CrowdMonitor: Mobile Crowd Sensing for Assessing Physical and Digital Activities of Citizens during Emergencies

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ABSTRACT
Emergencies such as the 2013 Central European flood or the 2013 typhoon Haiyan in Philippines have shown how citizens can organize themselves and coordinate private relief activities. These activities can be found in (physical) groups of affected people, but also within (digital) social media communities. There is an evident need, however, for a clearer picture of what exactly is going on to be available for use by the official emergency services: to enlist them, to keep them safe, to support their efforts and to avoid needless duplications or conflicts. Aligning emergency services and volunteer activities is, then, crucial. In this paper we present a mobile crowd sensing based concept, which was designed as well as implemented as the application CrowdMonitor and facilitates the detection of physical and digital activities and the assignment of specific tasks to citizens. Finally we outline the findings of its evaluation.

Author Keywords
Emergency Management; Crowdsourcing; Mobile Crowd Sensing; Social Media; Design Case Study

ACM Classification Keywords
H.5.3 Group and Organization Interfaces.

INTRODUCTION
Various events during recent emergencies show that in addition to formal crisis management through emergency services, citizen-based crisis management, characterized by situated altruism [8], is a common behavior. Individuals and groups get together to form emergent and temporary organizations [30] for improvised relief and rescue activities [37]. Although citizen-initiated activities have always existed during emergencies [34], the sheer pervasiveness of social media and mobile devices has changed the kinds of mobilization possible during and after emergencies. Via social media, volunteers can now quickly establish self-help groups and relief communities for dealing with response and recovery activities [25, 26]. It is already possible, to a degree, for volunteers to integrate such activities with those of the emergency services. Citizens can either help physically, e.g. by filling sandbags [25], or online, e.g. by providing crisis-related information [11]. Although emergency services have recognized the relevance and importance of citizen-initiated physical and digital activities, problems still arise. How to identify, integrate and manage on-site as well as online activities into official work practices in time-critical and uncertain situations remains an open question. Not least, this is important to prevent the disruption of both official interventions and existing volunteer work.

This design case study [39] aims to address this issue and examines how physical as well as digital activities of citizens can be made manageable for emergency services. In what follows, we analyze related approaches to crowdsourcing, mobile crowd sensing and use of social media in emergencies. In a qualitative empirical study of emergency services, we then explore the impact of citizen-generated content from social media as well as on- and off-site volunteer involvement. Based on our pre-studies we derive an approach, which allows monitoring and aligning of both civil on-site as well as digital activities. We use the empirical findings to implement the web-based application "CrowdMonitor", which is based on a mobile crowd sensing concept and is intended to support collaboration between emergency services, volunteers and others.

SOCIAL MEDIA, CROWDSOURCING AND MOBILE CROWD SENSING IN EMERGENCIES
In the recent years, open innovation concepts – emerging from Web 2.0 – have been geared to citizen involvement as well as community engagement. Those concepts mainly comprise support for a greater participation and integration of citizens into the tasks and activities of professional organizations [3]. *Crowdsourcing* is a "type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals via a flexible open call, the voluntary undertaking of a task" [9]. There are several approaches of crowdsourcing, which we will discuss below.

One subset of crowdsourcing, which emerged with the ubiquity of smart mobile devices is *participatory sensing* [4] in which individuals are asked to gather, analyze and share data and information using the integrated sensor ca-

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pabilities of their mobile devices. Application areas for participatory sensing include, for example, GPS or speed data from cyclists to infer route and traffic noisiness [24], audio data from microphones to discover biodiversity [19] or to measure the air quality [14]. The presence of such multimodal sensors is enabling a broad range of possibilities through the automatic collection of sensor data. The concept of *mobile crowd sensing* [40] combines the participatory sensing concept with a "collective" sensing view by supplementing sensor data collected via mobile devices on the ground with citizen-generated content from social media, such as opinions or experiences [12].

Social media are – of course also during emergencies – already widely used [22]. Facebook, Twitter and other services are used in different ways [13] and cover both real and virtual activities [25] such as the provision of on-site information or the reporting of news in order to achieve situational awareness [36]. Citizens can communicate and share information directly from an incident's location often before other data is available [18]. Furthermore digital volunteers can organize themselves [31] to generate collective pictures of events [32]. How emergency services use this available data and how they establish relationships with volunteers, however, can result in a variety of outcomes [7]. Although organizational and structural obstacles exist [15], there are already approaches that focus on useful relations between officials and citizens during emergencies [28], which we will outline in the following.

