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Exploring the evolving landscape of human-centred crisis informatics: current challenges and future trends

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Abstract: Modern Information and Communication Technology (ICT) has been used in safety-critical situations for over twenty years. Rooted in Human-Computer Interaction (HCI) and related disciplines, the field of crisis informatics made considerable efforts to investigate social media use and role patterns in crises, facilitate the collection, processing and refinement of social media data, design and evaluate supportive ICT, and provide cumulative and longitudinal research. This narrative review examines contemporary challenges of human-centred crisis informatics and envision trends for the following decade, including (I) a broadening scope of crisis informatics, (II) the professionalisation of cross-platform collaboration of citizen communities and emergency services, (III) expert interfaces for explainable and multimodal artificial intelligence for user-generated content assessment, (IV) internet of things and mobile apps for bidirectional communication and warnings in disruption-tolerant networks, as well as (V) digital twins and virtual reality for the effective training of multi-agency collaboration in hybrid hazards.

Keywords: crisis informatics; social media; safety-critical systems; usable safety and security

1 Introduction

Information and Communication Technology (ICT) has been used in safety-critical situations for over two decades. Already after the 2001 September 11 attacks, citizens set up wikis to collect information about missing persons while FEMA and the Red Cross used web-based technologies to inform the public and make status reports available internally and externally.[1] Especially large-scale events, such as the 2012 Hurricane Sandy, the 2013 European Floods, and the COVID-19 pandemic, showed that citizens are not passive victims but active participants utilising mobile and social ICT for crisis response.[2] Furthermore, emergency services such as fire and police departments started using online data to increase situational awareness and improve decision-making for a better crisis response.[3] The increasing relevance of ICT for crisis management led to the establishment of the research domain of *crisis informatics*, which is a multidisciplinary field combining computing and social science knowledge and "views emergency response as an expanded social system where information is disseminated within and between official and public channels and entities".[4]

In recent years, various studies have emerged that deal with the use of ICT in emergencies, often anchored in the discipline of Human-Computer Interaction (HCI), especially in Usable Safety and Security, as well as related disciplines, such as Computer-Supported Collaborative Work (CSCW) and Information Systems (IS). Journals worldwide have taken up the topic in special issues, as well as tracks and workshops at various conferences, such as *CSCW*, *ISCRAM*, and *MUC*.[5] Recently, corresponding researchers developed and published a literature resource on crisis informatics research to support research on the COVID-19 pandemic.[6] Despite these positive efforts, in light of challenges such as climate change and worldwide conflicts, the domain of human-centred crisis informatics has to overcome several issues in the following decades to unfold its transformative potential in practice. This narrative review briefly summarises the scope of crisis informatics (Section 2), discusses current challenges and future trends (Section 3) within a horizon of 10 years into the future using the disciplinary frame of HCI, and finishes the paper with a short conclusion (Section 4).

2 Background

Despite the variety of available ICT, crisis informatics research strongly focuses on social media use before, during and after emergencies.[7] Social media is used in almost every significant crisis worldwide[5] and is approached from both

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the citizens' and authorities' perspectives. The citizens' perspective was consolidated by the seminal work of Starbird and Palen[8] on the phenomenon of *digital volunteers* or voluntweeters. Based on this, further research examined the collaboration and relationship between on-site and virtual volunteers, identifying social media roles in Twitter/X, such as moderators, helpers, reporters, retweeters, repeaters, and readers.[9,10] From a technical point of view, plenty of ICT was developed to facilitate citizens' response in crises.[11] For instance, *CrowdMonitor* is a mobile crowd-sensing application for assessing citizens' physical and digital activities during emergencies.[12] At the same time, *XHELP* allows digital volunteers to acquire, manage and distribute information across media, such as Facebook or Twitter.[13]

Besides the integration of trusted volunteers, research on the authorities' perspective comprises studies on the use and perception of social media by emergency managers to facilitate situational awareness. Apart from a facilitating organisational culture and necessary personal skills, emergency managers indicate that specific ICT is required as an enabler of social media use.[3] Studies by Plotnick and Hiltz[14] outline that information overload and trustworthiness of information are among the most critical social media challenges that supportive ICT can overcome. Despite the availability of many social media analytics tools, which sometimes employ methods of Artificial Intelligence (AI), most of them are not tailored to the requirements of emergency managers.[11] Furthermore, authorities or emergency services comprise different organisational roles and tasks, such as incident managers or public relations officers, that require diverging information from social media and, thus, the tailorability of social media analytics tools to gather actionable information.[15]

