the pronounced requirement for design knowledge in the field of information systems in natural disaster management [40], but also to satisfy the DSR requirement to derive scientific knowledge from solving practical problems [38, 88]. Therefore, they constitute a starting point for new designs and/or instantiations of planning and training systems with spontaneous volunteers.

The developed scenario language offers a contextualized and conceptualized representation of spontaneous volunteer scenarios relevant to both academia and practice. Therefore, the scenario language model can be used beyond the context of IS2SAVE, e.g., to be adapted and instantiated for other use cases. Particularly, its application to more scenarios remains an open research field to prove a wider applicability or, even, an improvement of the scenario language itself.

The conceptualized spontaneous volunteer behavior in the UML statechart notation represents the behavior and actions of spontaneous volunteers in natural disasters. It serves as a general understanding of the phenomenon of spontaneous volunteers on the individual level and provides researchers with an instantiable solution to implement this behavior in software. The obtained knowledge is valuable for developing spontaneous volunteer solutions beyond predicting their influx. One interesting aspect for future research is the comparison of the behavior in different countries, or in response to man-made disasters. Since the focus was on natural disasters, a different behavior in other situations is to be expected.

The lack of knowledge regarding the willingness of spontaneous volunteers to actively help on-site in disasters was addressed with a DCE approach. The introduced study revealed attributes and their effects on the willingness to help in flood disasters. Thereby, the use of DCE for eliciting spontaneous volunteer preferences was confirmed as a suitable method and documented to assist researchers in answering similar questions.

Particularly interesting may be an analysis, if influences beyond the flood context are different in their effects, or if the attributes vary in general. Further, cultural or national differences can be examined in the future. Yet, the examined effects serve researchers and disaster managers equally well in gaining an understanding about spontaneous volunteering in disasters.

The understanding of spontaneous volunteers was further extended by a machine learning model of the operating site choice, which was realized with a machine learning approach. The approach followed in the related article can be applied to train new models in the context of other disaster types or countries to, again, identify differences and provide machine learning models for other contexts. Furthermore, the resulting model can be used for operating site predictions that go beyond the objective addressed in IS2SAVE.

In addition to the aforementioned contributions, an operational prototype of IS2SAVE was developed and published on GitHub. Organizations can use the prototype to establish planning and training with spontaneous volunteer scenarios. Additionally, researchers may revise and improve the prototype with new findings, or build upon the implementation. The modular nature of the implementation, as shown in Chapter 5, allows for replacing components. For example, the prototypical web application can be exchanged or extended by a mobile application.

Finally, the contributions of this dissertation were both developed from and applied in a variety of research projects. In *KUBAS*, the simulation of spontaneous volunteers served to test the developed coordination system. Within *SiK*, the DCE study was conducted to improve IS2SAVE and further the simulation model and design knowledge was demonstrated in an academic context with students in several university courses. Additionally, the conceptual scenario language was applied in the research project *ILAS* for disaster management training beyond the context of predicting spontaneous volunteer influx.

In addition, IS2SAVE in general and the contributions in particular are an integral part of two newly applied government-funded research projects in the disaster research domain (*KatHelferPro* and *DITAK*). Thus, the findings from the dissertation are result, applied, and basis for a total of five funded research projects, highlighting the relevance for both academia and practice.

7.2 Limitations

The presented research project neither intends to explain all aspects of spontaneous volunteer predictions nor to find a holistic solution for disaster management training and planning. Instead, the research project represents one possible scientifically grounded approach that offers a solution to spontaneous volunteer problems without claiming to be universally valid. Accordingly, the research project is subject to limitations that serve, on the one hand, to assess the findings adequately and, on the other hand, to derive research desiderata that can initiate future research.

The method of systematic literature analysis described in the dissertation and partly in the articles is not free of methodological weaknesses. Thus, none of the literature reviews claims to be exhaustive, as it cannot be excluded that relevant publications exist which were not considered in the research process. Consequently, it means that potentially relevant articles were overseen. The continuous discourse with researchers from the domain and experts at academic conferences at least partially mitigates this aspect. Furthermore, following a systematic procedure enables reproducibility of the findings [78]. Moreover, the identification of disaster management planning and training approaches took place in the course of the research project and was not specifically addressed by a systematic literature review. A systematic literature review may lead to a more comprehensive selection of the current research in these areas.

Using agent-based simulations to simulate spontaneous volunteer behaviors was grounded on related publications. However, it cannot be ruled out that other approaches may lead to similar or even better results. For example, the behavior of spontaneous volunteers could be implemented directly in executable program code to not rely on technological limitations of the AnyLogic simulation software. Furthermore, complex agent-based simulations are subject to the resources of the modeler. The complexity of IS2SAVE limited the assessment of standard tests such as sensitivity analysis, which indicate the effect of the different parameters and their values [121]. Thus, it could not be analyzed if the simulated influx is prone to individual parameters, since sensitivity analysis requires numerous simulation runs. Simulations in IS2SAVE, however, take up to tens of minutes, even for the most basic scenarios, whereas sensitivity analysis is practicably impossible, due to the performance of the system. This limitation was partially circumvented since operating site predictions for individual agents come from the machine learning model that, by contrast, was extensively investigated. Further model calibration [121] was limited to a lack of empirical data. Other approaches may offer results significantly more resource-efficient, especially in terms of computational power. Consequently, more efficient models remain an open research field.

Further, in this reference, the conceptualization of spontaneous volunteer behaviors was mainly developed for the use in agent-based simulations, leaving other approaches to explain the behavior more generally an open research field. Moreover, the states were retrieved from the literature rather than interviewing spontaneous volunteers. Therefore, the model may be revised and improved in future by findings from interviews and by new findings from the literature. Also, the implementation in a running prototype is subject to the developer or researcher, and, accordingly, the choice of parameters for state changes are. These were not provided from within the conceptual model, so that other instantiations may vary.

Apart from that, the choice of alternative implementation decisions is explicitly addressed in the design theory so that future research may lead to an enhanced solution for the behavior simulation.

The conceptual scenario language is subject to limitations in that relevant elements were initially identified from the literature. The validation of the scenario language was conducted with proving its applicability to only one real world scenario. Thus, other real world scenarios may reveal more aspects and elements that were not considered in the development process. Consequently, findings from future validations could enhance the scenario language and lead to a revision.

The identification of behavior-affecting attributes and their effects on the willingness to help originated from a theoretical analysis of behavior influences. In preparation of the DCE study, the number of attributes was drastically reduced to achieve a feasible analysis. Thus, not all potential effects were fully examined. In addition, the study was conducted in two introductory university courses, thereby potentially biasing the findings. Future work must approve the findings from a more general sample, and, incorporating more attributes. The limitation of the number of attributes was partly addressed with the second study implementing a machine learning approach to evaluate more attributes. However, also this study is limited to the sample, that was both limited to flood disasters in Germany, and did not represent the German population. Moreover, the limited number of responses may affect the performance of the machine learning model. The accuracy was around 71% which is improvable with more and more versatile data. This further affects the general instantiation of IS2SAVE, since the model is an integral part. Improved models in future may enhance the predictions from IS2SAVE in general.

Another limitation is the general choice of design science research as a guiding research framework. Although the choice was based on comprehensible justifications and the development of IS2SAVE is well documented, the choice of a different approach may lead to different outcomes. The cyclic approach incorporating continuous prototype development and evaluation should be emphasized in this regard. On the one hand, this ensures that the development is carried out in constant exchange with experts; on the other hand, applying a different research approach might have led to faster results, which would have provided more time for expanding the functionality or efficiency of IS2SAVE. Furthermore, the decisions made in the design process are subjective. It cannot be excluded that other designers would have potentially concluded on different design principles [144].

Although the artifacts developed in the design process are primarily of general applicability and detached from specific implementations, two artifacts were explicitly developed with flood disasters in Germany in mind. Accordingly, the predictions generated in the system are only valid and applicable for this specific use case. Nevertheless, it could be demonstrated that the prerequisites were created for the adaptation to other disasters. The investigation of the behavior in other types of disasters or other countries thus represents a central research desideratum that can be addressed in the future. In addition, the quality of predictions in machine learning may also benefit from a more representative survey; respectively, the choice of the sample currently limits the model.

The chosen approach for assessing the plausibility of the predictions in IS2SAVE is based on the lack of empirical data and comparable models. The predictive validity cannot be finally judged despite the overall good correspondence between simulated outcomes and expert knowledge, considered as ground truth. Therefore, the model may predict better or worse in comparison with actual data of comparable disasters. A resulting demand is, therefore, the collection of empirical data on an observed spontaneous volunteer influx in disasters.

Finally, the system can be calibrated with actual data to potentially improve the overall predictions. Also, the interpretation of influx changes on a 5-point scale for simplicity may result in a lack of detail. The assessment, e.g., in percentage changes, may lead to different results, which shows a methodological weakness. Additionally, the interpretation of the changes relied on one researcher's opinion, which may cause biases. A broader assessment of the interpretation of changes with more researchers can potentially lead to different results in the correspondence in either way.

Another limitation is the choice of the indicator for the correspondence between simulated and expert predicted outcomes. Therefore, the *mean absolute error* was chosen. The applicability of the *mean absolute error* for the purpose is discussable, since the predictions were collected on a rating scale. Characteristics between the ratings may be very subjective. The *mean absolute error* indicates that the predictions differ by about 0.69 rating in either side on average (see p. 85). Although this means that the simulated and expert predictions are very close, it is not possible to interpret the effect of the difference on the actual influx. Whether influx predictions compare well with other models needs to be verified when such models are developed. The model of Paret [85] was not suitable for that, since it was neither available, nor able to represent dynamic scenarios with changing parameters, as IS2SAVE can. The approach followed in this research project moreover addressed the limitations from his work, independent of the knowledge about the limitations, and before they were published. Additionally, the evaluation of the predictions depends on the choice and number of experts. Although these were widely experienced disaster managers and the predictions varied very little among the experts, it is still possible that other experts would have evaluated the influx at operating sites differently.

The sample also influences the evaluation of performance expectancy, effort expectancy, and the general discussion of the IS2SAVE prototype. Other experts would have potentially rated the system differently, possibly even less useful. In this regard, the associated discussion led to valuable considerations for the enhancement of IS2SAVE. However, a broader discussion with experts from other disaster management organizations might have led to further suggestions for improvement.

Further research is needed to determine whether IS2SAVE can be applied in other countries. The requirements were collected from a selection of German disaster management experts and only addressed their perspective on managing spontaneous volunteers. The exact requirements in other countries will likely vary. Differences also refer to the behaviors represented in the system, which are based on national samples.

The IS2SAVE prototype is based on a complex interaction of various system components and subsystems, which makes actual implementations rather complicated. Other instantiations of the design principles may conduct a more integrated approach to achieve a more straightforward implementation in the organizational context.

Although the research project is formally completed with the dissertation, there are many opportunities to develop the system further and, thus, to address the training and planning of disaster managers with the spontaneous volunteer influx more thoroughly. The noted integration of road closures and the extension to additional disaster types (see p. 90) are just two of many ideas to mention.

7.3 Concluding remarks

The demand for tools to enable disaster management training and planning with the influx of spontaneous volunteers at operating sites initiated the research project to design, develop, and evaluate an information system for this specific purpose. The goal of solving this organizational problem was pursued through a DSR doctoral research project, summarized in this cumulative dissertation. The findings obtained in the doctoral research project were published in scientific articles and demonstrated in the IS2SAVE software prototype. Apart from the academic contributions, the utility of IS2SAVE was positively evaluated by disaster management experts, which deem the doctoral research project findings valuable for practice. Although the prototype and its constituent artifacts, as well as the research approach in general, have limitations, these were thoroughly discussed. Both research and practice can build upon the findings in this research to contribute to the general improvement of spontaneous volunteer management, resulting in an even more effective response to an increasing number of natural disasters.

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Data for assessing the predictive validity

	General Participation						Operating Site Influx																	
	Scenario 1		Scenario 2		Scenario 3		Scenario 1						Scenario 2						Scenario 3					
							Event 1			Event 2			Event 1			Event 2			Event 1			Event 2		
							OS Brachwitz	OS Center	OS South	OS Brachwitz	OS Center	OS South	OS Brachwitz	OS Center	OS South	OS Brachwitz	OS Center	OS South	OS Brachwitz	OS Center	OS South	OS Brachwitz	OS Center	OS South
ITEM CODE	S1SIE11	S1SIE21	S2SIE11	S2SIE21	S3SIE11	S3SIE21	S1SIE12	S1SIE13	S1SIE14	S1SIE22	S1SIE23	S1SIE24	S2SIE12	S2SIE13	S2SIE14	S2SIE22	S2SIE23	S2SIE24	S3SIE12	S3SIE13	S3SIE14	S3SIE22	S3SIE23	S3SIE24
Expert 1	2	4	5	4	4	5	1	2	2	5	2	3	4	3	5	1	2	5	3	4	4	4	3	5
Expert 2	1	3	4	3	3	3	1	1	1	4	2	4	3	3	4	3	2	3	3	4	4	4	3	4
Expert 3	2	4	4	3	4	4	3	2	2	4	5	4	3	3	4	2	3	4	3	4	4	4	3	5
Expert 4	2	4	5	3	4	4	1	2	1	5	2	2	1	3	5	1	2	5	1	4	4	4	4	5
Expert 5	2	4	5	4	4	4	1	2	1	5	3	2	4	4	5	2	4	5	3	4	4	4	3	3
Expert 6	1	5	5	5	4	4	1	2	2	5	2	2	4	2	5	1	3	5	2	4	4	4	3	5
Expert 7	2	2	4	2	4	4	3	1	2	4	2	2	4	3	4	2	3	4	3	4	4	4	3	4
Expert 8	1	4	4	3	4	4	2	2	2	5	2	3	3	3	5	1	1	4	3	4	4	4	3	5
Expert 9	2	4	3	3	3	3	2	2	2	4	3	3	4	3	3	3	2	4	3	3	3	4	3	3
Expert 10	3	4	4	4	4	5	3	3	3	5	2	3	4	3	5	3	3	5	3	4	4	5	4	4
Standard Deviation (SD)	0.63	0.79	0.67	0.84	0.42	0.67	0.92	0.57	0.63	0.52	0.97	0.79	0.97	0.47	0.71	0.88	0.85	0.70	0.67	0.32	0.32	0.32	0.42	0.82
Simulation	***1***	***5***	***4***	***2***	***3***	***2***	***1***	***1***	***1***	***5***	***4***	***4***	***4***	***2***	***5***	***1***	***4***	***3***	***1***	***4***	***4***	***4***	***2***	***4***
																			Absolute Difference					
Expert 1	1	1	1	2	1	3	0	1	1	0	2	1	0	1	0	0	2	2	2	0	0	0	1	1
Expert 2	0	2	0	1	0	1	0	0	0	1	2	0	1	1	1	2	2	0	2	0	0	0	1	0
Expert 3	1	1	0	1	1	2	2	1	1	1	1	0	1	1	1	1	1	1	2	0	0	0	1	1
Expert 4	1	1	1	1	1	2	0	1	0	0	2	2	3	1	0	0	2	2	0	0	0	0	2	1
Expert 5	1	1	1	2	1	2	0	1	0	0	1	2	0	2	0	1	0	2	2	0	0	0	1	1
Expert 6	0	0	1	3	1	2	0	1	1	0	2	2	0	0	0	0	1	2	1	0	0	0	1	1
Expert 7	1	3	0	0	1	2	2	0	1	1	2	2	0	1	1	1	1	1	2	0	0	0	1	0
Expert 8	0	1	0	1	1	2	1	1	1	0	2	1	1	1	0	0	3	1	2	0	0	0	1	1
Expert 9	1	1	1	1	0	1	1	1	1	1	1	1	0	1	2	2	2	1	2	1	1	0	1	1
Expert 10	2	1	0	2	1	3	2	2	2	0	2	1	0	1	0	2	1	2	2	0	0	1	2	0
Mean Absolute Error (MAE)	**0.8000**	**1.2000**	**0.5000**	**1.4000**	**0.8000**	**2.0000**	**0.8000**	**0.9000**	**0.8000**	**0.4000**	**1.7000**	**1.2000**	**0.6000**	**1.0000**	**0.5000**	**0.9000**	**1.5000**	**1.4000**	**1.7000**	**0.1000**	**0.1000**	**0.1000**	**1.2000**	**0.7000**
							0.8333			**1.1000**			**0.7000**			**1.2667**			**0.6333**			**0.6667**		
	1.0000		**0.9500**		**1.4000**		**0.9667**						**0.9833**						**0.6500**					
	1.1167						**0.8667**																	
	0.6881																							

Operating Site Order																		
Scenario 1						**Scenario 2**						**Scenario 3**						
Event 1			**Event 2**			**Event 1**			**Event 2**			**Event 1**			**Event 2**			
OS Brachwitz	**OS Center**	**OS South**	**OS Brachwitz**	**OS Center**	**OS South**	**OS Brachwitz**	**OS Center**	**OS South**	**OS Brachwitz**	**OS Center**	**OS South**	**OS Brachwitz**	**OS Center**	**OS South**	**OS Brachwitz**	**OS Center**	**OS South**	
S1SUE11	S1SUE12	S1SUE13	S1SUE21	S1SUE22	S1SUE23	S2SUE11	S2SUE12	S2SUE13	S2SUE21	S2SUE22	S2SUE23	S3SUE11	S3SUE12	S3SUE13	S3SUE21	S3SUE22	S3SUE23	
1	2	3	3	1	1	1	2	3	1	2	3	1	3	3	1	1	3	
1	3	2	1	3	2	1	3	2	1	3	3	1	3	2	1	3	3	
1	3	2	3	1	1	1	1	3	1	2	3	1	3	3	2	1	3	
1	3	1	3	2	1	1	2	3	1	1	3	1	3	2	1	1	3	
1	3	2	3	1	2	1	1	3	1	3	3	1	2	2	2	2	2	
1	3	3	3	1	1	1	1	3	1	2	3	1	3	3	1	1	3	
1	3	3	1	3	2	1	3	2	1	3	2	1	3	2	1	2	3	
3	1	2	3	1	2	1	2	3	1	1	3	1	3	2	1	2	3	
1	3	2	2	3	2	1	3	1	2	2	2	1	3	3	2	2	2	
1	3	2	3	1	2	2	1	3	2	1	3	1	3	2	3	1	2	**MEAN**
0.63	0.67	0.63	0.85	0.95	0.52	0.32	0.88	0.70	0.42	0.82	0.42	0.00	0.32	0.52	0.71	0.70	0.48	**0.63**
1	***3***	***2***	***3***	***1***	***2***	***1***	***2***	***3***	***1***	***2***	***3***	***1***	***3***	***2***	***1***	***2***	***3***	
0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	**0.67**
0	0	0	2	2	0	0	1	1	0	1	0	0	0	0	0	1	0	**0.60**
0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	**0.64**
0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	**0.67**
0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	1	**0.62**
0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	**0.57**
0	0	1	2	2	0	0	1	1	0	1	1	0	0	0	0	0	0	**0.76**
2	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	**0.62**
0	0	0	1	2	0	0	1	2	1	0	1	0	0	1	1	0	1	**0.86**
0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	2	1	1	**0.88**
0.2000	**0.3000**	**0.4000**	**0.5000**	**0.7000**	**0.4000**	**0.1000**	**0.7000**	**0.4000**	**0.2000**	**0.6000**	**0.2000**	**0.0000**	**0.1000**	**0.4000**	**0.5000**	**0.6000**	**0.3000**	
0.3000			**0.5333**			**0.4000**			**0.3333**			**0.1667**			**0.4667**			
0.4167						**0.3667**						**0.3167**						
0.3667																		

Data for assessing the performance and effort expectancy

Job Experience in years	Performance Expectancy				Effort Expectancy			
	PE01	PE02	PE03	PE04	EE01	EE02	EE03	EE04
39	4	5	6	5	5	6	4	5
8	5	6	6	6	5	6	6	4
42	6	7	6	7	6	7	6	6
23	4	4	6	4	5	6	6	5
20	6	7	5	7	7	5	5	7
8	7	7	7	5	6	6	5	6
7	4	5	6	6	5	5	6	5
12	6	6	7	7	5	5	5	4
1	6	6	5	6	5	6	6	5
7	6	7	7	7	7	6	6	7

Author’s statement about the work shares of the articles

Title

- Simulating Spontaneous Volunteers - A Conceptual Model

Published in

- Kees Boersma, & Brian Tomaszeski (Eds.), Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (pp. 159-169). Rochester, NY (USA): Rochester Institute of Technology. 2018.

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- Lindner, Sebastian (LS)
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Work shares

Aspect	Author/s
Problem and objective	LS
Research concept	LS
Literature research	LS
Conceptualization of the topic	LS
Development of the Conceptual Model	LS with the cooperation of KS
Development of the example scenario and prototypes	LS
Preparation of the manuscript	LS with the cooperation of KS
Review and revision before submission	LS, KS, BH, SaS
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- Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios

Published in

- In Z. Franco, J. J. González, & J. H. Canós (Eds.), Proceedings of the 16th International Conference on Information Systems for Crisis Response And Management (pp. 516 - 527). Valencia, Spain. 2019.

Authors

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Work shares

Aspect	Author/s
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Research concept	LS
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Authors

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Work shares

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Evaluation and interpretation of the results	HC, LS
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Authors

- Lindner, Sebastian (LS)
- Kühnel, Stephan (KS)

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Definition of the evaluation strategy	LS
Derivation of the design theory	LS
Development of the software prototype	LS
Development and implementation of the case studies	LS
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Planned submission

- Journal of Decision Systems

Authors

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Work shares

Aspect	Author/s
Problem and objective	LS, HC
Literature research	LS, HC
Development of the questionnaire and collection of the data	LS, HC
Training and evaluation of the machine learning models	HC
Implementation of the model in a software prototype	LS
Discussion of the implications	HC, LS
Preparation of the manuscript	HC, LS
Review and revision before submission	LS, HC
Revision after the appraisal	HC, LS

Design and Instantiation of IS2SAVE: An Information System to Predict the Influx of Spontaneous Volunteers at Operating Sites

Title	Design and Instantiation of IS2SAVE: An Information System to Predict the Influx of Spontaneous Volunteers at Operating Sites
Authors	Lindner, S., Kühnel, S.
Year	2023
Published in	Proceedings of the 56th Hawaii International Conference on System Sciences
Abstract	Disaster managers are in charge of encountering natural disasters, yet, more often supported by citizens, so-called spontaneous volunteers. Their help has repeatedly been reported to be valuable for reducing disaster scales, regarding an increase in natural disasters occurrences with devastating effects. However, their characteristic to emerge in large groups has led to an unpredictable influx at operating sites from the perspective of disaster management. Finally, this led to problems such as congestions and blocked emergency routes, overcrowded operating sites and hampering officials in doing their work. To address this unpredictability, we apply a design science research approach to design and develop an information system to predict the influx of spontaneous volunteers at operating sites. We examine three design requirements and ten design principles, that we instantiate in a prototype. We finally validate our design theory empirically with experts, who positively highlight its perceived usefulness, conciseness, extendibility, explanatory power.
Keywords	design science, design principles, spontaneous volunteer, disaster management, influx prediction
Artifact	Design Theory, Design Principles
Evaluation	Focus Group
Contribution	design knowledge for an information system to predict the influx of spontaneous volunteers at operating sites, instantiated prototype IS2SAVE

Design and Instantiation of IS2SAVE: An Information System to Predict the Influx of Spontaneous Volunteers at Operating Sites

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Abstract

Disaster managers are in charge of encountering natural disasters, yet, more often supported by citizens, so-called spontaneous volunteers. Their help has repeatedly been reported to be valuable for reducing disaster scales, regarding an increase in natural disasters occurrences with devastating effects. However, their characteristic to emerge in large groups has led to an unpredictable influx at operating sites from the perspective of disaster management. Finally, this led to problems such as congestions and blocked emergency routes, overcrowded operating sites and hampering officials in doing their work. To address this unpredictability, we apply a design science research approach to design and develop an information system to predict the influx of spontaneous volunteers at operating sites. We examine three design requirements and ten design principles, that we instantiate in a prototype. We finally validate our design theory empirically with experts, who positively highlight its perceived usefulness, conciseness, extendibility, explanatory power.

Keywords: design science, design principles, spontaneous volunteer, disaster management, influx prediction

1. Introduction

Disaster management is primarily the responsibility of civil protection authorities and volunteer organizations (Roth & Prior, 2019). Yet, recent events have unveiled numerous citizens assist reducing disaster scales on-site. Disaster research refers to this phenomenon as spontaneous volunteering (Twigg & Mosel, 2017). Spontaneous volunteers (SVs) are citizens who converge at disaster sites in the immediate aftermath of a disaster to offer resources and help, even usually not being trained for disaster response activities (Ludwig et al., 2017). SVs have no affiliations with recognized volunteer organizations or civil protection authorities (Lowe & Fothergill, 2003).

Not only that disaster managers have reported much more devastating scales without the support of SVs, there is also an increase in natural disaster occurrences with more dramatic proportions, and significant economic losses (Coronese et al., 2019). Moreover, civil protection volunteerism, as a crucial pillar of disaster management, suffers from membership declines caused by demographic change and a general lack of motivation for affiliating with organizations (Salmani et al., 2019). This shortfall of affiliated volunteers, more frequent and stronger disasters, and reports on successfully reduced disaster scales emphasize the importance of SVs.

Irrespectively, SVs have also caused variegated problems, resulting in a new field of disaster research. The unforeseen and massive influx of SVs at operating sites has led to congested roads, blocked emergency routes and hindering first responders from reaching their deployed sites (Twigg & Mosel, 2017). SVs hampered on-site disaster management staff doing their assigned work. Overwhelmed disaster managers rejected SVs leading to wandering crowds, congestions, and consequently to SVs questioning their support to help on-site, sometimes even whether they would ever help again in a disaster. In contrast to crowded operating sites in populated central areas, understaffed operating sites in peripheral areas urgently required help.

While being indispensable for disaster mitigation, their unpredictable influx at operating sites caused and causes negative effects. Originating in the natural disaster management domain, the problems can be addressed with tools and methods of information system research. For instance, app-based coordination systems integrate SVs into command-and-control structures and deploy them according to the disaster management's needs, e.g., Betke (2018) and social media and public display approaches improve self-coordination, e.g., Ludwig et al. (2017). All approaches promote balancing operating site utilization, yet, neither providing information about the SV influx, nor about emerging congestions. Thus, to the best of our knowledge, design knowledge for an information system to predict the SV influx at operating sites is still lacking. Consequently, we study the following research question (RQ):

RQ: *What are the design requirements and design principles of an information system for disaster managers to predict the influx of spontaneous volunteers at operating sites in disasters?*

We apply an IS design science research (DSR) approach in the domain of natural disaster management, since both information system research and natural disaster management consider the synergy of persons, structures, technologies and working systems (Hevner et al., 2004; Schryen & Wex, 2012). DSR allows for applying a scientific research method to solve practical problems while also adding to the body of knowledge by building and evaluating new research artifacts. Even though DSR is a very well established research methodology in information system research, there is a lack, yet, a demand, of design knowledge in the domain of natural disaster management (Schryen & Wex, 2012). We particularly meet the demand for design knowledge in the natural disaster management domain with this paper.

2. Research method

The paper aims at exploring design knowledge for an information system to predict the influx of spontaneous volunteers at operating sites. We, therefore, applied a DSR approach inspired by (Vaishnavi & Kuechler, 2015). Our approach is multi-cyclical, with each consecutive cycle consisting of the five phases (Vaishnavi & Kuechler, 2015): 1. problem awareness, 2. suggestion, 3. development, 4. evaluation, and 5. conclusion (see Figure 1). To ensure scientific rigor, we followed the well-known evaluation framework of Venable et al. (2016). The design knowledge in the form of design principles (DP) obtained from all cycles is explained in the remainder of this paper. Additionally, we present the instantiation of the DPs and the development of the prototype, which we refer to as IS2SAVE, in Section 4.

