IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

UA. BUKAR[1,4], MARZANAH A. JABAR[1], FATIMA SIDI[2], ROZI NOR HAIZAN NOR[1], SALFARINA ABDULLAH[1], and MOHAMED OTHMAN[3,5]

[1]Department of Software Engineering and Information System, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor D.E., Malaysia.

[2]Department of Computer Science, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor D.E., Malaysia.

[3]Department of Communication Technology and Network, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor D.E., Malaysia.

[4]Department of Mathematical Sciences, Computer Science Unit, Taraba State University Jalingo.

[5]Laboratory of Computational Science and Mathematical Physics, Institute for Mathematical Research (INSPEM), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor D.E., Malaysia.

Corresponding authors: Umar A. Bukar (e-mail: umarfalmata@gmail.com), Marzanah A. Jabar (e-mail: marzanah@upm.edu.my).

ABSTRACT The involvement application and use of crisis and emergency management and communication are increasing rapidly. This study conducts a systematic literature review to identify the development of theoretical models in the area of social media crisis communication and management. The study aims to review and analyse the relationship of social media-based crisis communication in the context of crisis informatics and its taxonomy and the related crisis communication theoretical models to derive the challenges and limitations. A total of 207 articles were selected for the evaluation based on quality, relevancy, and contribution. The findings revealed that the situational crisis communication theory (SCCT) is the most dominant theory, followed by social-mediated crisis communication (SMCC) and integrated crisis mapping (ICM) models. The study identified theories such as the STREMII model, social media crisis management matrix/framework (SMSMF), and an interactive crisis communication model (ICCM) as emerging models. Moreover, the result of the finding shows that stakeholder interaction is an understudied field, while information reliability and processing for decision-making purposes, the wider application of social media sites, privacy issues, and how social media interaction can improve community resilience or build stakeholders relationships remain suitable topics for future research.

INDEX TERMS Crisis Informatics, Crisis Communication, Social Media, Response Strategy, Systematic Literature review (SLR)

I. INTRODUCTION

THE crises of natural type are inevitably compared to human-induced type, and no community, organisation, public or private, is immune from crises [1] as cited in [2]. Crises are unexpected, and crisis management focuses on how stakeholders (organisations and public) cope with surprising negative events. Crises induce a high degree of uncertainty [3] and anxiety among most actors involved. This led to the involvement of various stakeholders to provide effective response and recovery plans. Recent technological advancements and the use of social media is nowadays part of everyday life [4]. People used social media platforms (Facebook, WeChat, Twitter, etc.) to share the crises surrounding oneself or loved ones. Share in this context means sharing of text or images, retweet as the case may be for twitter users. Most times, this information gets replicated over a period in the name of sharing. The use of social media for these kinds of activities is sometimes referred to as crisis informatics [5].

[6] reported that social media enables effective crisis response by enabling accessibility of cross-platform and constant info flows. Advances in crises in social media offer new potentialities and opportunities for disaster response in real-time. When a disaster or crisis occurs, social media is used to render apology [7], or as a communication medium [8]

IEEE Access

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

and information source for decision-making [9], [10]. Data mining, media coverage, social sensing, and internal records from focal organisations are other areas that actively engage social media [7]. Social media applications have been recognised to be a reliable communication medium even when traditional mediums fail to deliver [8], and recently [11] presented the application of social media during a campus crisis. Subsequently, long-range interpersonal communication has been perceived as helpful channels for relationship building, while improper or customary systems can ignite social media crisis. Organisations are all encouraged to utilise an effective response system, yet crisis managers and professionals need to comprehend the hidden standards of building relationship and exchange to apply them adequately during a crisis [12].

The term "crisis informatics" views emergency response as an expanded social system where information is disseminated among stakeholders [31]. Crisis informatics is wrestled with the responsibility to handle methodological concerns, to develop new theoretical models and to support the development of both ICT and policy [32]. The theoretical models in the field of crisis informatics were mostly adopted from crisis communication, which in-turn used social media as a medium for communication. Researchers in crisis communication have proposed different models that considered social media [33]–[39], which are also termed social media crisis communication theories and models. Concerning this development, the purpose of this article is to review various crisis communication theories and models concerning social media and crisis informatics while building on the work of other crisis management scholars.

A. OVERVIEW OF CRISIS INFORMATICS

Emergency management, disaster management, and crisis management are often used interchangeably [40]. The application of technology intervention in crisis management is referred to as "crisis informatics" and researchers have linked the termed to be coined by Hargar (2006; 2007) [5], [15], [25], [41]–[44]. The crisis informatics field is a multidisciplinary area of studies, which is widely defined as sociotechnical interactions that exist between people, organisations, information and technology during crises. [41] elaborated that crisis informatics is the empirical study and the ICT development and deployment to manage the crisis. [5] stated that "social media use in emergencies has become a very big research field, sometimes summarised under the term crisis informatics". [42] further explained that the field examines the overlapping factors of social, technical, and information in disaster/crises exploring all phases including preparation, response, and recovery. Crisis informatics combines computing and social science knowledge of disasters [44], and views emergency management as a socio-technical system, in which information is disseminated within and among officials, public channels and entities [43]. The involvement of computing technologies has enabled widespread adoption and study of crisis informatics.

Moreover, crisis informatics is a new area of research [45] and many studies have reported a concrete used of social media [15], [25], [46]. The involvement of social media applications and use in crisis or emergency communication and management is increasing rapidly [5]. "Social media, such as YouTube, Twitter, Facebook, blogging, instant messaging, are necessary tools for effective crisis communication [2]. Crisis informatics sometimes tries to understand the behaviour of social media users, interactions between stakeholders, and the socio-technical side of crisis management services [25].

B. RELATED REVIEW

Table 1 presents the overview and brief description of the existing review on crisis informatics and crisis communication researches, and Table 2 provides a critical assessment of the related papers based on the categorisation of use patterns [5], which examine different practices and tools of social media usage in emergencies. The analysis focused on different usage patterns, such as digital volunteers, social sensing or social media analysis, and crowdsourcing.

The social media crisis communication theoretical models and its recent improvement are both emerging and still at their early stage. The social media crisis communication models emerge due to the advancement of information technology and new media. Most of the existing reviewed papers focus on usage and tool-based practice and the applications of social media [4], [5], [8], [13], [15], [20]–[23], [26], [27], [29], [30]. Although there were few papers that reviewed the application of social sensing, digital volunteerism and crowdsourcing. However, [16] is the only review article that first explores social media-based theoretical crisis communication models, showing how traditional crisis communication theories can be adopted for social media.

For example, [13] is an early study that provides an overview of the early practice of social media crisis and risk communication. [14] reviewed the overlapping domains of the sensor web, inclusive of social sensing for the public health crisis. Review of the use and the impact of social media on crisis management in the tourism industry was conducted by [15]. On the other hand, [16] is the first review that explores social media-based crisis communication models and how crisis communication theories can be adopted for social media, while [17] study focuses on social media methods, systems, and applications for disaster management and [18] focuses on social media usage patterns and data analytics framework. Also, [19] review informal volunteerism, while [20] focus on social media for emergency management. More details on the areas covered by previously reviewed studies can be seen from Table 1.

Moreover, [21] focuses on the use of social media during environmental concerns for information dissemination and prediction, while [22] discusses social media usage advances in data collection, evaluations and public participation. Also, the categorisation of digital technologies used in crisis management was conducted by [23], while [24] reviewed big crisis data analytics and its enabling technologies, such as

TABLE 1: Overview of previous review on crisis informatics and social media crisis communication

Ref	Year	Brief Description
[13]	2011	Provides an overview of early practice of social media crisis and risk communication; examples of social media use, tools, and best practices.
[14]	2011	Review on overlapping domains of Sensor Web, 'human-in-the-loop sensing', citizen sensing, the roles citizens play in environmental public health surveillance, and crisis or disaster informatics.
[15]	2011	Reviewed the literature to identify the use and impact of social media for crisis management in the tourism industry.
[16]	2014	First review that explores social media-based crisis communication theories or model and how crisis communication theory can be adopted for social media.
[17]	2014	The paper focuses on social media methods, systems and applications for disaster management for wildfire risk management.
[18]	2014	Reviewed usage patterns of social media, data analytics framework, associated tools, and data mining tools.
[19]	2015	Reviewed informal volunteerism and showed evidence of social media for digital volunteers as a new mode of volunteerism.
[20]	2015	Social media use for emergency management, preparedness, technology adoption and usage, crowdsourcing in disasters, information categories, and location-based information, and disinformation and inaccuracy.
[21]	2016	The use of social media during environmental concerns for information dissemination, prediction, awareness and promotion, and public participation.
[22]	2016	Brief essay review that discusses social media usage advances in data collection, audience needs evaluations, and public participation.
[23]	2016	Reviewed the digital technologies used in crisis management and categorised them based on crisis management service usage and affected public usage.
[24]	2016	Reviewed the use of big data analytics for processing and analysing big crisis data. Also, discussed enabling technologies, sources of big data and its challenges.
[25]	2017	The review analyses the engagement of various mobile apps with the people during risk and disaster situations.
[26]	2018	A special issue on "Exploitation of Social Media for Emergency Relief and Preparedness" conducted for the journal of Information Systems Frontiers.
[27]	2018	This study examines recommendation for effective social media crisis communication proposed by researchers in different sub-disciplines of strategic communication.
[28]	2018	Survey, as well as the tools and techniques used to process the information collected after disasters and the challenges faced.
[4]	2018	Assessed and analysed crisis informatics research, outlining the types of research, summarised accomplishments from a human-computer interaction view and outline challenges and trends for future research.
[5]	2018	The review summarised 15 years of research studies on social media in emergencies with emphasis on perception patterns, role patterns and use patterns across different crisis scenario.
[8]	2018	Analysed the application social media in emergency management, its use, support and complexities.
[29]	2018	Identified major approaches in using social media for disease outbreaks; 30 articles were evaluated in terms of social media used, theoretical framework, methodology and findings.
[30]	2018	Review the use of social media by low and middle-income countries in the health sector.

TABLE 2: Critical Analysis of Existing Review Papers

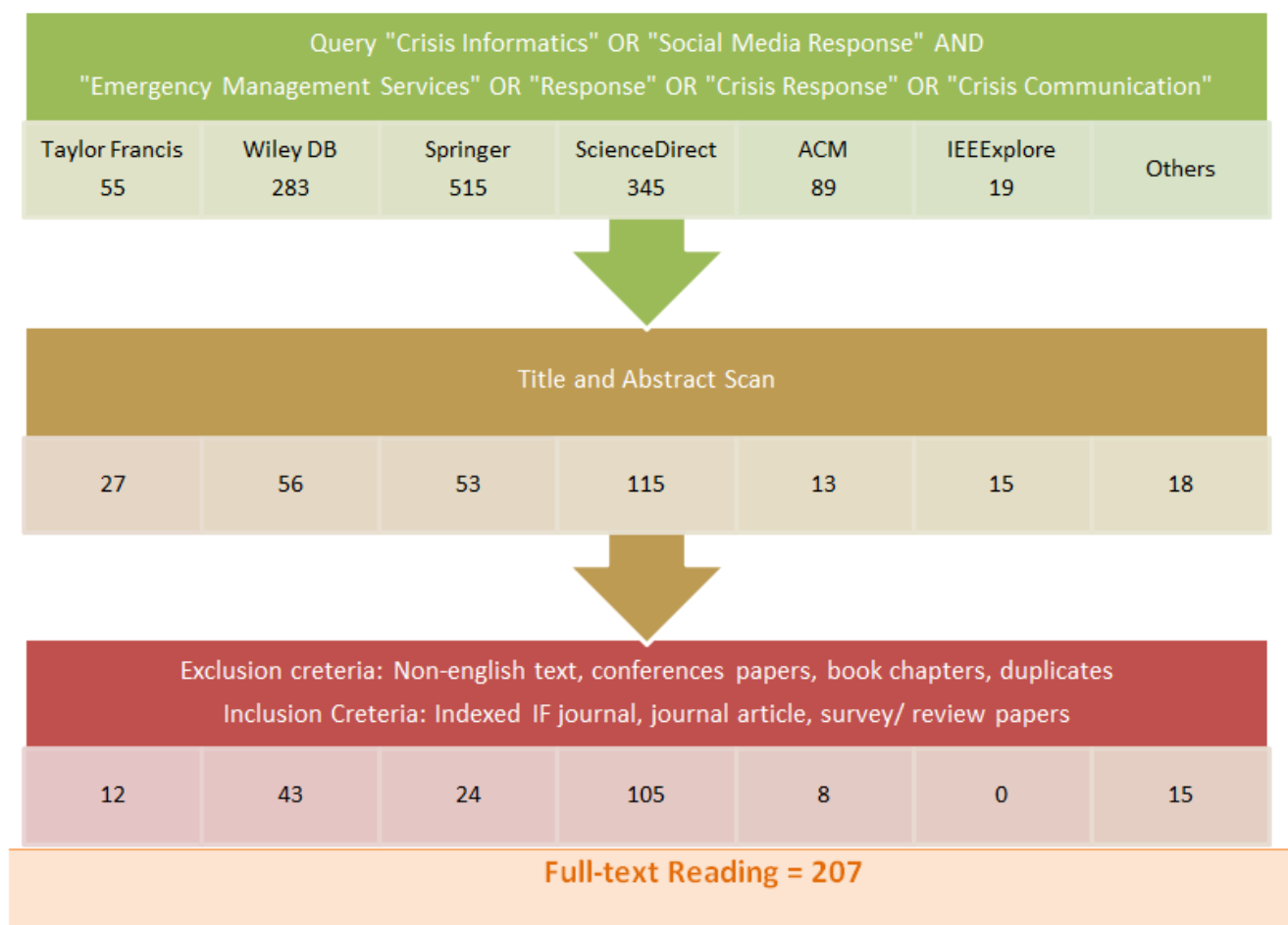| Related Work	Usage	Tools	Social sensing	CC Models	Digital volunteers	Crowdsourcing
[13]	✓	✓				
[14]			✓			
[15]	✓					
[16]				✓		
[17]		✓				
[18]		✓				
[19]					✓	
[20]	✓		✓			✓
[21]	✓	✓				
[22]	✓					
[23]	✓					
[24]	✓	✓	✓			✓
[25]		✓				
[26]	✓	✓			✓	✓
[27]	✓					
[28]		✓				
[4]	✓	✓	✓		✓	✓
[5]	✓	✓	✓		✓	✓
[8]	✓					
[29]	✓					
[30]	✓					

FIGURE 1: Literature Review Search and Selection Process.

TABLE 3: Phase I Data Extraction, Organisation and Synthesis of the Selected Papers

Ranking	Description	Keyword for Synthesis	Overall
3	Highly related	Model, framework, algorithms, implementations or improvement, data collection/ mining, social network analysis	95
2	Related	Evidence of complex statistical analysis and finding	43
1	Slightly related	General applications, usage, findings, review, essay, or letter	40
0	No related	No evidence of relation	29
		Total number of articles	**207**

the internet, mobile phones, crowdsourcing, artificial intelligence and machine learning. [25] on the other hand focuses on mobile application engagement during risk and disaster situations, and the exploitation of social media for emergency relief and preparedness was done by [26].

Also, [27] examines the recommendation for effective use of social media crisis communication. Tools and techniques used to process disaster information were evaluated by [28]. [4] assess and analyse various crisis informatics research, while [5] summarises 15 years of social media in emergencies with emphasis on perception patterns, role and use patterns across different crisis scenario. Besides, [8] focuses on the application of social media in emergency management, while [29] identifies major approaches in using

social media for disease outbreaks, and the use of social media by low and middle-income countries in the health sector was conducted by [30].