3 Current challenges and future trends

Overall, collaborative technologies and social software strengthened the role of affected citizens and digital volunteers during crises but also facilitated their interaction with emergency services.[8,9] To acknowledge that development, Reuter, Marx, and Pipek[1] developed a crisis interaction matrix which distinguishes authorities (A), such as emergency services, and the citizens (C), including affected citizens and volunteers, which can both act as sender and receiver of information. Besides crisis communication (A2C) and inter-organizational crisis management (A2A), which were widely established practices before the emergence of social media, citizens nowadays organise self-help communities (C2C) in response to crises and authorities are interested in integrating citizen-generated content (C2A) to enhance situation awareness and improve decision-making. Besides a general observation of the domain's scope (Trend I), this paper uses the crisis interaction matrix to identify four further trends (Trend II–V) of human-centred crisis informatics.

3.1 Trend I: towards a deeper integration of anthropogenic risks and new technologies in crisis informatics research

Since the 2001 September 11 attacks, a considerable body of knowledge has been established in the research domain of crisis informatics, including empirical investigations of social media use and role patterns in crises,[16] collection, processing, and refinement of social media data,[17] as well as

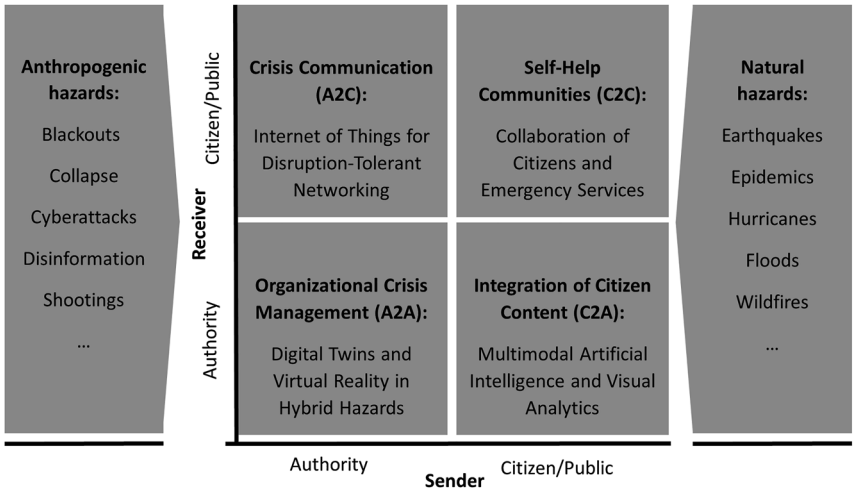

Figure 1: Extension of the crisis interaction matrix, which covers the sociotechnical interaction of authorities and citizens in crises, with trends embedded in anthropogenic and natural risks.[1]

system design and evaluation.[2] While the research field has matured, new theoretical and practical perspectives have appeared on the foundation of cumulative and longitudinal research.[5] Considering this relatively narrow focus on social media, crisis informatics started to expand the range of technologies under investigation, such as the role of mobile apps and smart home technology for crisis communication, disruption-tolerant networks for sociotechnical resilience, the interplay between social media and traditional communication technologies, participatory mapping in disaster risk modelling, or visual analytics for emergency management training.[7,18–22]

Although it is usual to distinguish anthropogenic and natural hazards in crisis informatics (Figure 1), only little domain-specific research considers the anthropogenic risks of cyberattacks and disinformation for the increasingly digitalised emergency management by both authorities and citizens. Like regular emergency services, Computer Emergency Response Teams (CERTs) and Law Enforcement Agencies (LEAs) provide preventive and reactive capabilities and will use social media (tools) to enhance their situational awareness. Their focus, however, lies in improving cybersecurity (e.g., managing cyberattacks and security vulnerabilities) and preventing cyber abuse (e.g., countering the impact of disinformation and hate speech). Still, CERTs and LEAs are confronted with similar issues when analysing open and social data, including information quality and information overload, and the risk of hybrid disasters increases (e.g., communication infrastructure hacks and disinformation campaigns during natural hazards). Thus, the next ten years will see a deeper integration of research between crisis informatics, cybercrime and cybersecurity domains, including shared situational awareness models, empirical research on hybrid hazards, and design heuristics for respective technology design.