The design of IS2SAVE depends on social factors such as the behavior of the spontaneous volunteers, as well as their behavior-influencing factors, and, also, on user requirements of disaster managers who are intended to use the system. Thus, the main risks involved in designing the information system are social- and user-oriented, for which Venable et al. (2016) recommend the evaluation strategy called "Human Risk & Effectiveness". Since the research was conducted in three consecutive iterations, we have undergone two formative and two summative evaluations (see Figure 1).

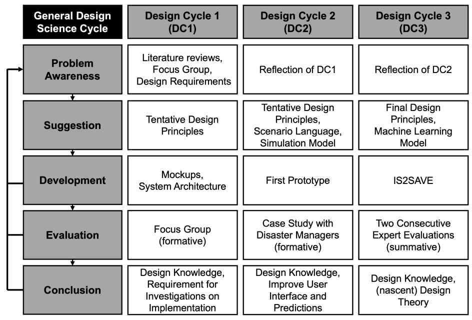

Figure 1. Design science research approach for IS2SAVE (following Vaishnavi and Kuechler 2015).

We started cycle 1 with a review of the theoretical background to identify the current state of research on the topic and to provide a theoretical foundation for our research goal. The results created a problem awareness for the insufficient ability of SVs to self-coordinate in disasters according to the demands of disaster managers (e.g., Ludwig et al. (2017)). Lacking information about the imminent influx of SVs at operating sites results in the incapacity of disaster management to tackle or counteract congested roads or overcrowded/understaffed operating sites. Furthermore, the individual decision if, when, and where people help relies on various influencing factors that make predictions hard to conduct (Lindner & Herrmann, 2020). The literature suggests that disaster management needs ad-hoc IT support for the largely manual decisions in disasters in general (Harris et al., 2017; Lodree & Davis, 2016). However, it turned out that an information system holistically addressing the mentioned problem space is still lacking. We performed a moderated focus group with domain experts to derive design requirements (DRs) and (five) initial DPs, followed by a literature review with two additional DPs. We evaluated the conceptual prototype (mockups, system architecture) of cycle 1 with a focus group (IS researchers). The evaluation was formative and artificial (Venable et al., 2016), and the discussion was with researchers rather than real users. Questions about the characteristics of disaster scenarios with spontaneous volunteers arose, and the simulating the influx remained unclear. These considerations initiated cycle 2, the development of new artifacts and, accordingly, the derivation of new design knowledge. We addressed this knowledge with a simulation model of the spontaneous volunteer influx in AnyLogic and presented it to disaster managers in the form of a case study. This second evaluation was again formative, because we suggested DPs that have not been proven to be sufficient to address the DRs. Since the second evaluation involved real users, a real problem (case study), and an instantiated prototype, it was more naturalistic according to Venable et al. (2016). Due to the focus on conceptual considerations for a running simulation model, the first version prototype heavily relied on assumptions regarding the operating site choice of SVs. The participants perceived these simulated predictions to be hardly realistic, and the usability of the system was considered as improvable. The requirement for deeper (and empirical) investigations on when and where individuals help along with the need for improved usability has led to another design cycle. Cycle 3 focused on realistic predictions and an improved user experience. We summarized our experiences in three additional DPs. Two distinct summative evaluations led to sufficient results to stop cycle 3 and the research process. We wanted the obtained design knowledge to be comprehensively represented for researchers and developers. Thus, we have evaluated the Perceived Usefulness, Conciseness, Extendibility, and Explanatory Power of the DPs for the specified goal of an information system for the prediction of the spontaneous volunteer influx at operating sites (see Section 5). Our experiences in developing IS2SAVE led to a design theory constituted by DRs and DPs, which together embody a general design solution for a class of problems (Baskerville & Pries-Heje, 2014).

3. Designing an information system to predict the spontaneous volunteer influx at operating Sites

3.1. Design requirements

We conducted a moderated focus group with experienced disaster managers from our local fire department in Halle, Germany to retrieve DRs for the information system. To address the requirements of disaster managers properly, which we consider to be the system users, our focus group consisted of two heads of disaster management and six staff members. All participants had experiences in the management of at least one major disaster with participating SVs. We conducted the focus group by processing the following steps: 1) motivating the research topic, 2) discussing the problem space and design requirements, 3) taking notes, and 4) evaluating the results.

We approved the statements from the focus group with findings from the literature to reduce subjective bias. The summary of statements from the focus group, related literature that confirms the statements, and the proposed DRs will be given in the remainder.

The focus group experienced differences between the influx of volunteers at operating sites in central (city centers) and peripheral areas, which we approved by the theoretical findings from, e.g., Fernandez et al. (2006). Questions arose why people were more willing to help in crowded central places rather than in peripheral places where their help was urgently needed. Moreover, they discussed the unexpected, massive influx of SVs resulting in their on-site colleagues being hindered in processing operations. The focus group summarized lacking information about the imminent SV influx at operating sites and insufficient knowledge about their behavior to be widely challenging disaster management. During the discussion, we came up with the idea of presenting spontaneous volunteer data on a dashboard. The idea was very well received, however, resulted in another discussion about meaningful indicators and data. In collaboration with the focus group, we identified, e.g., the (average) utilization of operating sites over time and the number of rejects of spontaneous volunteers at operating sites.

Based on the discussions, we suggest **DR1:** *The information system should provide a comprehensive dashboard of data about the spontaneous volunteer influx at operating sites.*

The focus group further discussed the requirement of comparing the effects of different courses of action, or variations of intended (or unintended) changes in a scenario, such as weather changes or an increased/decreased media coverage about operating sites. Estimating and understanding effects of actions or changes in environmental conditions on the influx of spontaneous volunteers has been discussed as a valuable requirement for the preparing of possible risks (i.e., volunteer shortfalls or overloads, or road congestion). Lodree and Davis (2016), e.g., approve this. The meaningfulness of performing "what-if" analysis for decision-making in the SV context was particularly highlighted by Fernandez et al. (2006).

Accordingly, we derive **DR2:** *The information system should enable the evaluation and comparison of the spontaneous volunteer influx at operating sites in different scenarios.*

From the experience of our focus group, in recent major disasters, SV crowds have led to congested roads and even worse, blocked emergency routes, that hindered or hampered first responders from arriving at their designated sites. This has also been discussed in, e.g., Twigg and Mosel (2017). Our focus group discussed visual representations of volunteer movements to identify potentially congested and blocked roads.

Hence, we suggest **DR3:** *The information system should show the movement of spontaneous volunteers on a map and highlight frequently used paths.*

The DRs helped us to propose initial Design Principles, that formulate precise design recommendations for the information system. The initial DPs were tentative and have been revised in the course of the research project. To build upon existing design knowledge, the DPs have further been extended by a literature review on explicit design knowledge for information systems in disaster management.

The concept of DPs has repeatedly led to misconception and, thus, resulted in a lack of utility for the IS community. Gregor et al. (2020) addressed that issue by providing a guideline on how to develop comprehensive DPs. Hence, the DPs have been formulated in accordance to Gregor et al. (2020). We do not present the Implementer, User, and Context according to Gregor et al. (2020), since these stay the same for all DPs. In our case, *Implementer* is the developer of an information system for the prediction of the influx of spontaneous volunteers at operating sites. We consider disaster managers as our *Users*, and spontaneous volunteer management in natural disaster management as the *Context*. The *Aim (A)* represents what the user or the artifact tries to achieve, whereas the *Mechanism (M)* explains how to achieve the aim. Further, the *Rationale (R)* is the justification that the proposed mechanisms will lead to the according aim (Gregor et al., 2020).

We firstly present DPs that have been directly derived from the DRs by the research team (DP1 – DP5). Next, we supplement the DPs by findings from a structured literature review on existing design knowledge (DP6 – DP7). Lastly, we describe DPs that have yielded design knowledge from the overall design process and the evaluations (DP8 – DP10).

3.2. Derivation of design principles from design requirements

The following DPs have directly been derived from the DRs in discourse with the research team. To guarantee scientific rigor, we enhanced the DPs, when it was held reasonable, by findings from the literature to support the rationale.

DP1: Principle of Influx Simulation *To predict the influx of spontaneous volunteers (A), reproduce the spontaneous volunteer behavior with a suitable simulation (M).* Simulations allow for the reproduction of human behaviors **(R)**, which has been acknowledged by academia (e.g., Mas et al. (2012)) and simulations have already widely been applied in disaster research (e.g., Pan et al. (2007), Takahashi (2007), and Wagner and Agrawal (2014)). Not exclusively, but especially agent-based simulations allow the simulation of emergent phenomena (Pan et al., 2007; Takahashi, 2007; Wagner & Agrawal, 2014) such as the imminent influx of spontaneous volunteers. Thus, simulations are a suitable method for predicting the influx of spontaneous volunteers.

DP2: Principle of Scenario Customization *To predict the influx in different disaster scenarios (A), provide a computational representation of scenarios and a front-end editor to customize scenario parameters (M).* A scenario editor enables adapting scenarios visually and in a commonly used form pattern. Representing such scenarios in a machine-processable format allows for being executed in the information system **(R)**. Computational representations of scenarios are supported by IEEE (2011) and are applied in both, simulation and prediction. Nevertheless, they are mainly represented in other application contexts, such as in military applications (e.g., Blais (2008) and Wittman Jr. (2009)). The scenario front-end editor emerged from the evaluation of the second design cycle, since before that, scenario development was only possible in the form of manually editing the JSON-representation of the scenario. We decided to revise DP2 instead of providing a new one.

DP3: Principle of Path Traceability *To detect congested and highly utilized roads (A), highlight spontaneous volunteer paths on a map (M).* Highlighting frequent paths is, among others, used in evacuation planning (Wong et al., 2017) to provide visual feedback about potentially blocked routes. For instance, heat maps provide such visualizations **(R)**.

DP4: Principle of Movement Visualization *To trace time-dependent paths (A), provide the visual representation of individual spontaneous volunteer locations at a certain time on a map (M).* Time-related location representations on a map enable a time-related and comprehensive understanding of the spontaneous volunteer movements **(R)**.

DP5: Principle of Influx Analytics *To draw actionable conclusions about the influx of spontaneous volunteers at operating sites (A), provide visualizations (e.g., in form of charts) and metrics on different levels of abstraction about the influx on a comprehensive dashboard (M).* Dashboards allow for quickly retrieving informative data to improve decision quality and to reduce cognitive efforts, which are the main objectives of human decision-making Meth et al., 2015; Wang and Benbasat, 2009 **(R)**. The choice and representation of data is highly related to the needs and goals of disaster managers and may vary in different software instantiations.

3.3. Derivation of design principles from literature

Even though DSR is still a rarely applied methodology in natural disaster management and, thus, design knowledge is lacking in the field (Schryen & Wex, 2012), our goal was the exploration of existing design guidelines, -theories or -principles that can be applied or adapted for the proposed information system.

Therefore, we have performed a structured literature review following the principles of the well-known method by vom Brocke et al. (2009). We searched five databases (IEEE Xplore, ScienceDirect, SpringerLink, ACM Digital Library, Wiley Online Library) with the string *((“design principle” OR “design guideline” OR “design theory”) AND (“disaster management”) AND (“information system”) AND (“design science”))*. Due to the diverse interpretations of design artifacts following different research methodologies, the search term has been limited to design science approaches. Compared to the identification of the research gap, the literature analysis aimed at existing design knowledge to build upon. As mentioned before, design knowledge is lacking in the field of disaster research, which has been confirmed by the limited number of results (overall 57), and only three meaningful contributions. This was further compounded by the wide range of formulations for DPs, which was also noted by Gregor et al. (2020). We excluded literature that is a) addressing corporate crisis management in a business context, b) not focusing on IS for disaster management, and c) providing unsuitable design guidelines/design theories/design principles.

While not explicitly pronouncing DPs, the implications of the framework for collaborative disaster response by Way and Yuan (2017) comply with our IS. Within their “Disaster Context Awareness” the authors propose “Disaster Geo-Location Awareness” as well as “Information Accuracy and Reliability” as important principles, since disaster managers require high quality contextual information to avoid information overload (Way & Yuan, 2017). “Disaster Geo-Location Awareness” supports our proposed DP3 and DP4, whereas “Information Accuracy and Reliability” has been considered in DP8 and DP9, since both address reliable and accurate information in the form of reproducibility and validated scenarios.

For a disaster response communication platform, Sakurai (2016) derives DPs based on frugal information systems. Frugal information systems are developed and deployed with minimal resources to match the intended purpose (Watson et al., 2013). For the intended information system, two DPs have been retrieved from the frugal information system design concept. Our information system should be accessible, unconstrained by time and space (Watson et al., 2013), thus, we derive Ubiquity from the frugal information system design.

DP6: Principle of Ubiquity *To allow for time- and location-independent system use and predictions **(A)**, provide internet accessibility **(M)**.* Immediate access to the system and avoiding shutdown times allows for utilizing the system and predictions anywhere and anytime. Internet accessibility for the system can be achieved by either using it or making it available (i.e., in form of downloadable programs) online **(R)**.

The second derived DP is in accordance with (Lips et al., 2021) and partly addressed in (Watson et al., 2013). (Lips et al., 2021) propose DPs for a Crisis Management Mobile Application (Lips et al., 2021). For our application, only rather user interface oriented DPs are considered and adapted to match the goal of this research. The information system should avoid user confusion, enable information consistency and provide a simple navigational structure (Lips et al., 2021; Watson et al., 2013). We combine the principles as follows:

DP7: Principle of User Experience *To guarantee the ease of use and reduce complexity **(A)**, use modern design frameworks and follow contemporary UI/UX guidelines **(M)**.* Both, design frameworks and UI/UX guidelines are particularly developed in accordance to the reduction of complexity and user-friendliness **(R)**.

3.4. Derivation of design principles from evaluations and experience

The following three DPs have been derived within the design process based on the evaluations and our experiences.

DP8: Principle of Error Proofing and Scenario Validation *To focus on the creation of disaster scenarios and to avoid user mistakes **(A)**, provide error checking mechanism in the form of validating scenarios against schemas and user errors **(M)**.* User mistakes can lead to system errors and/or false predictions. Providing a schema for the scenario disables faulty scenario execution. Form input validations provide visual feedback and avoid errors **(R)**. Within the first version prototype, we have not validated our scenarios. As mentioned before, the scenarios were provided in a JSON-representation, which has led to overwhelming the users not used to it. The development of the front-end scenario editor partly addressed the issue by allowing for form-checking.

However, the subsequent DP for exchangeability allows for scenario manipulations outside the IS2SAVE ecosystem. Thus, the so-far JSON-based representation had been complemented by an according JSON-schema to check for errors and avoid system crashes due to invalidated scenarios.

DP9: Principle of Exchangeability and Reproducibility *To enable exchanging and reusing scenarios **(A)**, provide an exchangeable scenario file format, its validation, and fixed simulation seeds **(M)**.* A file format for storing scenarios enables exchangeability and ensures validation in the information system to avoid user errors. Fixed simulation seeds serve for the reproducibility, since they initiate random number generators **(R)**. In our first version prototype, we had random simulation seeds for our predictions, which caused confusion with our domain experts. We performed several simulation runs with the same scenarios, yet leading to slightly different results. To maintain consistency when exchanging scenarios with different departments, we found the solution to set fixed seeds to be sufficient to address this. Exchangeability was therefore another request within the case study evaluation.

DP10: Principle of Comparability *To compare the effect of actions or scenario-dependent variations **(A)**, establish a side-by-side comparison of different prediction results along with an opportunity to store the results **(M)**.* A side-by-side comparison of prediction results and analytics allows for quick identification of similarities and differences **(R)**. In the first version prototype, comparing the effects of different scenarios remained only possible by printing or screenshotting the results. To support the requirement for the ease-of-use and a reduction of cognitive effort, we established an option to store prediction results in a database and enabled and the comparison to other simulation results.

4. Instantiation of IS2SAVE

To evaluate whether the final design is feasible, we relate to the framework of Sonnenberg and vom Brocke (2012), and perform evaluation activity 3 via a demonstration with a prototype. We will explain the features and the development of IS2SAVE on an abstract level, referencing according contributions (artifacts) as well as the addressed DP(s). A simplified technical concept of IS2SAVE is presented in Figure 2 and will be explained in the remainder. Furthermore, the prototype and a documentation can be found on GitHub (https://github.com/sebsebli/is2save). For the sake of this research project, we're focusing our instantiation on flood disasters, since they are by far the most frequent disasters worldwide (Institute for Economics and Peace, 2020). Nevertheless, our research methodology promotes follow-up research and adaptations to any other kind of disaster, which we explain at the corresponding place.

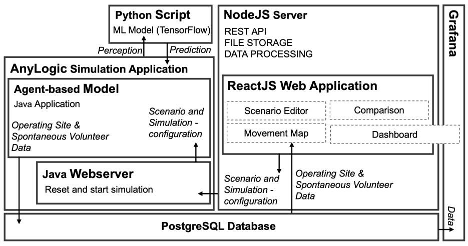

Figure 2. Simplified architecture of the IS2SAVE prototype.

To simulate emergent behavior of SVs and both analyze and predict their influx, we identify agent-based simulation (ABS) as a solid approach **(DP1)**. ABS has proven to be suitable for simulating human and social behavior, as well as numerous entities (Mas et al., 2012). We adapt ABS for disaster scenarios as core of IS2SAVE. To predict the SV influx at operating sites, we identify operating sites and SVs as agents of interest to be represented in the ABS (Lindner et al., 2018). Based on positive study experiences and integrated GIS-functionality, we use the *AnyLogic* simulation software. To address the requirements for dynamic scenarios with changing parameters in the simulation **(DP2)**, we have developed a machine-processable scenario language (Lindner et al., 2019). The IS2SAVE simulation framework processes the JSON-based scenario language and triggers time-related events during simulation runs, such as changing weather. The influx of SVs results from instantiating individual behaviors and decisions of numerous SV agents. To reproduce their behavior in disasters, we firstly identified influences on the decision to help in the literature (Lindner et al., 2017), then approved the findings with quantitative data retrieved from a survey for the case of flood disasters (Lindner & Herrmann, 2020). We presented our developed model to a panel of experts who provided us with new knowledge about SVs and proposed new potentially impacting influences on their behaviors that could improve the prediction quality. Hence, we performed an enhanced survey with 567 participants (completion rate = 0.83) and gathered 11,238 observations of whether a person helps or not at an operating site in a specific flood situation. The data was used to train a machine learning model for predicting the probability to which a person would help at a particular operating site.

After evaluating five machine learning algorithms, we used a random forest algorithm to train our model, resulting in an accuracy of 70%. Since we only conducted the survey for flood disasters and trained the machine learning model accordingly, an adaptation to other kinds of disasters requires the adjustment of the survey to the desired disaster type. The TensorFlow implementation of our model predicts the probability to help at an operating site for each agent (and its individual perception of the environment) by processing a Python script from AnyLogic. Due to the perception of poor usability in the first evaluation, we decided to disconnect the simulation from the user interface. Since then, we store simulation data in a *PostgreSQL* database. *PostgreSQL* offers the PostGIS extension that allows for storing (SV) locations, analyzing (frequently used) paths and processing geographic data for map representations. We use a *ReactJS* web application with the *BlueprintJS* UI framework to adhere to contemporary design guidelines (**DP6, DP7**). We run the application on a *NodeJS* server that supports (pre-)processing and storing data. The scenario editor necessarily corresponds with the scenario language (see Figure 3).

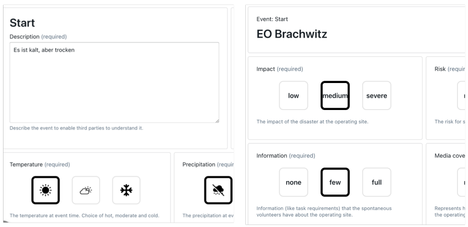

Figure 3. IS2SAVE scenario editor (screenshot).

Withal, we support manually coding scenarios, uploading, and testing against our JSON-schema to limit user errors (**DP8**). For the dashboard, we decided to use *Grafana*, since it can easily be adapted to the user needs and has direct access to the database (**DP5**). The Grafana dashboard is embedded in our web application. Within the dashboard, we calculate and present user-relevant and desired indicators from SQL queries (e.g., operating site utilization over time) and present them in common chart representations (see Figure 4).

We retrieved the indicators for our instantiation in accordance to our moderated focus group with disaster management experts from the local fire department. With *MapBox*, we address the aim of presenting volunteer movements and highlighting frequently used paths on a map (**DP3, DP4,** see Figure 5).

In IS2SAVE, SVs choose their routes to operating

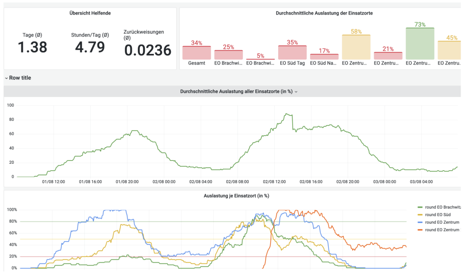

Figure 4. IS2SAVE dashboard (screenshot).

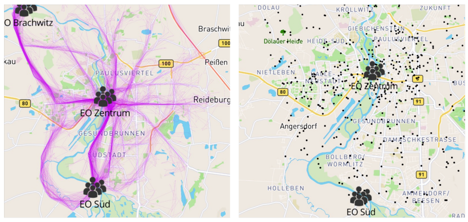

Figure 5. IS2SAVE movement maps (screenshot).

sites based on a realistic routing. This allows for detecting congestion and, hence, enables users to take actions to avoid road blocking. We provide data export and import for the predictions, as well as PDF export functionalities for the dashboard (**DP9**). Since the data of each scenario run is stored in the database, comparing different scenarios with each other becomes available (**DP10**). Such "what-if"-analysis support planning and evaluating management strategies. As mentioned before, SVs are needed at operating sites if they meet the official demands without crowding or heavily lacking volunteers. Thus, our users, e.g, were interested in the effect of heavy rain or increased media attention about one operating site on the influx of SVs in general and the influx at particular operating sites.

5. Evaluation

The feasibility of the design theory was successfully demonstrated with a prototype (Sonnenberg & vom Brocke, 2012) in Section 4. We decided for two consecutive summative evaluations. First, we examined the performance expectancy and effort expectancy (Venkatesh et al., 2003), as well as the plausibility of IS2SAVE's predictions with experts from the disaster management domain. Second, we evaluated our design theory constituted of DRs and DPs with IS experts. This is of particular importance to be compliant with the DSR methodology to add design knowledge to the knowledge base (Schryen & Wex, 2012) and to address the lack of validated DPs (Fu et al., 2016). We have completed the first evaluation with the result that the influx predictions of IS2SAVE were perceived as plausible and the IS2SAVE system was evaluated as very useful for the disaster management. For the sake of this paper's goals, we are setting a detailed focus on the second summative evaluation.

5.1. Method

To ascertain the quality of the design theory in general terms, we performed an online survey with IS (research) experts to conduct the perceived usefulness, conciseness, extensibility, and explanatory power of the suggested DPs examined in the development of IS2SAVE. Since perceived usefulness is not a directly measurable construct, we used six well-known scale items (SI) proposed by Davis (1989) for the evaluation: speed (SI1), performance (SI2), productivity (SI3), effectiveness (SI4), simplicity (SI5), and overall usefulness (SI6). Additionally, we asked the experts about the conciseness (CON), extendibility (EXT), and explanatory power (EXP) of the DPs following the approach of Nickerson et al. (2013). We adapted the items to our application context, specifically the development and design of an information system to predict the influx of spontaneous volunteers at operating sites. After introducing the topic, the participants were asked to answer sociodemographic questions, followed by the textual description and visual presentation of our design theory. The participants were then asked to put themselves in the role of a software engineer, who was asked to develop such a system with the help of the presented design theory. Subsequently, we asked for ranking statements related to this scenario for the SIs, CON, EXT, EXP on an 5-point Likert scale (1 = strongly disagree, … , 5 = strongly agree). We followed the so-called "10 ± 2 rule" (Hwang & Salvendy, 2010) for choosing our sample size, which states that 8 to 12 respondents are sufficient for evaluating the usefulness. In total, we received 12 completed questionnaires. All participants work in research and development in either large enterprises (83%) or micro enterprises (17%), with job positions as researcher (58%), project lead (17%), software engineer (17%), and no specification (8%) with a mean working proficiency of 7 years ($\sigma = 4.37$).

5.2. Results

For the perceived usefulness construct validation, we examine content validity, individual item reliability (loadings), composite construct reliability (CR), and average variance extracted (AVE) (Hulland, 1999). Content validity indicates whether the items of a measurement instrument are generally representative of a construct (Haynes et al., 1995). Given that we adapted our construct of perceived usefulness and the underlying items from the study of Davis (1989), we argue that content validity is present. The reliability of the items is measured by the loadings on their construct. For this purpose, we performed a confirmatory factor analysis in R. It is well known that items with low loadings (rule of thumb: not less than 0.4) should be dropped as they provide little additional explanatory power and may bias parameter estimates (Nunnally, 1994).

Table 1. Construct validation.

Load SI2	Load SI3	Load SI4	Load SI6	AVE	CR
.998	.410	.584	.803	.537	.808

Our initial factor analysis showed that SI1 and SI5 both have loadings less than 0.4 (SI1: 0.171 and SI5: 0.087) and, therefore, were dropped. We then determined the item loadings for the 4-item model and obtained values that were all above the threshold of 0.4 (see Table 1). The proportion of variance explained by the construct (AVE) in this model is above the threshold of 0.5, as defined by (Fornell & Larcker, 1981), i.e., the variance captured by the construct is greater than the measurement error. The overall reliability (CR) of the items loading on our construct perceived usefulness also exceeds the threshold of 0.7 (Nunnally, 1994). Based on the validity criteria, we continue our evaluation with four items for the construct of perceived usefulness. We received high levels of agreement for all items. This is supported by the fact that none of the statements were disagreed or strongly disagreed to (see Figure 6).

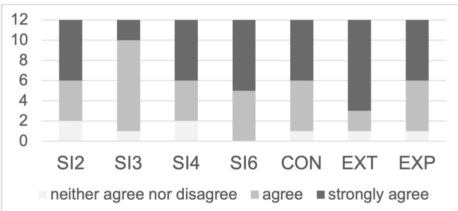

Figure 6. Evaluation results for the perceived usefulness, conciseness, extendibility, explanatory power.

Finally, the high rating of SI6 with median = 5 (strongly agree) can be seen as a confirmation of the overall usefulness of the DPs and the design theory.

With a median of 31 (σ = 3.3), the sum scores of all considered items are close to the maximum value of 35, which further indicates and highlights the usability of the DPs for developing an information system to predict the spontaneous volunteer influx at operating sites.

5.3. Formal evaluation

On top of the empirical summative evaluation, we formally assessed the quality of the design theory using the framework proposed by Gregor and Jones (2007), which defines six mandatory and two optional components that a design theory should contain. Figure 7 shows that our design theory addresses all components of the framework and presents corresponding explanations.