C. CONCLUSION

Despite the review of various applications of social media in crisis communication, to the best of our knowledge; [16] is the only study that predominantly focused on the specific aspect of crisis communication theoretical models dated since 2014. From the year 2014, we assumed that more theoretical models have been introduced. Therefore, this study pays special attention to the social media crisis communication theoretical models and their recent improvement from the literature. Therefore, the objectives of the study are:
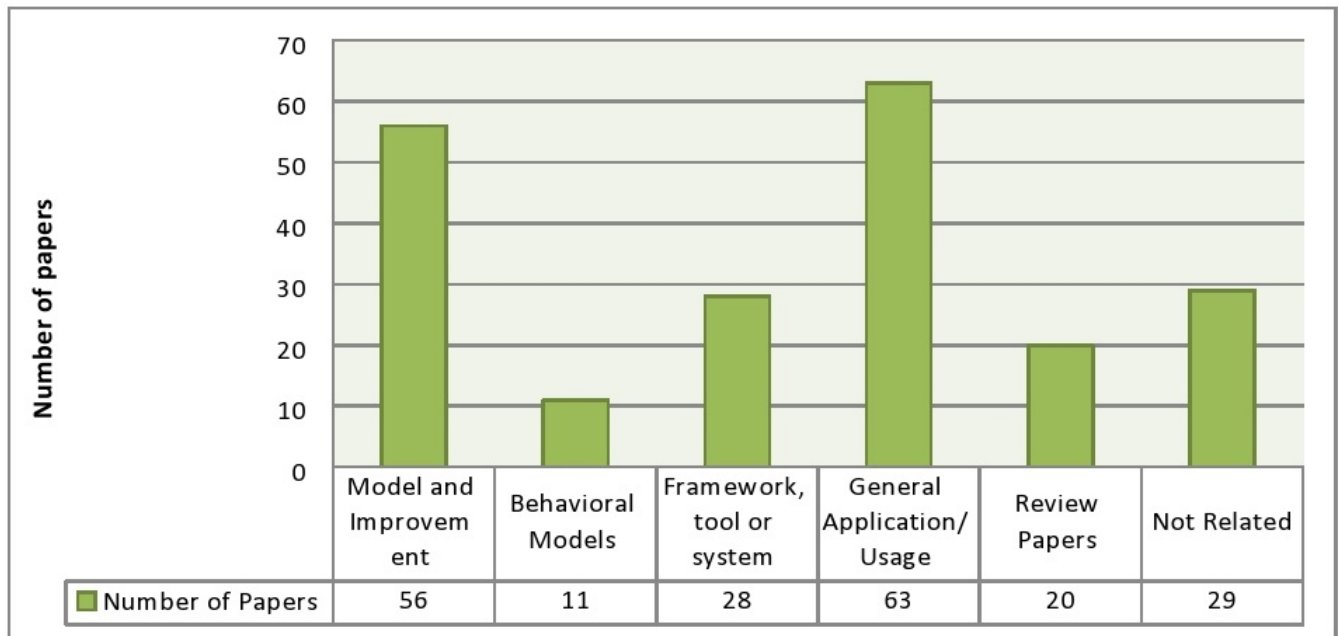
FIGURE 2: Phase II Data Synthesis of the Selected Papers.

- to study and understand the relationship between crisis communication, social media and crisis informatics.
- to identify the taxonomy and classify research studies associated with crisis informatics in the context of social media crisis communication.
- to identify theoretical models and their common features in the field of social media crisis communication.
- to identify challenges and limitations facing social media crisis communication.

To provide an inclusive review and address the objectives of this study, the following research questions ware formulated. Each research question corresponds to the objectives of the study. The research question was motivated by the fact that a review study on social media crisis communication theoretical models is needed and also to study the overlapping integration of crisis communication, social media, and crisis informatics from the literature. Also, the research questions were formulated to help the researchers identify gaps and motivation for future research. Specifically, the aim is to investigate existing crisis communication models in order to identify commonalities within these models. Then, adopt these common denominators to propose a social media crisis communication model, which will measure or investigate social interaction among stakeholders involved in crisis response on social media with the aim to improve public resilience.

- Q1. What is the relationship between crisis communication, social media, and crisis informatics from theoretical perspectives?
- Q2. What is the taxonomy of research studies conducted in the field of crisis informatics in the context of social

media crisis communication?
- Q3. What are the related crisis communication theoretical models and social media-based theories/models, and what are the common features of these models?
- Q4. What are the issues and challenges of the social media crisis communication theoretical model?

In order to answer the research questions, Section 2 explained the method followed in addressing the research questions. Section 3 presents the various crisis communication theoretical models from the literature, and it further surmises the development of the taxonomy of prior researches, and theoretical models used in crisis communication with their recent advancement, implementation and empirical test. Also, the section provides a rationale for considering dominant theoretical models together with challenges and open issues. Section 4 discussed the outcome of the study and clarified how the researchers aimed to bridge the gap identified in the literature. Section 5 ends with a conclusion.

II. RESEARCH METHOD

A systematic literature review (SLR) approach was adopted to identify the development of existing theoretical models in the field of social media crisis communication and management. Several studies have conducted SLR [47]–[51] in various research fields. Approaches used in conducting an SLR have been reported in various studies. These approaches shared many things in common and some phases were overlapped. For example, [47] and [48] suggested identification of research, study selection, study quality assessment, data extraction and data synthesis in their SLR. In [49], the stage of selection was further split into the development of inclusion and exclusion criteria, and the selection of studies

IEEE Access

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

during inclusion and exclusion criteria. [50] on the other hand collapsed most of the later stages into a title and abstract scanning, and full-text reading while the inclusion and exclusion criteria are applied simultaneously. Recently, [51] added a reporting stage as part of the SLR activities. In this study, the systematic review is divided into five major steps as presented linearly but was practically conducted in an iterative manner [49].

A. IDENTIFICATION OF RESEARCH AND SEARCH PROCESS

Keywords relevant to the research are generated and used in the form of a query to search for articles related to the area of interest in six different databases. All research keywords were obtained by following the guidelines obtained from [52]. These keywords terms are crisis informatics, OR social media response, AND emergency management services, OR response, OR crisis responses, OR crisis communication. The search used six databases and a few papers randomly identified from Google Scholar. These databases include Taylor Francis, Wiley, Springer, ScienceDirect, ACM and IEEExplore.

B. PAPER SELECTION PROCESS

Title and abstract scanning were the first criteria applied at the early phase to identify and screen irrelevant articles. This helps the researchers determine if the articles meet any of the exclusion or inclusion criteria. Additionally, the inclusion and exclusion criteria were applied to further sort papers based on pre-defined criteria. The exclusion criterion includes non-English text, conference papers, book chapters and duplicates, while the inclusion criterion includes indexed IF Journal and review papers. The inclusion criteria used to select papers from Google Scholar is consistent with other databases; publication must be indexed JCR. Papers selected from Google Scholar were verified to avoid duplicates. 207 papers were selected for full-text reading as shown in Fig. 1.

C. QUALITY ASSESSMENT

[47] cited in [53] provides guidelines in assessing the quality of articles for review purposes using a set of criteria. The quality of individual publications relied on the indexed IF journal criteria applied in the previous stage. Thus, articles not from impact factor journals are expunged for further reading. The evaluation criterion for quality assessment was used to ensure the credibility of the selected sources.

D. DATA EXTRACTION

The data extraction allows the researchers to classify the articles based on specific information. The authors formulated that information served as a criterion to consider the articles for further reading and analysis. The information includes topic relevancy, social media context, methodology and data collection and analysis process. Furthermore, specific information was ranked based on the suggestion by [48]. Therefore, the articles were ranked based on highly related,

related, slightly related and not related; equivalent to 3, 2, 1, and 0 respectively [53] as shown in Table 3. An article that is ranked 3, was considered to be of high relevance. All the subsequent articles were also ranked through the evaluation and extraction process. It is concluded that all the papers fulfill the criteria of 3, 2, 1, or 0. The papers that score 0, were excluded for further reading [48].

E. DATA SYNTHESIS

The objective of data synthesis is to derive the taxonomy of the various research conducted in the field of social media crisis communication. Therefore, thematic analysis was applied to the extracted articles [49]. The researchers closely examine the articles to identify common themes, such as topics, ideas, patterns and approaches that came-up repeatedly. The articles are sorted based on the introduction of new theoretical models, framework tools and systems, general application and review papers. A logical relation is established if an article shares the same attributes. Doing this helps the researchers to understand problems or issues that remain unsolved in some specific fields, and emerging trends and new approaches. In conclusion, 56 papers were used for a more comprehensive reading and evaluation.

III. RESULT

The result of the study is organised according to the research questions. A summary discussion has been expressed that attempted to answer the research question as precisely as possible.

A. OVERVIEW OF SELECTION PROCESS

The initial query returned 1306 articles from six databases; 55 from Taylor Francis, 283 from Wiley, 515 from Springer, 345 from ScienceDirect, 89 from ACM, and 19 from IEEE Xplore. A total of 1027 articles were eliminated after reading their title and abstract, and an additional 18 articles are added from the Google Scholar search, which took the tally to 297. Furthermore, 90 extra articles were excluded after applying additional exclusion and exclusion criteria, thus reducing the output to 207 as the final study sample for full-text reading. Fig. 3. presented the breakdown of the database sources and the number of articles from each source.

B. Q1. WHAT IS THE RELATIONSHIP BETWEEN CRISIS COMMUNICATION, SOCIAL MEDIA AND CRISIS INFORMATICS FROM THEORETICAL PERSPECTIVES?

1) Crisis Communication and Social Media

Crisis communication is defined as a form of strategic communication that can lessen the negative effects of a crisis on an organisation and stakeholders [54]. On the other hand, social media is an object or environment that enabled groups and individuals to collaborate [55]. The advancement of technology has enabled social media to serve as a tool for crisis communication. The conceptual overlapping integration of crisis communication and crisis informatics is seen from the work of [31]. The relationship between the two terms
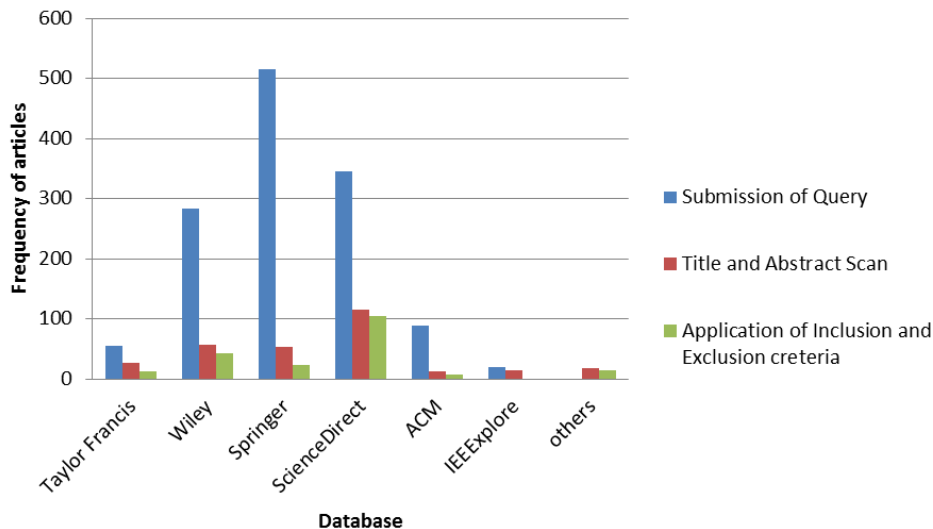
FIGURE 3: Frequency of Research Articles from Database.

has been used interchangeably in the literature. Specifically [56] addresses the use and adoption of social media-based tools for crisis communication, social media taking part in managing a crisis. While [57] emphasised that an important component of crisis management is crisis communication. During a critical event, communication serves several purposes from information collection, coordination, dissemination, planning and management, also building relationships according to [58] cited in [57]. It is no surprise why social media is such an important tool for crisis management services [59]. It is reported that social media are used as much as traditional media [35]. [60] added that social media provides a way for dialogue on crisis for individuals, in addition to the needs of responding to crisis rapidly. Fig. 5 represents the underlying understanding of the integration of crisis communication and crisis informatics. Fig. 4 shows the crisis communication matrix [61] that distinguishes between the four patterns of social media use in emergencies. Crisis management organisations communicate with each other (A2A). The citizens and volunteers communicate with each other via social media (C2C). The content generated on social media can be analysed by crisis response organisations (C2A) for improved decisions. The organisations that are responsible for recovery work also inform the public through social media (A2C).

Information and communication technology (ICT) is crucial in the field of crisis management [62]. Social networks are commonly used by citizens as a communication channel for sharing messages about a crisis and by emergency operation centers as a source of information for improving situational awareness [63]. To re-emphasise the importance of social media as a resource, this is derived from the fact that it has become a part of daily life. The digital convergence of people, information and resources during crises is increasingly taking place on social media platforms and

have been well-documented in various papers in the field of crisis informatics [64]. The public is far from being passive receivers, thanks to social media. They actively seek out crisis information and exchange views with others [61], [65]. Public participation in disaster/ crisis response on social networks is not new. The dependence of formal and informal stakeholders (management and public) response is an established requisite for effective crisis communication and management [66], [67]. Social media hypothetically intensifies the influence of the public's response [67].

2) Summary

Since crisis informatics is sometimes the term that describes the use of social media in crisis [4], [5], [31], and also the fact that addressing crisis on social media can be termed as social media crisis communication. Social media builds upon crisis informatics is a concept that views emergency response as an expanded social system where it encourages stakeholders (i.e. public, emergency managers) to participate in generating and sharing disaster-related information to a broader audience [31], [68]. Social media offers a platform to provide rapid real-time information and public access to it. The use increases especially during a crisis and social media is more dialogic and credible than traditional media [59].

C. Q2. WHAT IS THE TAXONOMY OF RESEARCH STUDIES CONDUCTED IN THE FIELD OF CRISIS INFORMATICS IN THE CONTEXT OF SOCIAL MEDIA CRISIS COMMUNICATION?

To address the aforementioned question, taxonomy of the literature to summarise the existing research in the field of social media crisis communication was created. Content and thematic analysis were conducted on the final sample (207 articles). The articles were studied in detail to evaluate the existing research in the subject area. The studies were con-
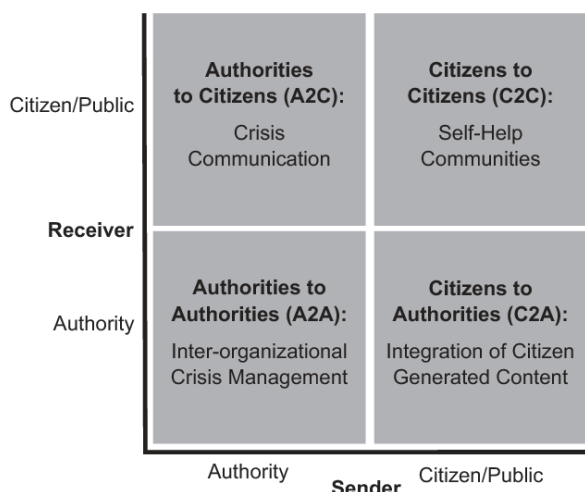
FIGURE 4: Crisis communication matrix [4], [5], [61].

ducted in various forms and the categorization was presented in Table 3 and Fig. 2. In particular, 95/207 either introduce, propose or improve existing theories, model, framework and algorithms. To be specific with respect to the aim of this study, 56/207 were proposals or improvement of theoretical models that aim to seek answers to the practical application of crisis communication theories. This research observed and studied each category to generate the taxonomy displayed in Fig. 6.

1) Taxonomy of research in crisis informatics

Fig. 6. presented the taxonomy of research in the field of crisis informatics and its related sub-disciplines. Crisis informatics encompasses using social media in crisis management [33], [36]. The classification and evidence of social media intervention for crisis management includes social sensing [69], [70], which is further classified into mapping [71], [72], location identity [73]–[75] and geoweb [76]–[78]. Crowdsourcing [6], [55], [79]–[81] and digital volunteers [82]–[84] are the additional areas identified from the literature. Furthermore, crisis communication [33]–[35], [38], [85]–[88] is another area of research that is further divided into social network [89], [90], issue arena which involve places for societal discussion on social media [90], [91], others areas include crisis responses in the form of information dissemination [87], [92]–[94] and information seeking [67], [95]–[100]. The effectiveness of social media for information dissemination and sharing has been discussed widely by [101], and [102] studies focus on the information dissemination dynamics, and their influence on emergency management. More explanation on the major domain of crisis communication identified from the literature is reported in the following section.

Furthermore, the methods of research identified from the literature were not limited to empirical study. Socio-semantic network analysis was used by [103]–[105], thematic analysis by [106], semantic analysis by [59], [106], [107], and actor analysis by [90], [91]. Machine learning and deep learning approaches were also seen through the implementation of lexico-semantic pattern and marching [74], support vector machine (SVM) [10], [108], modularly bayesian networks [109] and self-organising map algorithm from artificial neutral network [88] were also identified. The application of statistical techniques was also used. For example, [110]–[112] used SEM, PLS and Regression analysis in their studies, Anova by [87], [113]. Also, data mining techniques and applications [9], [108], [109] for decision-making purposes were seen in various studies. Nevertheless, our aim is to investigate the existing theoretical models use in crisis communication in the context of social media and crisis informatics that are used either in; to understand how social media is used in crisis response, the relationship of stakeholders involved, and stakeholders' social interactions during a crisis [25].

2) Summary

One of the objectives of this study is to identify the taxonomy of the existing work in the area of crisis informatics in the context of social media crisis communication. Several notes on the articles were reviewed and a running synthesis of all the papers have motivated the creation of the taxonomy. The taxonomy revealed that the classification and evidence of social media intervention for crisis management into social sensing (mapping, location identity, geoweb), crowdsourcing through digital volunteerism, and more importantly crisis communication through social networking, issue arena, information dissemination and information seeking. Hence, the taxonomy also includes papers that used the research methods to assess applicability in the domain. The taxonomy has helped in identifying the gap for future research to abridge. Specifically, crisis response through information dissemination, issue arena and social interaction remain as an area for future research.

D. Q3. WHAT ARE THE RELATED CRISIS COMMUNICATION THEORETICAL MODELS AND SOCIAL MEDIA-BASED THEORIES/MODELS, AND WHAT ARE THE COMMON FEATURES BETWEEN THEM?