3.2 Trend II: professionalization of the cross-platform interaction of citizen communities and emergency services

While the formation of emergent groups and self-help communities (C2C), such as for neighbourhood help, is no new phenomenon in disasters, social media facilitates the integration of digital volunteers into emergency response and recovery activities.[10] Across almost all significant past crises, social media such as Facebook and Twitter have been used to mobilise (remote) financial, material, and personal resources, express empathy and solidarity for affected citizens and disseminate status updates on the current situation.[5] However, several works have emphasised the persisting challenges of on-site and virtual self-help communities, such as mitigating the sometimes disorganised nature of bottom-up activities, properly balancing demand and supply of financial and material goods, overcoming

Figure 2: The city-share application is easily accessible using QR codes. It is designed to provide news, manage the demand and supply of spontaneous volunteers, and display hotspots during crises through public displays.[24]

information inconsistencies and quality issues across emerging communities, and mastering the cross-platform nature of social media response activities.[9] Furthermore, cases such as the 2011 Norway attacks or the 2013 European floods showcased how uncoordinated action put volunteers in danger and increased the task complexity of emergency services,[2,6] highlighting the need for better coordination between the top-down nature of emergency services and the emergence of bottom-up self-help communities.[23]

To exploit the potential of citizen participation in emergency response, HCI will design technologies for integrating citizens at different levels of involvement. Individually, social media and disruption-resistant apps will facilitate the formation and sharing activities at the local and neighbourhood levels. Furthermore, existing public infrastructures, such as digital advertising columns and public displays, will be equipped with on-demand crisis functionality to facilitate the evacuation of endangered citizens (e.g., information on blocked or crowded car routes) or the integration of spontaneous volunteers into emergency response (e.g., supply and demand functionality easily accessible by QR codes, such as in Figure 2), amongst others. Besides, emergency services have already begun to integrate trusted volunteers into their formal response efforts. Virtual Operations Support Teams (VOST) leverage these volunteers in creating, managing, and monitoring social media to maintain better engagement and communication with the public and rumour control during a disaster. Due to the unstable nature of social media, including the rapidly changing landscape of social media platforms, varying degrees of data access, and regular changes in public social media APIs, HCI research must consider this mixture of automation and manual work when designing systems for cross-platform interaction.

3.3 Trend III: expert interfaces for explainable and multimodal artificial intelligence and visual analytics in user-generated content assessment

Integrating citizen-generated content (C2A) offers new potential for emergency services since status updates, multimedia files, and public mood information can enhance situational awareness and inform crisis communication.[3] However, alongside a lack of organisational skills and resources, the perceived unreliability and sheer volume of such information during large-scale emergencies is a