Component	Description
Purpose and scope	The goal of an information system to predict the spontaneous volunteer influx at operating sites in disasters is: (DR1) to provide a comprehensive dashboard of data about the spontaneous volunteer influx at operating sites; (DR2) to enable the evaluation and comparison of the spontaneous volunteer influx at operating sites in different scenarios; (DR3) to show the movement of spontaneous volunteers on a map and highlight frequently used paths.
Constructs	Information System, Disaster Manager, Spontaneous Volunteer, Developer, Operating Site, Disaster Scenario Language, Scenario Editor, Influx Statistics, Simulation Model, Dashboard, Movement Map
Principles of form and function	DP1: Principle of Influx Simulation, DP2: Principle of Scenario Customization, DP3: Principle of Path Traceability, DP4: Principle of Movement Visualization, DP5: Principle of Influx Analytics, DP6: Principle of Ubiquity, DP7: Principle of User Experience, DP8: Principle of Error Proofing and Scenario Validation, DP9: Principle of Exchangeability and Reproducibility, DP10: Principle of Comparability
Artifact mutability	IS2SAVE is developed for the application in flood disasters. However, it can easily adapt for different disaster types, since the applied Design Science Research approach rigorously suggests and documents the required design principles on a general level. IS2SAVE can further be adapted to different application contexts, such as evaluating spontaneous volunteer coordination or deployment strategies and their effectiveness in different scenarios. The prediction model of when and where a spontaneous volunteer helps, as well as the disaster-scenario language, can be implemented in other research approaches following a different research goal.
Testable propositions	The information system itself provides valuable new insights that promote the management of spontaneous volunteers. The design knowledge in form of design principles enables designers and developers to easily adapt and implement such a system. The prediction model of when and where a spontaneous volunteer helps provides new knowledge about their decision-making process.
Justifactory knowledge	Across three design cycles, the approach presented builds on an analysis of background literature and theories (disaster management, design science, spontaneous volunteers), expert knowledge from focus group, and case study findings
Expository instantiation	Development of a prototype encompassing: an AnyLogic agent-based simulation method for simulating the spontaneous volunteer influx at operating sites; a TensorFlow model for predicting the individual decision to help; a PostgreSQL database for storing influx data from the simulation; a ReactJS web application powered by a NodeJS server for the purpose of creating (and exporting/importing) disaster scenarios, triggering simulation runs, presenting influx predictions on a Grafana-powered dashboard, exporting/importing prediction analytics for comparison

Figure 7. Components of a design theory for IS2SAVE following Gregor and Jones (2007).

6. Conclusion

We presented the results of three completed design cycles for the design and development of an information system to predict the influx of spontaneous volunteers at operating sites. In the design process, we examined three DRs and ten DPs constituting the main contribution of the paper, an empirically grounded design theory. With the instantiation of our DPs in an evaluated software prototype, we have demonstrated its feasibility. The perceived usefulness, conciseness, extendibility, and explanatory power of the design theory were evaluated positively by an expert survey. Due to this, we stop the DSR project and conclude with an evaluated, nascent design theory.

However, the following limitations should be considered for an adequate interpretation of our results. A typical weakness of any design theory is the subjectivity of design decisions. Although the definition of DRs and DPs in this paper builds upon discussions and workshops with experts, theoretically grounded by literature reviews, and supplemented by existing design knowledge, the conceptualization of our design theory is characterized by subjective influences. However, this is consistent with the philosophy of design science to search for useful, not necessarily optimal, solutions (Hevner et al., 2004). Further, the formulation of our design theory has been underpinned by the methodological notes of Gregor and Jones (2007). As with any evaluation, our results depend on our sample. The choice of other participants or different sample sizes may lead to different results. Yet, we believe that the selection of focus group participants with extensive practical and theoretical expertise in disaster management and IS research led to well-founded insights. The findings of our design theory can be included in other research projects aiming at information systems in natural disaster management. Moreover, in the future, the design theory can be updated according to technological and organizational innovations.

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Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios

Title	Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios
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Abstract	Fast and easy communication, e.g. via Twitter or Facebook, encourages self-coordination between spontaneous volunteers in disasters. Unfortunately, this is more and more challenging official disaster management. The need for the directed coordination of spontaneous volunteers triggered researchers to develop effective coordination approaches. However, evaluating and comparing such approaches as well as their exercising are lacking a standardized way to describe repeatable disaster scenarios, e.g. for simulations. Therefore, we present a novel System Entity Structure (SES) for describing disaster scenarios considering the disaster environment, communication infrastructure, disaster management, and population of spontaneous volunteers. The SES is discussed as a promising scheme for including spontaneous volunteers in disaster scenarios on a general level. Its applicability is demonstrated by a Pruned Entity Structure derived from a real disaster scenario. Based on the results, we give an outlook on our subsequent research, the XML-based Spontaneous Volunteer Coordination Scenario Definition Language (SVCSDL).
Keywords	agent-based simulation, spontaneous volunteers, spontaneous volunteer coordination scenario definition language (SVCSDL), system entity structure (SES), disaster scenario
Artifact	Scenario Language
Evaluation	Case Study
Contribution	system entity structure for defining dynamic spontaneous volunteer scenarios in disasters

Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios

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ABSTRACT

Fast and easy communication, e.g. via Twitter or Facebook, encourages self-coordination between spontaneous volunteers in disasters. Unfortunately, this is more and more challenging official disaster management. The need for the directed coordination of spontaneous volunteers triggered researchers to develop effective coordination approaches. However, evaluating and comparing such approaches as well as their exercising are lacking a standardized way to describe repeatable disaster scenarios, e.g. for simulations. Therefore, we present a novel System Entity Structure (SES) for describing disaster scenarios considering the disaster environment, communication infrastructure, disaster management, and population of spontaneous volunteers. The SES is discussed as a promising scheme for including spontaneous volunteers in disaster scenarios on a general level. Its applicability is demonstrated by a Pruned Entity Structure derived from a real disaster scenario. Based on the results, we give an outlook on our subsequent research, the XML-based Spontaneous Volunteer Coordination Scenario Definition Language (SVCSDL).

Keywords

Agent-based Simulation, Spontaneous Volunteers, Spontaneous Volunteer Coordination Scenario Definition Language (SVCSDL), System Entity Structure (SES), Disaster Scenario.

INTRODUCTION

Spontaneous volunteers, i.e. people who spontaneously help in urgent disaster situations and who are not affiliated to official civil protection organizations (Barraket *et al*., 2013; Ludwig *et al*., 2017; Zettl *et al*., 2017), play an important and active role in disaster response (Fernandez, Barbera and Dorp, 2006; Sauer *et al*., 2014; Lindner, Betke and Sackmann, 2017; Ludwig *et al*., 2017). For years, the phenomenon of spontaneous volunteers in major disaster events has moved both the media and research. Modern communication technologies, such as social media, have raised the phenomenon of spontaneous volunteers to a new level (Meissen *et al*., 2017; Reuter and Kaufhold, 2018) that makes an examination of the topic in disaster management indispensable. During the disastrous floods 2013 in Germany, the continuous presence of the disaster in social media led to massive participation of the population to cope with the disaster. While this spontaneous support of the official disaster relief forces was crucial for overcoming the disaster, it also led to various problems: due to incorrect and subjectively designed information some operating sites were overcrowded by volunteers whereas others were dramatically understaffed, and several volunteers exposed themselves to danger through unauthorized actions (Fernandez, 2007; Hofmann, Betke and Sackmann, 2014).

The enormous cooperativeness of spontaneous volunteers, as well as the lack of approaches for their coordination, have triggered a large number of new research projects (German Federal Ministry of Education and Research, 2018b). Several projects, e.g. KUBAS (Rauchecker and Schryen, 2016), AHA (German Federal Ministry of Education and Research, 2018a), REBEKA (Johanniter-Unfall-Hilfe e.V., 2018), ENSURE (Fraunhofer-Institut für Offene Kommunikationssysteme FOKUS, 2018), KOKOS (Project KOKOS, 2018) or K3 (German Federal Ministry of Education and Research, 2018c), explore the improvement of the coordination of spontaneous volunteers by using modern information and communication technologies. Recently developed concepts, demonstrators, and prototypes are confronted with the challenge of scientific evaluation to demonstrate and compare their usability and added value. This may be done in real disasters or field tests, that, however, are usually too expensive, elaborate, and partly impossible to conduct. Since field experiments are not sufficiently realistic, real disasters are too dangerous and both are hardly reproducible, computer simulation is an appropriate approach to test, evaluate, and optimize real-world scenarios and approaches with a minimal effort. Furthermore, simulations enable the disaster staff to perform exercises in using such systems at regular intervals due to the possibility to describe and define reproducible disaster scenarios. Simulating spontaneous volunteers can also facilitate the possibility of forecasting their behaviors in real disaster situations.

Regardless of how such evaluations or exercises are carried out methodically (e.g. field trials, simulations), a reusable, standardized, and ideally formalized description of disaster situations is required. Since such suitable methods do not yet exist, our research goal is to develop a model for the specification of disaster scenarios including spontaneous volunteers as an artifact that is further the basis for the subsequent development of an XML-based Spontaneous Volunteer Coordination Scenario Definition Language (SVCDSL). On the one hand, the model enables an understanding of disaster scenarios with spontaneous volunteers on a conceptual level, e.g. to develop scenarios for field trials. On the other hand, it provides the basis for developing an executable disaster scenario definition language for simulations.

The artifact development is part of a research project following the well-established Design Science Research Process methodology proposed by Peffers et al. (Peffers *et al*., 2007) and covers the third phase – "Design and Development". The whole project aims at the development of a universal spontaneous volunteer simulation application in disaster situations to evaluate and compare spontaneous volunteer coordination approaches as well as to predict the volunteers' behaviors in acute disaster situations. Agent-based simulation has therefore been identified as a proper method to simulate the behavior of spontaneous volunteers in a disaster context. Results of the first two DSRP-phases of this project are described in (Lindner *et al*., 2018; Lindner, Betke and Sackmann, 2017) where a structured literature analysis has been performed and a conceptual model of spontaneous volunteer behavior has been developed. To further enable the comparison and evaluation of spontaneous volunteer coordination approaches using agent-based simulations, it is required to identify all relevant entities as well as to establish reproducible and machine-processable scenarios. Since the development of the language artifact in this paper requires a constant exchange with experts, specialists and end-users and the results have to continuously be evaluated and improved, Action Design Research (ADR) according to Sein et al. (Sein *et al*., 2011) is utilized as a concrete method.

Based on other studies, as a first step, so-called System Entity Structures (SES) are identified and discussed as an adequate approach for our research (Section 2). Accordingly, in Section 3, relevant elements for describing disaster scenarios are identified from the literature. Following the corresponding IEEE guideline for scenario development, in Section 4 the identified elements are categorized and used for developing the aspired artifact. The applicability of the developed SES is demonstrated in Section 5 by using a concrete example of the 2013 flood disaster and transferring the SES into a so-called Pruned Entity Structure (PES). As a final step, the developed SES is discussed and an outlook for defining an open and extensible XML-based language called Spontaneous Volunteer Coordination Scenario Definition Language (SVSDL) is given.

DEVELOPING SCENARIOS WITH SYSTEM ENTITY STRUCTURES

Reproducible, reusable, and executable scenarios provide a sound foundation to evaluate coordination approaches and systems as well as to compare different ones since these scenarios enable the measurement of differences under identical circumstances. The IEEE defines scenarios on the one hand as a description of an exercise that "is part of the session database that configures the units and platforms and places them in specific locations with specific missions" (IEEE, 2011). On the other hand, scenarios are described as "[an] initial set of conditions and timeline of significant events imposed on trainees or systems" (IEEE, 2011). Although the definition and development of scenarios are defined by the IEEE on a general level, a particular method to perform scenario creation is not proposed. Instead, the selection of a proper tool or technique is seen as one explicit step of the scenario development (IEEE, 2011). To determine a suitable method for developing the aspired scenario, a literature review has been performed to identify publications that either have developed simulation scenarios in general or that have defined scenarios for the coordination of spontaneous volunteers in particular.

For the literature review, the keywords *simulation*, *scenario*, *reproducible*, *spontaneous volunteer*, *coordination*, *scenario language*, *scenario development, agent-based simulation, disaster* and some of their combinations have been searched in various scientific databases, such as WileyOnline, ScienceDirect, SpringerLink etc. as well as in Google Scholar. We have limited our search to publications after 2000 to maintain a certain topicality. In addition, forward and backward searches have been carried out to identify further relevant publications.

The literature review revealed that the development of models for standardization and description of scenarios is addressed in various areas. For example, the Military Scenario Definition Language (MSDL) published by the Simulation Interoperability Standards Organization (SISO) has been established in the military sector (Blais, 2008; Wittman Jr., 2009). Other models exist in the transportation sector where road traffic, particularly driver behavior, was described, e.g. (Adler *et al*., 2005; Fuchs *et al*., 2008). Standardized scenarios are also used in health management to train nurses for emergencies (Waxman, 2010; Alinier, 2011). Furthermore, Jafer et al. have developed a language that describes standard scenarios in aviation (Jafer *et al*., 2016). In addition, there are many contributions dealing with the development of scenarios for multi-agent systems on a general level (Murakami *et al*., 2003; Nakajima *et al*., 2006).

The literature review also revealed that several authors research on the question of how scenarios can be developed to better manage disasters and predict their progressions (e.g. (Sun *et al*., 2015)). However, the proposed models are either very specific (e.g. (Su, Wang and Zhang, 2016; Simões *et al*., 2011)) and not suitable for standardization or the scenarios rather focus on decision support for emergency forces and aid organizations (e.g. (Drury *et al*., 2009)) and do not take spontaneous volunteers as valuable resources into consideration. In summary, our literature review revealed that there is no description of disaster scenarios especially focusing on the coordination of spontaneous volunteers yet. This fosters our effort to develop a corresponding Scenario Definition Language for describing and executing such scenarios.

However, the identified work revealed successfully applied tools and techniques for developing scenarios. In particular, the Simulation Scenario Development (SSD) as a method proposed by the IEEE has already been approved, e.g. (Jafer and Durak, 2017). Following the SSD approach, the foundation of any scenario documentation is the identification of entities, their behaviors, and events that need to be represented in the scenario(s) (IEEE, 2011). Since the behavior inevitably results from the simulation environment, we focus on the identification of events and entities. The SSD approach described by the IEEE merely provides steps that are necessary for a successful scenario definition, but, unfortunately, it does not discuss its actual application. For applying the SSD, several researchers in different domains have already successfully used so-called System Entity Structures (SES) as a methodological framework (see, e.g. (Ntaimo *et al*., 2004; Lee and Zeigler, 2010; You, Chi and Kim, 2013; Schmidt, Durak and Pawletta, 2016; Durak *et al*., 2017)). SES is using a data model that reflects system-engineering concepts of hierarchical decomposition and specialization (Cheon, Kim and Zeigler, 2008). SES is also based on a limited set of elements (entity, aspect, specialization, and multi-aspect) and axioms that can be introduced as a directed labeled tree (Durak *et al*., 2017). Since this characteristics allow an automatic creation of XML schemata (Cheon, Kim and Zeigler, 2008), SES is seen as suitable to close the gap between structured scenario definitions proposed by IEEE and a machine-processable language and, thus, it is seen as an appropriate method leading to the aim of our research, namely the desired SVCSDL.

Simulation scenarios can be categorized into three types that need to be developed in the scenario development process, namely operational scenario, conceptual scenario, and executable scenario (Siegfried *et al*., 2012; Simulation Interoperability Standards Organization, 2015). Accordingly, the operational scenario usually describes the targeted real-world scenario in a textual form providing a broad description of the desired events and elements. For our research, descriptive reports on coordinating spontaneous volunteers have been analyzed to provide basic information on how volunteers were coordinated in real disaster situations. The results of this analysis as well as the required deeper investigation on element details and interrelations are presented in Section 3 leading to the identification of entities and, consequently, to the conceptual scenario, that usually is a formal metamodel representation. As the basis for a formal description of an executable scenario in an XML-Schema that can be processed by simulation applications, all scenario-specific information is subsequently represented as a System Entity Structure (see Section 4).

ELEMENTS FOR DESCRIBING DISASTER SCENARIOS WITH SPONTANEOUS VOLUNTEERS

To develop scenarios, it is important to understand what distinguishes them. According to the IEEE guideline, scenario(s) include "types and numbers of major entities/objects that must be represented within the simulation environment" (IEEE, 2011). Consequently, the IEEE describes scenarios to have various entities being represented within the aimed at environment. As SES has already been applied to define scenarios, we adopt this method to develop the spontaneous volunteer coordination scenario. In "Modeling & Simulation-Based Data Engineering: Introducing Pragmatics into Ontologies for Net-Centric Information Exchange" Zeigler and Hammonds explain the development of SES and all related elements. In general, SES consists of Entities, Aspects and Specializations. According to Zeigler and Hammonds "Entities represent things that exist in the real world or sometimes in an imagined world. Aspects represent ways of decomposing things into more fine-grained ones. Multi-aspects are aspects for which the components are all of one kind. Specializations represent categories or families of specific forms that a thing can assume" (Zeigler and Hammonds, 2007).

The required authoritative domain information for the scenario development (IEEE, 2011) have been identified and analyzed by literature reviews, preliminary work and expert discussions. In this section, according to the SES development by Zeigler and Hammonds, we will discuss the relevant entities for describing disaster situations and decompose them into specializations and multi-aspects and, if necessary, attach variables to the identified entities.

As basic entities that are discussed in the following in more detail, we identified **Disaster Management** and **Spontaneous Volunteers** inevitably resulting from the targeted domain and research goal. According to the IEEE guideline, the **Environment** must be taken into consideration and, thus, is a basic entity that represents a superset of the scenario components. As experiences show, communication has a significant influence on the self-coordination of spontaneous volunteers as well as on the possibilities for official disaster management to coordinate them according to the official needs. Sackmann et al. even see communication as a central design object for the coordination of supporting activities (Sackmann *et al.*, 2018). Thus, as forth entity, **Communication Infrastructure** is defined as a basic entity for our scenario description as well. Furthermore, the IEEE guideline suggests modeling scenario triggers and stop conditions. As a starting point, these are defined according to the typical phases of disaster scenarios (Thieken *et al.*, 2007): the scenario gets triggered by the disaster event and the beginning of the disaster response phase or its simulation. The stop of the scenario is given over to the scenario modeler since it depends on the particular goal.

Environment (Basis Entity #1)

According to the IEEE guideline, the environment is a superset of the scenario components comprising aspects, e.g. geographical regions, natural environment conditions, initial and termination conditions. This entity with its aspects defines the general behavior of entities and, consequently, the simulation of their behavior.

Inherently important for any disaster scenario and its simulation is the definition of **geographical areas**. There exist several concepts for defining areas, e.g. center point and radius (Nelson, Iii and Kravets, 2007) or polygonal pathways (Wagner and Agrawal, 2014). There might be good reasons for describing geographical regions in a very detailed manner. However, as a starting point for our scenario description, we decided to use a simple concept of overlapping circles that are defined by their center (longitude/latitude) and radius. Extending or replacing this simple concept is easy to realize without changing the general result of our research. These geographical areas are represented in our SES as a Multi-aspect as there can be several areas or locations within the environment and accordingly within the scenario. The definition of the geographical areas at the beginning of the scenarios enables the re-utilization of these regions in other entities within the SES.

Our literature review revealed **weather** to be one main aspect in the disaster context (e.g. (Geißler, 2014; Kircher, 2014)). It is not only relevant to the disaster itself but also for the willingness of volunteers to help (Geißler, 2014; Kircher, 2014). Thus, the weather was chosen to be represented within the SES. Reports and publications on past disasters proposing the weather as an influencing factor usually describe weather with attributes like "nice", "warm", "bad", "rainy" etc. (Geißler, 2014; Rauchecker and Schryen, 2018) However, since such terms are rather subjective and vague, we propose a more general type of description in terms like precipitation, rain intensity, temperature, humidity, etc. as variables in our SES. These variables can subsequently be interpreted and used to simulate the influence of weather on, e.g. the motivation of spontaneous volunteers to help. In the SES, we represent the weather as a Multi-aspect as, in combination with the geographical areas, weather can be defined locally and may be different within one scenario.

Communication Infrastructure (Basis Entity #2)

Recent disasters have shown that communication (between spontaneous volunteers themselves as well as between volunteers and official disaster management) and limited accessibility has played a crucial role in the (self-)coordination of spontaneous volunteers (Reuter and Kaufhold, 2018). Communication infrastructure and their availability in a disaster situation determine how information be disseminated and, thus, have to be described within the scenario definitions. Literature and experiences show that communication is at least determined by its technical as well as its organizational realization (see, e.g. (Asplund, Nadjm-Tehrani and Sigholm, 2009; Reuter and Kaufhold, 2018)). Thus, we defined these two dimensions as relevant aspects of our scenario description.

From a technical perspective (**technologies**), communication infrastructure can differ with respect to communication channels and, thus, with respect to communication content. For example, SMS are limited to text-only content and require at least a GSM network, whereas mobile applications or social networks are not necessarily limited to a number of characters or text/media but require different infrastructures such as the Internet via WIFI, LTE, or HSDPA. Since the availability or access to communication technology is usually confined (e.g. not all people use all communication channels in parallel, limited capacity on the side of network provider, blackout), the description of a disaster scenario should necessarily enable the definition of capacities for specific areas. Thus, we defined communication technologies as a Multi-aspect of communication infrastructure as one scenario can have several technologies in different areas with different capacities.

From an organizational perspective (**communication types**), a first relevant characteristic of communication is the type of communication **participants**. Since self-coordination between volunteers as well as directed coordination of volunteers by official disaster management is in the focus of our research, communication participants include at least the official disaster management (**DM**) and the spontaneous volunteers (**SV**). Since both parties can be sender as well as the receiver of information, this is seen as one main aspect for describing communication infrastructure. A second main aspect is whether the **relationship** between sender and receiver is a one-to-one (**one2one**) or a one-to-many (**one2many**) relation. The possibility to describe these relations allows, together with the categorization of the communication participants, to define general possibilities for uni- or bidirectional communication. Scenarios can, thus, be limited to, e.g. the communication between spontaneous volunteers among themselves in a broadcasting manner (one2many) and, thus, influence their behavior and the kind of information that may be disseminated. However, also the technological perspective may play a role in how and which information can be disseminated, why we see technologies as a third influencing and limiting aspect in the communication type. As we assume that technologies indispensably be linked with the relationship and participants, we represent both, relationship and participants as Specializations that necessitate a selection of each. E.g. one kind of participant (e.g. SV2SV), can have one relationship (e.g. one2many), that can be realized upon a selection of technologies. This general description allows remaining open for current (and also future) communication technologies.

Disaster Management (Basis Entity #3)

Disaster management is responsible for organizing response activities during a disaster in order to minimize its impact. Disasters are tackled at so-called **operating sites** by disaster management, where official disaster relief forces work—sometimes supported by spontaneous volunteers—to mitigate disaster scales. Typically, disaster response and mitigation are conducted based on a command and control structure of different levels whereas the disaster management is on a strategical level, e.g. in the form of crisis committees. Operating sites are on a tactical or operational level. Since disaster management is usually organized from an official site (e.g., government) and usually not supported by spontaneous volunteers, the disaster management entity in our approach is focused on the description of operating sites. Operating sites are commonly the only physical contact points between spontaneous volunteers and official disaster relief forces. However, a subsequent extension of the model may include the integration of other crisis units and/or on-site emergency personnel in the future.

Following literature and official organization rules, operating sites are mainly characterized by its location resp. area (**geographicArea**), its required tasks and durations, and required resp. available resources. Depending on the scenario, there can be different operating sites, while each operating site can require different **tasks** to be fulfilled for completion (Rauchecker and Schryen, 2018). For example, common tasks in a flooding scenario may be sandbag filling, carrying sandbags, and so on at different locations along a river. However, the tasks that may be required on operating sites can differ and, thus, have to be considered within the scenario. Since our research is focused on the use of spontaneous volunteers as a valuable resource on operating sites, the coordination of operating sites is restricted to tasks that could be supported or executed by spontaneous volunteers. Therefore, we modeled the operating sites consisting of tasks and its locations as well as by defining the required number of volunteers working at a specific task for completing it effectively. Also, we identified the estimated duration of the specific task as an important variable as it influences the number of required volunteers per time unit and further has an effect on volunteers' decision to help if it is known.

Spontaneous Volunteers (Basis Entity #4)

For describing a disaster scenario, it would not be helpful to define each spontaneous volunteer and his/her decisions and behaviors individually. This would lead to a deterministic scenario and would not fulfill the requirements for using the described scenario for the evaluation of coordination systems or performing disaster exercises. Consequently, spontaneous volunteers are described in the form of populations with probability distributions of relevant variables and entities.

To describe characteristics of individual spontaneous volunteers and their motivation to help during a disaster, the state-of-the-art is extensively discussed in (Lindner, Betke and Sackmann, 2017) providing a solid basis for describing spontaneous volunteers in disaster scenarios. Accordingly, the age, experience, concernment, etc. were exemplarily adopted into the SES as variables to describing the **general** characteristics of the population. A comprehensive list of all relevant variables is given in (Lindner, Betke and Sackmann, 2017). To assign these attributes, the required distributions can either be chosen at will or they can be derived from (demographic) data of the respective location. Since the related literature still is in an early research phase and its behavior impacting attributes have not yet fully been proven, we propose these variables to be extended in future versions. Also, the population size of potential volunteers might differ between different areas, like there are usually massive differences between rural and urban areas. To describe these location-dependent differences in disaster scenarios, we propose **geographic areas** to be an aspect of each population, particularly being an aspect of the general entity. The location-dependent modeling of populations may lead to the representation of many populations within the scenario.

In addition to these general characteristics, the description of spontaneous volunteers should be extended by their communication abilities. As mentioned, when discussing the communication infrastructure, the use of communication devices and, thus, **technologies** vary from person to person. Consequently, the availability of communication technologies is defined as an additional aspect for spontaneous volunteer populations that should be represented in disaster scenarios. For instance, the distribution of smartphone users, users of social media, etc. would be reasonable, if these infrastructures are modeled within the scenario in the communication infrastructures. Therefore, the distribution per each technology used in the scenario must be specified to affect the volunteer's behavior.

We have further identified variables and entities that are related to the **operations** spontaneous volunteers can have. One main characteristic of volunteers is their willingness and ability to perform specific tasks. Since not everybody is able to carry heavy sandbags or to take care of shocked people, this restriction has to be part of any scenario definition. The description of scenario-specific **tasks** has already been discussed in the context of disaster management, thus, to represent these tasks within the volunteer populations, we propose a distribution of all tasks within a scenario. Another behavior-impacting aspect of volunteers is external restrictions like country-specific legal requirements or regulations. Such regulations may limit the working time of spontaneous volunteers to a few hours per day. E.g., German law restricts the working time to 8 hours per day.[1] Also, physical abilities and other commitments may affect the working time. Furthermore, individual working duration preferences, i.e. for how many days a volunteer will help, have to be modeled. Thus, for describing the operation within the SES, we propose the variables "workTimeDistribution", "workDurationDistribution" as well as the aspect "tasks".

MODELING SCENARIO ELEMENTS WITH SYSTEM ENTITY STRUCTURE

The entities, (multi-)aspects, specifications, and variables defined and described in the previous section represent the static dimension of the aspired scenario description. To complete the SES according to the IEEE specification, a dynamic dimension is required, namely the time-dependent progression of simulation scenarios (IEEE, 2011). To describe the dynamics of a disaster scenario, the scenario itself, as well as the variables of the entities, have to be changeable during the scenario. The IEEE proposes time-related events that trigger a change in the parameters at the respective point in time and are accordingly interpreted by the simulation software. Since events can affect all identified SES elements, they are defined as a common characteristic at the top of the SES hierarchy. Depending on the dynamics and level of detail, a simulation scenario can consist of any number of events. We suggest the use of the actual time (time and date) for executing a disaster scenario, since time might also influence the behavior of the spontaneous volunteers (see (Lindner, Betke and Sackmann, 2017)). Consequently, we propose datetime as a variable of the event. Nevertheless, faster processing of the events in the scenarios can be facilitated by the acceleration of simulation experiments. As result, the identified and discussed mandatory elements for describing and executing disaster scenarios with taking spontaneous volunteers into consideration are depicted as an SES in Figure 1.