1) Theoretical Crisis Communication Models

Crisis management model was the first model for crisis communication in the virtual world [34]. The model indicates the internet technologies as the trigger or enabler of crisis. The situational crisis communication theory (SCCT) is the most widely used response strategy theory for crisis communication, which was extended and improved upon by several studies [57]. An enhancement of SCCT was proposed by [35], termed a social-mediated crisis communication model (SMCC) that focuses on types of public, information sources and form. The integrated crisis mapping (ICM) model is emotion-driven [115] while crisis messages based on hierarchical model show various characteristics and attributes of a good response message [116]. [85] proposed a crisis communication model that divides the dimensions of the
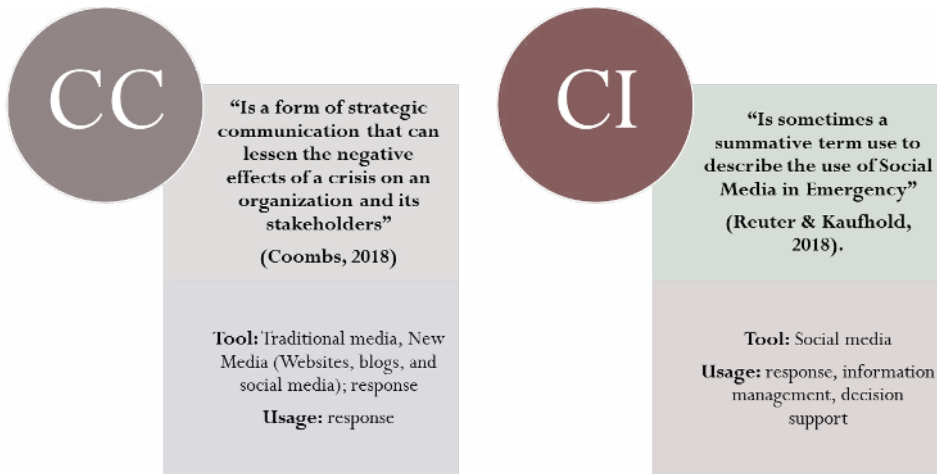
FIGURE 5: Integration of crisis communication and crisis informatics concept; adopted from [4].
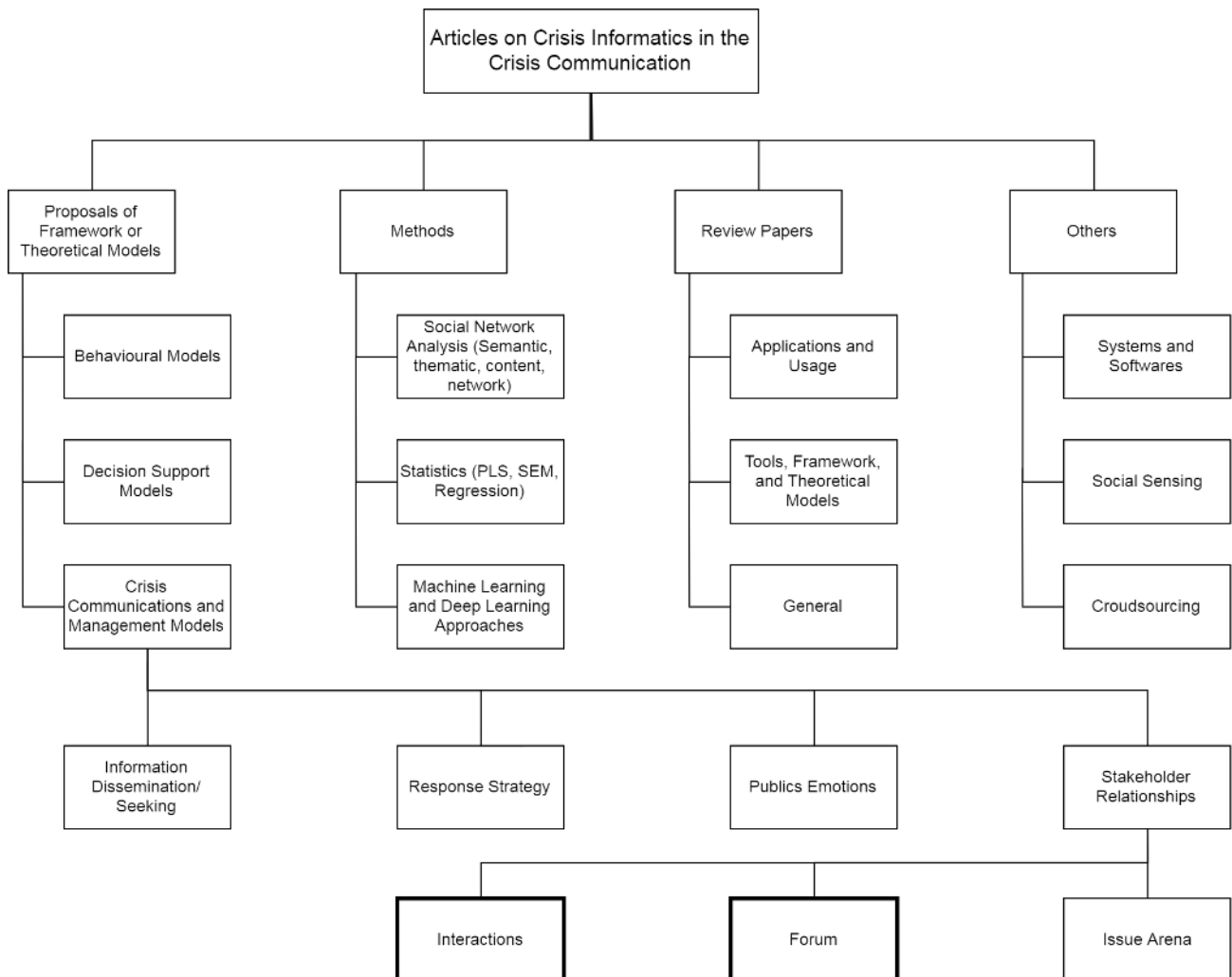

FIGURE 6: Crisis Informatics Management; the main classification has been identified based on the articles reviewed. (Note: Premature version of this figure has been presented at the AiIC2019 Conference) [114].

IEEE *Access*

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

crisis message. Recently, [36] proposed the STREMII model that is cyclic and dynamic for social media, although the model is limited to response and recovery during natural disasters [117]. Crisis and emergency risk communication model (CERC) was adopted for social media by [118]. Moreover, a model for information diffusion and propagation was proposed by [102] while [94] adopted socialization theory and structuration theory for crisis management that integrates the SCCT crisis phases. Also, [6] provides a concept for problem-solving based on the probabilistic approach for knowledge and disaster management. Channel specification theory (CST) was adopted to extend the use of gratifications theory (GT) for understanding the cognitive process in selecting communications messages [119]. [112] proposed a general structural path model for understanding stakeholder relationships in normal times and crises while [120] and situational awareness (SA) model explored the relationship between social media message complexity and type.

Moreover, dialogic communication theory is used to increase stakeholders' relationships during and after crisis [121]. On the other hand, [122] extends the agenda building theory to know the influence of PR and media on the online public. While [7] uses a network approach to apology based model through the stakeholder network management theory and balance theory. Nevertheless, social-mediated disaster resilience (SMDR) [39] was the only model that emphasised social media usage and effectiveness to improve community resilience through the 3Rs resilience model (robust, rapid and redundant).

Still, framing theory was used to identify framing use in social media [100], interactive crisis communication model (ICCM) is based on SCCT, SMCC, and traditional crisis communication strategies (CCS) [38]. The actor-network theory was introduced to show technology-enabled health discussions on social media [91]. Also, the social media crisis management matrix and framework (SMCMF) is an analytical framework for response strategies and crisis resolution [37]. Recently, [123] operationalised the social amplification/attenuation of risk framework (SARF) through modeling the perception of tweets during a health risk event, and [90] used network theory to identify the stakeholders involved in the issue arena. Appendix A presented various components and elements of the theories and models identified from the literature. In Table 4, the common features of various crisis communication models are presented.

2) Dominant Crisis Communication Theoretical Models

The work in [37] has furnished us with the most dominant theory and how researches base on these traditional theories links stakeholders' emotions and response strategies. In this section, we summarise these theories as elaborated in [37] from Table 5, and show how stakeholders' emotions are linked with response strategies in Fig. 7.

TABLE 4: The Features of Crisis Communication Models

Related Work	Precrisis	Crisis • Origin • type	Postcrisis	Response Strategy	Message oriented • PR • public • content	Relationship • PR • public	Emotions	Interactions
[34]	✓	✓	✓					
[33], [54], [124], [125]	✓	✓	✓	✓	✓			
[35]		✓		✓	✓	✓		
[115]		✓		✓			✓	
[116]					✓			✓
[85]				✓				
[36]	✓	✓	✓			✓	✓	✓
[118]	✓	✓	✓		✓			
[102]		Information propagation rates						
[94]	✓	✓	✓		✓			✓
[6]		Knowledge management						
[119]					✓			
[112]	✓	✓	✓			✓		
[122]					✓	✓		
[7]			✓	✓		✓		
[39]	✓	✓	✓					✓
[120]	✓				✓	✓	✓	✓
[121]		✓	✓			✓		
[100]				✓				
[38]	✓	✓	✓	✓	✓			
[91]				✓				✓
[37]		✓	✓	✓	✓		✓	
[123]	✓	✓	✓					
[90]						✓		

IEEE *Access*

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

FIGURE 7: Linking stakeholders emotions and response strategy. Source: [37] elaboration based on SCCT, SMCC and ICM.

TABLE 5: Dominant Theoretical Models of Crisis Communication. Source: [37] elaboration based on SCCT, SMCC and ICM.

Authors	Theoretical Model	Management Purpose	Description	Component/Constructs
Jin et al. (2007, 2009, 2012)	Integrated Crisis Mapping (ICM)	Conceptualisation of stakeholders' emotions	Determining the origin of the crisis (external/ internal and public/internal) allows determining and anticipating the emotions that stakeholders are likely to feel when facing the crisis	Three dominant emotions: anger, sadness and fright differ according to the 3-criteria origin of the crisis: internal-external, personal–public, and unnatural–natural
Coombs (2007)	Situational Crisis Communication Theory (SCCT)	Evidence-based guidance for crisis communication	The degree of responsibility for the crisis attributed by stakeholders to the organisation allows determining the type ("cluster") of the crisis and is positively correlated to the width of reputational threat.	Three clusters: victim, accidental and preventable Maximise reputational protection by identifying the cluster and reacting accordingly. Two strategies: defensive (deny, diminish) and accommodative (rebuild and bolster)
Austin et al. (2012) and Jin et al. (2014)	Social-Mediated Crisis Communication (SMCC)	Determination of best-suited responses strategies	The response strategy should be consistent with the crisis origin and the emotions it triggers	The crisis origin can trigger attribution dependent or attribution independent emotions to which the response, its content, form (social media, traditional media, WOM) and source (third party or organisation) should be adopted

TABLE 6: Crisis Communication Response Strategies Based on SCCT

Response Strategies/Ref.		[126]	[35]	[127]	[128]	[129]	[12]	[130]	[131]	[132]	[133]	[134]	[59]	[135]	[136]	[137]	[93]	[138]	[139]	[101]	[140]	[141]
Denial	**Attack**		✓	✓				✓			✓											
	Denial		✓	✓				✓						✓								
	Scapegoating													✓								
	Lamentation		✓	✓				✓				✓										
Diminish	**Excuse**		✓	✓				✓									✓					
	Justification		✓	✓				✓									✓					
	Redirection											✓										
	Satire											✓										
Rebuilding	**Compensation**		✓					✓														
	Apology	✓	✓	✓	✓	✓		✓		✓				✓	✓				✓			✓
Bolstering	**Reminding**			✓				✓						✓					✓			
	Ingratiation			✓				✓						✓					✓			
	victimage							✓						✓								✓
Information	**Information**				✓					✓												
	Adjusting Info							✓					✓	✓							✓	
	Instructing Info							✓						✓							✓	
	Internalising Info													✓								
	Bolstering Info																				✓	
Deal	Corrective action											✓										
	Collectivism											✓										
Others	**Sympathy**	✓			✓					✓												
	Sit-out				✓																	
	Divert Attention			✓																		
	Dialog						✓		✓									✓		✓		
	Defensive				✓																	
	Enhancing Awareness							✓														✓

IEEE *Access*

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues
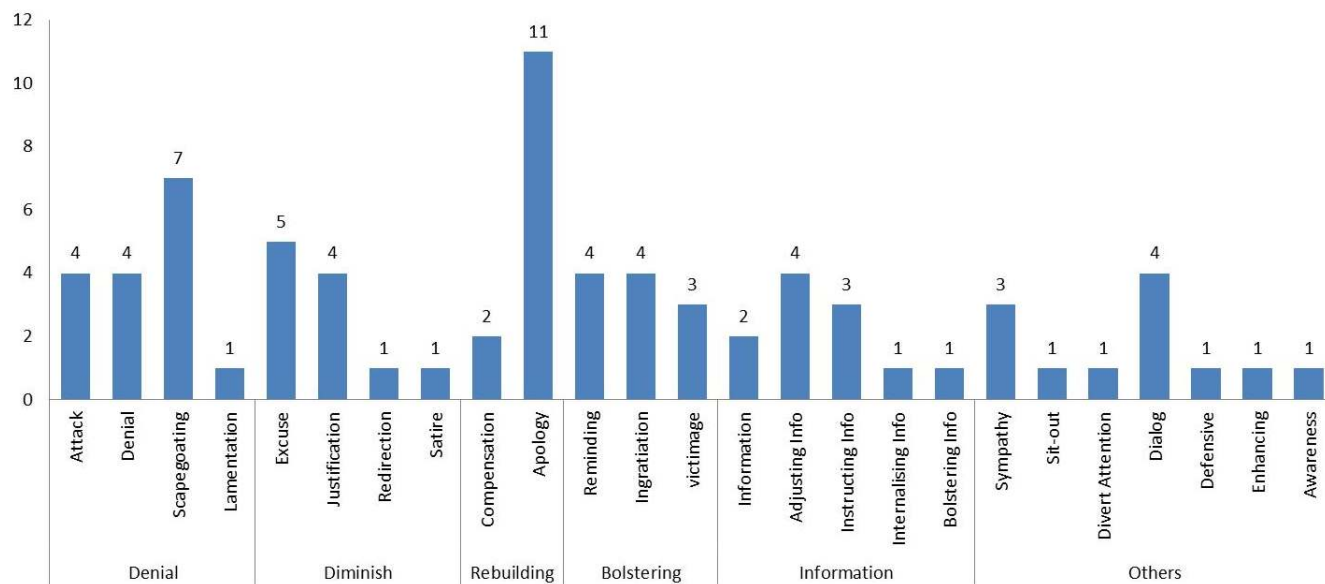
FIGURE 8: Popularity of the Response Strategy.

3) Extensions and Improvement of SCCT, SMCC, and ICM

Table 6 and Fig. 8. captured the response strategies introduced from the literature. It also presents the analysis of various response strategies that were introduced based on SCCT. The summary of various implementations and improvement of SCCT is presented in Appendix B(1). The study in [57], [60], [142], [143] are studies that did not mention any response strategy associated with the most dominant theory but literature evidence suggest that they are linked with traditional theory. Specifically, the study in [142] expanded the understanding of the role of social media in crisis communication, both the humanitarian and organisational crisis response. The finding of [57], [60] are based on traditional response strategy, in particular, the study extends the SCCT response strategy and Benoit (1997) image restoration theory [144]. Moreover, [57] study prioritised senders than receivers, and this supports the theoretical concept of SCCT. Also, [143] developed a model based on the attribution theory for reputation repair. The apology was the most used response strategy than a deal, excuse and bolstering. Information as a strategy was also applied in crisis response as presented in Fig. 8.

The Coombs SCCT is not the only theoretical model that was implemented and improved upon. The research in [35] evaluates the two components of the SMCC model, as well as the effects of crisis information form (traditional media, social media and word of mouth) and source (third party and organisation). Besides, [145] integrates the attribution theory with SMCC to analyse the challenges and opportunities of social media. The result suggested that the response strategy should be based on culture. Recently [146] extended the network crisis communication model (NCC) [146] and SMCC to evaluate the modality, sense of spatial presence, attitude toward the content and involvement with previous flood media coverage in a small experiment. The results show that the public also reacts to visual content after a disaster. Moreover, [147] used a multigroup confirmatory factor analysis (CFA) model to extend SMCC, the result suggests that social media influence is composed of four factors: output, reactive, outtake and proactive. The model offers refined conceptualisation and measurement of social media influence in the context of organisational crises response. Likewise, [148] and [149] are the two studies that extend the ICM model. Tweets' message according to elements of perceived controllability and predictability with emotions and coping strategies are used in assessing the emotional state of stakeholders [148], though the stakeholders are not categorised according to their social position on media usage. The [149] study examined online public crisis emotions and coping methods. The result reported that the public engaged in cognitive, emotional, action-based and discursive coping. This offered more suggestions to refine the ICM model. The summary of SMCC and ICM improvement and implementations can be seen from Appendix B.