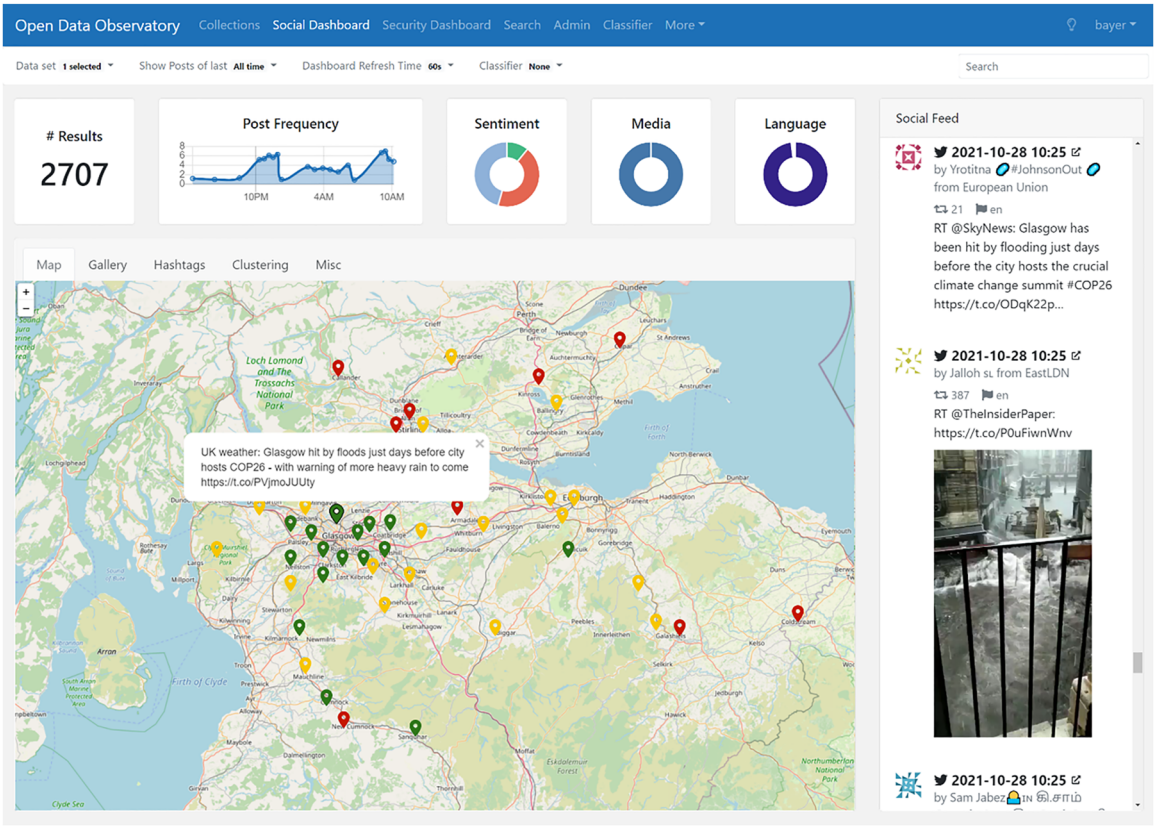

Figure 3: The open data observatory visualises public and social media data by feed and map. It facilitates searching for posts by keywords, filtering them by interactive charts, and assessing their relevance using AI classifiers.[26]

significant obstacle to exploring such opportunities.[25,26] Thus, crisis informatics has examined the design of supportive technology by applying social media analytics methods, which is defined as a process of social media data collection, analysis and interpretation in terms of actors, entities and relations.[27] By applying techniques of visual analytics, which "combines automated analysis techniques with interactive visualisations for an effective understanding, reasoning and decision making on the basis of very large and complex data sets",[28] social media alerting systems are capable of transforming the high volume of noisy data into a low volume of rich content valuable for emergency personnel.[11] While AI techniques can filter out irrelevant or low-quality content,[29,30] emergency managers must also understand algorithmic learning and decision-making to establish trust during critical and life-threatening situations.[11,31] However, current black-box implementations restrict the explainability and transparency of algorithmic decisions,[32] increasing the effort of configuring the system so that its behaviour becomes more valuable to emergency services' needs.[2]

Due to recent advancements in Large Language Models (LLMs), few-shot learning, and data augmentation, it will be easier and faster for emergency services to train and finetune emergency response models according to present emergencies. While large corporations own the most advanced LLMs today, open-source models like Llama will catch up within the next ten years, allowing for a model deployment in compliance with local data protection regulations. Furthermore, whilst most concurrent technologies focus on analysing textual data, future technologies will embrace multimodal approaches that acknowledge the value of other modalities, such as audio, image, and video files, for enhanced situational awareness. Finally, applying explainable AI technologies will help understand algorithmic decision-making and improve the users' acceptance and trust of complex algorithmic systems. Overall, HCI will be challenged to design visual analytics interfaces (Figure 3) which facilitate the setup and finetuning of multimodal deep learning and large language models, provide explanations of algorithmic decision-making, and allow the rapid reconfiguration of models in case they do not perform appropriately on the task at hand, i.e., by learning from user input.