[1] section 3 German Hours of Work Act (ArbZG)

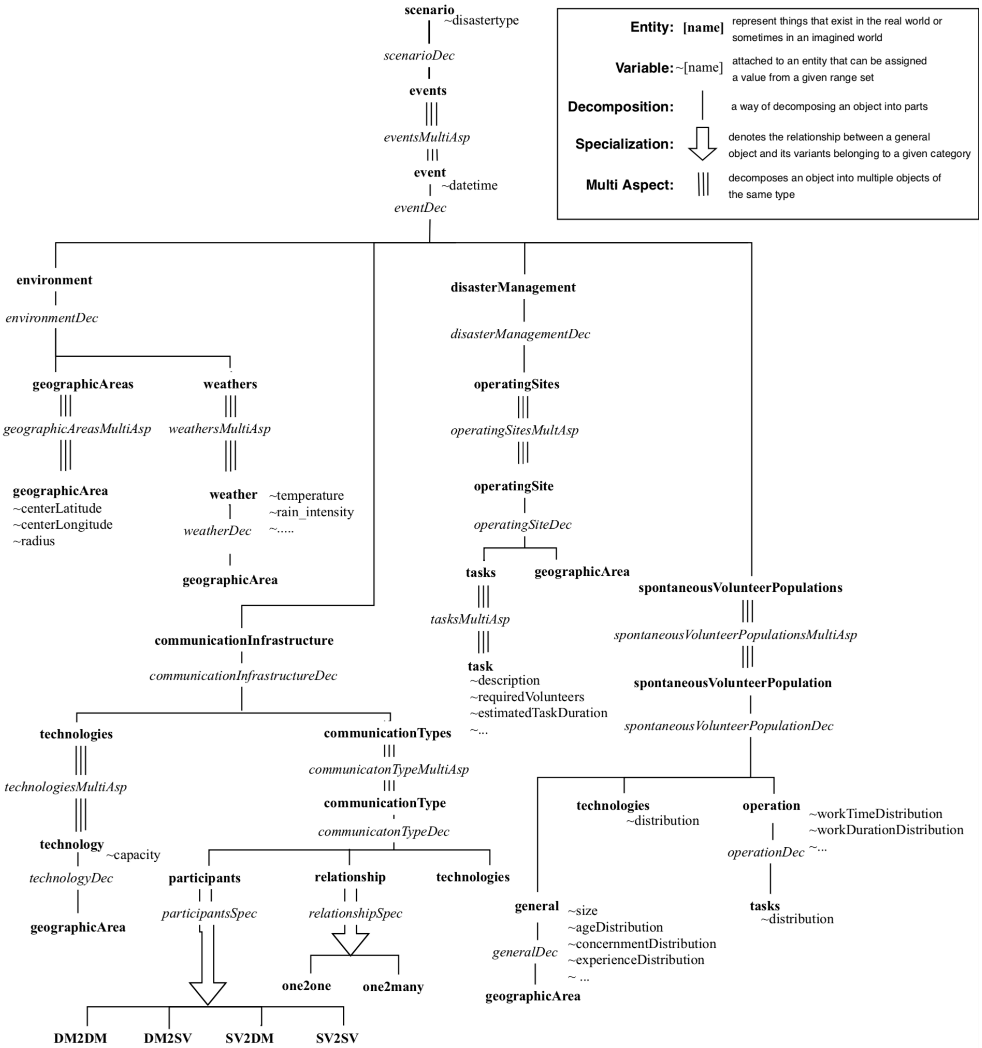

Figure 1. System Entity Structure for Disaster Scenarios

EXEMPLARY PRUNED ENTITY STRUCTURE ON 2013 FLOOD SCENARIO

To demonstrate the applicability of the proposed SES for disaster scenarios, an exemplary and simplified real-world scenario is described. Subsequently, this scenario is transformed into a so-called Pruned Entity Structure (PES) by resolving the elements of the scenario to the aspects, multi-aspects, specializations and by assigning values to the variables resulting in a selection-free tree (Durak *et al*., 2017).

The scenario has been developed in cooperation with the responsible leader of the local disaster management authority and represents an excerpt of the flood that took place in 2013 in Halle (Saale), Saxony-Anhalt, Germany. Firstly, the scenario is described in a textual form (translated from German) and secondly, it is used to derive the PES model. All scenario-relevant elements, i.e. elements that are represented in the SES, are marked bold to better understand the development of the PES.

“The **flooding** in **Halle (Saale),** became worse on the **4th of June**. Due to the impending flooding of downtown, further sand deliveries were transported to the **sandbag filling station** on the **market place** at around **2 pm**. Due to the **midsummer weather**, there were more volunteers on site than the **100 helpers actually needed**, which challenged our personnel with additional organizational effort. Probably the central location and the proximity to the university played a role in the overcrowding market place but also the dissemination of subjective information by the local citizens via **social media** such as Facebook. In contrast, the crisis management team focused on the dissemination of information via traditional media, such as **radio**. Nevertheless, we were thankful for the numerous volunteers who helped by **filling the sandbags** at the marketplace for **more than 18 hours**."

This scenario is just a very short and basic example for pruning the SES for the disaster type: **flooding** and the datetime: **06/04/13 02:00 pm**. Since the textual scenario description is free in its structure and not complete at all, some variable assignments have to be interpreted resp. assumed. The **city** and the **market place** have been defined as geographical areas according to their center coordinates and an adequate radius. Furthermore, **midsummer-weather** has been assumed for the whole city and resolved in a temperature of 29°C and rain intensity of 0 mm/h.

As available (or relevant) communication technologies, **social media** and **radio** have been defined for the whole city. The technical capacity for both technologies is set to 100% since there haven't been reports of lacking communication availabilities during the disaster event. Since **social media** has only been used by the volunteers among themselves to communicate one-to-many, it has been interpreted as communicationType. Since official disaster management has only used **radio** for informing the volunteers, it has been defined in the same manner.

The **sandbag filling station** on the **market place** has been defined as one operating site with only one task, namely **sandbag filling**. The variables have been set to 100 volunteers needed and 18 hours estimated duration.

To define the population of volunteers, some information were not given in the textual description. E.g., we have assumed one population representing the number of inhabitants of **Halle** in 2013 according to the official statistics. The technology distributions have been chosen in line with official statistics for the percentage of people who daily use radio or social networks in Europe (European Commission, 2017).

Since we have no information on how long and how many days people have worked, we have assumed triangular distributions for workingTime (min: 2 hours, peak: 4 hours, max: 8 hours) and workingDuration (min: 1 day, peak: 3 days, max: 7 days) that seem logical to us.

Furthermore, we have assumed that only half of the population is able or willing to do heavy work. Consequently, the distribution for the task **sandbag filling** has been set to 50%. The resulting PES for the representation of the textual scenario description including all identified and interpreted information is depicted in Figure 2.

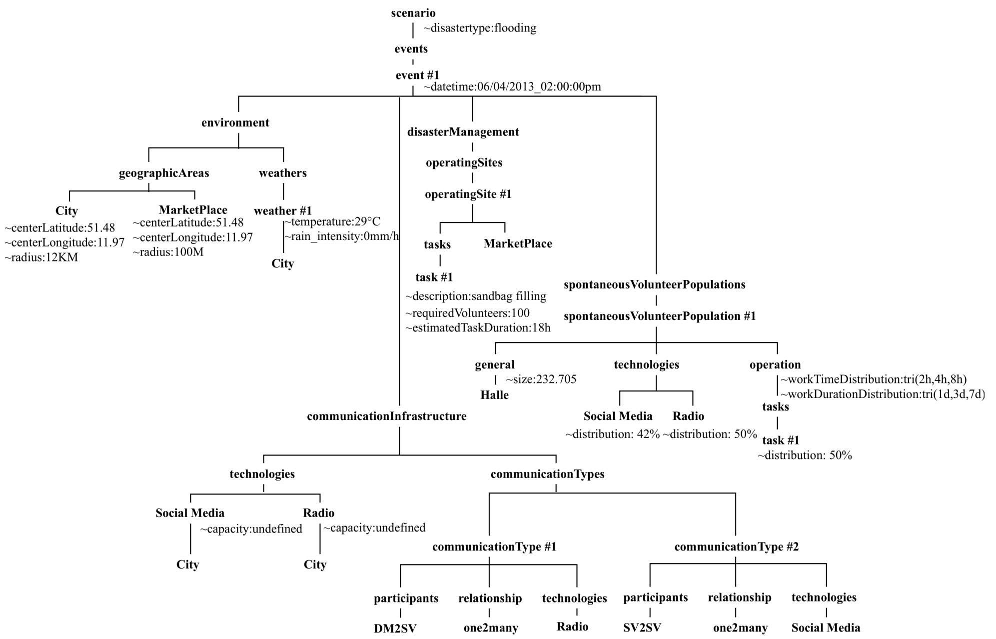

Figure 2. Pruned Entity Structure for Example Scenario

DISCUSSION AND OUTLOOK

The increasing relevance of spontaneous volunteers has led to the development of numerous research approaches aiming at their improved coordination. However, these approaches require on the one hand evaluations to test their added value and, on the other hand, a comparison to choose the approach that matches the requirements of official disaster management to transfer these approaches into practice. Computer simulations, particularly agent-based simulations, seem promising to simulate human behaviors in a disaster context and, thus, to enable evaluations and comparisons of coordination approaches. Nevertheless, agent-based simulations require reproducible disaster scenarios to compare the effects of different coordination approaches. To perform reproducible simulations in the context of spontaneous volunteer coordination, as a first step, scenarios and their related entities have to be analyzed. A second step is to provide these scenario insights as a machine-processable format to be used within the simulation.

The SES model proposed in this paper is a fundamental step for developing a Standard Scenario Definition Language for the coordination of spontaneous volunteers that can be processed within a simulation. In the presented initial version, the focus is restricted to coordination scenarios particularly for simulation experiments and, thus, only contains elements for this purpose. Following an Action Design Research approach (Sein *et al.*, 2011), the SES will be further developed and supplemented in several iteration steps in the future resulting in the SVCSDL. This is necessary, since depending on the purpose, the model may still lack information or higher level of details that may be required by other researchers. Although the SES model contains all basic entities that have been identified in our literature search and interviews addressing the coordination of spontaneous volunteers, an extensive and structured literature review (e.g. following the methodology proposed in (vom Brocke *et al.*, 2009)) is expected to bring further results. Thus, a structured literature review may supplement the proposed model and is part of our future research.

Although the SES was mainly developed for simulations, it might also be valuable for field trials in the spontaneous volunteer coordination context or even as a basis for digital volunteering scenarios as it gives insights and an understanding of what impacts and influences spontaneous volunteer scenarios. Consequently, the proposed SES model contributes to disaster research as it conceptualizes information that relate to scenarios with spontaneous volunteers.

Even though the general goal is to enable the evaluation and comparison of spontaneous volunteer coordination approaches promoted by the scenarios, we have not yet proposed and evaluated adequate measures for evaluating or comparing different coordination approaches. Since this is required for the evaluation of coordination approaches and systems, simulations, exercises, and experiments, it is one focus of our generic research project and an open research topic for the future.

Last but not least, the proposed SES model is the basis to develop an XML-based scenario language that may lead to the implementation and exchangeability of scenarios in simulation software. By defining an extensive standard language based on the SES, research on spontaneous volunteers in disaster situations, as well as the evaluation and comparison of different coordination approaches, will be supported and promoted. Thus, after completing the SES, the next step will be the language definition as a practical research question.

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Simulating Spontaneous Volunteers – A Conceptual Model

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Abstract	Recent disasters have revealed growing numbers of citizens who participate in responses to disasters. These so called spontaneous unaffiliated on-site volunteers (SUVs) have become valuable resources for mitigating disaster scales. However, their self-coordination has also led to harm or putting themselves in danger. The necessity to coordinate SUVs has encouraged researchers to develop coordination approaches, yet testing, evaluating, and validating these approaches has been challenging, as doing so requires either real disasters or field tests. In practice, this is usually expensive, elaborate, and/or impossible, in part, to conduct. Simulating SUVs' behaviors using agent-based simulations seems promising to address this challenge. Therefore, this contribution presents a conceptual model that provides the basis for implementing SUV agents in simulation software to perform suitable simulations and to forecast citizens' behaviors under a given set of circumstances. To achieve adequate simulations, the conceptual model is based on the identification of 25 behavior-affecting attributes.
Keywords	spontaneous volunteers, disaster management, agent-based simulation, conceptual model, citizen behavior
Artifact	Conceptual Model
Evaluation	Case Study
Contribution	conceptual representation of spontaneous volunteer behaviors, instantiation as simulation model in AnyLogic

Simulating Spontaneous Volunteers – A Conceptual Model

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ABSTRACT

Recent disasters have revealed growing numbers of citizens who participate in responses to disasters. These so-called spontaneous unaffiliated on-site volunteers (SUVs) have become valuable resources for mitigating disaster scales. However, their self-coordination has also led to harm or putting themselves in danger. The necessity to coordinate SUVs has encouraged researchers to develop coordination approaches, yet testing, evaluating, and validating these approaches has been challenging, as doing so requires either real disasters or field tests. In practice, this is usually expensive, elaborate, and/or impossible, in part, to conduct. Simulating SUVs' behaviors using agent-based simulations seems promising to address this challenge. Therefore, this contribution presents a conceptual model that provides the basis for implementing SUV agents in simulation software to perform suitable simulations and to forecast citizens' behaviors under a given set of circumstances. To achieve adequate simulations, the conceptual model is based on the identification of 25 behavior-affecting attributes.

Keywords

spontaneous volunteers, disaster management, agent-based simulation, conceptual model, citizen behavior

INTRODUCTION

Disasters during the last decade have revealed a growing number of untrained citizens participating in disaster responses. Along with the increasing number of natural and man-made disasters worldwide, the relevance of these so-called spontaneous unaffiliated on-site volunteers (SUVs) has increased dramatically. Disaster managers and practitioners have reported that several disasters would have been far more lethal and on a more dramatic scale without the help of SUVs (Detjen et al., 2015; Geißler, 2014). Beyond these undoubtedly positive aspects of their help, however, SUVs have also caused unintentional harm or put themselves in dangerous situations.

Utilizing SUVs as a valuable resource in disaster response requires proper coordination by disaster managers (Betke, 2018; Betke et al., 2017; Rauchecker and Schryen, 2018) and has led to a growing field of research for IT-supported disaster management. In Germany, e.g., the government has focused on this issue specifically by funding several projects such as KUBAS and REBEKA in order to effectively assign SUVs in disaster management (BMBF, 2017). This contribution is part of the research project KUBAS that aims at (a) an IT-based solution for coordinating SUVs, (b) a general evaluation method to measure the effectiveness/efficiency of approaches/methods/tools and drills aiming at the integration and coordination of SUVs during disaster response and (c) predicting volunteer participation in various disaster scenarios.

The main challenge of all these research efforts lies in testing, validating, and evaluating new approaches as well as proofing the concept, e.g., in practitioners' drills. New approaches are usually evaluated through field experiments, yet field experiments with many SUVs require massive numbers of participants, may have durations of many days, and can take place at several locations simultaneously. Such experiments are often expensive, elaborate, and, in part, even impossible to conduct (Balasubramanian et al., 2006; Sautter et al., 2015; Takahashi, 2007). Research approaches may also be evaluated and validated in real disasters, even though testing using human beings seems to be too dangerous, and disasters cannot be controlled to occur when testing is the objective.

Another common approach for evaluating and optimizing real-world scenarios with minimal effort is the use of computer simulation (Arai and Sang, 2012). Furthermore, a proper simulation of SUVs enables disaster managers to forecast citizen participations under given circumstances to better manage disaster situations and, beyond that, to visually track potential operating-site utilizations.

Nevertheless, the simulation of SUV's has not yet been intensively researched (Lindner et al., 2017). In our prior work (Lindner et al., 2017), we, in particular, have identified agent-based simulation as a sound approach for simulating SUVs' behaviors in disasters since it has already been proven to be appropriate for simulating human and social behavior as well as many entities (Mas et al., 2012; Pan et al., 2007; Takahashi, 2007; Wagner and Agrawal, 2014). Simulating SUVs' behaviors requires the development of software agents, and therefore, it first requires the analysis of their real-world behaviors and all behavior-affecting attributes (Macal and North, 2007). Secondly, the behaviors of SUVs have to be conceptualized in order to be implemented and run in simulation software.

Based on the attributes for representing and influencing SUVs' behaviors identified in our prior work (Lindner et al., 2017) this paper aims to develop a conceptual model that represents the behaviors of SUVs in disaster situations and represents the foundation for a later implementation in simulation software.

To achieve this aim, in the first section, related literature is discussed and a summarizing overview of SUV attributes is given. A common representation of behaviors in agent-based simulations is the statechart notation (see, e.g., Emrich et al., 2007; Fujisawa et al., 2014; Garifullin et al., 2007). To ensure broad applicability for implementing the model in simulation software, we provide the conceptual model following the statechart notation based on the Unified Modeling Language (UML) standard, which, as well as the method, will be described briefly in the second section of this work. In the third section, behavioral attributes according to our prior work will serve as the foundation for deriving behavior-affecting states, events, and transitions and, thereby, for developing a conceptual model to represent SUVs' behaviors. To prove its applicability and ability to be implemented in simulation software, in the following section, the proposed model will exemplarily be implemented in a simulation software. A conclusion with an outlook for further research is offered in the final section.

This contribution is part of a research project following the well-established methodology for Design Science Research proposed by (Peffers et al., 2006). According to this methodology, this research paper refers to the third phase of the Design Science Research Process (DSRP), i.e. the "Design and Development" phase. The results of this paper provide an indispensable foundation for the implementation and thereby the next DSRP phase "Demonstration".

RELATED WORK: ATTRIBUTES FOR SIMULATING SPONTANEOUS ON-SITE VOLUNTEERS

In our paper "Attributes for Simulating Spontaneous On-Site Volunteers," we described the enormous potential of spontaneous unaffiliated on-site volunteers (SUV) for disaster mitigation and confirmed the requirements for the proper coordination of these SUVs in order to avoid nonproductive and even counterproductive help.

Comprehensive research support for developing coordination approaches and, accordingly, the necessity to test, evaluate, and validate these approaches triggered our research efforts. Since the current practice in testing, evaluating, and validating research efforts in regard to the topic of disasters requires either real disasters or field experiments and is thus expensive, elaborate, and/or partially impossible to conduct, new opportunities to address these issues need to be explored. In (Lindner et al., 2017) we therefore, suggested developing a multi-agent-based simulation framework to simulate SUVs' behaviors.

Our literature review based on a keyword search in scientific databases resulted in a large number of research papers and practice reports. It revealed that agent-based simulation is a major topic in disaster related research, whereas many research efforts focus on evacuation scenarios: e.g. evacuation impacts on traffic flows from disaster areas (Chen and Zhan, 2008), evacuation scenarios for concert venues (Wagner and Agrawal, 2014), evacuation behavior of pedestrians and car drivers in a tsunami scenario (Mas et al., 2012). It further revealed a massive amount of research efforts on SUVs: e.g. research on their interaction, cooperation, and communication especially via social networks (e.g. Peary et al., 2012; Starbird and Palen, 2011), the role of digital volunteers during the Haiti earthquake in 2010 (Starbird and Palen, 2011) or research approaches and applications to improve communication or coordination (e.g. Reuter et al., 2015; Hofmann et al., 2014). Nevertheless, none of the related works applied simulation for SUVs in the disaster context and, hence, fostered our effort in developing a multi-agent simulation framework for simulating SUVs' behaviors.

The evaluation of the search results further led to the identification of 25 attributes (Table 1), which were then briefly described. In the process of analyzing behavior-affecting attributes, we further identified numerous dependencies and interrelations among these attributes that were initially described yet need to be analyzed in greater detail in future research. In accordance with the definition of software agents by Lind (2001), we grouped the attributes into individual, social, and environmental attributes as an indispensable step for understanding the behaviors.

Consequently, the groundwork is an adequate source for developing a conceptual model to represent SUVs' behaviors, as we have already identified and described all the attributes that affect SUVs' behavior. Furthermore, the state-of-the-art literature review has led to many literature sources that may confirm the assumptions we make within our model.

Table 1. SUV Attributes

Number	Attribute	Description
A1	Age	age of the SUV
A2	Group Affiliation	e.g. clubs, religious groups
A3	Motivation	trigger to participate in disasters
A4	Concern	emotional reactions to disasters
A5	Information Channel	e.g. social media
A6	Personal Connections	e.g. friends, family
A7	Social Networks	characteristics of the individual social network
A8	Perception	how SUVs perceive the situation
A9	Kind of Disaster	size, scale and type
A10	Weather	temperature, rainfall
A11	Experience	in prior disasters (positive, negative, non)
A12	Time of Day	e.g. day, night
A13	Supporting Tasks	e.g. filling sandbags
A14	Task Preference	preferences on what to do
A15	Capabilities	physical capabilities/ability to be led by officials
A16	Resources	provided resources (e.g. shovels)
A17	Working Time	time (in h) per day
A18	Time Preference	e.g. to work on day/night
A19	Working Duration	days somebody wants/can help
A20	Operating Site	locations where SUVs are needed
A21	Kind of Information	e.g. number of needed/current SUVs at operating site

A22	Location	current location
A23	Operating Site Preference	where an SUV is willing to help
A24	Travelling	e.g. car, walk
A25	Randomness	something unexpected happens

METHOD: CONCEPTUAL DESIGN

We constructed the proposed conceptual model for the SUVs' behaviors in consideration of the methodological notes on models of (March and Smith, 1995). Conceptual models can be constructed based on domain knowledge and can be used to represent new theories or phenomena through domain-specific elements and their associations (March and Smith, 1995). Accordingly, the concern of such models is utility, not truth (March and Smith, 1995). The model is based on our attribute identification, derives behavioral characteristics of it and was constructed under use of the Unified Modelling Language (UML). Since this conceptual model is descriptive and part of the early design phase, the evaluation is part of the subsequent iterative implementation (Gleasure, 2014).

Our recent research revealed that there is no universally valid modeling convention for developing software agents. However, based on other research outcomes in the field of agent-based simulation (see, e.g., Dawson et al., 2014; Ozik et al., 2015; Uhrmacher and Kullick, 2000; Verma, A. and Singh, Y., 2017), the UML statechart modeling notation by the Object Management Group seems to be a common conceptualization of behaviors. Furthermore, UML statechart modeling is used in early-bird representations before functional assignments in the implementation phase are made (Borshchev and Filippov, 2004) and is, by far, the most often used formalism for modeling the behavior of object systems (Fortino et al., 2004). Since our research effort is currently in the pre-implementation phase, statechart modelling is an appropriate method for descriptive purposes.

The general purpose of statecharts is to specify, visualize, construct, and document the artifacts of a software system (Latella et al., 1999). The artifact in the present research will be the software agent that represents the behaviors of SUVs. Additionally, statecharts represent a sequence of states through which an object passes during its life cycle (Khriss et al., 1999). As our aim here is to represent the behaviors of SUVs in disaster situations, the life cycle comprises all the supporting activities undertaken during a disaster.

In general, UML statecharts consist of the following (Murray, 2004):

– states that are considered as a period in the life of a system or agent during which a certain condition holds or an activity is performed;

– events that trigger state changes; and

– transitions that connect states and change states based on external events and conditions.

UML as specification and modeling language is already widely accepted (Murray, 2004) and is thus a good foundation for a broad acceptance of the model and its implementation.

The next section discusses the actual development of the conceptual model and, as a consequence, the derivation and identification of all required states, events, and transitions featuring SUVs in disaster situations based on the proposed attributes and their descriptions. The reference to the original attributes will further be given as "*<name of the attribute>* (A ##)."

DEVELOPING THE CONCEPTUAL MODEL: SUV AGENT BEHAVIOR MODEL

UML statechart diagrams require an initial state to trigger the behavioral process (Object Management Group, 2015). Perceiving a situation as emergency or disaster has been identified as a precondition for spontaneous volunteering (Geißler, 2014; Reuter et al., 2013). The perception (A 8) can, therefore, be seen as the trigger to participate in a disaster as a spontaneous volunteer and is thereby the trigger and initial state for behaving as an SUV (***attention***). It is clear that one has to recognize a disaster; otherwise, there would be no need to volunteer. In (Lindner et al., 2017), we identified several additional attributes that may influence perception, e.g., social networks (A 7), information channels (A 5), or personal connections (A 6). As perception may be further triggered by other attributes, we summarize this first state as *"**has attention.**"*

To summarize, *"**has attention**"* means that, first, a disaster must strike as a precondition for participating in disaster relief, and, secondly, the agent must perceive this situation as an emergency. Starting here, the behavioral process of an SUV begins. Based on the attribute of location (A 22), we assume that the SUV agent is initially located at a distance from the disaster, most likely at his or her home. Furthermore, the location has a behavior-affecting influence, especially in the upcoming operating-site (A 20) search process.

After triggering the behavioral process, the first state is *“**has attention.**”* As previously described, this state requires the perception of the disaster and may be triggered/influenced by (social) media coverage or by friends or associates, more precisely other agents, who communicate with the SUV. It is crucial to be aware that broad media coverage and personal communications from friends motivate citizens to volunteer in disasters. We assume that the agent is then informed about the situation and a decision-making process about whether to participate in the disaster or not must be initiated. The transition to the next state will be triggered by a time-out event consisting of the motivation and the respective decision-making process of the volunteer agent.

We identified motivation (A 3) as the trigger to participate in a disaster response and revealed that motivation could either be increased or decreased by dependent attributes. The assumption of being highly motivated to offer support in disaster situations further leads to the assumption that people with a “high” degree of motivation are more willing to help than people with a “low” degree of motivation. We also revealed that motivation is not deterministic and, as yet, cannot be completely simulated. The motivating process has to take into consideration other attributes that affect motivation. Based on this knowledge, we assume two conditions, *“**[motivated]**”* or *“**[not motivated]**,”* that determine the following state of being either *“**ready to help**”* or *“**not ready to help.**”* However, the actual logic of deciding is not part of the statechart representation and thus must be considered in the implemented model.

Since the time-out event includes the motivating process, we assume that people won’t respond to help instantly after a disaster has struck. Furthermore, the time-out event simulates the recovery phase at home, or particularly at the initial location, that SUVs need to process, perhaps, before continuing to help on another day. This assumption is underpinned by the attribute of working time (A 17), which describes that SUVs usually work between 4 and 8 hours a day (ARC, 2010). Thus, as we attempt to model the behavior of participating in disaster situations, spare-time activities are of no interest to us, and so we assume a time-out.

Some disasters have durations of several days whereby a volunteer who decided not to help initially and thus was in the *“**not ready to help**”* state may decide to help on another day. Given the complexity of the motivation and its interdependencies and relationships, e.g., environmental attributes like weather that may affect motivation and may change over time, we assume that an SUV agent can be *“**temporarily not motivated**”* and, thus, more likely to help on another day. Accordingly, entering the *“**not ready to help**”* state will first cause the agent to enter the *“**temporarily not ready to help**”* state until deciding whether the SUV is conclusively not motivated. A conclusively not motivated state could be caused by very low overall motivation *(**[motivation very low]**)* due, e.g., to prior negative experiences (A 11) related to helping as well as by the SUV having exceeded his or her working duration (A 19). Depending on other attributes such as age, working duration varies from several hours to several weeks or even months. Deciding to discontinue all supportive tasks will result in the agent’s final state and thereby end the SUV’s behavioral process. Otherwise (***[else]***), he or she is probably going to help again on another day, will enter the starting state *“**has attention,**”* and, given a time-out, may become motivated again.

If the SUV is motivated, his or her state will then be *“**ready to help**”* and, based on the kind of information received (A 21), will either choose a preferred operating site or move around to search for places to help. SUVs do have operating-site preferences (A 23). Individually, they will consistently show a preference for an operating site where they know help is needed over sites that are described as overcrowded. However, the operating-site preference as well as the final operating-site selection process is part of the implementation phase.

In regard to being *“**ready to help,**”* we identified randomness (A 25) as an important attribute that affects SUV behavior. Randomness is described thusly: even if the *“SUV may have [..] high motivation to help, there is still a probability that something unexpected happens preventing him or her from actual helping”* (Lindner et al., 2017). This randomness is depicted by the decision related to whether *“**[something unexpected]**”* happened or not. If *“**[something unexpected]**”* turns out to be true, the agent is still motivated but will enter the starting state *“**has attention**”* to perhaps provide help on another day. Otherwise (***[else]***), the SUV is going to move to the operating site *(**moving to operating site**)*. This assumption is made by the attribute travelling (A 24), which describes how SUVs move to operating sites. Travelling will be integrated in the implementation phase and will then probably affect the time a volunteer needs to move from his or her initial location to the preferred operating site.

