# 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

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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).

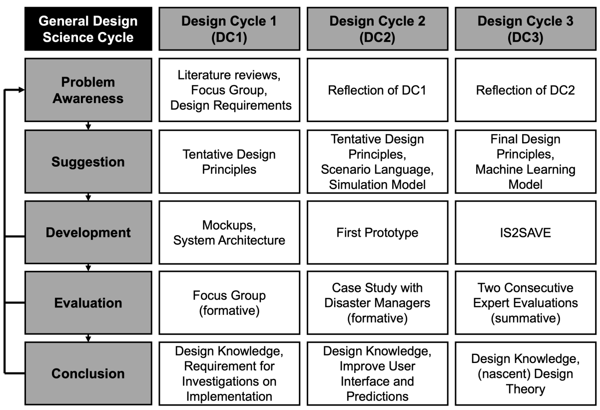


**Figure 1. Design science research approach for IS2SAVE (following Vaishnavi and Kuechler 2015).**

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.

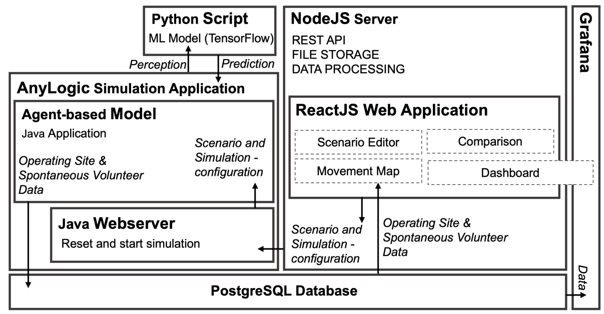


**Figure 2. Simplified architecture of the IS2SAVE prototype.**

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).

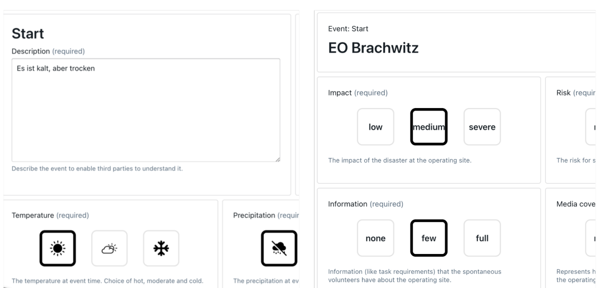


**Figure 3. IS2SAVE scenario editor (screenshot).**

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

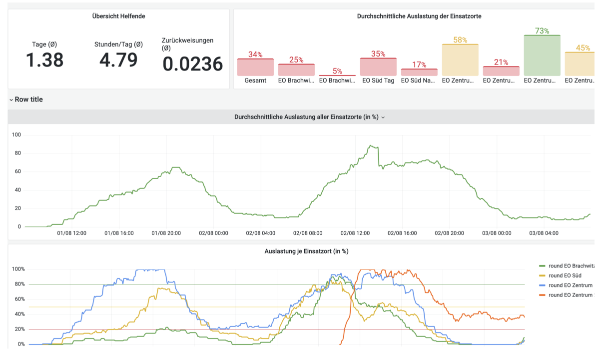


**Figure 4. IS2SAVE dashboard (screenshot).**

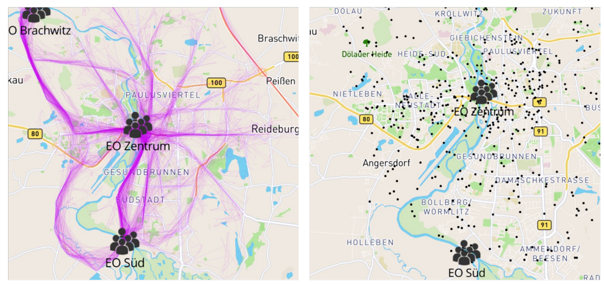


**Figure 5. IS2SAVE movement maps (screenshot).**

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).

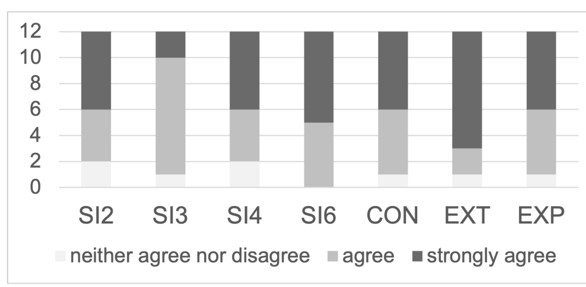


**Figure 6. Evaluation results for the perceived usefulness, conciseness, extendibility, explanatory power.**

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 ($\sigma$ = 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.