4) Social media-based crisis communication models

[37] expressed that addressing crisis on social media with existing models, such as SCCT [33], ICM [115], CERM [118], SARF [123] did not offer the best solutions. [16] stated that there are two potential crisis communication theoretical models that have strengths to integrate social media that could offer reputation making, resilience, and complexity understanding; the networked crisis communication model (NCC) [146] and SMCC. Most of these models are straightforward, ignoring the dynamic features of social media. Although, despite the improvement of SMCC, the model focuses mainly on the types of public crisis respondents found in social media. The ICM focuses on the understanding of the full range of emotions for an effective crisis response strategy. [36] proposed the STREMII model purposely for social media crisis management, which is dynamic and cyclic, emphasised by [117], the model is limited to response and recovery, especially during natural disasters. [150] proposed a new model to manage the crisis on social, termed a new integrated crisis mapping approach based on traditional ICM. The model provides a general approach and directions for building a crisis model, and a direct way of handling crisis response for effective reactions of the public's emotions [151]. A recent introduction of a model based on social media is the ICCM [38], which demonstrates and represents the full interaction of stakeholders in the social media environment. Furthermore, SMCMF is the first model that provides an integrated strategy toolkit that synthesises SCCT and CCS into five main crisis responses for social media crisis communication.

The STREMII model (dynamically cyclic in nature), and the present social media-based models for crisis communication and management, particularly the CERC [152] cited in [118], SMCMF [37], and the ICCM [38] are state-of-the-art social media crisis management and communication models. Fig. 9. presented the most dominant and recent crisis communication theoretical models adopted for social media. Consequently, [37] model focuses on emotions, responsibility and response strategy while the STREMII focuses on the systematic approach of responding to crises dynamically. [153] on the other hand developed an agent-based model that is responsible for the effectiveness of communicating flood risk and the influence of the social network.

5) Key Features of Theoretical Crisis Communication Models

The key features of crisis communication models and their area of focus were presented in Table 4. Some of these elements are reported in Table 7. These features are briefly explained as follows;

Crisis Phases

The crisis is defined widely as "a sudden and unexpected event that threatens to disrupt an organisation's operations and poses both a financial and a reputational threat" [3], [33]. [58] cited in [154] defined crisis as "a sense of threat, urgency and destruction often on a monumental scale" [154].

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2020.3030184, IEEE Access

IEEE Access

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

TABLE 7: Component and Attributes of Existing Social Media Crisis Communication Models in Relation to SCCT, SMCC, and SMDR

	SCCT [33]	SMCC [35]	SMDR [39]	STREMII [36]	SMCMF [37]	ICCM [38]
Attributes	Crisis - Pre crisis - Crisis - Post crisis Crisis responsibility Crisis response strategy - Denial - Diminishing - Rebuilding - bolstering Crisis history Prior reputation Organisation reputation	Social Media - Followers - Inactives - Influentials Organisation - Crisis origin - Crisis type - Infrastructure - Message strategy - Message form Traditional media	Pre-disaster - Social Media During Disaster 1. Disaster - Severity - Duration - Surprise 2. Resource - Robustness - Redundancy - Rapidity 3. Balance between disaster and resources - resistance 4. Transient Dysfunction - vulnerability - resilience Post-disaster Post event functioning	1. Surveillance and social listening 2. Identify Target Audiences 3. Respond and Engage 4. Monitor and Interact 5. Interact 6. Implement changes	Origin of the crisis; - External origin - Internal origin Crisis responsibility; - Weak - Strong Response Strategy; - Defensive - Accommodative Emotions - Sympathy - Sadness - Fright - Anger Types of crisis - Victim - Accidental - Preventable	Types of Organisation - Corporation - Non-profit - Govern Organisational form - Dialogic - Consist - Precise - Timely Strategy Toolkit - Base - Denial - Evasion - Justification - Concession Tones of contents - Negative, neutral or positive Types of Social Media - Facebook etc Generated contents - Visual, text etc Stakeholders - Aware, active, inactive, and aroused Response Form - Large in quantity - Chaos in leadership
Main Focus	Strategy	Public	Resilience	Dynamic	Emotions	Strategy toolkit

TABLE 8: The Relationship of Existing Social Media Crisis Communication Models

Models	Crisis Management Model [34]	CERC [152] 2005 cited in [118]	STREMII model [36]	SMCMF [37]	ICCM [38]
Stages/ Phases	(1) Issues Management (2) Planning Prevention (3) Crisis (4) Post-crisis	(1) Precrisis (2) Initial event (3) Maintenance (4) Resolution (5) Evaluation	(1) Surveillance and Social Learning (2) Indentify Target Audiences (3) Respond and Engage (4) Monitor and Evaluate (5) Interact (6) Implement Changes	(1) 'pre-crisis' (2) Response (3) Post-crisis	(1) Pre-crisis (2) Crisis (3) Post-crisis
Strenghts	Early model that demonstrates the Internet technologies as trigger or enabler of crisis	Best for awareness and how to avoid risk related concerns;	It is dynamic, specifically developed for social media.	Best for response strategy, emotions and type of public.	It is dynamic, focus on response strategy, information and emotions.
Weakness	Early model to consider internet technologies when social media crisis communication usage is not matured	Not flexible and does not consider social media dynamics	Limited to response and recovery during natural disasters (Syed, 2018).	Not much attention given to pre-crisis stage	It is based mostly on traditional SCCT and SMCC.

IEEE *Access*

Bukar *et al.*: Crisis Informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues
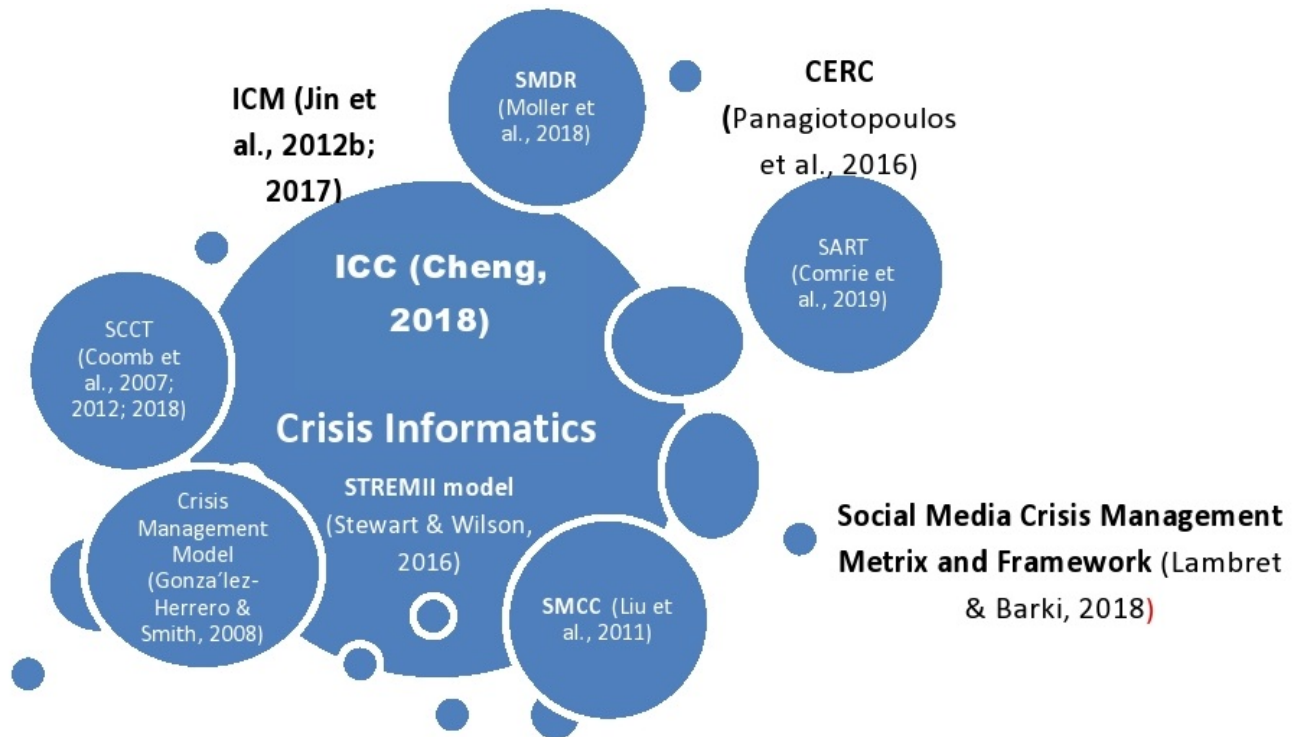

FIGURE 9: Most dominant crisis communication models adopted for social media

The literature identified five theoretical models that demonstrate the phases of a crisis lifecycle for social media crisis communication as presented in Table 8. Though, the traditional SCCT commonly references the three-phase model. While the crisis management model [34] presents a four-stage model, CERC framework [118] explains five stages of a crisis lifecycle. The SMCMF and ICCM uphold the three-phase lifecycle. Consequently, the STREMII reported six-phase lifecycle, a cyclical process consisting of six elements: (1) surveillance and social listening, (2) targeting the appropriate audience, (3) responding to the crisis and conversation, (4) monitoring the landscape and evaluating outcomes, (5) interacting with consumers and public, and (6) implementing necessary changes. Most of the researchers in crisis communication have reported three phases of crisis [35], [37], [38], [125] which include pre-crisis, crisis, and post-crisis. Pre-crisis exist before the crisis occurs, situational awareness is the most important activity in this stage and social media is in an enabler. The second stage is the crisis phase, sometimes referred to as 'during-crisis'. Stakeholders tend to used social media as a medium during crisis response, the users can be used as crowdsourcers and the information collected could help the decision-makers improve emergency management. Sometimes the information could be analysed to understand the level of resistance among the public, so that an appropriate strategy could be adopted to manage the situations, improve resilience or build a relationship between the stakeholders [37], [39]. The final stage is the post-crisis stage, also referred to as the recovery phase. Social media

information is used in this stage to improve recovery efforts, understand the level of the damages, and to prepare against future events. Information about crises is important for victims, such as crisis history, crisis origin and crisis responsibility, either accidental or preventable [33], [125].

Stakeholders

Stakeholders are groups and individuals that collaborate and engage in crisis communication on social media. The stakeholders are classified as formal and informal stakeholders (organisation or management and the public) [66], [67]. The public are individuals participating in crisis response, seen as the consumers and producers of crisis information on social media. [35] identify different types of public in their models; first public (influencers) who creates or posts information on social media, second public (followers) who share or like the information created by the first public, and the third public are inactive users. Understanding the full range of the public's emotions improves effective crisis response strategy.

Response Strategy

Crisis response strategies are what an organisation says and does after a crisis [155]. SCCT is the most popular theory and is based on response strategies. The SCCT is composed of four elements used to assess potential threats to the organisation: (1) the crisis type, (2) severity of damage, (3) crisis history, and (4) relationship history. SCCT linked the crisis element and response strategies. The theory assesses the reputational threat of a crisis to select the appropriate

crisis response strategy. Crisis response strategies composed of messages designed to repair organisational image.

Emotions

Emotion is argued to be a critical stimulus defined as an "organised cognitive-motivational-relational configurations whose status changes with changes in the person-environment relationship as this is perceived and evaluated (appraisal)" (Lazarus, 1991 as cited in [115]). In a crisis, emotions are evidence in the public's interpretation of what is unfolding, changing and shaping. Understanding the full range of the public's emotions from public responses helps improve effective crisis response strategy [37]. The ICM model is based on emotions which stated that determining the origin of crisis helps in determining and anticipating the emotions that stakeholders are likely to feel.

Relationship and Interactions

One of the objectives of crisis informatics is to understand the interaction and relationship between stakeholders involved in crisis response [25]. Interactions are the representations of human connections that occur in socio-technical interaction places (social media) [55]. Each interaction is evidence that someone is performing some action; it could be reading, posting, liking or sharing. Interactions occur between two people or between people and organisations on social media. The interaction could show the intensity of stakeholders' responses or sentiments as positive, neutral or negative. The analysis could classify patterns of interaction and can explain how these patterns can contribute to how an organisation should engage in crisis management [36], [55], [156]. The crisis communication matrix in Fig. 4 also depict patterns of this relationship.

6) Summary

A comprehensive summary of the theoretical models of crisis communication and management can be seen from Appendix A. Table 4 presented the extraction of major features covered from these theories. The emphasis was based on the use of social media before, during, and after emergencies. Most of the researches conducted are based on the dominant situational crisis communication theory (SCCT) [54]. Although, other theories were adopted from various fields to cope with the challenges facing crisis informatics. Most of these researches covered majorly or partly areas, such as the stages of crisis (pre-crisis, crisis, and post-crisis), response strategy used by organisation or public, the orientation of strategy messages used, relationship, emotions and understanding the behaviour of social media users and their interactions. Tables 7 and 8 justify the relationship between various crisis communication models and their traditional models. The distinctive features and attributes were synthesised to understand the weakness and strengths of each model. Fig. 9. presented an artifact representing these models and their influence on providing effective crisis management and communication.

E. Q4. WHAT ARE THE ISSUES AND CHALLENGES OF SOCIAL MEDIA CRISIS COMMUNICATION THEORETICAL MODELS?

1) Open Issues and Challenges

The following section provides current issues, challenges and open questions facing existing related social media-based crisis communication models. Coombs's SCCT theory is majorly based on image repair theory. Also, SCCT was founded in attribution theory [85]. According to [85] the stakeholder attribution in SCCT was used in the context of apology strategies in attribution theory. Despite the contributions of SCCT, the theory focuses mainly on the sender which overlooks the perception of receivers on the sender's message. A further limitation of the SCCT is that it focuses more on the organisation while less attention is given to the public. [157] cited in [57] emphasised that crisis communication consists of communicative activities between senders and receivers. This limitation impacted the effectiveness of SCCT to guide organisations in responding to crises [57], especially in dynamic settings enabled by social media. Social networking sites have created more concerns on the ability of the public to scrutinize information and potential visibility of challenges posed by crisis [138]. Also, [158] adopted the most dominant theory to find out how male and female crisis communication differs. The prediction of an effective response strategy is the strength of the SCCT [34]), far more efficient for a natural crisis [159]. The SCCT is a traditional theory that focuses on the message and ignores the medium of communication. [36] added that despite the improvement made on the theory, it cannot provide the solutions needed by the dynamic nature of social media. [159] cited in [70] reported that "a versatile application of crisis theory is surely more urgently relevant when the crisis is a natural disaster". Similarly, SMCC was proposed to bridge the weakness found in SCCT for the new media (Social media). The SMCC reported that social media comes with a different kind of public engagement and interactions between stakeholders as everyone participates in crisis response. SMDR was introduced to examine how social media usage contributes to community resilience [39]. The SMCMF [37] and ICCM [38] adopted the strengths of SCCT for social media crisis management and communication. However, further refinement is still needed to address the holistic picture and characteristics of both social media in the first part and also the dynamic nature of the crisis in the second part.

The study in [90], [112], [121] are the three studies that investigated the impact of interactions of various stakeholders involved in crisis communication. [112] used a general structural path model to understand the organisational stakeholder relationship during normal times and in crisis times. The study provides an insight into how relationships change when an organisation is under pressure. [121] on the other hand used dialogic communication theory to increase the stakeholder's relationship during and after a crisis, added that

the dialogic content should be open, responsive, transparent, interactive and the content should aim to support and build a relationship and advance the renewal of reputation. While [90] network theory identified actors involved in an issue arena. It is therefore understood that [112] study focused on the relationship between all stakeholders involved in crisis communication while [121] study focused on analysing content to understand which can support and build a relationship. Although, [90] identifies the relationship between authors and topics and addressed actors during a public health crisis communication, none of the studies enable the construction of a static relationship between social media, citizens, crisis communication and crisis that represent the nature of social-mediated crisis communication and the nature of the context of organisational crisis communication and public. Also, none of the studies measure the impact of interaction and it is observed that one of the objectives of crisis informatics is to understand the interactions between the stakeholders involved [25]. Future research should focus on measuring the interaction of the public with the organisation. Moreover, it is observed that the most recent introduction of crisis communication models gives more attention to the medium (social media). This paves way for new questions in crisis communication because of the introduction of social media, including how and to what purpose organisations will use social media to have interaction in inter-media dialog, how neutral crisis management voices stay neutral on social media, whether or not organisational social-mediated communication practices affect the ways that stakeholders have interaction with the organisation via that medium or how a separate communication streams taking place on the same medium progresses to every alternative throughout the crisis [131]. Besides, crowdsourcing is also "a model that uses the general public, or the crowd, to utilise skills, talents or observations as sources of knowledge and expertise" cited in [6] that can provide real-time data to enable quick disaster or crisis response. Future research can focus on analysing and incorporating additional media and associated additional voices, which can add to an understanding of how online media permits media, stakeholders and organisations to co-create crisis response and management strategies effectively.