Recent disasters have shown that SUVs, after ***[arriving at the operating site]***, could possibly be ***[rejected]*** by operating sites by official forces, especially if the limits for required on-site volunteers are about to be exceeded (Teixeira, 2012). However, rejection leads to frustration and negative experiences that can potentially affect motivation to help on another day or in future disasters (Geißler, 2014; Kircher, 2014). In the past, not all volunteers who have been rejected have immediately lost their motivation and thus discontinued their help. Some SUVs start searching again (***[else]***) and move to other operating sites. As we described in (Lindner et al., 2017), the probability of being rejected is most closely related to the kind of information SUVs have about operating sites. It is clear that those who have a lot of information about operating sites choose sites where help is desperately needed instead of choosing overcrowded operating sites, and therefore, they are not likely to be rejected by official forces.

At any rate, if SUVs are rejected too often (***[too many rejections]***), their ambition to help on a particular day may decrease drastically, and they may discontinue their supporting activities. If this is true, the SUVs may then return home or at least go somewhere else but without helping (***[moving back home]***). However, rejected volunteers do continue to pay attention to the disaster and will therefore enter the state *"**has attention**"* when they arrive home (***[arriving at home]***). These negative experiences may then affect motivation the next day following the defined time-out event.

Not being rejected (***[else]***) results in helping at the arrived-at operating site and will thereby result in entering the state *"**helping at operating site.**"* As we revealed in (Lindner et al., 2017), the working time (A 17) depends on several other attributes and may vary from agent to agent. Exceeding the individual time preference (A 18) by helping at the operating site is an event that will cause a transition to the next state, namely, the *"**moving back home**"* state. Arriving at home will then lead to the *"**has attention**"* state again, which may lead to another round of participation.

The proposed statechart model is depicted in Figure 1. Based on our prior work, the states in the model were derived from all behavior affecting or featuring attributes and their descriptions. It is clear that spontaneous volunteering in disasters requires disaster situations, and therefore the behavior ends if the disaster situation no longer requires the help of volunteers, if the volunteer is no longer motivated, or if his or her working duration (A 19) preference has been exceeded. The end of the disaster is not modeled as a final state in the model, as the simulation will terminate when the disaster ends.

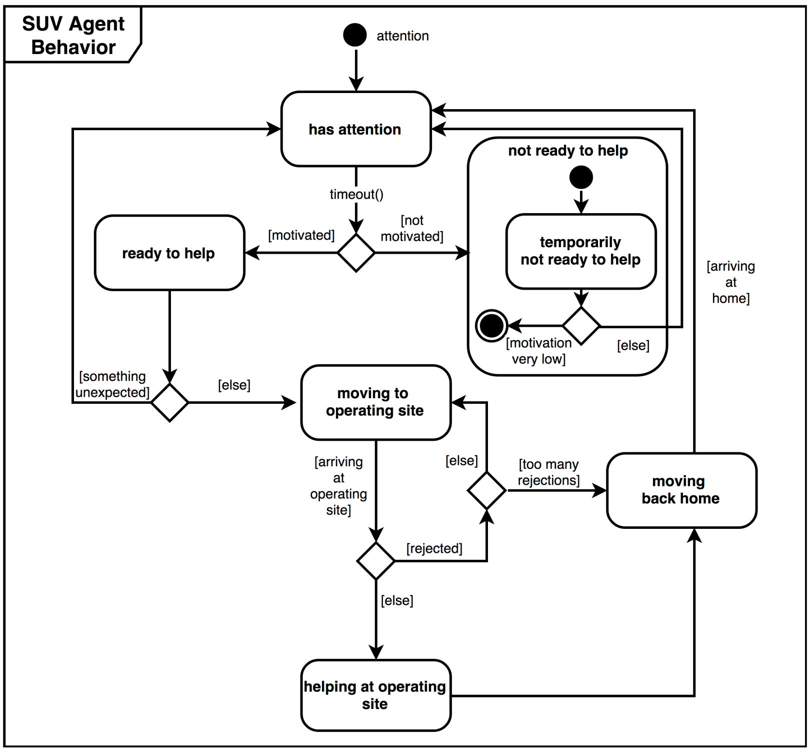

Figure 1. SUV Agent Behavior – A Conceptual Model

EXEMPLARY IMPLEMENTATION OF THE CONCEPTUAL MODEL

As the proposed conceptual model is the basis for implementing an SUV's behavior in simulation software, we exemplarily implemented the model in AnyLogic to show its applicability. Accordingly, the realistic simulation of SUVs requires further research and is not being aimed at by this implementation. AnyLogic is already being used to perform disaster-related simulations in other research projects (see, e.g., Barthe-Delanoë et al., 2015, and Barahona et al., 2013) and appears to be the proper software to test.

We implemented a population of 100 agents representing SUVs. The individual behavior of each agent originates with the behavior-affecting attributes as well as the behavioral model proposed in this contribution. Thus, we implemented the SUV's behavior exactly as the derived conceptual model in the AnyLogic simulation software (see Figure 2).

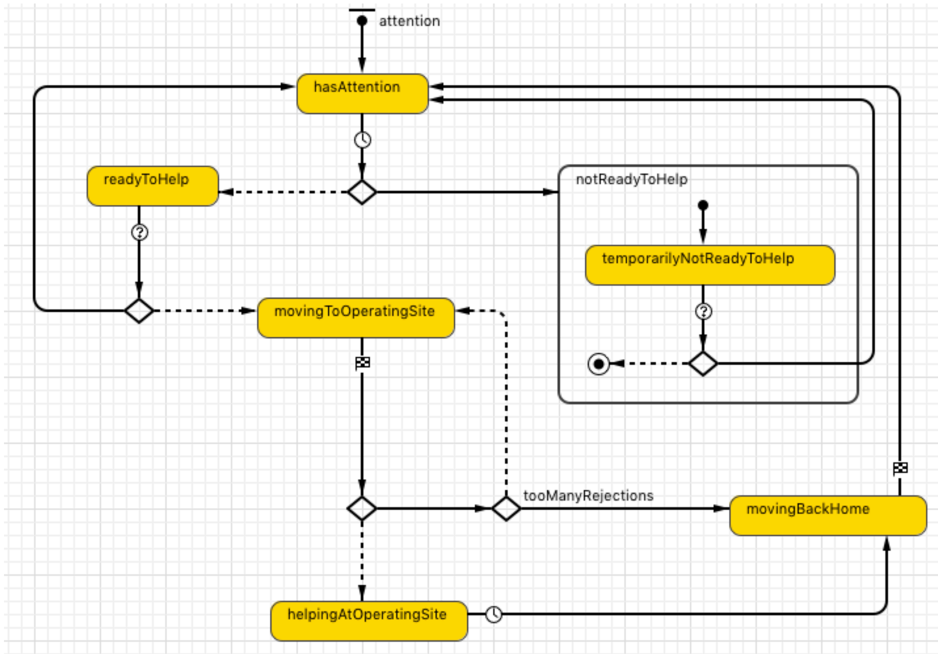

Figure 2. SUV Behavior in AnyLogic

To perform a basic simulation, we proposed the agents initial position to be randomly distributed in the area of "Halle (Saale), Germany" The city was massively affected by flooding in 2013 and where spontaneous volunteering made an enormous contribution to mitigate the scale of the disaster. AnyLogic allows the integration of GIS maps to visualize the agents in their current locations. Furthermore, we need to implement operating sites that simulate places where SUVs may help and can thereby be either empty or overcrowded. Even though operating site agents are not part of this contribution and will not be described in more detail, they are required to run realistic simulations. To show the applicability of the proposed model, the implemented logic is kept very simple, which means that the proposed decisions rely on random distributions. For example, being *"ready to help"* turns out to be true by an equally distributed probability of 50 percent.

By starting the simulation, the initial state pointer *"attention"* will be triggered, and the agent enters the state *"has attention."* The proposed time-out function in this implementation pauses the agent's actions for 8 hours before the decision of *either "ready to help"* or *"not ready to help"* is made. As previously mentioned, the decision relies on random distributions. Performing realistic simulation in the future necessitates the implementation of the decision logic as well as the attributes and their interdependencies proposed in (Lindner et al., 2017).

If the SUV agent is *"ready to help,"* the probability that something unexpected happens is 20 percent;

otherwise, the agent is *"moving to operating site."* Regarding the "kind of information", we assume that the agent knows about all operating sites and randomly chooses one (Lindner et al., 2017). In this very basic example, we represent three operating sites, each with a requirement of 20 SUVs. Arriving at the operating site either leads to being rejected or to *"helping at operating site."* Being rejected will be the result if more than 20 SUVs are already helping at this particular operating site. If the agent has been rejected more than twice, he or she will return home; otherwise, he or she will move on to another of the operating sites. We assume that an agent provides help for 5 hours before returning home.

Running this simulation will lead to defined behaviors that can be proven visually by the simulation representation (see Figure 3). Although this sample implementation is very basic, it can still simulate the SUV's behavior and thereby offers a sound foundation for improving the implementation iteratively.

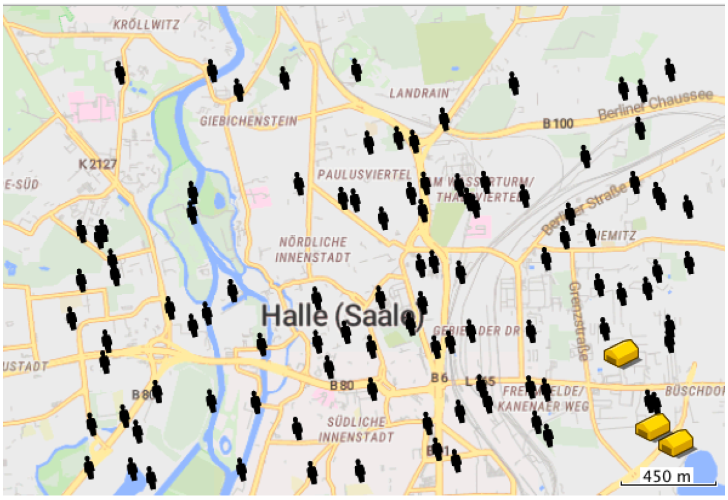

Figure 3. SUV Simulation in AnyLogic

CONCLUSION AND FUTURE RESEARCH

The numerous research efforts that have focused on spontaneous unaffiliated on-site volunteers (SUV) as well as recent disasters have revealed the enormous potential of SUVs for mitigating the scales of disasters. However, there are limitations in regard to evaluating, testing, validating, and also in comparing research approaches concerning the necessity of real disasters or field tests that are expensive, elaborate, or impossible, in part, to conduct. Simulations, in general, and multi-agent simulations, in particular, seem to be a promising attempt to complement existing approaches. Multi-agent simulations require the analysis of the behaviors of SUVs, and therefore we identified, analyzed, and classified all behavior-affecting attributes of SUVs to provide a sound foundation for developing software agents in our prior work.

The next step in simulating software agents is, therefore, conceptualizing the representation of the SUV's behavior for providing a model that can finally be implemented in simulation software. The implementation of a conceptual model in simulation software serves for improving the evaluation and validation of novel research methods and tools aiming at effective and efficient coordination of SUVs in disaster response. Furthermore, it's the foundation to develop tools that enable practitioners such as disaster managers to predict SUVs' behaviors.

Thus, the aim of this contribution was to develop a conceptual model representing the SUV's behaviors. Toward that aim, we recapitulated the attributes of the paper "Attributes for Simulating Spontaneous On-Site Volunteers" in order to identify events, states, and transitions to subsequently be modeled. Accordingly, this contribution provides: (i) a first and sound insight into the behaviors of SUVs and their corresponding states and (ii) a proof for the applicability of the conceptual model to be implemented in simulation software. The identified conceptual model is further expected to be useful for researchers/practitioners who either want greater insights into the behavior of SUVs or to implement the model in their simulations. In addition, this paper is part of a research project that necessitates a proper investigation of the volunteer's behavior as well as the foundations for the upcoming iterative implementation phase.

However, this research paper also has several limitations. Although the proposed conceptual model of this contribution is based on the latest research outcomes of (Lindner et al., 2017) it may be revised if and when there is an update on the underlying attributes. Furthermore, an implementation requires greater details on how the transitions may be triggered. For example, motivation level is assumed to be high or low, and there is not yet a specific operationalization for implementing it in simulation software. Moreover, a very low level of motivation may lead to an SUV discontinuing to help in a disaster situation and will thereby have a relevant impact on the SUV's behavior. To summarize, the decisions especially are on a high level of abstraction and consequently require further investigations before being implemented. Additionally, performing these simulations requires further agent types such as operating sites. These agents can also be derived by the attributes and, hence, will be addressed in future research.

Since the development of the artifact, i.e., the SUV agent, is based on an iterative process, the quality of the model and the level of detail can be expected to improve. However, the development cycle requires an implementation foundation to further improve the outcomes. In addition, the iterative cycle will involve interviewing a large number of SUVs and disaster experts in order to evaluate the model and to develop and survey a structured equation model for operationalizing motivation and a willingness to help.

Our entire research project follows the DSRP methodology proposed by (Peffers et al., 2006). Accordingly, this research paper is in the third phase, "Design and Development," of the artifact, and its results provide necessary fundaments for the iterative implementation and, thus, the next phase, "Demonstration."

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The Behavior of Spontaneous Volunteers: A Discrete Choice Experiment on the Decision to Help

Title	The Behavior of Spontaneous Volunteers: A Discrete Choice Experiment on the Decision to Help
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Keywords	agent-based simulation, decision support, discrete choice experiment, spontaneous volunteer, volunteer behavior
Artifact	Behavior Influences
Evaluation	Model Performance
Contribution	analysis on influences and according effects on the decision to help, discrete choice experiments as methodological approach for spontaneous volunteer behaviors in disaster research

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The Behavior of Spontaneous Volunteers: A Discrete Choice Experiment on the Decision to Help

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Abstract

Modern communication technology has enabled new ways to exchange information and is one of the main drivers for citizens participation in disaster response. During the last decades, so-called spontaneous volunteers have become an important resource in coping with disasters. However, their unpredictable behavior has also led to several problems. Disaster managers urgently need insights into volunteers behavior to effectively use the offered potential. To gain and provide these insights into explaining what drives the decision to help, we performed a discrete choice experiment based on previously identified behavior-affecting attributes. Our results indicate that attributes like the scale of the disaster and the media coverage are among the most important factors in the decision to help. The model correctly predicts volunteers scenario-specific decisions with an accuracy of 65%. Hence, the experiment offers valuable insights into volunteers behaviors for disaster research and is a sound foundation for decision support for disaster management.

1. Introduction

Modern communication technologies and, accordingly, the rising interconnection of society have enabled new ways of information retrieval and information dissemination. Technologies like social media have led to new opportunities for businesses and also the public sector. Since the advent of social media, this media has also affected the ways how people perceive disasters and how people interact and exchange information during disasters. These new opportunities have also led to a massive increase in citizens participation in disasters [1]. Consequently, social media has become a substantial topic in disaster research.

During the last decade, several disasters have shown increasing numbers of citizens helping spontaneously in mitigating disaster scales. These so-called spontaneous volunteers, sometimes also referred to as emergent groups, are people who are not affiliated with a disaster response or humanitarian organization and are, thus, usually not trained in disaster response [2, 3]. In a disaster context, spontaneous volunteers assist official disaster relief forces by, e.g., filling sandbags or clearing up locations[4, 5].

According to disaster managers, scales of many disasters would have turned out to be much more dramatic without the help of spontaneous volunteers [3, 6]. However, these volunteers often coordinate their actions mainly based on information retrieved from social media platforms such as Facebook or Twitter. This information is often disseminated and collected by the citizens themselves and are, thus, subjective or even wrong. Self-coordination has led to several problems, e.g., overloading operating sites in main areas while peripheral areas are understaffed [7, 8]. Although people have been willing to help, they have been rejected at overloaded operating sites by officials. That has led to their frustration [2, 9] as well as to a potential decrease in their willingness to help in future disasters.

Not only have spontaneous volunteers been frustrated, but also official disaster management has been confronted by this massive participation and the inability to intercept this situation [4, 10]. The undeniable importance of spontaneous volunteers and the problems related to their self-coordination have triggered many researchers to develop concepts to integrate the coordination of spontaneous volunteers into official disaster management [2, 10, 11, 12]. Additionally, because not all people want to be or can be led or coordinated by official disaster management, disaster managers urgently need insights and information on how spontaneous volunteers act and react in particular situations to promptly intervene and plan with these resources instead of being overwhelmed.

To provide these insights, this paper aims to elicit the preferences of spontaneous volunteers methodically grounded on discrete choice experiments. The analysis leads to the identification of effects of

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behavior-influencing attributes on the willingness to help as well as to influences on scenario-specific decision-making. The resulting model can forecast a volunteer's decision within different scenarios.

Our results give an understanding of which factors influence the behavior, which is the main driver of spontaneous volunteering and how they affect individuals decisions to help. The model can forecast an individual's scenario-specific decision whether and where to help. Implementing this model and providing individual decisions within an agent-based simulation framework [13, 14] enables the observation of the emergent behavior of citizens in disasters. Hence, this can serve as a foundation to developing a decision support system for disaster management that, e.g., enables the monitoring of disaster-related key performance indicators, such as operating site utilization and allows developing strategies for spontaneous volunteers in the preparedness phase.

2. Theoretical background and related work

The behavior and especially the motivation of organized, or affiliated, volunteers have already intensively been investigated [15, 16, 17, 18, 19]. However, we focus on spontaneous instead of planned volunteers as their behavior is, at this point, unpredictable and they have caused problems in past disasters.

A major part of disaster-related research regarding citizens' participation in disasters constitutes the analysis of citizens behaviors and interactions within social networks and, thus, focus on so-called digital volunteers [1, 2, 3, 6, 7]. Whereas the efforts of spontaneous volunteers that physically help at operating sites and particularly the analysis of their behaviors are still relatively unexplored fields, researchers have discovered that spontaneous volunteers need proper coordination and an integration in official disaster management based on the previously described problems [8, 9, 4, 10]. Therefore, many researchers have come up with ideas and IT-supported coordination approaches, which constitute a major part of the research area. Furthermore, some researchers have already begun to analyze the drivers of spontaneous volunteering to provide insights into their behaviors and motivations [11, 20, 21, 22]. For instance, [14] have identified 25 attributes that affect the behavior of spontaneous volunteers. Although some researchers have begun to analyze drivers of spontaneous volunteering to provide insights, forecasting the behavior and actual actions of spontaneous volunteers in specific scenarios has, to the best of our knowledge, not yet been considered in disaster research. However, these study results serve as a sound foundation for this paper. Nonetheless, there are results from psychology and behavioral economics on the willingness to help in general. For instance, Amato discusses the influence of personality and social network involvement on the helping behavior on a general level [23]. Amato distinguishes between three types of helping activities: formal planned helping, informal planned helping, and spontaneous helping [23]. He concludes that the greatest number of helping activities is planned. Furthermore, he emphasizes that the willingness to participate in planned helping is more predictable than the willingness to help spontaneously. For this reason, the motivation of our approach is to improve the predictability of spontaneous volunteering.

Barraket et al. performed a comprehensive survey that gives first insights into motivational, intentional, and network-related aspects of spontaneous volunteering [11]. However, they do so only in a descriptive way.

Seo et al. strengthen the position that media can influence the willingness to help after a disaster [12]. Moreover, they emphasize the importance of media messages as a mediator to inform the public about the necessary actions needed to reduce harm. Besides, economists often investigate charity and donation behavior in the context of volunteering behavior. Donation activities are not spontaneous. Although the general research analyzes the effect of incentives on helping behavior like blood donation and investigates the so-called crowding-out effect [24, 25, 26], it only takes a shallow look at the actual triggers to donate. Considering the huge differences between the research on affiliated volunteers and that of spontaneous volunteers [22] the insights from planned helping cannot be adopted for spontaneous helping. Thus, insights into spontaneous helping require a comprehensive analysis.

Due to the nature of spontaneous volunteers in the context of natural disasters, one issue in investigating spontaneous volunteers behavior is that it is only observable if disasters occur. In such a situation, it is not practicable to observe or survey the spontaneous volunteers behavior and their decision to help. To overcome this issue, it is required to investigate the behavior and their decisions in an experimental frame with realistic simulated scenarios. Therefore, we propose a discrete choice experiment as an appropriate method to elicit the preferences of spontaneous volunteers decisions [27, 28, 29]. Within recent decades, the use of discrete choice experiments has increased in areas like health economics, transport economics, ecological economics, marketing efforts, and many more areas [29, 30, 31, 32]. However, there is no research using discrete choice experiments to identify the main drivers of potential spontaneous volunteers in the context of disaster response.

The lack of existing comprehensive investigations into spontaneous volunteers willingness to help and their decisions to physically help within different scenarios has motivated our effort to provide novel insights into spontaneous volunteer behaviors for research and practice. Thereby, the results of our discrete choice experiment can provide comprehensive data for, e.g., decision support systems for disaster management.

3. Experimental design

In conducting a discrete choice experiment, there are several steps to pass through to get valid results [33, 34].

Firstly, we have to decide how many alternatives will be given in the choice set [34, 35]. Since we are interested in insights into why people will or will not help in different scenarios, we also examine the decision not to help and provide three alternatives: two scenarios with different combinations of attribute levels and one opt-out alternative (see Figure 1). The participant has to choose one alternative: either one of two helping scenarios or the choice to not help at all. This allows the examination of the influence of different attributes on the decision and on the opportunity not to help. Veldwijk et al. find that including an opt-out can structurally change the results of the experiment since this reduces the number of missing data related to not being able to choose one of the alternatives [36]. Furthermore, Ryan and Skåtun figure out that a correctly included opt-out alternative is very important to illustrate a real-life situation [37].

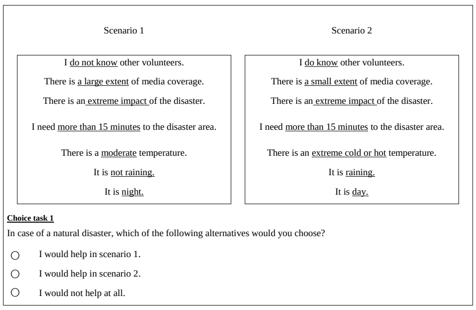

Figure 1. Example of a choice task

Secondly, we have to define the number of and the attributes themselves. There is an trade-off between including as many attributes as possible and the feasible cognitive load of the participants. The number of attributes, which should be incorporated into this step, varies in the literature. Maddala et al. propose to include only the key attributes in a decision task [38]. Louviere et al. find that the influence of the number of attributes on completion time is small [39]. Moreover, typically the number of attributes vary in the range from 4 to 8 [40], whereas more than 6 attributes can decrease the completion rate [39]. There are several ways to identify attributes affecting spontaneous volunteers willingness to help. One way is the identification of attributes based on a qualitative analysis of a literature review [41]. A literature review on factors that affect spontaneous volunteers behaviors has already found 25 potential attributes and serves as the foundation for our study.

To reduce the number of attributes given in the study, we have firstly excluded attributes that cannot be measured (e.g. attribute: randomness) or that do not directly affect the behavior (e.g. attributes: resources and traveling). To further reduce the number of attributes, we have secondly surveyed a group of experts (disaster researchers, people who have spontaneously helped in disasters before) to identify the main influences on the decision to help or not help. The overall process has led to 7 attributes that have been chosen for our further investigation.

The attributes and their associated levels are shown in Table 1: the first written level is the reference level.

Table 1. Selected Attributes

attribute	levels	description
$impact$	small/big	How is the scale of the disaster?
$friends$	no/yes	Do friends already help?
$exp.time$	short/long	What is the expenditure of time to get to the operating site?
$daytime$	night/day	The daytime of the present scenario.
$temp$	extreme/normal	The temperature of the present scenario.
$media$	low/high	How is the media coverage?
$rain$	no/yes	Is it raining?

Thirdly, to limit the number of choice sets appropriately, we decided to give each attribute two levels [42]. We did so for two reasons: The levels have to be as relevant and as easy to understand as possible and, the number of levels should be equal for all attributes because individuals weigh attributes with more levels higher [33, 43]. Due to the local conditions of the respondent's city, the levels of expenditure of time have been translated to more resp. less than 15 minutes.

Therefore, we indicate, as represented in Table 1, the level of the attribute $impact$ as small and big. Seo et al. argue that the scale of a disaster is the main influence on the willingness to help spontaneously [12]. We also include personal connections [11, 21] as an attribute in the analysis because several psychological studies emphasize the role of personal connections in the context of helping. Additionally, the expenditure of time to get to operating sites [44, 21] is a relevant attribute. Although the influence of weather conditions and the time of day is discussed contradictorily in the literature, we include attributes like temperature, precipitation and whether the volunteers would be working during the day or night when help is needed to test if an influence exists [14]. Seo et al. address the role of media coverage [12]. For this reason, we also examine the effect of information by media coverage. Moreover, we decided to include individual-specific variables in our analysis. We incorporate the gender of our participants into the survey to test if there are any gender-specific differences. Moreover, we partly deduce the willingness to help by adding the willingness to install a coordination app as well as previous experiences in helping and the willingness to spend time to help on the participants days off.

Lastly, after setting the survey frame, we had to identify the number and composition of the choice sets to estimate the main effects of specific attributes. Therefore, we use the R-package support.CEs [45]. The L^{MA} method is used to create the experimental design directly from a symmetric orthogonal main-effect array with M times A columns of L level factors [46]. Hence, we have an orthogonal main-effect array with 2 times 7 columns of 2 levels to create a choice set with 2 alternatives of 7 attributes with 2 levels. We do not have to include the opt-out alternative the levels of the attributes do not vary over the choice sets and, thus, we only have two alternatives in the main-effect array. The support.CEs' function divides the choice set into subsets of the choice sets [45]. Our experimental design contains 32 different choice tasks which are divided into five questionnaires. Figure 1 displays an example of a choice task. The participants had an introduction into the topic where we have explained the given situation and the scenario. We have focused on a flood scenario to eliminate disaster type effects and, also, because floods are among the most realistic disasters at the location of the survey. Furthermore, we have also explained scenario-related typical tasks like filling sandbags, distribute food and drinks and clean up operating sites. We present two alternatives with their corresponding attributes and levels in boxes and underline the key characterizations. Underneath the boxes, the participants have to select which of the three alternatives they choose (single-choice).

After developing the experimental design we collected the following data: we conducted two samples, one in January 2018 (Sample 1) and another one in October 2018 (Sample 2). In Sample 1, 170 undergraduate students in an introductory statistics course took part. In general, we had 1360 ternary decisions which make 4080 observations. Since we only had a small number of responses where no or more than one alternative was chosen, we decided to discard these responses [47]. After reviewing the data, we ended up with 3492 observations. Additionally, 311 undergraduate students in another introductory statistics course took part in Sample 2. Hence, we have 2488 ternary choices that result in 7464 observations.

Subsequent to collecting the surveys and sorting out those with missing data, Sample 1 was used to estimate the utility function defined in Equation 1. It is used to evaluate the accuracy of our model that will be presented in Section 4. To analyze our data, we have to derive a utility function which captures all possible attributes and individual aspects that could influence the decision

4. Model framework

Since we are using a discrete choice experiment to retrieve the attributes that affect spontaneous volunteers decision to help, we consider that each individual maximizes her/his utility if she/he faces a decision [48, 49, 28]. These assumptions follow the random utility framework of McFadden [28]. Hence, each individual chooses the alternative with the highest personal benefit. We define the following utility function. The utility of an individual i in alternative j and choice task t is:

$$U_{ijt} = \alpha_i' z_{jt} + \beta_j' x_i + \varepsilon_{ijt}, \tag{1}$$

where z_{jt} describes a vector of attributes (alternative-specific variables) and α_i' are the corresponding vectors of coefficients. Since we have repeated measurements for each individual, we can take the heterogeneity between individuals into account. Therefore, we use a step-wise reduction of random parameters based on likelihood ratio tests. We end up with 3 random parameters ($impact$, $friends$, $daytime$).