## 7. References


Baskerville, R., & Pries-Heje, J. (2014). Design theory projectability. *Working Conference on Information Systems and Organizations*, 219–232.

Betke, H. J. (2018). A volunteer coordination system approach for crisis committees. *15th International Conference on Information Systems for Crisis Response and Management*, 786–795.

Blais, C. (2008). Military Scenario Definition Language (MSDL). *Proceedings of the Spring 2008 Simulation Interoperability Workshop*.

Coronese, M., Lamperti, F., Keller, K., Chiaromonte, F., & Roventini, A. (2019). Evidence for sharp increase in the economic damages of extreme natural disasters. *Proceedings of the National Academy of Sciences*, *116*(43), 21450–21455.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319–340.

Fernandez, L. S., Barbera, J. a., & Dorp, J. R. V. (2006). Strategies for Managing Volunteers during Incident Response : A Systems Approach. *Institutional Archive of the Naval Postgraduate School*, *10*(3), 1–15.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*(1), 39–50.

Fu, K. K., Yang, M. C., & Wood, K. L. (2016). Design principles: Literature review, analysis, and future directions. *Journal of Mechanical Design*, *138*(10).

Gregor, S., & Jones, D. (2007). The Anatomy of a Design Theory. *Journal of the Association for Information Systems*, *8*(5), 312–335.

Gregor, S., Kruse, L. C., & Seidel, S. (2020). The anatomy of a design principle. *Journal of the Association for Information Systems*, *21*(6), 1622–1652.

Harris, M., Shaw, D., Scully, J., Smith, C. M., & Hieke, G. (2017). The involvement/exclusion paradox of spontaneous volunteering: New lessons and theory from