CROWDSOURCING SYSTEMS WITHIN EMERGENCIES

Various crowdsourcing systems (which often base on social media) for the use in emergencies exist that try to support the actions of emergency services and volunteers, especially in time-critical situations. *Twitinfo* [17] is a platform for exploring Twitter in real-time. It "extracts the posts that match keywords in the query and provides a graphical timeline interface that labels peaks of high-volume posts as sub events and highlights important terms and tweets". Although providing important information, it supports no interaction or sensing. In *Twitcident* [1] tweets relevant to an automatically broadcasted crisis event are collected in real time. By analyzing and filtering tweets, a crisis profile is created to support awareness. Like Twitinfo, it does not support any sensing functionality. *Ushahidi* is a platform that supports emergency services in requesting citizens to gather and structure information [21]. It mainly contains reports about, for instance, local or medical needs. In addition, it encompasses different sources, like social media, E-Mail or SMS. In Ushahidi, reports are visualized on a map to improve the situation overview [5]. Ushahidi was used, for example, for the allocation of food during the tsunami in Japan 2011 [11]. In Ushahidi, information from individuals is embedded, but aggregated social media data is not. With *Mobile4D* [10], emergency services request reports about the local situation from members of the public via a dedicated mobile application. Emergency services can use this application to directly communicate with people and verify submitted information. In addition Mobile4D supports broadcast warnings based on submitted reports or directly via integrated communication channels. Mobile4D was used in Laos in 2013, where reports about floods and the avian flu were collected. Providing an appropriate participatory sensing functionality using social media is not part of the approach. Existing reverse-911 systems use telephone numbers and addresses of residents within a geographical area to be able to send out warnings to specific groups, but lack a dynamic response capability and do not monitor social media.

CROSS [6] does use social media to initiate the participation of members of the public by a call to use a mobile application. Users can then collect local information and transmit it, enriched with data about their location. The location allows emergency services to purposefully coordinate participants. But potentials of digital volunteers were not addressed. *DIADEM* [38] represents another means to gather and validate information. Here, a pre-selected group of volunteers is requested by emergency services to use a mobile application for identifying strange smells during chemical disasters. Information obtained can be shared between experts and visualized on a map so that emergency services can locate the source of the smell [38]. Microtasking applications like *MicroMappers* [23] where emergency services ask digital volunteers to perform small tasks by submitting requests to a crowdsourcing-platform. Such applications were used during the 2013 typhoon in the Philippines to check relevant tweets and categorize photos.

These approaches are mainly used for data gathering or evaluation purposes. The potential, we argue, for using the social media to integrate crowdsourced information and to integrate local "on the ground" activities is still substantially unexplored. Nevertheless, "the incorporation of social media into pre-existing emergency management systems is inevitable" [2]. Our research question was therefore how the digital and physical activities of volunteers and other citizens might be integrated within the practices of emergency management through IT.

EMPIRICAL STUDY: INTEGRATION OF ACTIVITIES OF VOLUNTEERS AND OTHERS DURING EMERGENCIES

Our objective is to examine the potential of social media generated information for situation assessment and at the same time the potential for involving volunteers into the current work of emergency services. We therefore conducted and analyzed 42 interviews (Table 1) with different organizations involved in emergencies (police, fire department, authorities and emergency call center) in Germany (Bonn, Dortmund, Kerpen, St. Augustin, Siegen) as well as in the European Union (Amsterdam, Antwerp, London, Ljubljana, Oslo, Twente, Warszawa) with a view to establishing, inter alia, the potential for volunteer-initiated activities as well as other content from social media in emergen-

cy management. We focused on collecting responses from a wide range of authorities.

Name	Title and Focus	Year	Quantity	Place
I1-24	Work Practices and IT Support	2010/11	22	GER
IM1-5	Mobile Collaboration practices	2012	5	GER
C1-11	Social Media in Emergencies	2014	11	EU
IS1-4	Citizen involvement in Crisis	2014	4	GER
Sum:			42	

Table 1: Interviews (2010-2014)

We aimed for a cross selection of hierarchical units ranging from a (lower level) Head of Section to a (high level) Head of Control Center. The aim was to get a comprehensive overview of the entire organization. Each interview lasted between 1 and 2 hours and followed a guideline. I1-24 focused on the participants' role and work activities under normal conditions; participants' tasks during emergencies in our scenario framework; applied information and communication systems and perceived problems with these tools. To study mobile collaboration practices more closely with regard to the creation, exchange and use of information by response teams and control centers, five additional interviews were conducted (each 1 hour; IM1-5) [27]. C1-11 and IS1-4 focused on different types of official users and their motivation for using social media and involving volunteers during emergencies.

All interviews (I1-24; IM1-5; IS1-4) were audio recorded and transcribed or documented (C1-11) for subsequent data analysis. The analysis was based on the inductive approach of *grounded theory* [33], at least to the extent that we used open coding associated with grounded theory to derive categories from empirical data by the careful reading aggregation of categories. Transcripts were therefore open coded and the statements of the agents were divided into text modules and later into categories. The knowledge previously acquired in the literature study was used to heighten *theoretical sensitivity* [33]. *Theoretical sampling* led us to select certain interviews for further analysis as our categories emerged.