The other alternative-specific variables are estimated at the mean. By x_i we define the individual-specific control variables. Here, β_j are the associated coefficients which are estimated for each alternative. Finally, ε_{ijt} is the independently identically extreme-value-type-1 distributed error term. We imply

Table 2. Model evaluation method

		predicted outcomes S1	S2	O	$\sum$
observed outcomes	S1	TP_1	FP_{21}	FN_1	N_{r1}
	S2	FP_{12}	TP_2	FN_2	N_{r2}
	O	FP_1	FP_2	TN	N_{r3}
	$\sum$	N_{c1}	N_{c2}	N_{c3}	N

that an individual chooses the alternative with the highest utility in a decision task.

After estimating α'_i and β'_j, we validate our model by calculating utilities for all alternatives and individuals. We take the alternative with the highest estimated utility as the individuals estimated choice. Additionally, each individual faces three alternatives. This result is a multinomial outcome variable. To evaluate the prediction accuracy of our model, we compare the observed outcomes with the predicted outcomes. Cohen uses a similar procedure to measure the agreement for nominal scales [50].

Table 2 shows the possible cases which occur by comparing the observed and predicted outcomes. We particularly distinguish between four general results. TP_1, TP_2 we consider a *true positive* situation where the observed and predicted outcomes match each other and the prediction is a positive outcome. In our case, it means that the participant is predicted to help in a specific situation. In comparison, TN is a *true negative* situation. The only difference to a *true positive* situation is that the outcome is predicted as a negative one so that FP and FN (*false positive* and *false negative*) define a result where the observed and predicted outcomes do not match each other. Furthermore, we derive four measures to evaluate our model. These measures are recommended by McFadden [51]. First, we can calculate the overall predictive precision (accuracy) which we consider as:

$$acc = \frac{TP_1 + TP_2 + TN}{N}. \tag{2}$$

the accuracy that is defined as the matches between observed and predicted outcomes divided by the number of observations. Hence, we can accurately interpret the probability of a true prediction. Second, we can measure the precision of our model:

$$pre = \frac{TP_1 + TP_2}{N_{c1} + N_{c2}}. \tag{3}$$

by constraining on the positive predictions. Precision is the conditional probability that thethe levels of the attributes outcome of an individual is predicted as a positive outcome and, thus, is correctly predicted. Third, we can examine the sensitivity of our model:

$$sen = \frac{TP_1 + TP_2}{N_{r1} + N_{r2}}. \tag{4}$$

In contrast to precision, sensitivity denotes the conditional probability that an observed outcome of an individual is correctly predicted as a positive outcome. And fourthly, we can compute the specificity of our model:

$$spe = \frac{TN}{N_{r3}}. \tag{5}$$

Specificity is the opposite of sensitivity. Therefore, specificity is defined as the conditional probability that an observed outcome is correctly predicted as a negative one. These measures allow us to identify the strengths and weaknesses of our model. In the next step, we will take a closer look at the results of our study.

5. Results

Table 3 presents the estimation results of the attributes and random parameters. We consider the random parameters as normally distributed. However, we select only three random parameters ($impact$, $friends$, $daytime$), based on the results of several likelihood ratio tests. We set up a 5% significance level. All parameters are significant because the 95% confidence interval does not include a zero. The impact of the disaster has the largest effect, followed by $friends$.

Seo et al. emphasize the effect of the disasters impact [12]. The effect of $friends$ means that if friends are helping, the probability of the individuals helping increases. Amato finds a similar result [23]. He exposed that the social network of a person influences the spontaneous volunteering behavior. Furthermore, people prefer to help during the day. Hence, the probability of helping in a specific situation decreases if the alternative scenario is defined as helping at night. Additionally, normal temperatures have a positive

Table 3. Estimation results of the attributes

Alternative-specific variables:	Coefficients	Standard error	95% Confidence interval
$impact$	0.8237*	0.0807	0.6654 - 0.9819
$friends$	0.6853*	0.0788	0.5308 - 0.8399
$exp.time$	-0.6321*	0.0782	-0.7853 - -0.4789
$daytime$	0.5814*	0.0772	0.4302 - 0.7327
$temp$	0.3001*	0.0706	0.1618 - 0.4385
$media$	0.2956*	0.0689	0.1606 - 0.4306
$rain$	-0.2370*	0.0726	-0.3793 - -0.0948
Standard deviations of random parameters:			
$sd.impact$	1.0421*	0.1245	0.7980 - 1.2862
$sd.friends$	0.8621*	0.1219	0.6233 - 1.1010
$sd.daytime$	0.6583*	0.1198	0.4236 - 0.8931
N	3492		
McFadden R^2	0.2817		

* coefficients significant at the 5% level

impact on the decision to help. Schneider et al. chose a different approach to identify the temperatures effect on spontaneous helping. The people were in a specific environment where the temperature varies directly in four different treatments. Schneider et al. observed an unclear effect of temperature in this setting [52]. Furthermore, the extent of the media coverage has a positive effect. This finding is in line with Seo et al. who observe that media can increase the willingness to help [12]. In contrast, only two variables have a negative impact on the decision to help. The expenditure of time to get to the disaster area on the one hand and, the precipitation conditions on the other hand. This means that if the duration to get to the operating site is high, the probability to help decreases. We observe an equivalent effect for a raining situation. The random parameters indicate that the coefficients of $impact$, $friends$ and $daytime$ vary in population. These insights display that the other parameters (not random) do not vary in the population so that the effect is the same for each individual and, therefore, the mean.

The random parameters means and standard deviations are used to draw a distribution curve for each random parameter. Figure 2 shows the distributions of the random parameters. The distributions of the $impact$ and $friends$ coefficients indicate that the probability to have a negative effect is 21%. We obtain this probability by computing the area under the distribution curve for $impact$ smaller than zero. One explanation for the $impact$ variable is that a larger disaster results in higher probabilities of people willing to confront danger, which could be tested by including an attribute which illustrates the degree of willingness to put oneself in danger. The interpretation of the $friends$ variable is the indication that spontaneous volunteers may not be aware that there are enough people at a certain

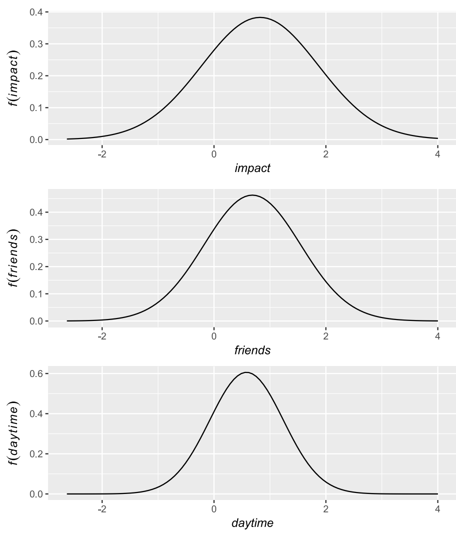

Figure 2. Distributions of the random parameters

operating site. To overcome this issue, we should add an attribute that indicates information about operating site utilization. However, the distribution of the $daytime$ coefficient shows that the probability to have a smaller coefficient than zero is 19%. Some individuals seem to prefer helping at night.

Amato found that planned helping behavior is generally driven by attitudinal, personality, and demographic variables [53]. This motivates us to take a closer look at the individual-specific effects displayed in Table 4. The coefficients are estimated for each

Table 4. Estimation results of the individual-specific variables

Individual-specific variables:	S1	S2	O
$intercept$	0	-0.2804	1.1402*
$gender$	0	-0.0635	-0.0159
$app-maybe$	0	0.4940	-0.7305*
$app-yes$	0	0.1966	-1.5858*
$helped$	0	-0.4227*	-1.0301*
$leisure.time$	0	0.0397	-0.1696*

* coefficients significant at the 5% level

alternative where Scenario 1 (S1) serves as the reference level so that all individual-specific coefficients have to be zero. As Scenario 1 (S1) and Scenario 2 (S2) differ only in the attribute levels, there should be no significant differences between S1 and S2. In contrast, there should be significantly different effects for the opt-out (O) alternative because the decision to choose between the reference level S1 and O depends to a large extent on the individual. We include five individual-specific variables plus intercept in the model. First of all, we control the effect of gender on the decision to help. The results show that there is no difference for male and female. This is in line with the literature [53, 54, 52]. Secondly, we look at the willingness to install a spontaneous volunteer coordination app. This partly captures the general willingness to help. We observe that the decision not to help decreases for participants who would maybe or certainly install such an app. We find a significant effect at the 5% level for maybe installing the app ,and for installing the app. For S2, both coefficients are not significant. Additionally, we include the experience of the participants with previously helping in a disaster situation and label it $helped$. We observe a significant negative effect for the second alternative. Moreover, the variable $helped$ has a negative effect on the decision not to help. This effect also is significant and means the probability to choose the opt-out alternative decreases if an individual has already helped in a disaster. Lastly, we observe a negative effect on choosing the opt-out alternative for people who report the willingness to help longer on their days off. This effect differs significantly from zero. We do not find a significant positive effect for Scenario 2. The four individual-specific variables $app-maybe$, $app-yes$, $helped$ and $leisure.time$ are all related to motivation and empathy. There are many contributions that confirm our findings that empathy and intrinsic motivation play a major role for explaining helping behavior [54, 55, 24].

To evaluate the goodness of fit of the model we can use the McFadden Pseudo-R^2 and the methods explained in Section 4. In Table 3, the McFadden Pseudo-R^2 of the model is reported as approximately 0.28. McFadden determines a Pseudo-R^2 between 0.2 and 0.4 as a good fit [51]. The measure can be interpreted as the ratio of information gain when dividing the log likelihood of the full model by the log likelihood of the null model [51]. Because we are also interested in the predictive accuracy of our model, we compute the overall predictive accuracy, precision, sensitivity, and specificity of our utility function.

Table 5. Prediction results of both samples in percentages

Sample1		Predicted outcomes S1	S2	O
Observed outcomes	S1	30.76%	10.05%	1.37%
	S2	9.62%	31.53%	1.98%
	O	6.01%	5.58%	3.09%
Sample 2		**Predicted outcomes S1**	**S2**	**O**
Observed outcomes	S1	31.19%	9.59%	3.49%
	S2	12.59%	25.08%	2.95%
	O	6.78%	5.38%	2.95%

Table 5 shows the prediction results of Sample 1 which we use to estimate our model and Sample 2 which we use to validate our model. We illustrate the results in percentages by multiplying the results with 100. The frequency for Sample 1 of the TP_1 cases is 30.76% and of the TP_2 cases is 31.53%. In comparison, the frequency for Sample 2 of the TP_1 cases is 31.19% and of the TP_2 cases is 25.08%. Hence, there are only small differences between both samples in frequencies of TP_1 and TP_2. Moreover, we predict for Sample 2 Scenario 1 a bit better than for Sample 1, whereas we have a loss in prediction for Scenario 2. Only approximately 3% of all cases are TN for both samples. In contrast, we observe that the opt-out alternative was chosen approximately 15% out of all cases. Furthermore, if we compare the frequencies of the FP and FN cases for both samples, we find nearly small differences in the range 0.14 to 2.97 percentage points.

Table 6. Evaluation measures in percentages

	Sample 1	Sample 2	Δ
$acc \cdot 100\%$	65.38%	59.23%	6.15 pp
$pre \cdot 100\%$	66.57%	62.11%	4.46 pp
$sen \cdot 100\%$	73.01%	66.29%	6.72 pp
$spc \cdot 100\%$	21.05%	19.55%	1.50 pp

Finally, we calculate the measures to evaluate our model. Table 6 displays the evaluation measures.

We also compute the percentages of the measures by multiplying them with 100. First of all, we see that the overall predictive accuracy for Sample 1 is 65.38%. Therefore, we can improve our prediction accuracy by assuming the utility function of Equation 1. Out of a statistical point of view, where the aim usually is to increase the prediction, the result indicates that the model works. Moreover, we only have a loss of 6.15 percentage points when we predict the outcomes of Sample 2 on the basis of the estimation results from Sample 1. The loss of precision between Samples 1 and 2 is 4.46 percentage points. For this reason, the conditional probability that a predicted *positive* outcome of an individual is correctly predicted as helping in the right scenario is nearly the same.

The sensitivity is between 66.29% for Sample 2 and 73.01% for Sample 1. Thus, both samples have a high value of sensitivity. These findings are very helpful if the interest is to predict an observed outcome correctly compared to the observed helping scenario. Additionally, this means that if we want to predict to which operating site an individual will go, we will have a high success rate. This can be helpful in coordinating spontaneous volunteers. However, another result is that the alternative-specific variables explain especially the scenarios' choice whereas the the individual-specific variables explain the choice of the out-put option. Lastly, our model performs very poorly in predicting the opt-out alternative. One reason could be that we cannot control for all individual-specific attributes which we have found in the literature. To increase the specificity of our model, more individual-specific variables need to be included. Selecting the opt-out alternative depends mostly on individual-specific variables shown in Table 4 and selecting scenario 1 or 2 depend on the alternative-specific variables.

6. Conclusion

Recent disasters have revealed the undeniable importance of spontaneous volunteers for supporting the mitigation of disaster scales. However, several problems regarding the help of spontaneous volunteers have led to the assumption that official disaster managers require insights into spontaneous volunteer behaviors to utilize these volunteers as a valuable resource and to avoid problems related to their support.

To gain these insights, we have developed and performed a discrete choice experiment on attributes that have been identified in a prior study. We have retrieved a model that can, within the frame of the experiments, predict the decisions to help in different scenarios with an accuracy of 65%. The impact of individual attributes could be analyzed and compared to previous studies that have only partly focused on the attributes. Hence, the results can extend previous study results and give interesting insights into volunteers behaviors for practice and disaster research. Furthermore, the retrieved model is necessary to develop a simulation framework to forecast spontaneous volunteers' behaviors since it enables the individuals decision to help within a given scenario and, thus, allows observing emergent behaviors.

However, there are some limitations regarding the proposed experiment and model. Even though students (along with employees) have been the major group of spontaneous volunteers in recent disasters [11], we have exclusively surveyed the attitudes of students, which, thus, is a limiting factor regarding our outcomes. Furthermore, 25 behavior-affecting attributes had been identified within a literature review, but, due to the limitations of discrete choice experiments, we had to reduce the number of observed attributes to 7, which we have done by questioning only some experts. To sum up, discrete choice experiments deliver accurate results for a small number of attributes and can, if extended to a more generic group of participants, deliver even more valuable insights into spontaneous volunteers behavior.

Nevertheless, an analysis of 7 alternative-specific plus 5 individual-specific variables has led to a large improvement in prediction accuracy. Moreover, according to Reunanen, the increase in accuracy by adding more variables in the model would probably be small [56]. Furthermore, the selection of many behavior-affecting attributes can lead to over-fitting the model [56]. Certainly, there are opportunities to improve the model. In order to achieve this goal, however, one would have to either a) detect the subset of the most behavior impacting attributes (e.g. step-wise regression [57]) and perform another discrete choice experiment with this subset to get a frugal model preferable for the sake of statistics, or b) one would have to make use of another statistical method that can take all attributes into consideration, or c) one would need to use a combination of both. Also important, the literature review has proposed deeper investigations on some of the attributes because it revealed contradictory statements to some of the attributes, and, thus, the effect of some attributes is still not clear. A structural equation model (SEM) seems to be promising since SEM enables a more flexible model, which also measures relationships between variables and takes mediator effects into account. SEM can, moreover, incorporate latent variables, which are usually mediators like motivation and empathy.

The analysis provides deep insights into the impacts of attributes on the willingness of spontaneous volunteers to help in disaster situations. These insights are helpful for practitioners. Furthermore, the proposed method and the study results are good foundations for other researchers to extend the investigation or to, e.g., implement the results in a decision support system for disaster managers. For instance, researchers could also emphasize the role of image concerns as a factor of motivation for an interesting next approach. We will address the proposed desiderata within our future research.

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Where to help? — Combining a discrete choice experiment with machine learning algorithms to predict the operating site choice of spontaneous volunteers

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Artifact	Machine Learning Model
Evaluation	Model Performance
Contribution	machine learning model for predicting the operating site choice for spontaneous volunteers

Where to help? — Combining a discrete choice experiment with machine learning algorithms to predict the operating site choice of spontaneous volunteers

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Abstract

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1. Introduction

Over the last decades, the number of natural disasters (Dressler et al., 2016) and also the number of citizens helping spontaneously has increased. Flood disasters are by far the most frequent catastrophes worldwide. Usually encountered by official disaster organizations, recent disasters have also revealed a growing number of citizens spontaneously supporting official disaster personnel in the containment of disaster scales on-site (Hughes & Tapia, 2015). Within the domain of disaster management, these citizens, who spontaneously provide help and resources in disasters, are called spontaneous volunteers (SVs), sometimes also referred to as emergent groups. Both, practice and research community, discuss the support of SVs in natural disasters, resulting in reports about positive and negative impacts on disaster response and recovery (e.g., Coombs, 2016; Harris et al., 2017; dos Santos Rocha et al., 2016). According to reports about recent disasters, such as the Ahr valley flood in 2021 in Germany, the extents might have been much more dramatic, and their effects would have been removed far more slowly without their help (von Hein, 2021).

Nevertheless, disaster managers worldwide have repeatedly claimed criticism about the self-organization of volunteers, who often coordinated themselves via social networks, which led to an unpredictable influx at operating sites. According to reports from recent flood disasters, disaster management authorities were overburdened by the involvement of SVs, leading to overcrowded central operating sites, hampering officials in doing their work as well as to congested roads obstructing emergency forces in their arrival (Coombs, 2016; Hofmann et al., 2014; McLennan et al., 2016). Contradictory, some operating sites in peripheral areas were massively understaffed yet required help to support the official emergency forces. Therefore, disaster managers have called a requirement for improved coordination and information dissemination and general management of SVs (Barraket et al., 2013; Kaufhold & Reuter, 2016; Rauchecker & Schryen, 2018).

The undeniable importance of SVs for disaster management, the lacking knowledge about their behavior along with the complexity of human decisionmaking leads us to the following research question:

RQ: What is an efficient machine learning model to predict the operating site-choice behavior of spontaneous volunteers in flood disasters?

Therefore, our research combines two novel issues: a) using a discrete choice experiment for capturing the operating site decisions of potential SVs and b) applying machine learning algorithms for improving the prediction performance.

In section 2, we provide the fundamentals about SVs in general and their phenomenon in flood disasters in particular, as well as an overview of different applications of machine learning in the context of natural disasters. We will explain the survey and the experimental design of this study in section 3. We present the applied machine learning algorithms and performance metrics used to evaluate the algorithms in section 4. In section 5, we present the study results and conclude the primary outcomes in section 6.

2. Background

In the next step, we elaborate on the state-of-the-art of research in the domain of SVs during natural disasters. Additionally, we exhibit how different machine learning algorithms are used in the different phases of the disaster management cycle to support authorities. The review demonstrates the research gap and promotes to our effort for predicting the operating site choice behavior in order to obtain an improved management of SVs from a disaster manager's perspective. We particularly highlight how machine learning can contribute to this goal.

2.1. Spontaneous Volunteers in Disasters

Even though the term "spontaneous volunteer" has become recognized in the domain of disaster research, terms such as "emergent groups" exist, thus, necessitates a consideration when researching SVs. Regardless of the term, they commonly describe citizens who spontaneously help in coping with disaster scales on-site and who are usually not trained for disaster response activities (Barraket et al., 2013; Kaufhold & Reuter, 2016; Zettl et al., 2017). Further, these kinds of volunteers have no current affiliations with recognized civil protection authorities such as the Red Cross or other governmental emergency or disaster response authorities (Lowe & Fothergill, 2003). SVs are not a new phenomenon; Disaster researchers have observed the role of volunteer citizens since the early 1950s (Wenger, 1991) and especially since the Mexico City Earthquake in 1985, where reportedly over 2 million citizens volunteered in the aftermath (Dynes et al., 1990). However, their role drastically changed by the invention of social media and the increasing interconnection of society (Meissen et al., 2017; Reuter & Kaufhold, 2018). As a result of several past disasters, disaster managers from around the world repeatedly reported SVs to be valuable in the containment of disasters and some disasters would have become much more dramatic without their help (Reuter et al., 2015; dos Santos Rocha et al., 2016). Apart from that, reports also claim criticism on their self-organization leading to operating site overloads, congested roads, and impeding officials from work (Coombs, 2016; McLennan et al., 2016). Thus, people's decisions, where they have wanted to help, have not been in line with official disaster management's requirements and response plans, and disaster managers were not prepared for the imminent volunteer influx (Harris et al., 2017; Persson & Uhnoo, 2021). For this reason, disaster managers have called a requirement for improved management of SVs (Barraket et al., 2013; Kaufhold & Reuter, 2016; Rauchecker & Schryen, 2018). The problems became apparent in several disasters, such as the disastrous floods in Germany in 2013 and, most recently, during the 2021 floods in the Ahr valley in Germany. For instance, in the immediate aftermath of the 2021 floods, the massive societal willingness to help has led to thousands of people arriving at the disaster site by car to provide help and support. Consequently, congested roads hindered disaster response teams in arriving at the disaster area. Overwhelmed by the support, the county administration has forbidden all non-organized volunteers to come to the affected area for one day until establishing an organized approach (Fekete & Sandholz, 2021).

The gap between the SVs as a valuable resource and the problems related to their self-organization has led to new fields in disaster research for improving SV management. On the one hand, researchers aim at coordinating SVs by integrating them into the command-and-control structures of official disaster management or by providing platforms to improve their self-coordination (e.g., Ludwig et al., 2017; Rauchecker & Schryen, 2018). On the other hand, researchers have tried to understand the motivations and drivers of SVs in general to gain insights (Simsa et al., 2019). All approaches deliver important results and provide foundations to promote the improved management of SVs. However, there are also some considerable aspects: 1) The coordination approaches build upon technical infrastructures that can be affected in disasters. E.g., communication infrastructures can easily collapse during a disaster due to the overload caused by frequent information exchange and accumulations of people in disaster areas. In the worst case, such coordination systems would not work reliably and lead to a behavior of citizens as there were no such systems. 2) Some approaches are still in an early phase and have not yet been applied to practice. Hence, their impact on improved disaster management remains unclear.

In addition to spontaneous volunteers, there are also organized/affiliated volunteers and digital volunteers. The motivation of organized volunteers has been intensively investigated (e.g., Anderson & Moore, 1978; Bidee et al., 2013; Miller, 1985; Omoto & Snyder, 1995) and their behavior is generally well predictable since these kinds of volunteers are integrated into command and control structures. Digital volunteers, on the other hand, do not physically provide on-site support and thus represent a separate role, but one that is already the focus of research (e.g., Reuter et al., 2015; dos Santos Rocha et al., 2016).

As described above, there are investigations on spontaneous volunteers, which focus on IT-supported coordination approaches, as well as descriptive analyses of the characteristics of spontaneous volunteers. However, the primary question, namely, where SVs help in particular situations, cannot be answered based on their findings.

2.2. Machine Learning in Natural Disaster Management

The application of machine learning algorithms regarding disaster management has increased over the last years (Chamola et al., 2020; Yu et al., 2018). To provide an overview of disaster-related ML approaches, we classify the research efforts by the disaster management cycle. The disaster management cycle consists of four phases: mitigation, preparedness, response, and recovery (Adams, 1980; Bales, 1996; Maduz et al., 2019; Mayorga et al., 2017; Neal et al., 2011): The mitigation phase refers to the period between two disaster events. It involves reducing long-term risks for people and properties caused by disasters and effects (e.g., vulnerability evaluations). The preparedness phase describes options and measures to prepare for a disaster. Tasks in this phase include developing plans (e.g., hazard maps), establishing early warning systems, and training disaster personnel and affiliated volunteers. The response phase starts in the immediate advent of a disaster. The main goal is to reduce the hazards caused by the disaster and tackle the immediate threats of people and properties, including tasks like search, rescue, and emergency relief. The period of the subsequent recovery phase depends on factors such as the scale and kind of the disaster. The goals are restoring the pre-disaster state by removing and lowering physical, social, and psychological damages. While it is comparatively easy to restore infrastructural problems, the social and psychological problems pose a more important challenge (Bales, 1996; Mayorga et al., 2017; Neal et al., 2011).

To identify used ML approaches for the phases based on the disaster management cycle, we sum up the general literature. On the one hand, to provide an overview of current applications in the disaster context, and, on the other hand, to present the research gap.

For the mitigation or prevention phase, researchers examine the application of ML algorithms to investigate long-term risk assessments and the risk reduction concerning specific disasters (Chamola et al., 2020; Cinnamon et al., 2016; Skakun et al., 2014; Yu et al., 2018). For the preparedness phase, ML algorithms are used for disaster monitoring, detection, or early warning (Akshya & Priyadarsini, 2019; Amit & Aoki, 2017; Anbarasan et al., 2020; Stumpf & Kerle, 2011). Anbarasan et al. (2020), e.g., use a convolutional neural network to predict floods, whereas Stumpf and Kerle (2011) use a random forest classifier for the same purpose. Furthermore, crowd evacuation is a frequently addressed research area. The employed methods range from decision trees, support vector machines to deep neural networks (Anzengruber et al., 2013; Shibata & Yamamoto, 2019; Wolshon, 2008). The response phase is applying ML for damage assessment or post-disaster coordination and response (Amores et al., 2018; Antoniou & Potsiou, 2020; Assery et al., 2019; Imran et al., 2014; Sublime & Kalinicheva, 2019; Tian et al., 2009). For instance, ML algorithms such as random forests are applied to detect damages at buildings (Amores et al., 2018). ML algorithms in the recovery phase are rare and mainly used to get land use information (Ghaffarian & Emtehani, 2021; Jamali et al., 2019; Sheykhmousa et al., 2019).

The literature review indicates that, to the best of our knowledge, no study aims to apply ML algorithms to SVs in general and to the operating site choice behavior of SVs in particular. Hence, the literature highlights the research gap that is addressed in the paper.

3. Experimental design and data description

To enable predictions of the decision where SVs help in a flood disaster for disaster managers, we use a discrete choice experiment (DCE) as data record for our ML model. DCEs underlie the random utility theory (McFadden, 1973; Thurstone, 1927), which assumes that each individual maximizes her/his utility when choosing an alternative. It allows us to predict outcomes for choosing an alternative in a specific setting, a so-called choice set.

Johnson et al. (2013) and Lancsar and Louviere (2008) emphasize the importance of a well-evaluated design for DCEs. To identify relevant attributes and their levels, Lancsar and Louviere (2008) and Maddala et al. (2003) recommend literature reviews or qualitative research methods, e.g., focus groups or interviews. Additionally, the DCE needs to be pre-tested. To align with the requirements for DCEs, we address the requirements as follows: The attributes for our DCE rely on Lindner et al. (2017), which performed a literature review and identified 25 attributes influencing SV behavior. However, the study focuses on attributes and does not consider their according levels required to design a DCE experiment. To validate the literature findings and gain further understanding about the attribute characteristics and levels, we performed a **focus group discussion**. We discussed the attributes with twelve people consisting of experts from the domain of disaster management (3), senior disaster researchers (5) as well as former SVs (4). The discussion led to a reduction of attributes and a consideration of new attributes that might influence the operating site choice behavior from the focus group's perspective.

The focus group suggested including individual-specific and sociodemographic attributes such as gender, social network, and empathy in the survey to improve prediction performance. Along with discussing general attributes, we asked the participants to discuss the levels for the DCE-related alternative-specific attributes. Due to the number of identified attributes (9) for the choice sets and to reduce the cognitive effort in choosing alternatives for the study participant as well as to enable the investigation of interaction effects (Lancsar & Louviere, 2008), we asked our experts to provide three levels per each attribute. The generated attributes, their according levels, a short description, and examples of literature, which show that these attributes are crucial for the decision to help, are presented in Table 1.