winter flood episodes in england. *Nonprofit and voluntary sector quarterly*, *46*(2), 352–371.
Haynes, S., Richard, D., & Kubany, E. (1995). Content validity in psychological assessment: A functional approach to concepts and methods. *Psychological Assessment*, *7*, 238–247.
Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS quarterly*, 75–105.
Hulland, J. (1999). Use of partial least squares (pls) in strategic management research: A review of four recent studies. *Strategic management journal*, *20*(2), 195–204.
Hwang, W., & Salvendy, G. (2010). Number of people required for usability evaluation: The 10 +/- 2 rule. *Commun. ACM*, *53*, 130–133.
IEEE. (2011). IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP). *IEEE Std 1730-2010 (Revision of IEEE Std 1516.3-2003)*, *2010*(January), 1–79.
Institute for Economics and Peace. (2020). Ecological threat register 2020: Understanding ecological threats, resilience and peace.
Lindner, S., Betke, H., & Sackmann, S. (2017). Attributes for Simulating Spontaneous On-Site Volunteers. *International Conference on Information Systems for Crisis Response and Management*, (May), 846–856.
Lindner, S., & Herrmann, C. (2020). The behavior of spontaneous volunteers: A discrete choice experiment on the decision to help. *51th Annual Hawaii International Conference on System Sciences*, 2157–2166.
Lindner, S., Kühnel, S., Betke, H., & Sackmann, S. (2018). Simulating Spontaneous Volunteers - A Conceptual Model. *International Conference on Information Systems for Crisis Response and Management*, (May), 159–169.
Lindner, S., Sackmann, S., & Betke, H. (2019). Simulating Spontaneous Volunteers: A System Entity Structure for Defining Disaster Scenarios. *International Conference on Information Systems for Crisis Response and Management*, (May), 516–527.
Lips, S., Amola, O., & Draheim, D. (2021). Designing a crisis management mobile application solution in nigeria. In *The 23rd international conference on information integration and web intelligence* (pp. 571–579). Association for Computing Machinery.
Lodree, E. J., & Davis, L. B. (2016). Empirical analysis of volunteer convergence following the 2011 tornado disaster in tuscaloosa, alabama. *Natural Hazards*, *84*(2), 1109–1135.
Lowe, S., & Fothergill, A. (2003). A need to help: Emergent volunteer behaviour after September 11th. *Beyond September 11th: An Account of Post-Disaster Research*, (January 2003), 293–314.
Ludwig, T., Kotthaus, C., Reuter, C., van Dongen, S., & Pipek, V. (2017). Situated crowdsourcing during disasters: Managing the tasks of spontaneous volunteers through public displays. *International Journal of Human-Computer Studies*, *102*, 103–121.
Mas, E., Suppasri, A., Imamura, F., & Koshimura, S. (2012). Agent-based simulation of the 2011 great east japan earthquake/tsunami evacuation: An integrated model of tsunami inundation and evacuation. *Journal of Natural Disaster*, *34*(1), 41–57.
Meth, H., Mueller, B., & Maedche, A. (2015). Designing a requirement mining system. *Journal of the Association for Information Systems*, *16*(9), 799.
Nickerson, R. C., Varshney, U., & Muntermann, J. (2013). A method for taxonomy development and its application in information systems. *European Journal of Information Systems*, *22*(3), 336–359.
Nunnally, J. (1994). *Psychometric theory 3e*. Tata McGraw-Hill Education.
Pan, X., Han, C., Dauber, K., & Law, K. (2007). A multi-agent based framework for the simulation of human and social behaviors during emergency evacuations. *Ai & Society*, *22*(2), 113–132.
Roth, F., & Prior, T. (2019). *Volunteerism in disaster management: Opportunities, challenges and instruments for improvement* (tech. rep.). ETH Zurich.
Sakurai, M. (2016). Communication platform for disaster response. In J. Parsons, T. Tuunanen, J. Venable, B. Donnellan, M. Helfert, & J. Kenneally (Eds.), *Tackling society's grand challenges with design science* (pp. 223–227). Springer International Publishing.
Salmani, I., Seyedin, H., Ardalan, A., & Farajkhoda, T. (2019). Conceptual model of managing health care volunteers in disasters: A mixed method study. *BMC health services research*, *19*(1), 1–9.
Schryen, G., & Wex, F. (2012). Is design thinking in disaster management research. *2012 45th Hawaii International Conference on System Sciences*, 4102–4111.
Sonnenberg, C., & vom Brocke, J. (2012). Evaluations in the science of the artificial – reconsidering the build-evaluate pattern in design science research. In K. Peffers, M. Rothenberger, & B. Kuechler (Eds.), *Design science research in information systems. advances in theory and practice* (pp. 381–397). Springer Berlin Heidelberg.
Takahashi, T. (2007). Agent-Based Disaster Simulation Evaluation and its Probability Model Interpretation. *Iscram 2007*, (1), 369–376.
Twigg, J., & Mosel, I. (2017). Emergent groups and spontaneous volunteers in urban disaster response. *Environment and Urbanization*, *29*(2), 443–458.
Vaishnavi, V. K., & Kuechler, W. (2015). *Design science research methods and patterns: Innovating information and communication technology*. Crc Press.
Venable, J., Pries-Heje, J., & Baskerville, R. (2016). Feds: A framework for evaluation in design science research. *European journal of information systems*, *25*(1), 77–89.
Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS quarterly*, 425–478.
vom Brocke, J., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., Cleven, A., Brocke, J. V., & Reimer, K. (2009). Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process. *17th European Conference on Information Systems*, *9*, 2206–2217.
Wagner, N., & Agrawal, V. (2014). An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster. *Expert Systems with Applications*, *41*(6), 2807–2815.
Wang, W., & Benbasat, I. (2009). Interactive decision aids for consumer decision making in e-commerce: The influence of perceived strategy restrictiveness. *MIS quarterly*, 293–320.
Watson, R. T., Kunene, K. N., & Islam, M. S. (2013). Frugal information systems (is). *Information Technology for Development*, *19*(2), 176–187.
Way, S., & Yuan, Y. (2017). A framework for collaborative disaster response: A grounded theory approach. In M. Schoop & D. M. Kilgour (Eds.), *Group decision and negotiation. a socio-technical perspective* (pp. 33–46). Springer International Publishing.
Wittman Jr., R. L. (2009). Defining a standard: the Military Scenario Definition Language version 1.0 standard. *Proceedings of the 2009 Spring Simulation Multiconference*, 73:1–73:5.
Wong, S.-K., Wang, Y.-S., Tang, P.-K., & Tsai, T.-Y. (2017). Optimized evacuation route based on crowd simulation. *Computational Visual Media*, *3*(3), 243–261.