3.4 Trend IV: internet of things and mobile applications for bidirectional communication and warnings in disruption-tolerant networks

Public authorities plan to increasingly integrate social media into their crisis communication (A2C) to inform the public about preventive or behavioural measures for emergencies.[3] Today, various guidelines and strategies for organisational social media use before, during, and after emergencies have been designed.[33] Furthermore, while social media is characterised by its unstructured, less controllable nature and specific information challenges, plenty of *crisis apps*, which provide particular functionality needed during crises, emergencies, or disasters, were established in practice and examined in research.[34] In contrast to social media, they are tailored according to the needs of authorities or citizens and allow a more structured exchange of information. Although research has examined the potential of bidirectional communication between authorities and citizens, established crisis apps and social media practices focus on unidirectional communication from authorities to citizens,[34] sometimes due to a lack of personnel, regulatory issues, and supportive technologies.[3] Furthermore, a central problem of modern ICT for crisis communication is their dependence on centralised and critical infrastructures, such as energy and telecommunications. Thus, it is essential to harden centralised infrastructures against cyberattacks and natural hazards and explore decentralised means of crisis communication.[21,35]

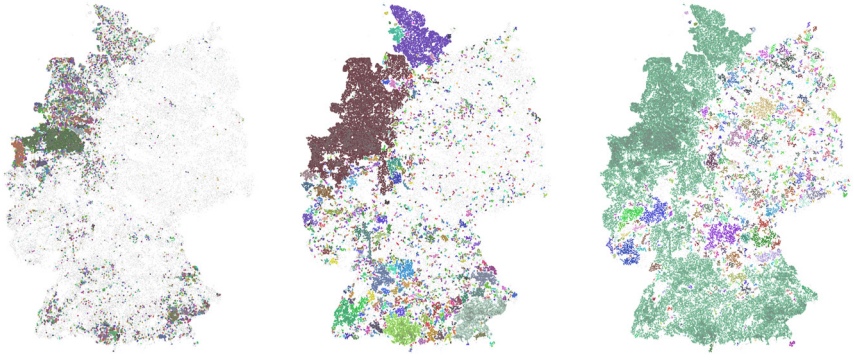

Figure 4: Simulation of low power wide area networks (LPWANs) between German farms using LoRaWAN gateways with 1000 m (left), 2000 m (middle) and 3000 m (right) ranges.[36]

In future, such decentralised and disruption-tolerant networks can be realised via Low Power Wide Area Networks (e.g., LoRaWAN), which lack the bandwidth of classical WIFI but can overcome distances of over three kilometres and, due to its low energy consumption, achieve long runtimes with batteries or emergency power generators (Figure 4). While these network technologies are interesting for at least smart rural areas, the prevalence of Internet of Things (IoT) devices will be exceptionally high in smart cities, including Unmanned Aerial Vehicles (UAVs), smart cars, smart lanterns, and smartphones, to create robust mobile ad-hoc networks. Within the next ten years, it seems feasible to establish the foundations of disruption-tolerant emergency networks for crisis communication. By considering not only smart devices on the ground but also UAVs in the air and satellites in space with both communication and sensing capabilities, it will be possible to connect local ad-hoc networks on the ground to achieve larger, decentralised, and more robust emergency networks. Since (mobile) applications and services will need to switch between different modes of centralised and decentralised operation, probably with varying sizes of networks and sets of functionalities available, HCI has to ensure context awareness and a seamless user experience during these transitions.

3.5 Trend V: digital twins and virtual reality for the training of effective multi-agency collaboration in hybrid hazards

Due to the citizen-including nature of crisis informatics, the related discourse comprises considerably less research on inter-organizational crisis management (A2A). However, considering the increasing threat of hybrid hazards in complex smart cities[37,38] or dispersed regions, such as during the 2021 European floods in combination with the COVID-19 pandemic and communication infrastructure failures,[39] the future importance of multi-agency disaster management becomes apparent. While subject to diverse information sharing and coordination problems,[30] multi-agency disaster management requires collaboration among geographically distributed public and private organisations to rapidly and effectively respond to an unexpected event.[40] However, as the necessary collaborative emergency training is costly, potentially dangerous and time intensive, disaster simulations based on digital twins and virtual reality (i.e., digital replicas of physical entities explored using virtual reality)[41,42] constitute a promising alternative if acceptance among participants can be reached.[43,44] While digital twins are capable of building "rich digital information about