[Table 1 Here]

Additional to the alternative-specific variables in Table 1, Lindner et al. (2017) identified further individual-specific variables in their literature review, which has been approved to be included by the focus group. For example, we include gender since we cannot exclude the feature and its influence from the analysis. The empathy-altruism hypothesis describes a need for empathetic emotion for someone in need to trigger altruistic emotions. Psychologists propose empathy as a mediator of pro-social behavior. E.g., Andreoni and Rao (2011) found out that an increase in empathy leads to an increase of altruism in a dictator game. Additionally, people recognize emotional experiences in others, experience matched sensations and emotions, and are motivated to alleviate those others' suffering, frequently resulting in helping behaviors (Batson & Ahmad, 2009; Batson et al., 1991, 1987). For this reason, we incorporate the Mehrabian and Epstein empathy scale in our survey (Mehrabian & Epstein, 1972). Personal social networks can have important influences on helping behaviors (Forbes et al., 2014). For instance, analysis of sports clubs or religious groups found an increased motivation of their members to supply food and clothing to those who lost their homes (Whittaker et al., 2015). Inspired by Amato (1990), we survey the personal network size and the network quality. We supplement our questionnaire with questions about the situational awareness, physical capabilities, education, and experience (Amato, 1990; Andreoni, 1990; McDonald et al., 2015; Whittaker et al., 2015).

After identifying the (alternative-)specific variables, the experimental design needs to be defined. The experimental design combines all attribute levels to construct alternatives and merge them into choice sets (Lancsar and Louviere, 2008). Additionally, implausible combinations, interaction effects, cognitive limitations of the respondents, labeled and constant alternatives, blocking, and overlaps are issues that must be considered (Johnson et al., 2013).

We construct the design according to d-efficiency, a frequently used efficiency measure, using the *dcreate* function incorporated in *Stata 15* (Hole, 2015). This efficiency measure can be used to create an optimal fractional factorial design concerning d-efficiency that allows for the estimation of interaction effects in addition to main effects.

We began our questionnaire with sociodemographic questions and questions about former experiences as SV, followed by the DCE. The DCE design consists of 48 choice sets divided into six blocks with eight choice sets to reduce the cognitive loads for the participants. Prior to the DCE, the participants had an introductory text in which the disaster situation was described. The intention was to enable the participants to put themselves into the disaster situation as good as possible. One exemplarily choice set is presented in Figure 1.

[Figure 1 Here]

We present two alternatives with their corresponding attributes and levels in boxes, and highlight the levels in bold text. Below the tables, the participants were asked to select either one of the scenarios or an opt-out alternative (single-choice). Each scenario thereby represents a specific operating site setting. The choice of a scenario enables us to predict whether an SV will help at all, and if, their operating site preference (where they would prefer to help). After the DCE section within our questionnaire, we provided questions about the additionally selected attributes such as the personal social network size and quality, situational awareness, physical capabilities, and empathy.

To guarantee rigorous research, we pre-tested the whole survey with 100 participants, divided into smaller groups, under the supervision of senior researchers and student assistants. The supervisors took notes on comprehensibility, plausibility, duration, orthography, and grammar during the pre-tests. The overall feedback has been positive and led to minor revisions, especially in the question formulation. The final survey has been separated into both online and street surveys and took place between November 2020 and February 2021. Whereas the online survey was published to gather as many participants as possible, the street survey staff has been advised to collect a well-balanced sample of citizens and took place in several German cities. Beforehand, the street survey staff got an introduction about surveying methodologies. The questionnaire was provided in the German language. The survey was fully anonymized and participation was voluntary. No personal data was collected that would allow conclusions to be drawn about individual persons. As the survey does not contain any ethically sensitive questions, it does not have to be submitted to an ethics committee under current national law.

Our survey resulted in 472 out of 567 completed questionnaires (completion rate = 0.83). In general, we had 3,746 ternary decisions resulting in 11,238 observations. Our sample includes 174 males, 293 females, and five other people. On average, the participants were 28.99 years old with a standard deviation of 10.92. Thus, our sample shifts to be younger and more female than the German population.

4. Methods

We apply ML algorithms to a DCE, since we are particularly interested in prediction performance (Omrani, 2015). One characteristic of ML algorithms is detecting relationships between variables in the data. Therefore, it can often improve the prediction performance compared to other methods. We define different ML models to predict the choice of SV for a specific scenario to help or not with the above-introduced set of features. We investigate several ML algorithms to find the best model concerning prediction performance.

4.1. Performance metrics

In this section, we explain the applied algorithms and their performance criteria. On the one hand, we evaluate the goodness-of-fit by calculating the accuracy, precision, recall, specificity, as recommended by McFadden (1979), as well as the 'Area under the receiver operating characteristic curve' (AUC) and the ROC curves. Accuracy defines the ratio between the correct predictions and the number of all observations. Precision defines the ratio between true-positive predicted outcomes and all positive predicted outcomes. In contrast, recall defines the conditional probability of correctly predicting an observed outcome as a positive outcome. Specificity defines the conditional probability that an observed outcome is predicted correctly as a negative outcome. Lastly, the AUC is a metric that indicates how well an algorithm can distinguish between true-positive and false-positive outcomes (Bradley, 1997).

4.2. Logistic Regression

Firstly, we defined a logit model (GLM) to estimate the outcome. The defined features in section 3 are mapped in the matrix X. Furthermore, the conditional probability for the independent variable to be one on the condition of X is $P(Y = 1|X) = exp(\beta X')/(1 + exp(\beta X'))$ (Hastie et al., 2009), whereas β is a vector of coefficients that explains the influence of the features on the independent variable. The coefficients β are estimated using the iterated re-weighted least squares algorithm for maximizing a penalized likelihood function in *h2o* (Friedman et al., 2010). For prediction performance, we tune the hyperparameters of all algorithms. For the GLM, we get a distribution of regularization between the Lasso and Ridge penalty of 1, which means that the algorithm performs a Lasso regression. Furthermore, we balance the classes of the training data set for all algorithms, since our outcome variable is imbalanced.

4.3. Random forest

The random forest (RF) is a composition of classification trees. n bootstrap samples are drawn from the original data set at the beginning of the algorithm. Subsequently, for each sample, an unpruned classification tree is estimated. To reduce the number of features at each node, *m* predictors are randomly drawn. The most selected class over all trees is used as the final prediction result (Breiman, 2001; Liaw & Wiener, 2002).

After the grid search process, the applied random forest has 150 trees. Four features are randomly drawn at each node. Additionally, the maximum tree depth is 12 and a row sample rate per tree of 0.9 is detected as optimal during the random grid search.

4.4. Gradient boosting

As the random forest algorithm, a number of weak learners (classification trees) are used to create a gradient boosting machine (GBM) (Freund & Schapire, 1997). A classification tree is estimated in each iteration concerning the residuals of the previous iteration by minimizing a loss function. Consequently, the predictions are updated by re-weighting the previous predictions. For creating a GBM, the algorithm recommended by Hastie et al. (2009) is used. In contrast to RFs, all the data is used within each iteration. The residuals depend on the previous iterations, leading to a dependency of the trees. The number of trees is retrieved by a hyperparameter grid search (exact for all algorithms) and finally set to 100. Furthermore, the maximum depth is defined as 14 and the learning rate is set up to 0.03. We also sample with a rate 0.2 from the columns and a row sample rate 0.6 per tree.

4.5. Neural network

Additionally, we apply a feed-forward neural network (NN) to predict the decision of each individual for each alternative. A neural network consists of 3 stages: an input layer, one or more hidden layers, and an output layer. The features provide the input layer, which activates the first hidden layer by an activation function. After traversing all hidden layers, the output layer is formed based on the last neurons considered. Thereby, the networks learn through re-weighting each neuron using back-propagation. Notably, feedforward neural networks do not include cycles or loops within the network (Kraus et al., 2020).

Our input layer consists of 30 features. After tuning, we get the following recommendations for the hyperparameters. The grid search selected two hidden layers as optimal. The first hidden layer has 60 neurons and the second hidden layer has 30 neurons. Furthermore, a rectified linear unit activation function is used. To avoid over-fitting, we define the ℓ_1 regularization parameter to 0.0001 and the ℓ_2 parameter to 0.01. The algorithm terminates after 168 epochs. Additionally, the input dropout rate is defined as 0.1 and the hidden layer dropout rate is respectively 0.3 for each hidden layer. Lastly, the adaptive learning rate is set up to 0.99.

4.6. Naïve Bayes classifier

The Bayes theorem is used as the basis for the naïve Bayes (NB) classifier. The classifier is a simple one and considers all features as independent. Consequently, the NB algorithm assumes that there are no correlations between the explanatory variables. Numeric variables are assumed to follow a normal distribution, with mean and standard deviation estimated based on the training set. The naïve Bayes classifier chooses the class that has the highest posterior probability, which is the product of the features' conditional probabilities given the class times the probability of the respective class (prior) (Friedman et al., 1997).

5. Results

As described in section 4, we apply five different algorithms to predict where to help and compute different performance metrics. All calculations are performed with R using the $h2o$ package (LeDell et al., 2020) as the estimation framework. To evaluate the performance of each ML algorithm, we cross-validate the data using ten folds as recommended by Kohavi (1995).

[Figure 2 Here]

Figure 2 shows the algorithm's performance metrics in terms of the test data. Remarkably, the GBM and RF algorithms outperform the other ones. The median accuracy of the two algorithms is approx. 0.71. Lindner and Herrmann (2020), who analyze a similar discrete choice experiment using a mixed-logit model to predict the decision to help, get an accuracy of 0.59 for their test sample. It indicates that our models substantially improve the prediction accuracy.

The median precision of the RF and GBM algorithm is approx. 0.54. The other algorithms have a lower median precision, with the neural network still closest in the median to the other two algorithms. The slightest standard deviations can be found for the GLM and RF algorithm, whereas the RF algorithm has a standard deviation of 0.0375 (GLM: sd = 0.0316, GBM: sd = 0.0395, NN: sd = 0.0476, NB: sd = 0.0389).

The NB performs best in terms of recall, followed by NN, which has a median recall of 0.804 (RF: x_{med} = 0.801, GBM: x_{med} = 0.787). A high value could indicate that there is an over-fitting problem. However, the specificity values are not remarkably low. The biggest standard deviation for the recall can be found with the NN (sd = 0.0689). Compared to Lindner and Herrmann (2020), who obtained a recall performance of 0.66, all machine learning algorithms in our study perform better. This difference becomes even more apparent when we take a look at the specificity. The NB algorithm interestingly seems to get its good recall performance from its poor specificity performance. Here, the algorithm performs noticeably worse compared to the other algorithms. The RF algorithm has the highest median in terms of specificity, and therefore the algorithm best predicts the observed outcomes as negative ones followed by GBM. Here, Lindner and Herrmann (2020) get a value of 0.20 clearly being outperformed by the algorithms used here. It may occur due to the different methods and the additional variables included in the model in this study.

Lastly, the AUC shows how well the algorithm can distinguish between true-positive and true-negative outcomes. As for most other performance metrics, the GBM and RF outperform the other ones. With a median AUC of approx. 0.79, the RF and GBM show the best performance demonstrated using the ROCs.

Almost all performance metrics favor the GBM and RF algorithm. Due to that, we focus our further analysis on these two algorithms. To reduce the number of features, we look at the relative variable importance according to each algorithm. It is indispensable to reduce the number of variables if the goal is to include the model in a decision support system. Figure 3 displays the 15 most important features regarding the algorithms for classifying the outcome. The feature importance is, simply spoken, its contribution to the classification.

[Figure 3 Here]

The most important variable is *friends* for GBM and *temperature* for RF, followed by other alternative-specific variables from the DCE such as *impact*, *threat*, or *daytime*. Some individual-specific variables such as the two factors of *empathy* or the *social network size* have a decisive impact. To reduce the model, we choose the number of the most important features for each algorithm concerning the variable importance. Feature selection is essential for data mining, especially for high-dimensional data (Kira & Rendell, 1992). Both algorithms show a similar importance structure, indicating the first ten features as reasonable. We, again, analyze the performance of the algorithms for the reduced variable set.

[Figure 4 Here]

Figure 4 shows the performance metrics for the reduced feature sets. Both algorithms perform similarly compared to the full set of variables. We get a median accuracy between 0.68 and 0.70, whereas the GBM achieves the best median accuracy. Additionally, the median precision is slightly better for GBM also compared to the performance using the entire variable set. RF has a higher median recall, but a lower median specificity. The highest median AUC can be observed for the GBM. Because of the minor differences between GBM and RF, both algorithms can be applied to predict where SVs help in a specific situation.

6. Conclusion

SVs are valuable for assisting first responders and civil protection authorities in reducing disaster scales. Nevertheless, their self-coordination and their unpredictable influx at operating sites caused problems such as congested roads and impeding officials in doing their work. The demands for improved SV management became apparent after several recent disasters, with many highly motivated citizens helping on the disaster sites. Whereas coordination approaches constitute a relevant part of SV research in disaster management, predicting the SV influx at operating sites has not yet been investigated. The paper addresses this research gap by providing a new methodical approach to enable and improve the prediction of SV behavior.

We use a DCE to improve the prediction accuracy of SVs. In contrast to Lindner and Herrmann (2020), we incorporate more variables into the experiment as suggested by a focus group. We, therefore, enable a more precise analysis and prediction and provide valuable information for disaster managers and research on SVs. We further choose a different approach to analyze the experiment. Usually, logit or probit models are used to estimate the variable effects and predict the outcomes of a DCE. However, if the main goal is the prediction of decision outcomes, several studies have indicated that ML algorithms can improve prediction performance (Lu et al., 2021; Wang et al., 2021). As a result, we applied several ML algorithms to predict the DCE outcomes. Compared to previous DCEs on the decision to help, our results show a better prediction performance.

Furthermore, we were able to reduce the set of variables for the two best-performing algorithms. The reduction led to ten features for the RF and GBM, whereas the most important variables were *friends* and *temperature* as alternative-specific variables as well as *empathy* as individual-specific variable. Empathy seems to be one of the main drivers for the general decision to help, as indicated by several other studies (Andreoni, 1990; Batson & Ahmad, 2009; Batson et al., 1991).

Within the focus of this research, there are also some limitations. Firstly, we conducted a study exclusively in Germany, resulting in a younger and more female sample compared to the German average. Therefore, we cannot provide representative results in the prediction of SV behaviors. However, the designed questionnaire can be used to gather a more representative sample in the future. A translation to other languages would further enable a) a prediction of SV behaviors in different countries and b) a sociocultural comparison of behaviors and variable importance. Secondly, the prediction accuracy may improve by applying other ML algorithms or changing the ML parameter settings.

Regardless of the limitations, the findings are indispensable for disaster managers as well as the research community and improve information for disaster management. A possible subsequent step is including the GBM or RF model in agent-based simulations to facilitate predictions and analysis on the operating site influx at an emergent level. The operating site choices of numerous people would allow for making predictions on the volunteer influx and, hence, allow supporting disaster managers in an actual disasters or trainings. Furthermore, the paper improves the understanding on operating site choice behavior of SVs.

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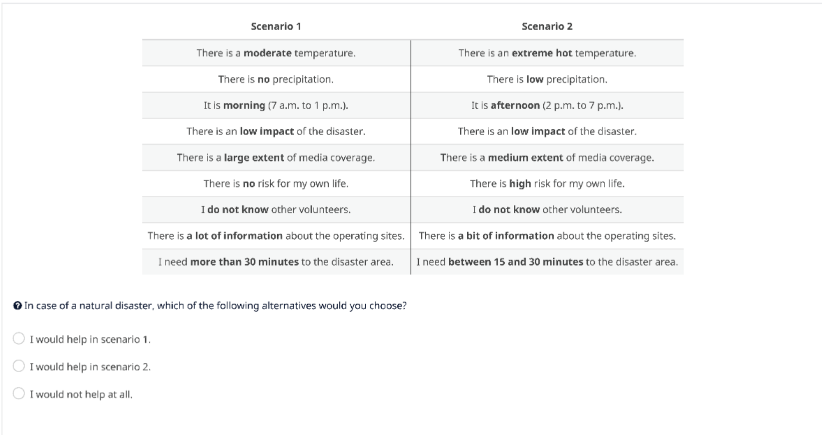
Table 1: Selected alternative-specific attributes

attribute	levels	description	literature
impact	low/medium/severe	The impact of the disaster at the operating site	(Seo et al., 2011)
friends	no/yes	Describes if friends already help at the operating site	(Barraket et al., 2013; McDonald et al., 2015)
exp.time	less than 15 minutes/between 15 and 30 minutes/more than 30 minutes	The expenditure of time to get to the operating site	(Luqman and Griss, 2010; McDonald et al., 2015)
daytime	morning/afternoon/night	The daytime at the operating site	(Lindner and Herrmann, 2020; Paton, 1996)
temp	cold/moderate/hot	The temperature at the operating site	(Belkin and Kouchaki, 2017, Lindner and Herrmann, 2020)
media	low/middle/high	The media coverage about the operating site	(Seo et al., 2011)
precipitation	none/low/heavy	the precipitation at the operating site	(Lindner and Herrmann, 2020)
threat	none/low/high	the risk for the own life at the operating site	
information	no/a bit/a lot	the information about if help is needed at the operating site	(Denis et al., 2014; Kaufhold and Reuter, 2016)



Scenario 1	Scenario 2
There is a **moderate** temperature.	There is an **extreme hot** temperature.
There is **no** precipitation.	There is **low** precipitation.
It is **morning** (7 a.m. to 1 p.m.).	It is **afternoon** (2 p.m. to 7 p.m.).
There is an **low impact** of the disaster.	There is an **low impact** of the disaster.
There is a **large extent** of media coverage.	There is a **medium extent** of media coverage.
There is **no** risk for my own life.	There is **high** risk for my own life.
I **do not know** other volunteers.	I **do not know** other volunteers.
There is **a lot of information** about the operating sites.	There is **a bit of information** about the operating sites.
I need **more than 30 minutes** to the disaster area.	I need **between 15 and 30 minutes** to the disaster area.

In case of a natural disaster, which of the following alternatives would you choose?

- I would help in scenario 1.
- I would help in scenario 2.
- I would not help at all.

Figure 1: Choice set example

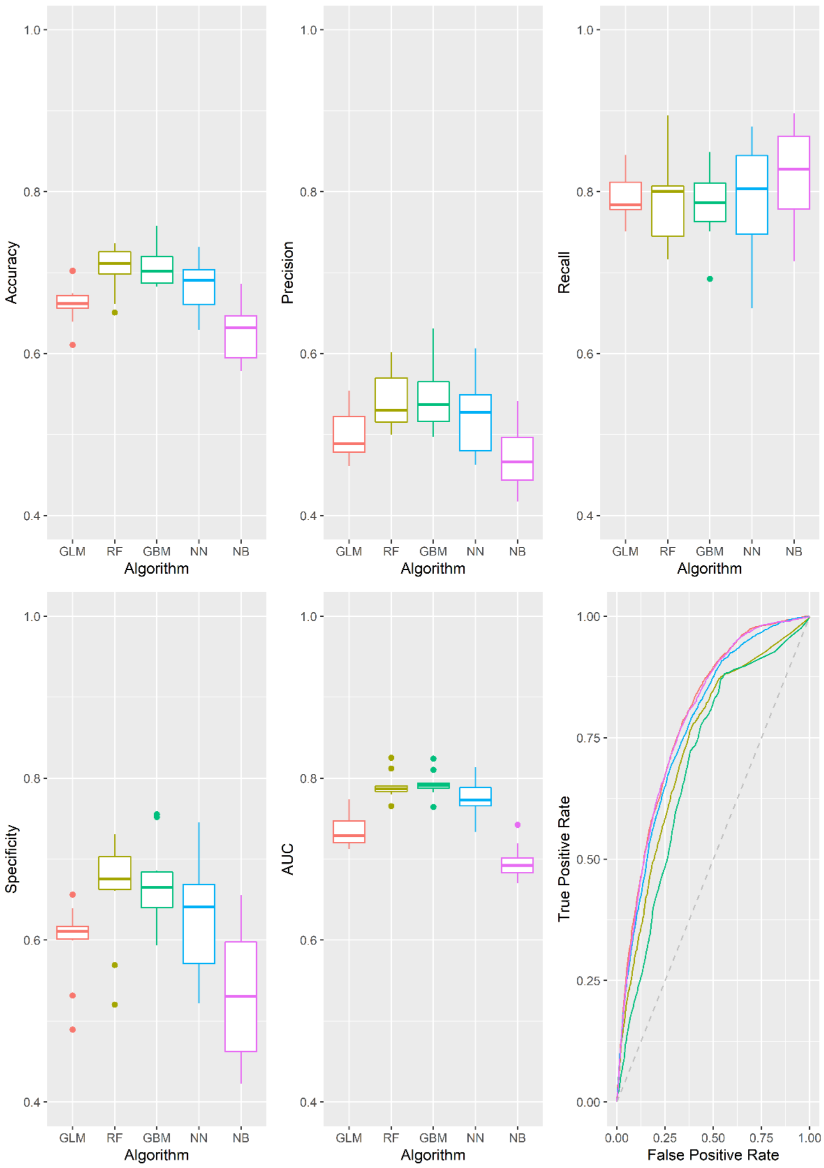


Figure 2: Performance metrics of the algorithms

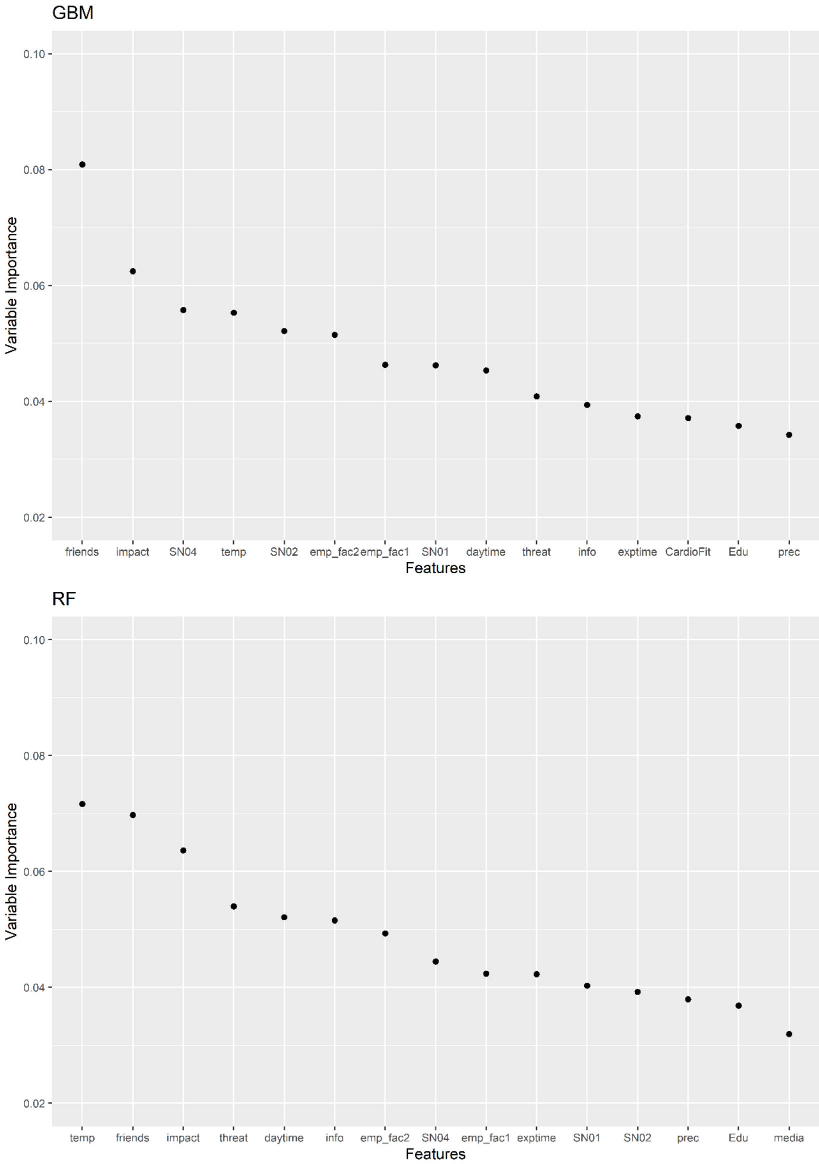


Figure 3: Variable importance of the GBM and RF

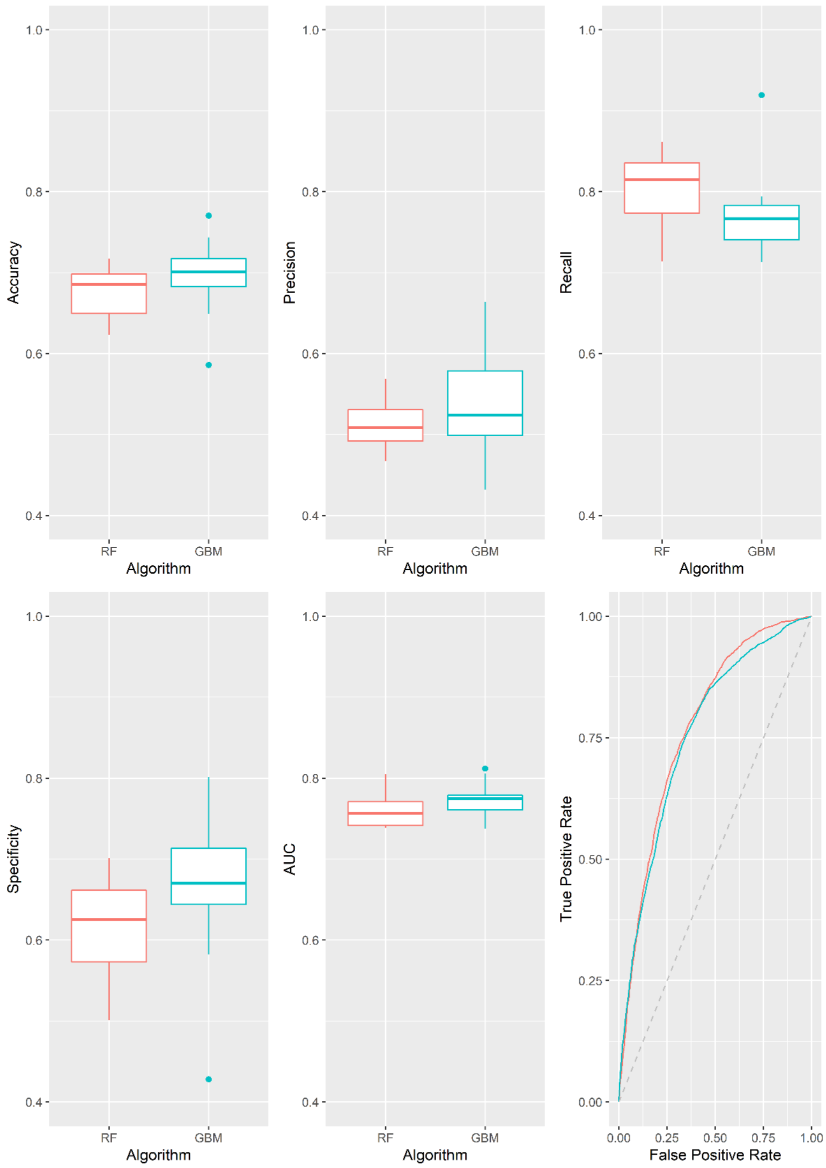


Figure 4: Performance metrics for the reduced variable set

Questionnaire on the Performance Expectancy, Effort Expectancy, and Plausibility of IS2SAVE (in German)

Fragebogen zur Erhebung der Leistungserwartung, Aufwandserwartung und Plausibilität von IS2SaVe

Liebe Teilnehmende,

mein Name ist Sebastian Lindner, wissenschaftlicher Mitarbeiter an der Martin-Luther-Universität Halle-Wittenberg. Im Rahmen meiner Promotion im Bereich Wirtschaftsinformatik habe ich ein Informationssystem entwickelt, das Krisenstäben Vorhersagen über den Zustrom von Spontanhelfenden an Einsatzorten in verschiedenen Hochwasserszenarien ermöglichen soll. Das System wird im weiteren Verlauf als *IS2SAVE* bezeichnet.