Integration of Citizens into work Practices

Currently, volunteers and other citizens are de facto not integrated into the everyday work practices of emergency services due to their lack of qualification (IS03). During large-scale emergencies or long-term disasters, however, collaboration with volunteers is seen as important:

"During our everyday work actually not, because one cannot work for fire services without any qualification. During major emergencies such as floods one can certainly fill sandbags, for instance. Then we really seek for the collaboration with citizens" (IS03).

In order to participate appropriately in such emergency situations, however, it is "*extremely important that we instruct the citizens"* (IS04), because otherwise they lack sufficient knowledge (IS01):

"*For instance, we also have to control the sandbags. What's the use of having 150 people and 50 bags or maybe nothing to do at all? I must get an overview on the entire area of operations and the situation itself"* (IS01).

The handling of resources with regard to volunteers requires coordination efforts by the officials. From the point of view of professional emergency services, too little is known about the actions of volunteers and others and the existing organizational capabilities of volunteers, and therefore "*[we can] allow them to act under our supervision, to try to convince them through conversations and to help them adapt our operational strategy"* (IS01).

This is necessary, not least, because of possible danger. For an integration of citizens on the ground it is necessary to detect possible danger areas (IS01), since volunteers must not put themselves in danger.

"*If it is about clearing something away or protecting something or something like this, we can include citizens who are already there wherefore we avoid that they only stand there and look around"* (I11).

For simple tasks the on-site integration of citizens makes sense, but even here this kind of danger exists: "*because they probably do not have the adequate equipment they would need. Or maybe because they do not have the necessary information"* (IS04).

Furthermore, an official integration of civil activities currently must not happen before emergency service units arrive "*because we would expose them to a risk which we could not assess if we are not there [on-site]"* (IS04). Citizens entering danger areas could interfere with the actions of relief forces (IS04) and "*there also are legal issues"* (IS02) such as insurance coverage.

Integration of volunteers is initially established in two different ways. The first is the physical contact on-site: "*We had that during the Oder floods when a few volunteers came and said: 'Here I am, I would like to help!'"* (IS01). The second way is to monitor citizens organizing themselves through social media. From the emergency services' perspective it is important to know "*where people are organizing themselves so that they can be coordinated somehow"* (IS02). Social media are already monitored spontaneously (IS02) and some attempts are made to explicitly coordinate citizens e.g. via Facebook pages: "*I become a member [of a group] and then I identify myself as emergency service and say: 'Okay, I need help there'"* (IS04).

In urgent situations "*people frequently want to receive really up-to-date and detailed information: 'What are we supposed to do now? What does that mean for us?'"* (IS02). Adequately data about the current situation as well as anticipated dangers is vital. Within large-scale emergencies such involvement of volunteers in simple tasks is straightforward: *"You don't need any special qualification for filling*

sandbags. We give a short instruction and then the citizens know how it can be done" (IS03).

Apart from this, special local knowledge and abilities (e.g. foresters, chimney sweepers) or language skills might be needed in this situation (IS01):

"*There are many special things for which you need basic knowledge or foreknowledge. But there are also things for which you can make use of the knowledge and skills of citizens because it is their daily bread"* (I11).

Enhanced Situation Assessment by Volunteers On-site

Besides physical relief activities, local citizens can provide important information. In major incidents the emergency services normally receive a large amount of emergency calls from citizens (IS03, IS04), which are used as initial situation overviews. The emergency services always ask five specific questions to get the needed information:

"*There are five questions: What has happened? Where did it happen? How many injured people are there? And at the end we wait, so that dispatchers at the control center, who are receiving the call, can ask further questions, that they actually know how the situation on-site looks like"* (IS03).

Based on information from those calls "*an assessment of the situation and appropriate measures such as sending an ambulance are taken"* (IS03). Call takers will continue to ask questions until official emergency forces arrive on-site.

"*But when the fire and rescue services are on-site, then our people are there. Why shouldn't I talk to them if they are there? So the question will only arise if we aren't there. That means to fill this time gap until we are there"* (IS04).

Consequently, acquiring information from the public makes sense until the official emergency services arrive. In major incidents local people can also provide information on poorly accessible areas:

"*Imagine we have an emergency over a large area – again I take Fukushima as an example. The fire service cannot be everywhere at the same time and there might be several separated areas. Then, of course, it is great if citizens tell us that unfortunately 20 dead bodies have already been found or we are having 500 injured here"* (I10).

However, there are often differences between the actual situations on-site and descriptions offered (I04) because members of the public do not always find it easy to assess the situation (IS03, IS04) or might be most useful (IS03). For that reason it is sometimes necessary that information is explicitly requested (IS01, I02), which becomes clear in an example about the reporting of car fires:

"*Somebody is driving on the highway and sees someone with a smoking engine on the breakdown lane. […] That means we have to go out because we can't rule out that the car really is on fire and the guy just doesn't know that white smoke might just be steam"* (IS03).

Thus, any input from the public has to be validated by further inquiries (IS04), sometimes even after relief forces arrive on-site.