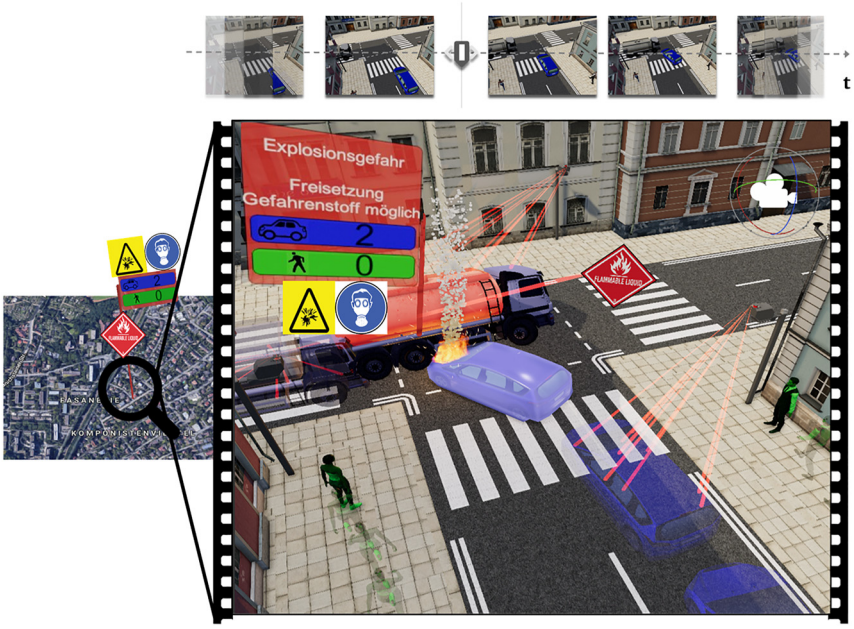

Figure 5: The program area information (INF) of the emergenCITY research centre examines 4D (3D + dynamics) semantically rich visual (immersive) and interactive environments for disaster-resilient smart cities.[45]

the [cyber-physical] system by seamlessly gathering data from IoT", virtual reality has the potential to "replicate the appearance of complex and dynamic systems and expose people to an artificial three-dimensional world".[22]

In the next ten years, digital twins will be increasingly used to replicate real-world settings, including public infrastructure, environmental conditions and human behaviour, under safety-critical conditions. Driven by HCI research, virtual reality will allow emergency managers to immerse themselves in these digital twins (Figure 5) to experience and respond to hybrid hazards in a controlled, cost-friendly, and safe environment. Considering different agencies' varying roles and responsibilities, introducing collaborative functionality will facilitate the geographically distributed conduction of joint exercises in simulated emergency settings, practising inter-organisational communication, task coordination, resource allocation, and decision-making in real-time. After completing training exercises in virtual environments, multi-agency teams can debrief, analyse their performance and identify potential for improvement using data collected during the simulations. The accumulated knowledge will help to enhance emergency risk assessments, evaluate organisational response strategies, and make informed decisions based on the exercise outcomes. Combined with real-world training, this feedback loop facilitates the continuous improvement of multi-agency collaboration in hybrid hazards.

4 Conclusions

This paper explored current challenges and future trends of human-centred crisis informatics. While the sociotechnical domain of crisis informatics focused on using citizen-generated content from social media in the past, researchers are starting to widen their scope across various underlying infrastructures and end-user technologies. In the following decade, HCI will have a significant impact on enhancing the cross-platform collaboration of citizen communities and emergency services, explainable and multimodal AI for user-generated content assessment, bidirectional communication and warnings in disruption-tolerant networks, as well as effective multi-agency collaboration in and training for hybrid hazards. Naturally, this paper is subject to limitations. By conducting a narrative review based on ten years of the author's experience in the field, other research groups might come to different conclusions or emphasise different trends, such as the demographics of technology access and social vulnerabilities. Thus, future research should consider more comprehensive and systematic literature review strategies, possibly in combination with an empirical enquiry of active researchers and practitioners, to achieve a more accurate and thorough picture of the future of human-centred crisis informatics.

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