Ich wäre Ihnen sehr dankbar, wenn Sie sich etwa **20 Minuten** Zeit nehmen könnten, um meine Forschungsarbeit zu unterstützen.

Hintergrund und Auslöser meiner Forschung

Die Vergangenheit hat gezeigt, dass Hochwasserkatastrophen, wie das Jahrhunderthochwasser 2013, auch in Deutschland unvorhergesehen auftreten können. In solchen Ausnahmesituationen erklären sich, neben den offiziellen Einsatzkräften, auch immer wieder Menschen aus der Bevölkerung spontan dazu bereit zu helfen. Tatsächlich wären die Ausmaße vergangener Katastrophen, ohne die Hilfe sogenannter Spontanhelfender deutlich gravierender gewesen. Jedoch ist anzumerken, dass die umfangreiche Bereitschaft der Zivilbevölkerung teilweise die Arbeit der offiziellen Einsatzkräfte am Einsatzort eingeschränkt oder erschwert hat. Ausgehend von der hohen Relevanz der Spontanhelfenden haben Forschende IT-gestützte Lösungsansätze bspw. zur Koordinierung entwickelt. Die Vorhersage der spontanen Hilfe der Zivilbevölkerung und der damit einhergehende Zustrom an Einsatzorten ist bis dato ein offenes Forschungsfeld, das ich im Rahmen meiner Promotion mit dem Ihnen zuvor präsentieren Szenario-basierten Vorhersagesystem *IS2SAVE* adressiere. Die Vorhersagen des Systems ermöglichen Krisenstäben „was-wäre- wenn-Analysen“ zu Trainings- oder Planungszwecken ebenso wie Entscheidungsgrundlagen im operativen Katastrophenmanagement.

Mit der Teilnahme am Fragebogen ermöglichen Sie mir eine Einschätzung, ob *IS2SAVE* aus Expertensicht eine praktische Relevanz hat. Weiterhin bilden die erhobenen Daten die Grundlage für Evaluierung der im System generierten Vorhersagen.

Hinweise zum Fragebogen

Der Fragebogen beinhaltet verschiedene Fragetypen. Wenn Sie eine Frage nicht beantworten möchten, lassen Sie diese einfach aus. Alle Daten werden anonym erhoben, können Ihrer Person nicht zugeordnet werden und werden streng vertraulich behandelt.

Die Daten werden ausschließlich für wissenschaftliche Forschungszwecke und unter Einhaltung der gesetzlichen Vorschriften zum Datenschutz verwendet. Die Ergebnisse der Studie werden wissenschaftlich publiziert. Falls Sie Interesse an den Ergebnissen der Studie haben, können Sie mich jederzeit kontaktieren. Schreiben Sie mir hierfür eine E-Mail an meine E-Mail-Adresse oder scannen Sie den QR-Code.

Vielen Dank für Ihre Teilnahme.

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Sebastian Lindner
Martin-Luther-Universität Halle-Wittenberg

Teil 1: Fragen zur Berufserfahrung (JE)

JE01	Wie viele Jahre Berufserfahrung weisen Sie im Bereich des Katastrophenschutzes auf?	__________ Jahre
JE02	Wo können Sie sich zuordnen? Bitte kreuzen Sie an.	☐ Mittlerer feuerwehrtechnischer Dienst ☐ Gehobener feuerwehrtechnischer Dienst ☐ Höherer feuerwehrtechnischer Dienst ☐ Sonstiges: ____________________________
JE03	Wie lautet Ihre aktuelle Berufsbezeichnung?	____

Teil 2: Leistungs- und Aufwandserwartung

Im Folgenden bitte ich Sie, basierend auf Ihren (bereits gesammelten) beruflichen Erfahrungen, eine Einschätzung der untenstehenden Aussagen. Die Aussagen beziehen sich dabei auf das IS2SAVE-System. Ihre Einschätzung erfolgt auf einer 7-stufigen Likert-Skala. Bitte setzen Sie ein deutlich zu erkennendes Kreuz bei der Ausprägung, die Ihrer Meinung nach am meisten zutrifft.

☒ Auswahl ■ Korrektur

Leistungserwartung an IS2SAVE (PE)

		stimme gar nicht zu	stimme nicht zu	stimme eher nicht zu	teils, teils	stimme eher zu	stimme zu	stimme vollständig zu
PE01	IS2SAVE hilft mir die Produktivität in meiner beruflichen Tätigkeit zu erhöhen. *(z.B.: IS2SAVE ermöglicht mir Übungen ohne großen Vorbereitungsaufwand durchzuführen)*	☐	☐	☐	☐	☐	☐	☐
PE02	IS2SAVE hilft mir schneller auf Schadenslagen mit Spontanhelfenden zu reagieren. *(z.B.: IS2SAVE ermöglicht mir unterversorgte/überfüllte Einsatzorte rechtzeitig zu erkennen)*	☐	☐	☐	☐	☐	☐	☐
PE03	IS2SAVE hilft mir besser auf Schadenslagen mit Spontanhelfenden zu reagieren *(z.B.: IS2SAVE ermöglicht mir auf neue Situationen vorbereitet zu sein und Maßnahmen zu planen)*	☐	☐	☐	☐	☐	☐	☐
PE04	Allgemein empfinde ich IS2SAVE nützlich für das Katastrophenmanagement.	☐	☐	☐	☐	☐	☐	☐

Aufwandserwartung an IS2SAVE (EE)

		stimme gar nicht zu	stimme nicht zu	stimme eher nicht zu	teils, teils	stimme eher zu	stimme zu	stimme vollständig zu
EE01	Es fällt mir leicht, die Nutzung von IS2SAVE zu erlernen.	☐	☐	☐	☐	☐	☐	☐
EE02	Der Umgang mit IS2SAVE ist klar und verständlich für mich.	☐	☐	☐	☐	☐	☐	☐
EE03	Ich finde IS2SAVE einfach zu bedienen.	☐	☐	☐	☐	☐	☐	☐
EE04	Es fällt mir leicht, geübt in der Nutzung von IS2SAVE zu werden.	☐	☐	☐	☐	☐	☐	☐

Teil 3: Plausibilität des Systems (PS)

Der folgende Teil zielt auf die Evaluierung der Plausibilität des IS2SAVE-Systems ab. Plausibilität bedeutet dabei, ob der Zustrom der Spontanhelfenden aus Ihrer Erfahrung heraus so auch in der Realität stattfinden kann. Ihnen werden insgesamt drei Szenarien präsentiert. Zu Beginn jedes Szenarios wird Ihnen die Ausgangssituation und der entsprechende Zustrom an Spontanhelfenden beschrieben. Anschließend daran werden Ihnen jeweils zwei weitere Ereignisse präsentiert, für die sie jeweils die Auswirkungen auf die Beteiligung der Spontanhelfenden einschätzen sollen.

Allen Szenarien liegt die folgende Ausgangssituation zugrunde:

Es findet ein Hochwasser in und um das Stadtgebiet von Halle (Saale) statt. Insgesamt stehen 700 Spontanhelfende zur Verfügung. Es werden drei Einsatzorte (*EO*) mit einem Bedarf von jeweils 80 Spontanhelfenden für den Zeitraum der Schadenslage gestellt.

Hinweis: *Im dargebotenen Szenario wird von Informationen zu den Einsatzorten gesprochen, welche wie folgt interpretiert werden können.*

Keine Informationen: Die Spontanhelfenden wissen, dass der Einsatzort existiert. Jedoch sind dessen Standort oder Helferbedarfe nicht bekannt.
Wenige Informationen: Die Spontanhelfenden kennen den Standort des Einsatzortes. Die Spontanhelfenden wissen nur teilweise Bescheid, ob Hilfe an den Einsatzorten benötigt wird.
Viele Informationen: Die Spontanhelfenden wissen, dass ihre Hilfe am Einsatzort benötigt wird.

Unter Medienberichterstattung werden alle Formen der Berichterstattung verstanden (Soziale Medien, Fernsehen, Radio, Printmedien, Online-Nachrichten).

***Karte:** Standorte der Einsatzorte*

Szenario 1

Ausgangssituation		
Am 07.07.2022, 08:00 Uhr werden die drei zuvor genannten Einsatzorte eingerichtet. Die Temperatur ist moderat und es regnet nicht. Die Ausmaße der Katastrophe sind an allen Einsatzorten sichtbar, aber nicht extrem und das Risiko für Spontanhelfende ist niedrig. Durch die geringe mediale Berichterstattung stehen den Spontanhelfenden nur wenige Informationen über die Einsatzorte zur Verfügung. In den ersten Stunden nach Bekanntwerden der Einsatzorte finden sich schnell Spontanhelfende an den Einsatzorten ein. Durch seine zentrale Lage wird *EO Zentrum* zunächst bevorzugt. Die Vielzahl an Helfenden führt jedoch dazu, dass teilweise Spontanhelfende an diesem Einsatzort zurückgewiesen werden. Die allgemeine Bereitschaft zu helfen, ist dennoch sehr hoch. Die Spontanhelfenden bieten ihre Hilfe am nächstgelegenen *EO Süd* an. Die Bedarfe an *EO Süd* und *EO Zentrum* können durch Spontanhelfende gedeckt werden. Weiterhin werden die zwei Einsatzorte gegenüber dem, deutlich außerhalb liegenden, *EO Brachwitz* bevorzugt. Im Vergleich zu den zentraleren Einsatzorten helfen am *EO Brachwitz* deutlich weniger Spontanhelfende. An allen Einsatzorten ist ein deutlicher Rückgang der Hilfsbeteiligung in der Nacht zu erkennen.		
SF1	Könnte das Szenario so in der Realität stattfinden bzw. stattgefunden haben?	☐ Ja ☐ Nein
S1FP	Wenn ja, für wie plausibel halten Sie den beschriebenen Zustrom bzw. die Beteiligung der Spontanhelfenden an den Einsatzorten? ☐ niedrig ☐ mittel ☐ hoch	
	Begründung *(optional):*	

Unabhängig von Ihrer Einschätzung, bitte ich Sie, die nachfolgenden Ereignisse und deren Auswirkungen auf den Zustrom von Spontanhelfenden zu bewerten.

Ereignis 1
09.07.2022, 15:00 Uhr: Starker Niederschlag setzt ein
Beschreibung
Die Temperatur ist nach wie vor moderat, allerdings setzt plötzlich ein starker Regenschauer ein.

Beurteilen Sie, wie sich das Ereignis auf die Unterstützung der Spontanhelfenden auswirkt.

		Nimmt stark ab	Nimmt eher ab	Bleibt unverändert	Nimmt eher zu	Nimmt stark zu
S1SIE11	Die allgemeine Unterstützung durch Spontanhelfende …	☐	☐	☐	☐	☐
S1SIE12	Der Zustrom an Spontanhelfenden an *EO Brachwitz …*	☐	☐	☐	☐	☐
S1SIE13	Der Zustrom an Spontanhelfenden an *EO Zentrum …*	☐	☐	☐	☐	☐
S1SIE14	Der Zustrom an Spontanhelfenden an *EO Süd …*	☐	☐	☐	☐	☐

Gibt es Unterschiede in der Auslastung der Einsatzorte mit Spontanhelfenden?

Ordnen Sie die Einsatzorte nach der Auslastung mit Spontanhelfenden. Setzen Sie hierfür ein Kreuz bei der jeweiligen Nummer, wobei 3 die höchste und 1 die geringste Auslastung darstellt.

		1	2	3
S1SUE11	*EO Brachwitz*	☐	☐	☐
S1SUE12	*EO Zentrum*	☐	☐	☐
S1SUE13	*EO Süd*	☐	☐	☐

<u>Beispiel</u>

Die meisten Helfenden sind am EO Brachwitz, EO Zentrum und EO Süd sind gleich ausgelastet, aber geringer als EO Brachwitz.

		1	2	3
SUE11	*EO Brachwitz*	☐	☐	☒
SUE12	*EO Zentrum*	☐	☒	☐
SUE13	*EO Süd*	☐	☒	☐

Ereignis 2
12.07.2022, 07:00 Uhr: Starke Medienberichterstattung
Beschreibung
Die Temperatur ist nach wie vor moderat. Der Regenschauer ist vorbei. Der Regenschauer hat jedoch dazu geführt, dass die Katastrophenausmaße an *EO Brachwitz* deutlich zugenommen haben und gravierend ausfallen. Durch das Ausmaß der Katastrophe findet eine starke Medienberichterstattung über diesen Einsatzort statt. Die Spontanhelfenden haben nun viele Informationen über *EO Brachwitz*. Die Lage an *EO Süd* ist unverändert. Während an *EO Brachwitz* die Ausmaße deutlich zunehmen, konnten die Ausmaße am *EO Zentrum* bereits deutlich reduziert werden, sodass diese dort nur noch gering sind.

Beurteilen Sie, wie sich das Ereignis auf die Unterstützung der Spontanhelfenden auswirkt.

		Nimmt stark ab	**Nimmt eher ab**	**Bleibt unverändert**	**Nimmt eher zu**	**Nimmt stark zu**
S1SIE21	Die allgemeine Unterstützung durch Spontanhelfende …	☐	☐	☐	☐	☐
S1SIE22	Der Zustrom an Spontanhelfenden an *EO Brachwitz* …	☐	☐	☐	☐	☐
S1SIE23	Der Zustrom an Spontanhelfenden an *EO Zentrum* …	☐	☐	☐	☐	☐
S1SIE24	Der Zustrom an Spontanhelfenden an *EO Süd* …	☐	☐	☐	☐	☐

Gibt es Unterschiede in der Auslastung der Einsatzorte mit Spontanhelfenden?

Ordnen Sie die Einsatzorte nach Auslastung mit Spontanhelfenden. Setzen Sie hierfür ein Kreuz bei der jeweiligen Nummer, wobei 3 die höchste und 1 die geringste Auslastung darstellt.

		1	**2**	**3**
S1SUE21	*EO Brachwitz*	☐	☐	☐
S1SUE22	*EO Zentrum*	☐	☐	☐
S1SUE23	*EO Süd*	☐	☐	☐

Beispiel

Die meisten Helfenden sind am EO Brachwitz, EO Zentrum und EO Süd sind gleich ausgelastet, aber geringer als EO Brachwitz.

		1	**2**	**3**
SUE11	*EO Brachwitz*	☐	☐	☒
SUE12	*EO Zentrum*	☐	☒	☐
SUE13	*EO Süd*	☐	☒	☐

Szenario 2

Ausgangssituation		
Am 07.07.2022, 08:00 Uhr werden die drei zuvor genannten Einsatzorte eingerichtet. Es herrschen sommerliche Temperaturen und es regnet nicht. Das Ausmaß der Katastrophe ist an allen Einsatzorten eher moderat und das Risiko für Spontanhelfende gering. Die Spontanhelfenden wissen über die Existenz der Einsatzorte. Für *EO Brachwitz* und *EO Süd* liegen ihnen allerdings keine Informationen über Helferbedarfe oder deren konkrete Lage vor. Weiterhin gibt es keine Medienberichterstattung über diese Einsatzorte. Anders ist es bei *EO Zentrum.* Zwar liegen den Spontanhelfenden einige wenige Informationen über diesen Einsatzort vor, aber die Berichterstattung ist immer noch gering. Dennoch findet sich eine deutliche Mehrheit der Spontanhelfenden am *EO Zentrum* ein. Es sind so viele Helfende dort, dass die Bedarfe gedeckt und sogar Helfende zurückgewiesen werden müssen. Auch an den beiden anderen Einsatzorten wird, wenngleich deutlich weniger, geholfen. Die Spontanhelfenden präferieren klar *EO Zentrum*. Die Auslastungen der anderen beiden Einsatzorte sind vergleichbar gering. An allen Einsatzorten ist ein deutlicher Rückgang der Hilfsbeteiligung in der Nacht zu erkennen. Allerdings sind, im Vergleich zu *EO Brachwitz* und *EO Süd*, selbst in der Nacht einige Helfende am *EO Zentrum* anzutreffen.		
SF2	Könnte das Szenario so in der Realität stattfinden bzw. stattgefunden haben?	☐ Ja ☐ Nein
S2FP	Wenn ja, für wie plausibel halten Sie den beschriebenen Zustrom bzw. die Beteiligung der Spontanhelfenden an den Einsatzorten? ☐ niedrig ☐ mittel ☐ hoch	
	Begründung *(optional):*	

Unabhängig von Ihrer Einschätzung, bitte ich Sie, die nachfolgenden Ereignisse und deren Auswirkungen auf den Zustrom von Spontanhelfenden zu bewerten.

Ereignis 1
10.07.2022, 15:00 Uhr: Zunehmende Ausmaße an EO SÜD
Beschreibung
Das sommerliche Wetter hält an. Mittlerweile berichten die Medien zumindest teilweise über EO Brachwitz. Die Lage an *EO Zentrum* ist unverändert. Das Hochwasser hat sich allerdings deutlich ausgebreitet, was insbesondere am *EO Süd* zu spüren ist. Dort liegen nun schwerwiegende Katastrophenausmaße vor. Dies hat unter anderem dazu geführt, dass die Berichterstattung über den Einsatzort stark erhöht wurde. Die Spontanhelfenden haben nun sehr viele Informationen zu Helferbedarfen am Einsatzort.

Beurteilen Sie, wie sich das Ereignis auf die Unterstützung der Spontanhelfenden auswirkt.

		Nimmt stark ab	**Nimmt eher ab**	**Bleibt unverändert**	**Nimmt eher zu**	**Nimmt stark zu**
S2SIE11	Die allgemeine Unterstützung durch Spontanhelfende …	☐	☐	☐	☐	☐
S2SIE12	Der Zustrom an Spontanhelfenden an *EO Brachwitz …*	☐	☐	☐	☐	☐
S2SIE13	Der Zustrom an Spontanhelfenden an *EO Zentrum …*	☐	☐	☐	☐	☐
S2SIE14	Der Zustrom an Spontanhelfenden an *EO Süd …*	☐	☐	☐	☐	☐

Gibt es Unterschiede in der Auslastung der Einsatzorte mit Spontanhelfenden?

Ordnen Sie die Einsatzorte nach der Auslastung mit Spontanhelfenden. Setzen Sie hierfür ein Kreuz bei der jeweiligen Nummer, wobei 3 die höchste und 1 die geringste Auslastung darstellt.

		1	**2**	**3**
S2SUE11	*EO Brachwitz*	☐	☐	☐
S2SUE12	*EO Zentrum*	☐	☐	☐
S2SUE13	*EO Süd*	☐	☐	☐

<u>Beispiel</u>

Die meisten Helfenden sind am EO Brachwitz, EO Zentrum und EO Süd sind gleich ausgelastet, aber geringer als EO Brachwitz.

		1	**2**	**3**
SUE11	*EO Brachwitz*	☐	☐	☒
SUE12	*EO Zentrum*	☐	☒	☐
SUE13	*EO Süd*	☐	☒	☐

Ereignis 2
12.07.2022, 07:00 Uhr: Neue Risikobewertung
Beschreibung
Eine neue Risikobewertung hat dazu geführt, dass das Risiko für Spontanhelfende am *EO Zentrum* als sehr hoch eingeschätzt wird. Im Vergleich dazu konnte die Katastrophe am *EO Brachwitz* weitestgehend abgewendet werden. Dort sind die Ausmaße nur noch geringfügig spürbar. Am *EO Süd* ist die Lage weiterhin angespannt. Die Medien berichten intensiv über die Situation am *EO Süd* und es liegen viele Informationen vor. Dort wird das Risiko für Spontanhelfende weiterhin als gering eingeschätzt.

Beurteilen Sie, wie sich das Ereignis auf die Unterstützung der Spontanhelfenden auswirkt.

		Nimmt stark ab	**Nimmt eher ab**	**Bleibt unverändert**	**Nimmt eher zu**	**Nimmt stark zu**
S2SIE21	Die allgemeine Unterstützung durch Spontanhelfende …	☐	☐	☐	☐	☐
S2SIE22	Der Zustrom an Spontanhelfenden an *EO Brachwitz …*	☐	☐	☐	☐	☐
S2SIE23	Der Zustrom an Spontanhelfenden an *EO Zentrum …*	☐	☐	☐	☐	☐
S2SIE24	Der Zustrom an Spontanhelfenden an *EO Süd …*	☐	☐	☐	☐	☐

Gibt es Unterschiede in der Auslastung der Einsatzorte mit Spontanhelfenden?

Ordnen Sie die Einsatzorte nach der Auslastung mit Spontanhelfenden. Setzen Sie hierfür ein Kreuz bei der jeweiligen Nummer, wobei 3 die höchste und 1 die geringste Auslastung darstellt.

		1	**2**	**3**
S2SUE21	*EO Brachwitz*	☐	☐	☐
S2SUE22	*EO Zentrum*	☐	☐	☐
S2SUE23	*EO Süd*	☐	☐	☐

<u>Beispiel</u>

Die meisten Helfenden sind am EO Brachwitz, EO Zentrum und EO Süd sind gleich ausgelastet, aber geringer als EO Brachwitz.

		1	2	3
SUE11	*EO Brachwitz*	☐	☐	☒
SUE12	*EO Zentrum*	☐	☒	☐
SUE13	*EO Süd*	☐	☒	☐

Szenario 3

Ausgangssituation		
Am 07.07.2022, 08:00 Uhr werden die drei zuvor genannten Einsatzorte eingerichtet. Es herrschen moderate Temperaturen und es regnet nicht. Die Ausmaße der Katastrophe sind zunächst an allen Einsatzorten sehr gering und es herrscht an keinem der Einsatzorte ein Risiko für Spontanhelfende. Auch wenn bereits Spontanhelfende benötigt werden, um sich gegen eine potenzielle Ausweitung der Ausmaße zu schützen, berichten die Medien nicht darüber. Den Spontanhelfenden liegen keine Informationen vor. Dennoch finden sich Spontanhelfende an den Einsatzorten ein, um zu helfen. Insgesamt werden die zentralen Einsatzorte *EO Süd* und *EO Zentrum* etwas gegenüber *EO Brachwitz* von den Helfenden bevorzugt. An allen Einsatzorten ist ein deutlicher Rückgang der Hilfsbeteiligung in der Nacht zu erkennen.		
SF3	Könnte das Szenario so in der Realität stattfinden bzw. stattgefunden haben?	☐ Ja ☐ Nein
S3FP	Wenn ja, für wie plausibel halten Sie den beschriebenen Zustrom bzw. die Beteiligung der Spontanhelfenden an den Einsatzorten? ☐ niedrig ☐ mittel ☐ hoch	
	Begründung *(optional):*	

Unabhängig von Ihrer Einschätzung, bitte ich Sie, die nachfolgenden Ereignisse und deren Auswirkungen auf den Zustrom von Spontanhelfenden zu bewerten.

Ereignis 1
09.07.2022, 11:00 Uhr: Gefährdung nimmt zu
Beschreibung
Die Ausmaße der Katastrophe steigen an allen Einsatzorten auf ein mittleres Maß an. Ebenso besteht jetzt für Spontanhelfende ein geringes Risiko. Während über *EO Brachwitz* nach wie vor keine Informationen vorliegen und es keine Berichterstattung gibt, fangen die Medien langsam an über *EO Süd* und *EO Zentrum* zu berichten. Den Spontanhelfenden liegen jedoch nur wenige Informationen zu den Einsatzorten vor.

Beurteilen Sie, wie sich das Ereignis auf die Unterstützung der Spontanhelfenden auswirkt.

		Nimmt stark ab	**Nimmt eher ab**	**Bleibt unverändert**	**Nimmt eher zu**	**Nimmt stark zu**
S3SIE11	Die allgemeine Unterstützung durch Spontanhelfende …	☐	☐	☐	☐	☐
S3SIE12	Der Zustrom an Spontanhelfenden an *EO Brachwitz* …	☐	☐	☐	☐	☐
S3SIE13	Der Zustrom an Spontanhelfenden an *EO Zentrum* …	☐	☐	☐	☐	☐
S3SIE14	Der Zustrom an Spontanhelfenden an *EO Süd* …	☐	☐	☐	☐	☐

Gibt es Unterschiede in der Auslastung der Einsatzorte mit Spontanhelfenden?

Ordnen Sie die Einsatzorte nach der Auslastung mit Spontanhelfenden. Setzen Sie hierfür ein Kreuz bei der jeweiligen Nummer, wobei 3 die höchste und 1 die geringste Auslastung darstellt.

		1	**2**	**3**
S3SUE11	*EO Brachwitz*	☐	☐	☐
S3SUE12	*EO Zentrum*	☐	☐	☐
S3SUE13	*EO Süd*	☐	☐	☐

Beispiel

Die meisten Helfenden sind am EO Brachwitz, EO Zentrum und EO Süd sind gleich ausgelastet, aber geringer als EO Brachwitz.

		1	2	3
SUE11	*EO Brachwitz*	☐	☐	☒
SUE12	*EO Zentrum*	☐	☒	☐
SUE13	*EO Süd*	☐	☒	☐

Ereignis 2
11.07.2022, 15:00 Uhr: Kein Risiko mehr am EO Süd
Beschreibung
Mittlerweile berichten die Medien über *EO Brachwitz*, wodurch die Spontanhelfenden Informationen über den Einsatzort erhalten. Die Situation am *EO Zentrum* ist unverändert. Am *EO Süd* haben die Ausmaße der Katastrophe derweil deutlich zugenommen. Dennoch konnte die Gefährdung für Spontanhelfende deutlich reduziert werden, sodass nun kein Risiko mehr für sie besteht.

Beurteilen Sie, wie sich das Ereignis auf die Unterstützung der Spontanhelfenden auswirkt.

		Nimmt stark ab	Nimmt eher ab	Bleibt unverändert	Nimmt eher zu	Nimmt stark zu
S3SIE21	Die allgemeine Unterstützung durch Spontanhelfende …	☐	☐	☐	☐	☐
S3SIE22	Der Zustrom an Spontanhelfenden an *EO Brachwitz …*	☐	☐	☐	☐	☐
S3SIE23	Der Zustrom an Spontanhelfenden an *EO Zentrum …*	☐	☐	☐	☐	☐
S3SIE24	Der Zustrom an Spontanhelfenden an *EO Süd …*	☐	☐	☐	☐	☐

Gibt es Unterschiede in der Auslastung der Einsatzorte mit Spontanhelfenden?

Ordnen Sie die Einsatzorte nach der Auslastung mit Spontanhelfenden. Setzen Sie hierfür ein Kreuz bei der jeweiligen Nummer, wobei 3 die höchste und 1 die geringste Auslastung darstellt.

		1	2	3
S3SUE21	*EO Brachwitz*	☐	☐	☐
S3SUE22	*EO Zentrum*	☐	☐	☐
S3SUE23	*EO Süd*	☐	☐	☐

Beispiel

Die meisten Helfenden sind am EO Brachwitz, EO Zentrum und EO Süd sind gleich ausgelastet, aber geringer als EO Brachwitz.

		1	2	3
SUE11	*EO Brachwitz*	☐	☐	☒
SUE12	*EO Zentrum*	☐	☒	☐
SUE13	*EO Süd*	☐	☒	☐

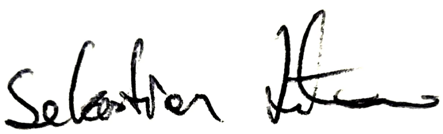
Teil 4: Anmerkungen

Sie haben nun die Möglichkeit weitere Anmerkungen, Anregungen, Feedback o.ä. zu geben.

Vielen Dank für Ihre Teilnahme!

Eidesstattliche Erklärung über verwendete Hilfsmittel

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertation selbstständig und ohne unerlaubte Hilfe angefertigt sowie keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe. Alle aus anderen Werken bzw. von anderen Autoren inhaltlich übernommenen Stellen wurden in der vorliegenden Dissertation als solche kenntlich gemacht und entsprechend zitiert.



Halle (Saale), 10. Oktober 2022