Integration of Off-Site Citizen Activities

In addition to the integration of on-site activities, the current practices of emergency services comprise requests to digital volunteers on social media. This can be seen in the provision of information: *"Authorities invoke the users on its Facebook page: 'Please give us some information on this and that topic'"* (IS02).

This information may contain impressions, feelings or pictures from incident locations (IS02). Citizens, for instance, can be asked about the evolving pattern of smoke to be seen (C02). However, such data requires validation:

"This is our computer, on which we receive this Facebook comment that 630 sandbags are missing. Then we contact the control center and say: 'Please check with Bad Laasphe [German city], what is going on there and there?'" (IS04).

Verification is always important. *"[We use] ... other […] reliable or official sources*" (IS02) to verify information. These might be other official sources (IS02) or the social media (IS03). Monitoring of social media, something that can be done by volunteers, allows emergency services to gain further knowledge about the situation on-site (S01). In doing so, they can either make use of existing data or actively make requests:

"One can just say: 'Please tweet information about how you feel or what problems you have on-site and label it with this or this hashtag', so that we can filter it more easily" (IS02). Needs and concerns are actively requested: *"What is the public thinking? What do they want? What do they probably need what we don't know about?"* (IS02).

The reason for integrating volunteers into a monitoring role is that currently the emergency services do not have any special staff for doing this (IS02, C07). Monitoring is carried out on an ad hoc basis by individual members (IS01, IS02, C10) of the incident command or the section staff of the control center (IS04), and is not part of the official structural plan (IS03):

"I was in Dresden [German city – flooded in 2013] for 14 days and we had selected a colleague who didn't do anything else but pay attention to Facebook or the media. He participated in press work, but he kept an eye on the monitor and was always browsing on Facebook: 'What is happening there? Where are they meeting?'" (IS01).

Consequently there is less time available for primary tasks of the control center (I02). As a result, monitoring and especially work with social media arguably needs to be done by specialized and focused volunteers:

"I tell you, the guys, who currently do this stuff and take it seriously, say that it should be done by people who only do social media" (IS02).

This task could also be taken over by citizens because no special knowledge is needed but only a common sense:

"If something like this happens, we need smart people on the platforms who read along, moderate and publish press releases. […] They don't have to be firefighters. They just need a firefighter as a contact person" (IS04).

Since tweets are publicly accessible, Twitter is more suitable for monitoring than Facebook where relevant information is mostly exchanged between friends and *"is actually not distributed publicly"* (IS02). Nevertheless, the emergency services use Facebook more often than Twitter due to its popularity within Europe (IS02):

"The vast majority of colleagues, who do this, definitely use Facebook and Twitter. I mean Facebook is simply the most popular" (IS02).

It has been shown that critical information, such as warnings or reports about an incident are often distributed to friends by liking a Facebook page and so on:

"But on Facebook everyone has this message on their timeline who has subscribed to us and who liked our news time. That's why we had such a wide audience. Although we only have 1,400 fans we could reach 14,000 people, because our users have shared it on their profile" (IS03).

During more routine work, social media are already used for publishing summaries of daily operations (IS03) and requests to the public, for instance, for the purpose of information provision or blood donation requests (IS01). When large-scale incidents happen, many of our respondents point to the potential of social media as they can be used by the emergency services for the search for missing persons (IS01), the support of evacuation measures (IS03), or for warning the public (IS03, IS04, C02, C09, C10). The latter is fostered, for example, by the distribution of critical information, citizen to citizens (IS03).

In large-scale emergencies, this information means that emergency services *"can better understand the activities of independent volunteers. I mean we can monitor them better because we have better information on what they are planning"* (IS02). Information containing *"location data is very important because in this way […] we can draw a more precise picture of the situation"* (IS02, C02, C11).

When communicating via social media, several aspects have to be considered, e.g. data privacy (IS04). Names or streets with house numbers, for instance, are not to be mentioned explicitly (IS03). Furthermore it should be noted that expertise in the use of social media is not evenly distributed. Officers sometimes lack daily experience (IS02). Moreover, when communicating with the public, technical terminology needs to be avoided:

"For example, when I'm posting something, I must be careful that I write it in a way that a citizen can understand it and it's not in a technical language" (IS03).

Discussion

Regardless of privacy and other concerns, volunteers and others could offer several benefits for integration into official crisis management from the emergency service's perspective. They can take over both real physical activities on-site, such as filling sandbags (IS03) or taking clearance measures (I11) as well as digital activities off-site, such as sharing (IS02, IS03) or validating (IS02) information that improves overall situation assessment (IS02, IS04) – especially during large-scale emergencies where certain areas might be difficult to access (I19) or relief forces have not yet arrived at the scene (IS03, IS04). Individual assessments can diverge from actual situations considerably and so constant interaction between officials and others has to be supported (IS03, IS04).