The review of this study is exclusive to evaluate the various crisis communication models with corresponding issues and challenges. However, crisis informatics is a multidisciplinary area of research, and various issues and challenges were reported from diverse literature and several of these challenges remain unanswered. [27], [75] reported the issue of dataset inaccessibility and inefficiency. This is important to link present research work with previous work [160]–[162]. [28] further suggested future research directions, such as domain adaptation and transfer learning, online and active learning, applications of deep learning, situational awareness to actionable insights, and humanitarian crises and health. While [9] added that researchers should focus on building an ontology according to the needs of the public, as well as develop a lexicon-based disaster-related keywords. This

will improve effective response to people in need during a disaster. The pre-crisis situation is a fundamental phase for the crisis response team because of the awareness and decision-making activities [163]. According to [33], one acknowledged bit of wisdom in crisis communication and management is that preventing a crisis is the best way to manage it. Neither the organisations nor the stakeholders are harmed if a crisis is averted. "Crisis prevention is the 'alpha' or starting point of crisis management and crisis communication" [33]. Situational awareness can be used for human-induced crises, organisation crisis, public health-related concerns [164]. Also, information provides useful intelligence for crisis communication and management purposes. Information systems (alert and warning) and machine learning methods are applied to crisis preparedness, response and recovery [165]. For example, [9], [108] shows the effectiveness of mining social media data for decision-making purposes. The first approach was based on machine learning, incorporates sentiment analysis that categories and classifies the data to provide a better decision, especially during the response (crisis) and the recovery phase (post-crisis) of disaster [9] while the second approach used hybrid method for mining crisis-related information to detect and identify people at risk [108]. Moreover, [88] is an earlier framework that collects, stores and analyses information for decision-making impacted by the big data concept [166]. [10] evaluates the behaviour of the public on how uncertainty is communicated on social media during a crisis and shows the effects of social positions on collective sense-making [10], which is consistent with [112] study that stated that collective sense-making among stakeholders can be advanced by good stakeholder relationships. The main issue identified from the aforementioned studies is that most of the researches conducted are towards emergency management; system, framework or algorithm was to support response management in making the right decision. However, users can also be active players in responding to crises. More theories and models, machine learning techniques, deep learning approaches, network, and semantic analysis [11] should harness more broadly and apply to manage the crisis and activities of users and the general public. Also, the identification of 'actionable' information is a pertinent challenge, as well as information from diverse sources with different modalities [26].

Moreover, social media has become an effective crisis communication tool. The public actively seek and exchange views about the crisis with others on social media [65]. Family and friends are used mostly as trusted sources [165] for the crisis. Warning messages are taken more seriously when the social position of the sender is the same as the receivers [167]. The discussion of crisis communication is incomplete without social media [2]. The objectives of crisis communication are to respond, resolve, lessen the uncertainty and learn from the crisis [1]. Crisis management evaluates what happened to increase resilience in future events [168]. Social networking sites should be used as a forum for crisis communication [154]. Though crisis management embraces many

roles as to managing social media for crisis communication; it is increasingly important to manage diverse outreach information and communication. According to [168], the best approach to successfully communicate crises is missing from the literature and communication is an essential component for decision-making. Social media influence shows how users assess messages cognitively in terms of behaviours, attitudes and beliefs. [147] provides validated measures for social media influence during crises that are tested in real crises accurately, capturing how organisations and the public can exercise their influence on social media. Furthermore, [110] suggested some recommendations that designers and managers of social networking sites should provide new strategies that modify the attitudes and subjective norms of the public. This will enhance intention since users are influenced by their behaviour; a strategy related to information should be employ. Future research should consider the social media influence measurement model on the perception of users [169], and investigate the social media influence on factor structure in other social media contexts [147].

Nevertheless, a recent study identifies factors that affect the acquiring and sharing of health-related information and the extent to which such is applicable [110]. Also, a study by [111] conducted on WeChat user's indicated social media crisis information sharing behaviour and explains the decision-making process of the users. Also, how social position affects the collective sense-making process in crisis communication by using a support vector machine (SVM) algorithm was proposed by [10]. Moreover, a four-phase model for evaluating crisis-management content curricula for teaching was proposed by [170]. A limitation of many studies is the potential selection bias of social networking sites. This review supported [84] assertion that twitter is being exaggerated in the literature. Facebook is the most popular social network worldwide accounting for 2.271 billion users while Twitter accounts for 326 million and ranks 12 on the list [171]. [84] added that Twitter has received almost 500 times as much attention as it deserves. [172] also reported that Facebook is a more useful tool for the crisis than Twitter.

Finally, social media use is impacted by privacy and information sharing values of the public and emergency management services [163]. Present challenges include surveillance, unauthorized use and disclosure of personal data, (unrestricted) collection and processing of personal and sensitive information, lack of informed consent, misinformation, and lack of measures to correct inaccuracies, the additional risk for children and inadequate security of and for personal information. Also, social media needs to address when monitoring users' [2] reactions of citizens affected by the crisis.

IV. DISCUSSION

The review of the literature has furnished us with many issues and challenges facing current social media crisis communication and management. It is vehemently clear that crisis communication cannot be complete without a discussion of the rise and impending dominance of social media [2] and

are becoming necessary for effective crisis communication. Therefore, the researchers plan to bridge one of the gaps identified in the literature. In particular, social interaction and crisis response are the areas that the researchers think can help the public recover from crisis quickly. Nevertheless, the objective of crisis informatics is to understand the interactions between stakeholders involved in crisis communication [25].

A. FAVOURABLE ELEMENTS

Based on the literature, studies investigating the impact of social media interaction on community resilience, and the impact of the crisis and crisis response that is mediated by social interaction on resilience are lacking. Therefore, this study draws upon the understanding of SCCT [125], ICCM [38], STREMII model [36] and SMDR [39] to investigate the impact of crisis, crisis response and social media interaction on public resilience. The constructs are explained as follows:

Firstly, since the crisis is a sense of threat, urgency and destruction often on a monumental scale [58], [125], the crisis influences crisis response formation and social interaction on social media. A crisis is associated with attributes, such as the phases of the crisis [38], crisis types and information. Crisis can be in the form of natural disasters (earthquakes, tsunami, wildfire, etc.) [117], human-induced crisis (terrorism) [88], public health concerns [132], organisational crisis (internal and external). Information about crises is important, such as crisis history, crisis origin, and crisis responsibility as victim, accidental or preventable [33]. For instance, the emergence of crisis/disasters exposed stakeholders to digital interaction, and the nature of its range makes people have minimum physical interaction. Specifically, following the emergence of Coronavirus (COVID-19), stakeholders are increasingly exposed to digital interaction. As a result of the crisis and the nature of its spread, it becomes more difficult to have physical interaction. The situation worsens as crisis management authorities force citizens to stay at home for several weeks in the name of self-isolation or quarantine. Community resilience to the crisis has become even more important to avoid panic. While social media interaction has proven to be effective in helping the affected citizens, it is also important as an information source [109].

Secondly, crisis response is the reaction of stakeholders (public and management) concerning the crisis. Stakeholders are individuals participating in crisis response, which are seen as consumers and producers of crisis information on social media. [35] classified the public as; first public (influencers) who create or post information on social media, second public (followers) who share or like the information created by the first public, and the third public seen as inactive users. Understanding the full range of the public's emotions through public responses improves effective crisis response strategy. Stakeholders' relationship and public resilience are important to understand the effectiveness of crisis management and response effort. The public generates content and engages in social interaction expressing their

opinion on/about the crisis or the entity managing the crisis [35]–[37].

Thirdly, interactions are the representations of human connections that occur in socio-technical interaction places (social media), each interaction is evidence that someone is performing some action; it could be reading, posting, liking, or sharing [55]. Social media is an object or environment that enables groups and individuals to collaborate in the form of text, visual, voice, or mix which is also referred to as the content of the interaction [35], [36], [38], [39]. Interactions occur between two people, or between people and organisations on social media [156]. People use social media during emergencies for a wide range of purposes. The ICCM substantiates social interaction as important because of its ability to serve as the four gratifications adopted by [173]. Also, the entire ICCM is reported as an interactive model, showing basic elements of interaction between crisis management and the public. Moreover, one of the elements of the STREMII model is also interaction.

Lastly, resilience is the ability to mentally or emotionally cope with crises or to return to pre-crisis status quickly. Public resilience is important to understand the impact of crisis management (organisation) effort in the advent of the crisis. Crisis management action is aimed to improve relationships and increase community resilience. [39] proposed social-mediated disaster resilience (SMDR) model that shows how social media usage is integrated into resilience-building and discusses its potential for increasing hotel resilience.

B. MODEL STRUCTURE

To represent the nature of the interactions between various stakeholders, and to aid the reader's conceptualisation of how this methodological approach is differentiated from existing approaches of crisis communication, we refine and introduce ICCM [38] that represent the social interaction between crisis management and the public on social media environment, supported by UGT [174] and STREMII [36] models that justify social interaction as gratifications sort, and as one of the crisis lifecycles respectively. Then, the SMDR model proven how social media usage improves community resilience. The most important gap the future work intends to address is to investigate the mediating impact of social interaction and crisis response on public resilience.

First, the crisis is the trigger that allows crisis response [125] to take place on social media. Therefore, the nature of the crisis and crisis response are factors influencing the stakeholders' formation on social media, which influences social interaction. Second, we refer to the online contexts in which stakeholders interact as socio-technical interaction places as represented in ICCM. This is where peoples interact as groups, for a specific purpose, and mediate consistent and meaningful aspects of their activity through technology. The ICCM emphasised the importance of interaction between stakeholders involved in crisis responses. The whole ICCM is referred to as social media interaction in this study. This is supported by the fact that social interaction is one of the

most important gratifications in UGT, and found to be one of the crisis phases proposed in the STREMII model. Third, the SMDR proved the use of social media for building resilience. Therefore, the model intends to investigate the impact of crisis response and social interaction on public resilience. Crisis management action is aimed to improve relationships and increase community resilience. The theoretical model is presented in Fig. 10.

C. NEXT STEP AND FUTURE DIRECTIONS

Advances of crisis communication on social media offer new potentialities and opportunities for disaster response in real-time. The public are far from being passive receivers as a result of social media [65]. The evaluation of the literature shows that prior studies investigating the mediating impact of social media interaction and crisis responses on public resilience are lacking. With this gap and recommendation in mind, the future research effort is to bridge this gap by conducting both qualitative and quantitative research, to apply and test, hypothetically, the theoretical model. The theoretical model could undergo expert validation and verification to test the content, construct, face validity and model fitness [175]–[177]. Researchers could assess the effectiveness of the model through data collected from social network sites to measure the interaction by using tools, such as sentiment analysis, natural language processing (NLP), thematic analysis, etc [59], [103], [105], [108]. In this regard, features of the content generated by the stakeholders, such as content type, frequency of interaction, time distance, mode of interaction, and intensity could be evaluated using thematic analysis. An appropriate machine learning method could be applied and tested on these data and the potential impact could be understood. Empirically, an instrument could be developed to investigate the relationship between the structural elements. Structural equation modeling, regression model, and the artificial neural network could be adopted to validate the model [87], [88], [113], [173].

V. CONCLUSION

Technology-driven emergency management is continuously evolving as a new research field where each step to improve methods or tools can make a significant contribution to save human lives and resources. The existing theoretical models of social media crisis communication were studied through a systematic review. The taxonomy of the literature summarised the existing research in the field of crisis communication. Content and thematic analysis was conducted on 207 papers and identified 56 articles that introduced new or improved existing theories/models. The result shows that ICM, SCCT, and SMCC are the dominant communication theories. The study identified theories, such as the STREMII model, SMDR, SMCMF and ICCM as emerging models.

Comprehensively, the study answered the following questions: What is the relationship between crisis communication, social media and crisis informatics from theoretical perspectives? What is the taxonomy of research studies conducted
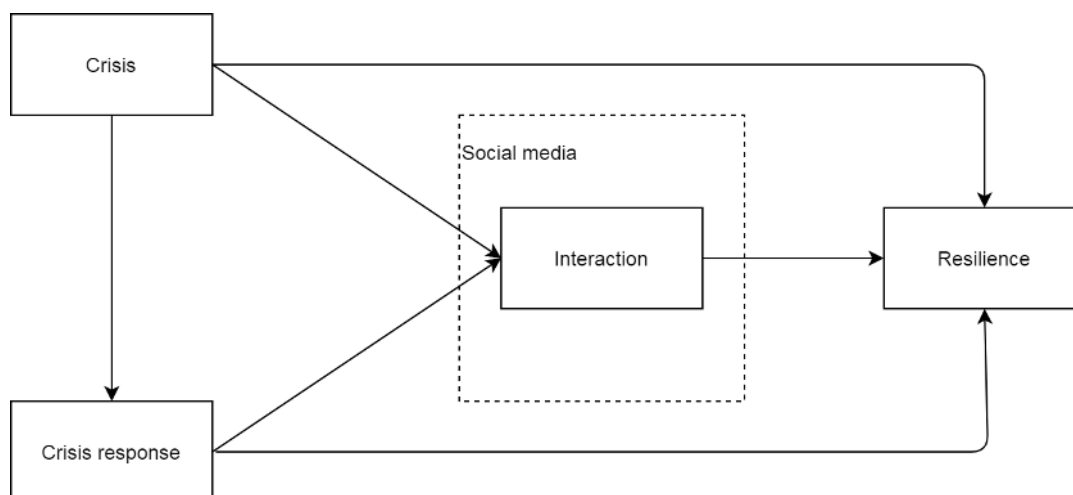
FIGURE 10: Constructs adopted from; motivations: crisis and crisis response (Coombs, 2007), gratifications: social interaction (Cheng, 2018; Whiting and Williams, 2013), significance: resilience (Moller et al., 2018)

in the field of crisis informatics in the context of social media crisis communication? What are the related crisis communication theoretical models and social media-based theories/models, and what are the common features of these models? and What are the issues and challenges of the social media crisis communication theoretical model? The finding shows that social media is both found in crisis informatics and crisis communication and assist in crisis management and communication. The taxonomy of the research revealed that the classification and evidence of social media intervention for crisis management into social sensing (mapping, location identity, geoweb), crowdsourcing through digital volunteerism, and more importantly crisis communication through social networking, issue arena, information dissemination, and information seeking. The review also revealed so many crisis communication theoretical models, which include crisis management model, SCCT, SMCC, ICM, crisis messages-based hierarchical model, crisis communication model dimension, information diffusion theory, socialization theory and structuration theory, problem-solving model based on a probabilistic approach, channel specification theory and gratifications theory, general structural path model stakeholder-organisation relationship, agenda building, network approach to apology based model. More recently, the SA model, dialogic communication theory, framing theory, actor-network theory, CNN, operationalize the SARF framework and network theory. The social media-based crisis communication models include crisis management model, SMCC, CERC, STREMII model, SMCMF, SMDR and ICCM. Issues and challenges for future research are highlighted in this paper.

Firstly, SMCC identified the type of public engagement in social media and the type of organisational interactions when responding to crises. SMCMF and ICCM adopted the strengths of SCCT for crisis management and communication. While ICCM is based predominantly on SCCT, SMCC

and traditional CCS. Despite the contributions of SCCT, the theory focuses mainly on the sender and overlooks the perception of receivers on the sender's message, also it is an organisational-based crisis response model; traditional cannot provide the solutions needed by the dynamic nature of social media.

Secondly, understanding interactions between stakeholders involved in crisis communication is an integral part of crisis informatics. Social networking sites have created more concerns on the ability of the public to scrutinise information and the potential relationship-building through social interaction among them. However, the finding shows that none of the studies enable the construction of the relationship between social media, citizens, crisis communication and crisis, and measure the impact of the interaction between the stakeholders. This can add to an understanding of how online media permits media, stakeholders and organisations to co-create crisis response and management strategy effectively.

Thirdly, crisis informatics is a multidisciplinary area of research, several challenges remain unanswered. For instance, some of the challenges are inefficient or absent dataset of previous work, situational awareness to actionable insights, humanitarian crises, and health concerns especially for pre-crisis situation, building ontology according to the needs of the people with disaster-related keywords to improve effective response to people in needs. Another issue identified in this study is that most of the research conducted is towards emergency management; system, framework, or algorithm was to support response management in making the right decision. Also, the best approach to successfully communicate diverse crises is missing from the literature and communication is an essential component for decision-making. Also, future research should consider the social media influence measurement model on the perception of users to influence social media usage, wider application of social media and privacy of information concerns.

To bridge one of the challenges identified from the literature. The next plan and future research are to investigate the impact of the crisis, crisis responses, and social interaction on public resilience. More importantly, the study will examine the mediating impact of crisis response and social interaction by adopting both qualitative and quantitative research approaches. Moreover, the researchers intend to validate the favourable elements identified from this study to introduce a new model from twofold. Constructs of the new model will be validated by experts and content validation tools, and secondly, the content of interaction records will be collected to measure the intensity of social interaction and crisis response on public resilience.