Several problems can arise when volunteers are engaged in activities on the ground. They can operate in dangerous areas and get hurt or interfere with the actions of emergency services (IS04) and vice versa. It is all the more important, therefore, that volunteers are sufficiently informed about the overall situation (IS02), advised in accordance with organizational demands, and integrated into the operational strategy (IS01). The careful coordination of their activities is therefore absolutely necessary (IS01, IS02, IS04). Currently, however, civil community work is a kind of black box for many of emergency services (IS02). Initiatives to foster collaborations between emergency services and citizens happen through local on-site collection points and direct contact (IS01) or (relatively) rarely via social media in a rather ad hoc fashion as coordinators of Facebook pages or within groups. (IS02). There is an evident need for a more systematic approach (IS04). Not least, as pointed out, information has to be validated in some fashion (IS02, IS04) and besides, information overflow (IS01) is always likely due to the independent actions of volunteers [29].

CROWDMONITOR: A CONCEPT FOR ASSESSING PHYSICAL AND DIGITAL ACTIVITIES OF CITIZENS

Our empirical study demonstrated the need for an integrated approach for handling citizen-generated content from social media and advising on the ground civil activities in order to collaborate with them in an appropriate manner. The existing current approaches do not facilitate a combined assessment and management of social media and volunteer-initiated activities. On the basis of our findings, therefore, we designed – with regard to the current state of the art – the mobile crowd sensing application CrowdMonitor.

For improving situation awareness (IS02, IS04), CrowdMonitor seeks to passively collect and display social media information (from ordinary people without their knowledge) alongside volunteered information in response to public requests via a mobile application (i.e. from knowledgeable volunteers). Formal responders of official emergency services, the main operators and users of the tool, can create requests for particular information or targeted alerts, which can then be pushed to users of the mo-

bile app within a particular location. Such requests are necessary to prevent volunteers engaging within dangerous areas or interfere with actions of formal emergency services (IS04) or to validate citizen-generated information from social media (IS03, IS09). The aim of CrowdMonitor is to synchronize and harmonize actions performed by emergency services and those of the public by (1) monitoring social media and (2) integrating volunteers into activities coordinated and led by emergency service officials. The following will describe the detailed functionalities of CrowdMonitor.

The central part of CrowdMonitor is an Open Street Map, which displays information on different layers (**A**). As literature has shown, a layer-based map is an important part for situation assessment activities during emergencies. Those layers (**B**) contain, on the one hand the well-known map types (roads, satellite, topographic view) and standardized map services (like web feature services, e.g. hydrant layers), but also time-critical data (citizen-generated content from social media, volunteered report responses to prior requests or movement data) to which we will refer later. Time-related information can be selected by date and time (**C**) and displayed as clusters (with regard to the zoom level) based on their type, amount and location. Depending on the selected layers, the legend (**D**) aligns itself. The information is visualized by markers and details will be shown in the detail view (**E**). On the left side, the user has the option to load map extracts and related data for a specific type of emergency, e.g. displaying flood-areas, water levels or water protection authorities for a flood situation (**F**). It is possible to save the current map, which can then be recalled at any time.

The search functionality offers a query for 'locations of interest' or for specific 'citizen-generated content' (**G**). The search for social media content uses an implemented social media API that returns all message results for different social media services by a keyword. Due to performance issues, the values are returned always based on the current visible map area as well as defined time. The results are displayed and sorted on the right side as a list (**H**) and at the same time visualized directly on the map. To help validate the results they are sorted by a simple algorithm that ranks the messages by e.g. number of retweets and their up-to-datedness. In the detail view, the entire content of a message as well as the author are displayed. A button in the detail view (**I**) allows immediate access to the corresponding platform on which any particular message can be accessed and the user can immediately use established communication channels.

The aforementioned visualization and searching functionalities are not, we acknowledge, particularly novel and are to some degree already addressed in previous literature, e.g. [16, 17]. The actual innovative functionality, that we argue goes beyond the current state of the art, is the combination of the social media content and the emergent civil activities on-site as well as the inclusion of options for instructions and advice. For example, movement data of volunteers can be collected via the mobile part of CrowdMonitor, a module with an emergency app, providing additional information during emergencies. Within this app it is possible to select whether – during an emergency and in an anonymized way – the movements of participating volunteers can be tracked. Volunteers use the app always voluntarily, are constantly aware of being tracked and have options to quit tracking anytime.