The limitation of this study is the selection bias of the article published in IF impact factor journals. We used the IF ranking as a benchmark for quality selection and assessment of the articles. The second limitation is the application of exclusion criteria for conference proceeding papers, workshops, and book chapters. We assume that papers from such publications are mostly repetitions of ideas, concepts or work-in-progress that are mostly found in journal articles sooner or in advance.

.

APPENDIX A COMPREHENSIVE SUMMARY OF CRISIS COMMUNICATION AND MANAGEMENT MODELS

Related Work	Theoretical Models	Component and Description	Benefit	Limitations
[34]	Crisis Management Model	First model for crisis communication in the virtual world; phases including issues management, planning-prevention, crisis, post-crisis.	Internet technologies as a trigger or enabler of crisis	Social media usage for crisis has not matured
[33], [54], [124], [125]	SCCT	Coombs response strategy; denial (Attack, denial and scapegoating), diminish (Excuse and justification), rebuilding (compensation and apology), and bolstering (reminding, ingratiation and victimage). Additional improvement of 2006; deal (ingratiation, concern, compassion, regret, and apology)	Link crises response strategy and elements of crisis situations,	Context oriented and based on the public's relations, Focus on senders, does not consider medium [57]
[35]	SMCC	Influencers attributes of involvement and motivations; crisis origin, crisis type, infrastructure, message, strategy, and message form; types of public; first public (influencers), second public (followers), and third public (inactives)	Focus on information form and source, Social media effectiveness to improve resilience	
[115]	Integrated Crisis Mapping (ICM) Model	The Integrated Crisis Mapping (ICM) model is public-based, emotion-driven perspective- cognitive coping and high engagement; the four quadrant includes anger, anxiety, sadness and fright	Understanding full range of emotions for effective crisis response strategy	Further refinements is needed to generate "analytic generalization" for social media
[116]	Crisis Messages based Hierarchical Model	The model proposes primary function of a "good" crisis message; communicate quickly, simple, credible, complete, accurate, and communicate broadly	Shows various characteristics and attributes of a good message for response	Video, pictures and information sheet were not considered
[85]	Crisis Communication Model Dimension	The model divided the dimensions into; Operational (Reputation oriented or resilience oriented) strategic (Reputation oriented or resilience oriented)	The dimension of crisis communication model from the literature	Empirical materials
[36]	STREMII model	A cyclical process consisting of six phases: surveillance and social listening, targeting the appropriate audience, responding to the crisis and conversation, monitoring the landscape and evaluating outcomes, interacting with consumers and publics, and implementing necessary changes.	It is dynamic, specifically developed for social media	Limited to response and recovery during natural disasters (Syed, 2018) and monitoring interaction.
[118]	Crisis and emergency risk communication model (CERC)	Adopted for social media; pre-crisis, initial event, maintenance, resolution, and evolution;	Awareness and how to avoid risk related concerns	Integration of social media with office systems for more control
[102]	Information Diffusion theory	Examined the impacts of key elements on information propagation rates on social media (variables includes diffusion, influence, awareness, lateness, boost, and false)	Focus on the dynamics of information dissemination and their influence on EM	Hashtag content and situational awareness were not compare

[94]	Socialization theory and structuration theory	Manage crisis based on socialization and structuration theories, and also adopted SCCT crisis phases.	Role of social media in knowledge sharing of each phase of crisis	Types of crisis and local technological readiness was not considered
[6]	Problem solving model based on probabilistic approach	A model that offer a classification of disaster literature according to three paradigms corresponding to types of science, termed 'post normal' science, Kuhnian 'normal' science and Lakatosian 'structural science.'	Integration of crowdsourcing and social media for new era of knowledge management and disaster management	Provides new concept and the literature not enough to support the new approach
[119]	Channel Specification Theory and Gratifications Theory	CST is adopted to extend use and GT for understanding the cognitive process in selecting communications messages; how first information respondents (FIRs) react to crisis response message, re-framing messages and their dissemination patterns		
[112]	General structural path model stakeholder-organisation relationship	The model depict the relationship of stakeholder in normal times and in crises times; pressure, time of pressure and uncertainty; diffused public (news media, environment, and citizens), functional public (employees, unions, customers, victims), and enabling public (management)	Provide an insight into how relationship change when an organisation in under pressure from normal time to time of crises	Other variables like crisis responsibility, type, response-strategy and interaction monitoring not included in the study
[122]	Agenda Building	Extend the theory of Agenda building; public relations efforts, media coverage, and public opinion on micro blogs are examined.	Online public are not influence by media or PR activities	Does not account for ethical issues in decision-making
[7]	Network approach to apology based model	The model is based on apology in crisis communication, stakeholder network	It is a stakeholder-centric approach to evaluate crisis response which provides a new approach for studying crisis response strategies	Interaction among stakeholders not investigated
[39]	Social Mediated Disaster Resilience (SMDR)	The model components includes 3Rs model (Robust, Rapid and Redundant apply through the three phases of disaster.	Social media effectiveness to improve community resilience	Engagement and interactions of users and managers, and resilience not measured
[120]	Situational Awareness (SA) Model	Social media-assisted SA model in emergency response, explore the relationship between social media message complexity and type (emergency respondents' message type, platform affordance, content complexity, situational awareness and action)	Message complexity as a critical elements in SA process	Relationship between message complexity and SA is not investigated
[121]	Dialogic Communication Theory	Dialogue to increase stakeholders relationship during and after crisis from twitter, Gitlab blog and YouTube; dialogic content should be open, responsive, transparent and interactive	Content to support and build relationship to advance renewal of reputation	Interaction among stakeholders not investigated

[100]	Framing Theory	Identified type of framing based on framing theory; the networked, celebrity, proximity, easy access, interactivity & gamification, and suspicion	Show the importance of children in developing effective response strategy	Focus on children as information designers
[38]	ICC (Interactive Crisis Communication Model)	ICC in based predominantly on SCCT, SMCC and traditional CCS. The ICC comprises types of organisations, response form, strategy; types of stakeholders, response form and strategy; tones of content (positive, negative, neutral), type of social media. Adopted three phases, responses toolkit are base, denial, evasion, justification and concession;	First model to provide integrated strategy toolkit that synthesize SCCT and CCS into five main crisis responses; dynamics for social mediated crisis	Variable of interaction and its context is overlooked
[91]	Actor Network Theory	Technology enabled health discussion on social media model- using twitter to discuss health related information; Health (disease), people, and technology on discussion on twitter	Evidence of twitter use for health (disease) discussions	Interaction among the group was not investigated
[37]	Social Media Crisis Management Metrix and Framework	Analytical framework for response strategies and model for crisis resolution; origin of the crisis, the degree of attribution of responsibility for the crisis, and the stakeholders' emotions in reaction to the crisis, while the metrix build on two axes, the degree of attribution of responsibility and crisis origin; accommodative and defence strategy; emotions are sympathy, sadness, fright and anger	Questions the relevance of classical crisis management theory to an online environment; adopted most dominant theories (SCCT, SMCC, and ICM) for a better social media solution	Does not cover the pre-crisis stages;
[123]	Operationalise the SARF framework	Modelling the perception of twitter during a health risk event; totality of the system, dynamic nature of events, and feedback are the key elements.	The use of CLD to operationalise SARF for risk communication	Unclear how twitter will impact it role on amplification and attenuation
[90]	Network Theory	The models comprises three component; authors, topics and addressed actors. Relationship model	Identified stakeholders involves in issue arena.	Component of interaction and social media lacking

APPENDIX B EXTENSIONS, IMPROVEMENT OR IMPLEMENTATION DOMINANT THEORIES

A. EXTENSIONS, IMPROVEMENT OR IMPLEMENTATION OF SCCT

Related Work	SCCT Components or Improvements	Benefit	Limitations
[126]	A model based on SCCT that examines the effect of different crisis communication strategies and media; communication strategy (apology, sympathy, information) and media type (newspaper, blog, twitter)	Expand SCCT reputation repair to secondary crisis communication and reaction	" "
[178]	Using social media to response to crisis and the understanding of how crisis responses are framed		Traditional response strategy
[127]	Analysis of users response based on SCCT strategy for reputation repair; ingratiation, reminder, attack the accuser, and divert attention are primary for coping, others include denial, justification, scapegoat, excuse, and apology	Identified other methods; reminder, and divert attention for reputation repair	Conventional strategies
[128]	Identified the strategy used in crisis response; information, sympathy, defensive, apology, and sit-out strategy	Implement SCCT crisis response strategy and Benoit (1997) image restoration theory [144];	Traditional response strategy
[129]	Examined Facebook usage by fortune 500 companies through the lent of SCCT. Justification and full apology were the response strategy used the most.		Prior involvement of social media use was not measured
[12]	Analysed organisation response to identify which strategy is the best from SCCT response strategies; dialogic strategy is effective for vitims; conventional strategies can ignite social media crises;	More engagement in response result in more crisis	The data is qualitative
[130]	The use of various response strategies based on SCCT; Instructing information (basic and general), adjusting information (sympathy and corrective action); response strategies include deny (attack the accuser, denial and scapegoat), diminish (excuse and justification), rebuild (compensation and apology), bolster (reminding, ingratiation, victimage), and enhance (follow-up and ask for another chance)	Crisis on beg bugs in a hotel	The study is based on hotel; tourist, hotel brand, customer experiences are ignored
[131]	Expand crisis communication research on response strategy from organisational, media and stakeholders' perspectives;	Identified new element of dialogic called inter-media	Does not capture wide stakeholder crisis impressions
[132]	Evaluated the SCCT crisis response strategies and their impact on reputation; apology, sympathy, information dissemination; impact on perception of reputation, trust, and message credibility.	Evaluate stakeholders perceptions and behavioural intentions	Facebook and health setting
[133]	Expand SCCT reputation repair; adopted crisis response strategy of humorous self-mockery and mocking the accuser.	Re-emphasized the importance of crisis response	The study only investigated Paracrisis case
[134]	Examine the audience responses to the crisis based on SCCT and extend to; deny (lamentation), diminish (redirection, satire), and deal (corrective action, collectivism)	Evidence of Twitter use to express the public's emotions and coping	Lack analysis of the users network setting
[142]	Expand the understanding of the role of social media in crisis communication; humanitarian and organisational crisis response		" "

Ref	Description	Contribution	Limitation
[59]	Compares both AirAsia's crisis-response strategy and the public response to those on social media; Adjusted information (info and emotions).	Identified the public frame used based on framing theory	Few variables
[135]	Response strategies are; instructing information, adjusting information, internalising information, denial, scapegoating, excusing, compensation, apology, reminding, ingratiation and victimage	Extend SCCT organisational social media use.	
[136]	Shows how organisations apologise to the public (response strategy); Manner (source, content and timing), content (acknowledgement, empathy and action) and evaluation	Extend SCCT with ethical apology theory	Traditional response strategy
[137]	Organisations dealing with positive and negative comments through dialogic communication; personalized response, conversational human voice, consumer scepticism, organisational reputation- consumer comment valence	The study can be relevant in the context of health related behaviour	When to respond is not justifiable in the study
[57]	The finding prioritized senders, to the public who are the receivers of the information, because the public dictates if crisis response message have been accepted, and the public's response shape the organisation reputation and legitimacy.	The study extend SCCT response strategy and Benoit (1997) Image restoration theory [144].	Traditional response strategy
[93]	Examine the type of response strategy based on SCCT; crisis repair strategies (scapegoat, provocation excuse, defeasibility excuse, accident excuse, excuse, justification, reminder, and ingratiation)	Crisis strategies, sources, and topics influenced response	Do not consider comments made based on response
[138]	Implemented and extend SCCT; tested deny response strategy (scapegoating) in para-crisis situations		Few strategies
[139]	Proof of concept of how crisis response turns to opportunity; Corrective action and full apology strategies	Integrated response strategies on various media platforms	Traditional media is compared with social media
[101]	Analysed users dialogue after terrorist attack based on SCCT; The results express emotions and coping in para-crisis	Shows the effectiveness of social media in information dissimination	Social network structures of users tweets is not considered.
[60]	The paper analyses the crisis involving racial tensions among student and how the management communicate the crisis and restore the image.	Based on SCCT and Benoit (1997) image restoration theory [144].	Traditional response strategy
[140]	Adoption of social media to response to crisis based on SCCT response strategies; instructing, adjusting, and bolstering information	Evidence of response strategies used across crisis response stages	Does not include public data
[143]	Developed model based on SCCT attribution theory for reputation repair; message framing, perceived severity or sincerity, perceived responsibility, perceived reputation	Shows effectiveness of rumour message on reputation	The study does not use any of the response strategies
[141]	Examines online response from crisis communication and image restoration perspectives; awareness, apology, diminishing (victim blaming) scapegoating (manager blaming), rebuilding, and bolstering	Practical implications for image restoration and marketing efforts	Analyse only Weibo social media messages

B. EXTENSIONS, IMPROVEMENT OR IMPLEMENTATION OF SMCC AND ICM MODEL

Social Mediated Crisis Communication (SMCC) Model

Related Work	SMCC Components or Improvements	Benefit	Limitations
[35]	The paper evaluates two component of SMCC models; effects of crisis information form (traditional media, social media and word of mouth) and source (third party and organisation)	Focus on information form and source	Consider only few component
[145]	Analysed challenges and opportunities of social media by adopting attribution theory for SMCC model; they suggested that response strategy should be based on culture.		
[146]	Extend NCC and SMCC models; Modality (360 degree content vs flat content), sense of spatial presence, attitude towards the content, and involvement with previous flood media coverage.	Experiment that examine how public reacts to visual content after a disaster	Only flooding, small experiment, and ignore influencing resilience and prosocial attitudes
[147]	Multigroup Confirmatory Factor Analysis (CFA) Model to extend SMCC; Twitter influencers suggest that social media influence is composed of four factors: output, reactive outtake, proactive outtake, and network positioning. Each factor is associated with a distinct set of users' behavioural indicators (e.g., retweet).	Theorizes different dimensions, and offers refined conceptualization and measurement of social media influence	Developed in the context of organisational crises

Intergrated Crisis Mapping (ICM) Model

Related Work	SMCC Components or Improvements	Benefit	Limitations
[148]	Analysed Tweets according to elements of perceived controllability and predictability, as well as the emotions and coping strategies based on ICM	The importance of assessing the emotional state of stakeholders	The stakeholders are not categorised according to their social media usage
[149]	Examined online the public's crisis emotions and coping methods; the public engaged in cognitive, emotional, action-based, and discursive coping	Offer suggestions to refine ICM Model	Public sentiment and different segment of public

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI
10.1109/ACCESS.2020.3030184, IEEE Access

IEEE *Access*

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

ACKNOWLEDGMENT

REFERENCES

[1] R. R. Ulmer, T. L. Sellnow, and M. W. Seeger, Effective crisis communication: Moving from crisis to opportunity. Sage Publications, 2017.

[2] C. Soehner, I. Godfrey, and G. S. Bigler, "Crisis communication in libraries: Opportunity for new roles in public relations," The Journal of Academic Librarianship, vol. 43, no. 3, pp. 268–273, 2017.

[3] J. Nijkrake, J. F. Gosselt, and J. M. Gutteling, "Competing frames and tone in corporate communication versus media coverage during a crisis," Public relations review, vol. 41, no. 1, pp. 80–88, 2015.

[4] C. Reuter, A. L. Hughes, and M.-A. Kaufhold, "Social media in crisis management: An evaluation and analysis of crisis informatics research," International Journal of Human–Computer Interaction, vol. 34, no. 4, pp. 280–294, 2018.

[5] C. Reuter and M.-A. Kaufhold, "Fifteen years of social media in emergencies: a retrospective review and future directions for crisis informatics," Journal of Contingencies and Crisis Management, vol. 26, no. 1, pp. 41–57, 2018.

[6] C. W. Callaghan, "Disaster management, crowdsourced r&d and probabilistic innovation theory: Toward real time disaster response capability," International journal of disaster risk reduction, vol. 17, pp. 238–250, 2016.

[7] A. Yang and J. Bentley, "A balance theory approach to stakeholder network and apology strategy," Public Relations Review, vol. 43, no. 2, pp. 267–277, 2017.

[8] S. Luna and M. J. Pennock, "Social media applications and emergency management: A literature review and research agenda," International journal of disaster risk reduction, vol. 28, pp. 565–577, 2018.

[9] J. R. Ragini, P. R. Anand, and V. Bhaskar, "Big data analytics for disaster response and recovery through sentiment analysis," International Journal of Information Management, vol. 42, pp. 13–24, 2018.

[10] S. Stieglitz, D. Bunker, M. Mirbabaie, and C. Ehnis, "Sense-making in social media during extreme events," Journal of Contingencies and Crisis Management, vol. 26, no. 1, pp. 4–15, 2018.

[11] U. A. Bukar, M. A. Jabar, and F. Sidi, "Crisis informatics in smart campus: Opportunities, challenges, and future directions," in International Symposium on ICT Management and Administration (ISICTMA2019), 2019, p. 65.

[12] L. Ott and P. Theunissen, "Reputations at risk: Engagement during social media crises," Public Relations Review, vol. 41, no. 1, pp. 97–102, 2015.

[13] S. R. Veil, T. Buehner, and M. J. Palenchar, "A work-in-process literature review: Incorporating social media in risk and crisis communication," Journal of contingencies and crisis management, vol. 19, no. 2, pp. 110–122, 2011.

[14] M. N. K. Boulos, B. Resch, D. N. Crowley, J. G. Breslin, G. Sohn, R. Burtner, W. A. Pike, E. Jezierski, and K.-Y. S. Chuang, "Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, ogc standards and application examples," International journal of health geographics, vol. 10, no. 1, p. 67, 2011.

[15] M. Sigala, "Social media and crisis management in tourism: Applications and implications for research," Information Technology & Tourism, vol. 13, no. 4, pp. 269–283, 2011.

[16] B. F. Liu and J. D. Fraustino, "Beyond image repair: Suggestions for crisis communication theory development," Public Relations Review, vol. 40, no. 3, pp. 543–546, 2014.

[17] V. Slavkovikj, S. Verstockt, S. Van Hoecke, and R. Van de Walle, "Review of wildfire detection using social media," Fire safety journal, vol. 68, pp. 109–118, 2014.

[18] P. M. Landwehr and K. M. Carley, "Social media in disaster relief," in Data mining and knowledge discovery for big data. Springer, 2014, pp. 225–257.

[19] J. Whittaker, B. McLennan, and J. Handmer, "A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges," International journal of disaster risk reduction, vol. 13, pp. 358–368, 2015.

[20] T. Simon, A. Goldberg, and B. Adini, "Socializing in emergencies—a review of the use of social media in emergency situations," International Journal of Information Management, vol. 35, no. 5, pp. 609–619, 2015.

[21] K. C. Finch, K. R. Snook, C. H. Duke, K.-W. Fu, Z. T. H. Tse, A. Adhikari, and I. C.-H. Fung, "Public health implications of social media use during natural disasters, environmental disasters, and other environmental concerns," Natural Hazards, vol. 83, no. 1, pp. 729–760, 2016.

[22] P. R. Spence, K. A. Lachlan, and A. M. Rainear, "Social media and crisis research: Data collection and directions," Computers in Human Behavior, vol. 54, pp. 667–672, 2016.

[23] S. Mesmar, R. Talhouk, C. Akik, P. Olivier, I. H. Elhajj, S. Elbassuoni, S. Armoush, J. Kalot, M. Balaam, A. Germani et al., "The impact of digital technology on health of populations affected by humanitarian crises: Recent innovations and current gaps," Journal of public health policy, vol. 37, no. 2, pp. 167–200, 2016.

[24] J. Qadir, A. Ali, R. ur Rasool, A. Zwitter, A. Sathiaseelan, and J. Crowcroft, "Crisis analytics: big data-driven crisis response," Journal of International Humanitarian Action, vol. 1, no. 1, p. 12, 2016.

[25] M. L. Tan, R. Prasanna, K. Stock, E. Hudson-Doyle, G. Leonard, and D. Johnston, "Mobile applications in crisis informatics literature: A systematic review," International journal of disaster risk reduction, vol. 24, pp. 297–311, 2017.

[26] S. Ghosh, K. Ghosh, D. Ganguly, T. Chakraborty, G. J. Jones, M.-F. Moens, and M. Imran, "Exploitation of social media for emergency relief and preparedness: Recent research and trends," Information Systems Frontiers, vol. 20, no. 5, pp. 901–907, 2018.

[27] M. Eriksson, "Lessons for crisis communication on social media: A systematic review of what research tells the practice," International Journal of Strategic Communication, vol. 12, no. 5, pp. 526–551, 2018.

[28] M. Imran, C. Castillo, F. Diaz, and S. Vieweg, "Processing social media messages in mass emergency: Survey summary," in Companion Proceedings of the The Web Conference 2018. International World Wide Web Conferences Steering Committee, 2018, pp. 507–511.

[29] L. Tang, B. Bie, S.-E. Park, and D. Zhi, "Social media and outbreaks of emerging infectious diseases: A systematic review of literature," American journal of infection control, vol. 46, no. 9, pp. 962–972, 2018.

[30] E. Hagg, V. S. Dahinten, and L. M. Currie, "The emerging use of social media for health-related purposes in low and middle-income countries: A scoping review," International journal of medical informatics, vol. 115, pp. 92–105, 2018.

[31] C. Reuter, T. Ludwig, M.-A. Kaufhold, and T. Spielhofer, "Emergency services attitudes towards social media: A quantitative and qualitative survey across europe," International Journal of Human-Computer Studies, vol. 95, pp. 96–111, 2016.

[32] L. Palen, S. Vieweg, S. B. Liu, and A. L. Hughes, "Crisis in a networked world: Features of computer-mediated communication in the april 16, 2007, virginia tech event," Social Science Computer Review, vol. 27, no. 4, pp. 467–480, 2009.

[33] W. T. Coombs and J. S. Holladay, "The paracrisis: The challenges created by publicly managing crisis prevention," Public Relations Review, vol. 38, no. 3, pp. 408–415, 2012.

[34] G.-H. Alfonso and S. Suzanne, "Crisis communications management on the web: how internet-based technologies are changing the way public relations professionals handle business crises," Journal of Contingencies and Crisis Management, vol. 16, no. 3, pp. 143–153, 2008.

[35] B. F. Liu, L. Austin, and Y. Jin, "How publics respond to crisis communication strategies: The interplay of information form and source," Public Relations Review, vol. 37, no. 4, pp. 345–353, 2011.

[36] M. C. Stewart and B. G. Wilson, "The dynamic role of social media during hurricane# sandy: An introduction of the stremii model to weather the storm of the crisis lifecycle," Computers in Human Behavior, vol. 54, pp. 639–646, 2016.

[37] C. Vignal Lambret and E. Barki, "Social media crisis management: Aligning corporate response strategies with stakeholders' emotions online," Journal of Contingencies and Crisis Management, vol. 26, no. 2, pp. 295–305, 2018.

[38] Y. Cheng, "How social media is changing crisis communication strategies: Evidence from the updated literature," Journal of contingencies and crisis management, vol. 26, no. 1, pp. 58–68, 2018.

[39] C. Möller, J. Wang, and H. T. Nguyen, "# strongerthanwinston: Tourism and crisis communication through facebook following tropical cyclones in fiji," Tourism Management, vol. 69, pp. 272–284, 2018.

IEEE Access

Bukar *et al.*: Crisis Informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

[40] V. Mijović, N. Tomašević, V. Janev, M. Stanojević, and S. Vraneš, "Emergency management in critical infrastructures: A complex-event-processing paradigm," Journal of Systems Science and Systems Engineering, vol. 28, no. 1, pp. 37–62, 2019.

[41] L. Palen, S. Vieweg, J. Sutton, S. B. Liu, and A. Hughes, "Crisis informatics: Studying crisis in a networked world," in Proceedings of the Third International Conference on E-Social Science. Citeseer, 2007, pp. 7–9.

[42] C. Hagar, "Crisis informatics: Perspectives of trust–is social media a mixed blessing?" School of Information Student Research Journal, vol. 2, no. 2, p. 2, 2013.

[43] V. Pipek, S. B. Liu, and A. Kerne, "Crisis informatics and collaboration: a brief introduction," Computer Supported Cooperative Work (CSCW), vol. 23, no. 4-6, pp. 339–345, 2014.

[44] L. Palen and K. M. Anderson, "Crisis informatics—new data for extraordinary times," Science, vol. 353, no. 6296, pp. 224–225, 2016.

[45] C. Hagar, "Crisis informatics," Journal of Geography & Natural Disasters., vol. 4, no. 1, 2014.

[46] C. Reuter, M.-A. Kaufhold, T. Spielhofer, and A. S. Hahne, "Social media in emergencies: A representative study on citizens' perception in germany," Proceedings of the ACM on Human-Computer Interaction, vol. 1, no. CSCW, p. 90, 2017.

[47] B. Kitchenham and S. Charters, "Guidelines for performing systematic literature reviews in software engineering," 2007.

[48] S. Nidhra, M. Yanamadala, W. Afzal, and R. Torkar, "Knowledge transfer challenges and mitigation strategies in global software development—a systematic literature review and industrial validation," International journal of information management, vol. 33, no. 2, pp. 333–355, 2013.

[49] E. G. Hansen and S. Schaltegger, "The sustainability balanced scorecard: A systematic review of architectures," Journal of Business Ethics, vol. 133, no. 2, pp. 193–221, 2016.

[50] O. Zughoul, F. Momani, O. Almasri, A. Zaidan, B. Zaidan, M. Alsalem, O. Albahri, A. Albahri, and M. Hashim, "Comprehensive insights into the criteria of student performance in various educational domains," IEEE Access, vol. 6, pp. 73 245–73 264, 2018.

[51] Y. A. Qasem, R. Abdullah, Y. Y. Jusoh, R. Atan, and S. Asadi, "Cloud computing adoption in higher education institutions: A systematic review," IEEE Access, vol. 7, pp. 63 722–63 744, 2019.

[52] C. Reuter, T. Ludwig, C. Kotthaus, M.-A. Kaufhold, E. von Radziewski, and V. Pipek, "Big data in a crisis? creating social media datasets for crisis management research," i-com, vol. 15, no. 3, pp. 249–264, 2016.

[53] Y. A. Ahmed, M. N. Ahmad, N. Ahmad, and N. H. Zakaria, "Social media for knowledge-sharing: A systematic literature review," Telematics and informatics, 2018.

[54] W. T. Coombs, "Crisis communication: The best evidence from research," in The Routledge Companion to Risk, Crisis and Emergency Management. Routledge, 2018, pp. 51–66.

[55] S. P. Goggins, C. Mascaro, and G. Valetto, "Group informatics: A methodological approach and ontology for sociotechnical group research," Journal of the American Society for Information Science and Technology, vol. 64, no. 3, pp. 516–539, 2013.

[56] M. W. Graham, E. J. Avery, and S. Park, "The role of social media in local government crisis communications," Public Relations Review, vol. 41, no. 3, pp. 386–394, 2015.

[57] M. Gascó, P. S. Bayerl, S. Denef, and B. Akhgar, "What do citizens communicate about during crises? analyzing twitter use during the 2011 uk riots," Government Information Quarterly, vol. 34, no. 4, pp. 635–645, 2017.

[58] M. W. Seeger and T. L. Sellnow, "Theorizing crisis communication," 2013.

[59] F. Gerken, S. F. Van der Land, and T. G. van der Meer, "Crisis in the air: An investigation of airasia's crisis-response effectiveness based on frame alignment," Public Relations Review, vol. 42, no. 5, pp. 879–892, 2016.

[60] J. A. Fortunato, R. A. Gigliotti, and B. D. Ruben, "Analysing the dynamics of crisis leadership in higher education: A study of racial incidents at the university of missouri," Journal of Contingencies and Crisis Management, vol. 26, no. 4, pp. 510–518, 2018.

[61] C. Reuter, A. Marx, and V. Pipek, "Crisis management 2.0: Towards a systematization of social software use in crisis situations," International Journal of Information Systems for Crisis Response and Management (IJISCRAM), vol. 4, no. 1, pp. 1–16, 2012.

[62] A. Ginige, L. Paolino, M. Romano, M. Sebillo, G. Tortora, and G. Vitiello, "Information sharing among disaster responders-an interactive

spreadsheet-based collaboration approach," Computer Supported Cooperative Work (CSCW), vol. 23, no. 4-6, pp. 547–583, 2014.

[63] T. Onorati, P. Díaz, and B. Carrion, "From social networks to emergency operation centers: A semantic visualization approach," Future Generation Computer Systems, vol. 95, pp. 829–840, 2019.

[64] L. Palen and S. B. Liu, "Citizen communications in crisis: anticipating a future of ict-supported public participation," in Proceedings of the SIGCHI conference on Human factors in computing systems, 2007, pp. 727–736.

[65] Y. Ji and S. Kim, "Communication-mediated psychological mechanisms of chinese publics' post-crisis corporate associations and government associations," Journal of Contingencies and Crisis Management, vol. 27, no. 2, pp. 182–194, 2019.

[66] L. Palen, K. M. Anderson, G. Mark, J. Martin, D. Sicker, M. Palmer, and D. Grunwald, "A vision for technology-mediated support for public participation & assistance in mass emergencies & disasters," ACM-BCS Visions of Computer Science 2010, pp. 1–12, 2010.

[67] H. Purohit, A. Hampton, S. Bhatt, V. L. Shalin, A. P. Sheth, and J. M. Flach, "Identifying seekers and suppliers in social media communities to support crisis coordination," Computer Supported Cooperative Work (CSCW), vol. 23, no. 4-6, pp. 513–545, 2014.

[68] B. Kar, "Citizen science in risk communication in the era of ict," Concurrency and Computation: Practice and Experience, vol. 28, no. 7, pp. 2005–2013, 2016.

[69] J. Barker and C. J. Macleod, "Development of a national-scale real-time twitter data mining pipeline for social geodata on the potential impacts of flooding on communities," Environmental Modelling & Software, vol. 115, pp. 213–227, 2019.

[70] M. Avvenuti, M. G. Cimino, S. Cresci, A. Marchetti, and M. Tesconi, "A framework for detecting unfolding emergencies using humans as sensors," SpringerPlus, vol. 5, no. 1, p. 43, 2016.

[71] S. B. Liu and L. Palen, "The new cartographers: Crisis map mashups and the emergence of neogeographic practice," Cartography and Geographic Information Science, vol. 37, no. 1, pp. 69–90, 2010.

[72] M. M. Maresh-Fuehrer and R. Smith, "Social media mapping innovations for crisis prevention, response, and evaluation," Computers in Human Behavior, vol. 54, pp. 620–629, 2016.

[73] F. Yuan and R. Liu, "Feasibility study of using crowdsourcing to identify critical affected areas for rapid damage assessment: Hurricane matthew case study," International journal of disaster risk reduction, vol. 28, pp. 758–767, 2018.

[74] J. Gelernter and S. Balaji, "An algorithm for local geoparsing of microtext," GeoInformatica, vol. 17, no. 4, pp. 635–667, 2013.

[75] A. Kumar and J. P. Singh, "Location reference identification from tweets during emergencies: A deep learning approach," International journal of disaster risk reduction, vol. 33, pp. 365–375, 2019.

[76] R. Burns, "Moments of closure in the knowledge politics of digital humanitarianism," Geoforum, vol. 53, pp. 51–62, 2014.

[77] J. Anderson, R. Soden, B. Keegan, L. Palen, and K. M. Anderson, "The crowd is the territory: Assessing quality in peer-produced spatial data during disasters," International Journal of Human–Computer Interaction, vol. 34, no. 4, pp. 295–310, 2018.

[78] K. M. Carley, M. Malik, P. M. Landwehr, J. Pfeffer, and M. Kowalchuck, "Crowd sourcing disaster management: The complex nature of twitter usage in padang indonesia," Safety science, vol. 90, pp. 48–61, 2016.

[79] T. Ludwig, C. Kotthaus, C. Reuter, S. Van Dongen, and V. Pipek, "Situated crowdsourcing during disasters: Managing the tasks of spontaneous volunteers through public displays," International Journal of Human-Computer Studies, vol. 102, pp. 103–121, 2017.

[80] S. B. Liu, "Crisis crowdsourcing framework: Designing strategic configurations of crowdsourcing for the emergency management domain," Computer Supported Cooperative Work (CSCW), vol. 23, no. 4-6, pp. 389–443, 2014.

[81] D. Dailey and K. Starbird, "Journalists as crowdsourcerers: Responding to crisis by reporting with a crowd," Computer Supported Cooperative Work (CSCW), vol. 23, no. 4-6, pp. 445–481, 2014.

[82] B. Haworth, "Emergency management perspectives on volunteered geographic information: Opportunities, challenges and change," Computers, Environment and Urban Systems, vol. 57, pp. 189–198, 2016.

[83] W. Norris, "Digital humanitarians: citizen journalists on the virtual front line of natural and human-caused disasters," Journalism Practice, vol. 11, no. 2-3, pp. 213–228, 2017.

[84] R. Munro, "Crowdsourcing and the crisis-affected community," Information retrieval, vol. 16, no. 2, pp. 210–266, 2013.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2020.3030184, IEEE Access

IEEE Access

Bukar *et al.*: Crisis informatics in the context of social media crisis communication: Theoretical models, taxonomy, and open issues

[85] E.-K. Olsson, "Crisis communication in public organisations: Dimensions of crisis communication revisited," Journal of Contingencies and Crisis management, vol. 22, no. 2, pp. 113–125, 2014.

[86] B. Zheng, H. Liu, and R. M. Davison, "Exploring the relationship between corporate reputation and the public's crisis communication on social media," Public Relations Review, vol. 44, no. 1, pp. 56–64, 2018.

[87] Y. Huang, C. White, H. Xia, and Y. Wang, "A computational cognitive modeling approach to understand and design mobile crowdsourcing for campus safety reporting," International Journal of Human-Computer Studies, vol. 102, pp. 27–40, 2017.