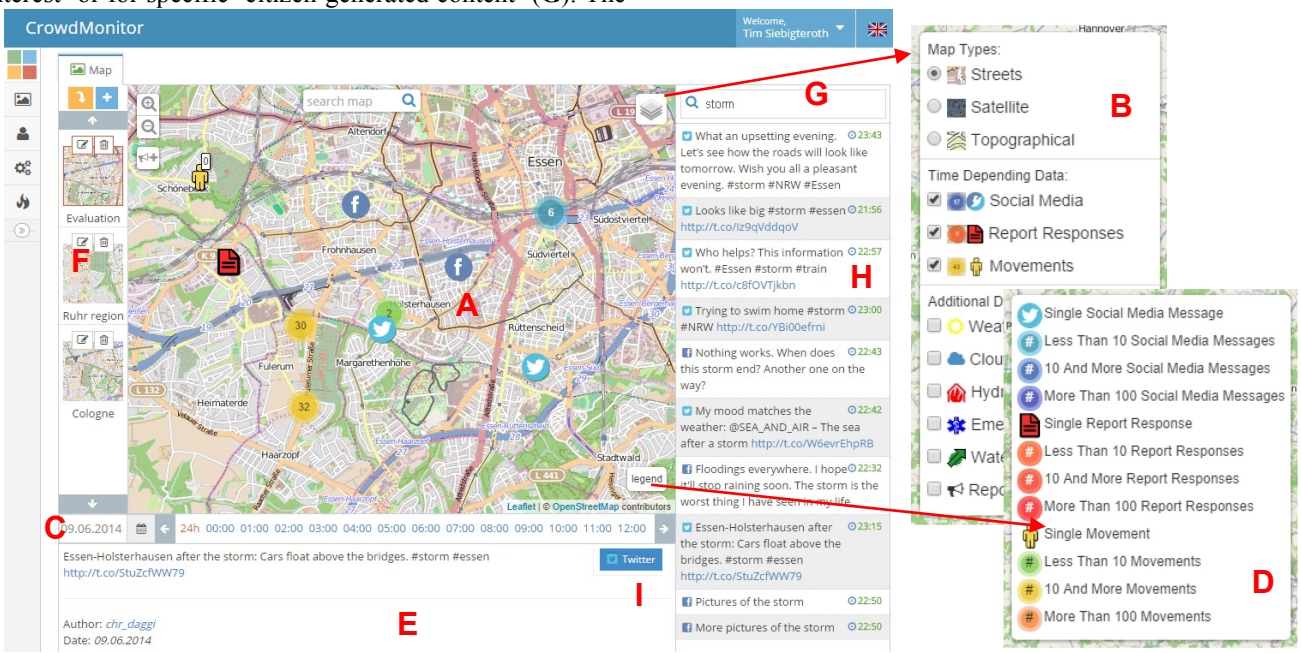

Figure 1: CrowdMonitor: Assessing of Digital Activities during Emergencies

The individual movements of volunteers are presented as persons (**J**) related to a certain location and time. The small box represents the anonymous identification number. In addition, the path of a volunteer's movement and direction (**K**) is presented within the selected period of time between two time stamps. The speed with which the volunteer on the ground has moved between different locations is displayed (**L**). This data is also listed in the detail view of a marker with an accurate date and time to discover potential local patterns of movements. Officials further have the option to contact volunteers directly via chat functionality (**M**).

Public calls to the crowd can be initiated either by requesting all mobile app users or by defining a rectangle on the map (**N**). This rectangle presents the intended area where users should be notified about defined public calls or instructions. After defining an area, a dialog pops up to further specify the call (**O**). Emergency services must define a title, a description and the specific questions (include multiple choice, single choice or open questions). If a volunteer enters the pre-specified location, the request or instruction will start automatically and the volunteer can respond to it. All responses are displayed on the map by time and its location (**P**). The detail area contains the report's title, description and corresponding questions along with the responses of participating volunteers.

EVALUATION OF CROWDMONITOR

In order to evaluate CrowdMonitor, we conducted several evaluations, mainly with emergency services as they are the primarily users of such an application. The conceptual basis has been evaluated in two iterations (first with 12 and second with 16 emergency service officials) focusing on aspects of information gathering and sharing as well as situation assessment [16, 27]. To evaluate the mobile crowd sensing, we made an additional evaluation with a total of eight people. We aimed at testing both usability, for which we used a group of four students (E1-4), and practice relevance, for which we enlisted four emergency services units (E5-8). In the second instance, we were primarily concerned with identifying in what ways CrowdMonitor would be used, and what difficulties in use might be encountered. The philosophy behind the evaluation was derived from the notion of 'situated evaluation' [35] in which qualitative methods are used to draw conclusions about the real-world use of a technology using domain experts. The aim was not to measure the relationship between evaluation goals and outcomes but to derive views from experts about how useful the tool might be in use. Although our system had been fully implemented, IT security regulations of the emergency services prevented us from conducting an in-use and real-world evaluation.

The evaluation was therefore predicated on a scenario-based walkthrough coupled with subsequent semi-structured interviews. The scenario was designed to introduce the participants to the context of a disaster and to simulate the special characteristics of a crisis situation. The scenario was based on a big storm in western Germany, which caused heavy floods and damages. During the storm, it was intended that participants should manage four tasks: (1) getting an overview about the current situation, (2) creating and saving an appropriate map, (3) creating a public request and (4) making an informed decision based on the reports that are received. During this exploration of CrowdMonitor the participants were asked to 'think aloud' [20] and were audio-recorded. Further, the semi-structured interviews focused on a deeper understanding of usability issues (students) as well as application fields, potentials and obstacles in using the system (emergency services).

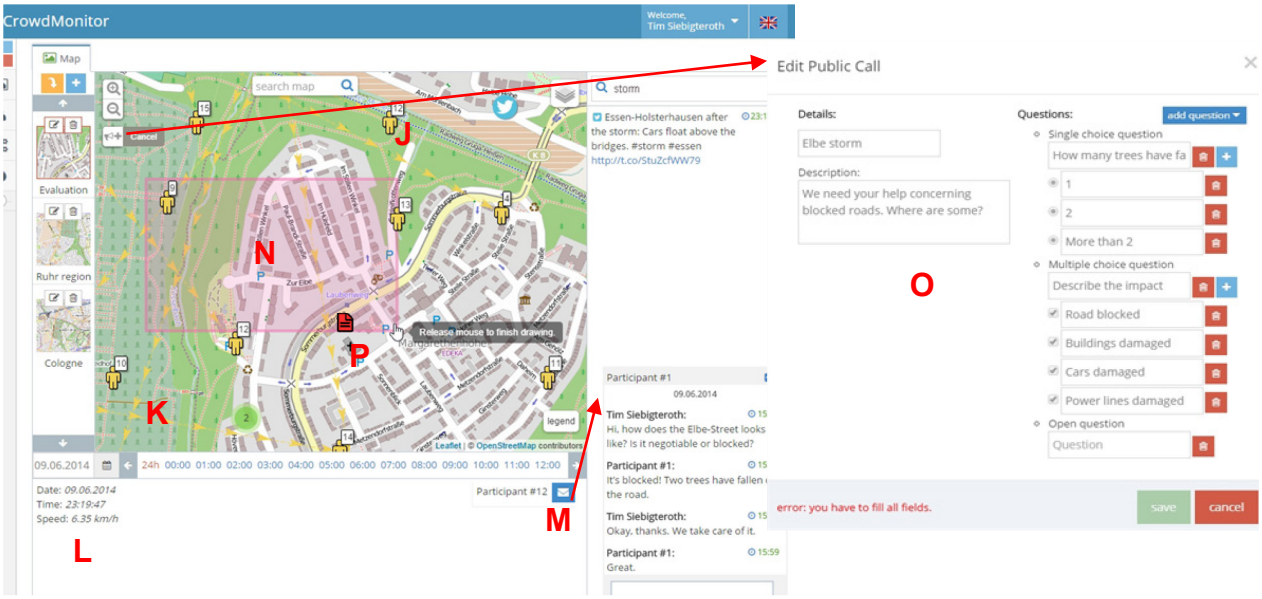

Figure 2: Crowd Monitor: Assessing of Physical On-site Activities

Overall the participants praised the system's usability. They argued that it is intuitive (E5), simple to use (E8), and easy to understand (E2). As a result, the given scenario was generally solved without need for supervision, which is a precondition for its deployment during crisis management. The options for public calls (E8) and the color chosen for the visualization of movement paths and directions were criticized for not standing out from the background (E2).

Results I: Advanced Situation Assessment

The potential for emergency services during large-scale emergencies, such as storms or large fires (E5) was apparent. Supporting emergency services, e.g. for localizing smells, was mentioned as a concrete use case:

"I think of Cologne [German city], where we had this odor nuisance last year. We could make requests here, where does the smell come from, where do we need to perform actions?" (E5).

Displaying citizen-generated content from social media in combination with volunteered movement data and reports provides a good overview about the current situation of actions on-site: *"It surely makes a lot of sense for the initial rough assessment to find out where my priorities are"* (E8).

During use, the participants particularly emphasized the value *"that the messages, when I zoom out, are more summarized. Then I don't have 20 markers next to each other"* (E5). In this way, it is possible, on the one hand, to assess a situation and, on the other hand, to differentiate between affected areas and to react correspondingly:

"[…] that I know which districts are more affected than others. From where are we receiving more extreme damage reports, then I would see that I quickly send an authority's car to check whether it's really like this or not" (E8).

Results II: Facilitate Coordination with Volunteers

The potential of a synchronized view on citizen-generated data, volunteered on-site information and subsequent possibilities to for coordinating with volunteers were identified, because if social media data or emergency calls do not fulfil the emergency services' needs, they have with CrowdMonitor an additional information source:

"If it is described inaccurately within social media, I could ask persons, who are near that place, for more details […] otherwise I have to send somebody to check it" (E5).

Citizens providing information need always feedback from the officials: "*In any case they need a feedback, regardless of whether a message was helpful or not. Otherwise – I think – he would lose the motivation after two times"* (E6).

With regard to the feedback to citizens, the functionality for defining an area for targeted instructions as well as the anonymous chat become important, because if citizens have a feeling that no one cares about them, they feel isolated:

"You can be addressed directly with this chat. This is very positive, because you directly have the feeling that someone takes care of you, if one someone writes" (E7).

Public calls are important not only for provision of information by volunteers, but also for monitoring their activities and collaborating with them during emergencies. With the overview of social media data and options for public calls, a 'bridge' (E6) is built that allows interacting with online as well as offline self-help communities:

"*To get a bridge to social media and prevent a bit of this [uncoordinated] self-help and help organize. We can initiate public calls to manage it a bit.*" (E6)

With approaches for coordinating with citizens, locations and points of interest can be announced and directed:

"You could, if you have food stores somewhere at five sand packing stations and then you would start a public call, you can directly specify the address. He [volunteer] knows right where he must go" (E6).

Results III: Individual and Targeted Warnings

With an application that provides information about locations, citizens and volunteers can be specifically and – above all – individually be warned in case of dangers:

"If I know here is a river that will overflow within the next two hours, and then I can start this public call, frame the area and then notify the people: 'The river will overflow!' And then the people can react and ask themselves: 'Will I leave the house or will I seal it off somehow and get sandbags?' That is definitely very practical" (E7)

Such individual targeted warnings will potentially mean that warnings are more likely to be noticed. In serious situations, a display of movement data enables the monitoring of individuals to determine whether there are persons in danger areas or not:

"The movement data of people certainly are very nice. If someone fell into the water or something like that, then that would certainly be very useful" (E7).

Moreover the possibility of providing an overview of the current situation with the aid of social media was emphasized: *"I can see directly on Facebook and Twitter what people are posting and what their concerns are"* (E7).

However, it was remarked that right now the deployment of the system in real world situations is still not sure "*because currently too many things take place in parallel via phone and radio. This would require some alignment in a realistic and sufficient way"* (E2).

Results IV: Pictures enhance Citizens' Activities

Emergency services wanted volunteers to be able to transfer multimedia content as additional responses to public calls:

"I think a picture would be helpful for situation assessment. Especially for power lines or cars when you don't know

whether you need a tow-truck, whether you need an energy operator for disconnecting the power or whether the power has already been turned off" (E6).

The need for pictures also becomes apparent in the context of messages from social media: *"Probably there are pictures in the posts. It would certainly be perfect if I could look at the pictures from here [system]"* (E1).

In addition, the need for a classification of the responses of public requests was mentioned, because it would allow a more effective reaction to the reports:

"That I know: 'There is only a small branch on the car; he has sent me a photo; it's not that bad. But behind, a tree has fallen on a house and it must be removed first'. I can say which is important and which can be done later" (E7).

DISCUSSION AND CONCLUSION

In recent years, the work practices of emergency services have been confronted with (at least) two separate issues: The first and newly emergent issue is the appropriate handling of citizen-generated content from social media. The second is the need for the appropriate management of on-site activities by volunteers (newly coordinated through social media). Our paper focuses on both types of citizen involvement (social media / on-site) during emergencies and contributes with an approach how a combination of digital and physical activities as well as the content generated in social media could support the work of emergency services and vice versa volunteers.

Based on our empirical work, which outlines current intersections between volunteer activities and the actions of emergency services, we have developed the web application CrowdMonitor that develops the concept of mobile crowd sensing [40] to create coordination mechanisms for interacting and collaborating with the public during emergencies. It provides functionality for gathering 'on the ground' movements, requesting data publicly and access to social media information and therefore covers real and virtual activities. The evaluation of our approach showed its potential and suggested possible improvement, such as a better first overview of incidents or warnings geared to individual needs of citizens. We outline four lessons learnt when designing approaches that deal with combining physical and digital citizens' activities during emergencies:

(1) For situation assessment, emergency services can use the crowd by official public calls that request gathering, or validating of citizen-generated social media content. Additionally, volunteered individual reports, especially pictures, are of particular value.

(2) Combined visualization of social media and volunteer activities, especially movements on-site, enables the monitoring of and coordination with citizens on an individual as well as collective level.

(3) Monitoring of individuals as well as the crowd is appropriate for a first overview and less so during the entire progress of an emergency, because officials arriving on-site will act as contact persons to emergency management and the importance of volunteer generated content decreases. Later coordination with volunteers becomes more important than the overview, so as to align their activities with the emergency services.

(4) When considering volunteer integration into the current work practices of emergency services, large-scale and long-term situations provide more potential (and traffic) than daily or small incidents.

Misinterpretation remains a problem, even with CrowdMonitor. Citizens using social media or the mobile app (with tracked positions) are more likely technophile. This will not be true for all people affected and we cannot assume that an accurate picture will always be possible. A retirement home, for instance, creates less information, but is more affected by most kinds of emergencies.

Based on our results, a next version of CrowdMonitor must provide options for enhanced responses with multimedia information to public calls and mechanisms for movement predictions based on the provided location information. One limitation of our approach is that social media, in the context we examined, are currently not part of the official work structures (which is about to change), and is only informally used for getting an unofficial situation overview.

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