[88] M. Cheong and V. C. Lee, "A microblogging-based approach to terrorism informatics: Exploration and chronicling civilian sentiment and response to terrorism events via twitter," Information Systems Frontiers, vol. 13, no. 1, pp. 45–59, 2011.

[89] M. S. Jensen, C. Neumayer, and L. Rossi, "'brussels will land on its feet like a cat': motivations for memefying# brusselslockdown," Information, Communication & Society, pp. 1–17, 2018.

[90] I. Hellsten, S. Jacobs, and A. Wonneberger, "Active and passive stakeholders in issue arenas: A communication network approach to the bird flu debate on twitter," Public Relations Review, vol. 45, no. 1, pp. 35–48, 2019.

[91] P. Grover, A. K. Kar, and G. Davies, ""technology enabled health"– insights from twitter analytics with a socio-technical perspective," International Journal of Information Management, vol. 43, pp. 85–97, 2018.

[92] K. A. Lachlan, P. R. Spence, and X. Lin, "Expressions of risk awareness and concern through twitter: On the utility of using the medium as an indication of audience needs," Computers in Human Behavior, vol. 35, pp. 554–559, 2014.

[93] M. Formentin, D. S. Bortree, and J. D. Fraustino, "Navigating anger in happy valley: Analyzing penn state's facebook-based crisis responses to the sandusky scandal," Public Relations Review, vol. 43, no. 4, pp. 671–679, 2017.

[94] L. Kaewkitipong, C. C. Chen, and P. Ractham, "A community-based approach to sharing knowledge before, during, and after crisis events: A case study from thailand," Computers in Human Behavior, vol. 54, pp. 653–666, 2016.

[95] R. Gaspar, S. Gorjão, B. Seibt, L. Lima, J. Barnett, A. Moss, and J. Wills, "Tweeting during food crises: A psychosocial analysis of threat coping expressions in spain, during the 2011 european ehec outbreak," International Journal of Human-Computer Studies, vol. 72, no. 2, pp. 239–254, 2014.

[96] S. Park and E. J. Avery, "Effects of media channel, crisis type and demographics on audience intent to follow instructing information during crisis," Journal of Contingencies and Crisis Management, vol. 26, no. 1, pp. 69–78, 2018.

[97] A. Schroeder, L. Pennington-Gray, H. Donohoe, and S. Kiousis, "Using social media in times of crisis," Journal of Travel & Tourism Marketing, vol. 30, no. 1-2, pp. 126–143, 2013.

[98] X. A. Zhang, J. Borden, and S. Kim, "Understanding publics' post-crisis social media engagement behaviors: An examination of antecedents and mediators," Telematics and Informatics, vol. 35, no. 8, pp. 2133–2146, 2018.

[99] X. Lu, "Online communication behavior at the onset of a catastrophe: an exploratory study of the 2008 wenchuan earthquake in china," Natural hazards, vol. 91, no. 2, pp. 785–802, 2018.

[100] U. Sjöberg, "It is not about facts–it is about framing. the app generation's information-seeking tactics: Proactive online crisis communication," Journal of Contingencies and Crisis Management, vol. 26, no. 1, pp. 127–137, 2018.

[101] B. G. Smith, S. B. Smith, and D. Knighton, "Social media dialogues in a crisis: A mixed-methods approach to identifying publics on social media," Public Relations Review, vol. 44, no. 4, pp. 562–573, 2018.

[102] E. Yoo, W. Rand, M. Eftekhar, and E. Rabinovich, "Evaluating information diffusion speed and its determinants in social media networks during humanitarian crises," Journal of Operations Management, vol. 45, pp. 123–133, 2016.

[103] M. C. Getchell and T. L. Sellnow, "A network analysis of official twitter accounts during the west virginia water crisis," Computers in Human Behavior, vol. 54, pp. 597–606, 2016.

[104] K. Jung, M. Song, and H. Park, "Filling the gap between bureaucratic and adaptive approaches to crisis management: lessons from the sewol ferry sinking in south korea," Quality & Quantity, vol. 52, 2017.

[105] S. Stieglitz, M. Mirbabaie, and M. Milde, "Social positions and collective sense-making in crisis communication," International Journal of Human–Computer Interaction, vol. 34, no. 4, pp. 328–355, 2018.

[106] J. Jiang, Y.-H. Huang, F. Wu, H.-Y. Choy, and D. Lin, "At the crossroads of inclusion and distance: Organizational crisis communication during celebrity-endorsement crises in china," Public Relations Review, vol. 41, no. 1, pp. 50–63, 2015.

[107] N. Dabner, "'breaking ground'in the use of social media: A case study of a university earthquake response to inform educational design with facebook," The Internet and Higher Education, vol. 15, no. 1, pp. 69–78, 2012.

[108] J. R. Ragini, P. R. Anand, and V. Bhaskar, "Mining crisis information: A strategic approach for detection of people at risk through social media analysis," International journal of disaster risk reduction, vol. 27, pp. 556–566, 2018.

[109] F. C. Groen, G. Pavlin, A. Winterboer, and V. Evers, "A hybrid approach to decision making and information fusion: combining humans and artificial agents," Robotics and autonomous systems, vol. 90, pp. 71–85, 2017.

[110] H.-C. Lin, Y. J. Chen, C.-C. Chen, and W.-H. Ho, "Expectations of social networking site users who share and acquire health-related information," Computers & Electrical Engineering, vol. 69, pp. 808–814, 2018.

[111] Y. Chen, C. Liang, and D. Cai, "Understanding wechat users' behavior of sharing social crisis information," International Journal of Human–Computer Interaction, vol. 34, no. 4, pp. 356–366, 2018.

[112] T. G. van der Meer, P. Verhoeven, H. W. Beentjes, and R. Vliegenthart, "Communication in times of crisis: The stakeholder relationship under pressure," Public Relations Review, vol. 43, no. 2, pp. 426–440, 2017.

[113] M.-A. Kaufhold, A. Gizikis, C. Reuter, M. Habdank, and M. Grinko, "Avoiding chaotic use of social media before, during, and after emergencies: Design and evaluation of citizens' guidelines," Journal of Contingencies and Crisis Management, vol. 27, 10 2018.

[114] U. Bukar, M. A. Jabar, and F. Sidi, "Crisis informatics: A systematic evaluation," vol. 9, no. 1. Blue Eyes Intelligence Engineering and Sciences Publication, 2019.

[115] Y. Jin, A. Pang, and G. T. Cameron, "Toward a publics-driven, emotion-based conceptualization in crisis communication: Unearthing dominant emotions in multi-staged testing of the integrated crisis mapping (icm) model," Journal of Public Relations Research, vol. 24, no. 3, pp. 266–298, 2012.

[116] K. Freberg, K. Saling, K. G. Vidoloff, and G. Eosco, "Using value modeling to evaluate social media messages: The case of hurricane irene," Public Relations Review, vol. 39, no. 3, pp. 185–192, 2013.

[117] R. Syed, "Enterprise reputation threats on social media: A case of data breach framing," The Journal of Strategic Information Systems, vol. 28, no. 3, pp. 257–274, 2019.

[118] P. Panagiotopoulos, J. Barnett, A. Z. Bigdeli, and S. Sams, "Social media in emergency management: Twitter as a tool for communicating risks to the public," Technological Forecasting and Social Change, vol. 111, pp. 86–96, 2016.

[119] L. M. Omilion-Hodges and K. L. McClain, "University use of social media and the crisis lifecycle: Organizational messages, first information responders' reactions, reframed messages and dissemination patterns," Computers in Human Behavior, vol. 54, pp. 630–638, 2016.

[120] N. Pogrebnyakov and E. Maldonado, "Didn't roger that: Social media message complexity and situational awareness of emergency responders," International Journal of Information Management, vol. 40, pp. 166–174, 2018.

[121] C. Du Plessis, "Social media crisis communication: Enhancing a discourse of renewal through dialogic content," Public Relations Review, vol. 44, no. 5, pp. 829–838, 2018.

[122] Y. Cheng, Y.-H. C. Huang, and C. M. Chan, "Public relations, media coverage, and public opinion in contemporary china: Testing agenda building theory in a social mediated crisis," Telematics and Informatics, vol. 34, no. 3, pp. 765–773, 2017.

[123] E. Comrie, C. Burns, A. Coulson, J. Quigley, and K. Quigley, "Rationalising the use of twitter by official organisations during risk events: Operationalising the social amplification of risk framework through causal loop diagrams," European Journal of Operational Research, vol. 272, no. 2, pp. 792–801, 2019.

[124] W. T. Coombs and S. J. Holladay, "Helping crisis managers protect reputational assets: Initial tests of the situational crisis communication theory," Management Communication Quarterly, vol. 16, no. 2, pp. 165–186, 2002.

[125] W. T. Coombs, "Protecting organization reputations during a crisis: The development and application of situational crisis communication theory," Corporate reputation review, vol. 10, no. 3, pp. 163–176, 2007.

[126] F. Schultz, S. Utz, and A. Göritz, "Is the medium the message? perceptions of and reactions to crisis communication via twitter, blogs and traditional media," Public relations review, vol. 37, no. 1, pp. 20–27, 2011.

[127] N. A. Brown and A. C. Billings, "Sports fans as crisis communicators on social media websites," Public Relations Review, vol. 39, no. 1, pp. 74–81, 2013.

[128] P. Verhoeven, R. Tench, A. Zerfass, A. Moreno, and D. Verčič, "Crisis? what crisis?: How european professionals handle crises and crisis communication," Public Relations Review, vol. 40, no. 1, pp. 107–109, 2014.

[129] E.-J. Ki and E. Nekmat, "Situational crisis communication and interactivity: Usage and effectiveness of facebook for crisis management by fortune 500 companies," Computers in Human Behavior, vol. 35, pp. 140–147, 2014.

[130] B. Liu, H. Kim, and L. Pennington-Gray, "Responding to the bed bug crisis in social media," International Journal of Hospitality Management, vol. 47, pp. 76–84, 2015.

[131] L. V. Chewning, "Multiple voices and multiple media: Co-constructing bp's crisis response," Public Relations Review, vol. 41, no. 1, pp. 72–79, 2015.

[132] M. W. DiStaso, M. Vafeiadis, and C. Amaral, "Managing a health crisis on facebook: How the response strategies of apology, sympathy, and information influence public relations," Public Relations Review, vol. 41, no. 2, pp. 222–231, 2015.

[133] S. Kim, X. A. Zhang, and B. W. Zhang, "Self-mocking crisis strategy on social media: Focusing on alibaba chairman jack ma in china," Public Relations Review, vol. 42, no. 5, pp. 903–912, 2016.

[134] N. Pang and J. Ng, "Twittering the little india riot: Audience responses, information behavior and the use of emotive cues," Computers in Human Behavior, vol. 54, pp. 607–619, 2016.

[135] M. Roshan, M. Warren, and R. Carr, "Understanding the use of social media by organisations for crisis communication," Computers in Human Behavior, vol. 63, pp. 350–361, 2016.

[136] A. Diers-Lawson and A. Pang, "Did bp atone for its transgressions? expanding theory on 'ethical apology' in crisis communication," Journal of Contingencies and Crisis Management, vol. 24, no. 3, pp. 148–161, 2016.

[137] H. Crijns, V. Cauberghe, L. Hudders, and A.-S. Claeys, "How to deal with online consumer comments during a crisis? the impact of personalized organizational responses on organizational reputation," Computers in Human Behavior, vol. 75, pp. 619–631, 2017.

[138] S. Roh, "Examining the paracrisis online: The effects of message source, response strategies and social vigilantism on public responses," Public Relations Review, vol. 43, no. 3, pp. 587–596, 2017.

[139] S. B. C. Ngai and J. Falkheimer, "How ikea turned a crisis into an opportunity," Public Relations Review, vol. 43, no. 1, pp. 246–248, 2017.

[140] W. Liu, C.-H. Lai, and W. W. Xu, "Tweeting about emergency: A semantic network analysis of government organizations' social media messaging during hurricane harvey," Public Relations Review, vol. 44, no. 5, pp. 807–819, 2018.

[141] L. Su, S. Stepchenkova, and A. P. Kirilenko, "Online public response to a service failure incident: Implications for crisis communications," Tourism Management, vol. 73, pp. 1–12, 2019.

[142] S. Madden, M. Janoske, and R. L. Briones, "The double-edged crisis: Invisible children's social media response to the kony 2012 campaign," Public Relations Review, vol. 42, no. 1, pp. 38–48, 2016.

[143] Y. Xiao, V. Cauberghe, and L. Hudders, "Humour as a double-edged sword in response to crises versus rumours: The effectiveness of humorously framed crisis response messages on social media," Journal of Contingencies and Crisis Management, vol. 26, no. 2, pp. 247–260, 2018.

[144] W. L. Benoit, "Image restoration theory," The International Encyclopedia of Communication, 2008.

[145] L. Zhu, D. Anagondahalli, and A. Zhang, "Social media and culture in crisis communication: Mcdonald's and kfc crises management in china," Public Relations Review, vol. 43, no. 3, pp. 487–492, 2017.

[146] J. D. Fraustino, J. Y. Lee, S. Y. Lee, and H. Ahn, "Effects of 360 degree video on attitudes toward disaster communication: Mediating and moderating roles of spatial presence and prior disaster media involvement," Public Relations Review, vol. 44, no. 3, pp. 331–341, 2018.

[147] X. Zhao, M. Zhan, and B. F. Liu, "Disentangling social media influence in crises: Testing a four-factor model of social media influence with large data," Public Relations Review, vol. 44, no. 4, pp. 549–561, 2018.

[148] J. Brummette and H. F. Sisco, "Using twitter as a means of coping with emotions and uncontrollable crises," Public Relations Review, vol. 41, no. 1, pp. 89–96, 2015.

[149] S. J. Guo, "The 2013 boston marathon bombing: Publics' emotions, coping, and organizational engagement," Public Relations Review, vol. 43, no. 4, pp. 755–767, 2017.

[150] Y. Jin, A. Pang, and G. T. Cameron, "Integrated crisis mapping: Toward a publics-based, emotion-driven conceptualization in crisis communication," Sphera Publica, no. 7, pp. 81–95, 2007.

[151] Y. Jin, J.-S. Lin, B. Gilbreath, and Y.-I. Lee, "Motivations, consumption emotions, and temporal orientations in social media use: A strategic approach to engaging stakeholders across platforms," International Journal of Strategic Communication, vol. 11, no. 2, pp. 115–132, 2017.

[152] B. Reynolds and M. W. SEEGER, "Crisis and emergency risk communication as an integrative model," Journal of health communication, vol. 10, no. 1, pp. 43–55, 2005.

[153] T. Haer, W. W. Botzen, and J. C. Aerts, "The effectiveness of flood risk communication strategies and the influence of social networks—insights from an agent-based model," Environmental Science & Policy, vol. 60, pp. 44–52, 2016.

[154] N. T. Iannarino, S. R. Veil, and A. J. Cotton III, "Bringing home the crisis: How us evening news framed the 2011 j apan nuclear crisis," Journal of Contingencies and Crisis Management, vol. 23, no. 3, pp. 169–181, 2015.

[155] W. T. Coombs and S. J. Holladay, "Further explorations of post-crisis communication: Effects of media and response strategies on perceptions and intentions," Public Relations Review, vol. 35, no. 1, pp. 1–6, 2009.

[156] R. Valecha, "An investigation of interaction patterns in emergency management: A case study of the crash of continental flight 3407," Information Systems Frontiers, pp. 1–13, 2019.

[157] F. Frandsen and W. Johansen, "Krisekommunikation. når virksomhedens image og omdømme er truet [crisis communication. when organizations' image and reputation are in question]," 2007.

[158] R. D. Maiorescu, "Crisis management at general motors and toyota: An analysis of gender-specific communication and media coverage," Public Relations Review, vol. 42, no. 4, pp. 556–563, 2016.

[159] R. Kriyantono, "Measuring a company reputation in a crisis situation: An ethnography approach on the situational crisis communication theory," International Journal of Business and Social Science, vol. 3, no. 9, 2012.

[160] W. Hughes, "What makes a good research paper?" ARCOM Newsletter, vol. 16, no. 3, pp. 1–4, 2001.

[161] J. E. Oxley, J. W. Rivkin, M. D. Ryall, and S. R. Initiative, "The strategy research initiative: Recognizing and encouraging high-quality research in strategy," 2010.

[162] D. Silverman, Doing qualitative research: A practical handbook. SAGE publications limited, 2013.

[163] H. Watson and R. Rodrigues, "Bringing privacy into the fold: Considerations for the use of social media in crisis management," Journal of Contingencies and Crisis Management, vol. 26, no. 1, pp. 89–98, 2018.

[164] C. Lombard, L. Brennan, M. Reid, K. M. Klassen, C. Palermo, T. Walker, M. S. Lim, M. Dean, T. A. Mccaffrey, and H. Truby, "Communicating health—optimising young adults' engagement with health messages using social media: Study protocol," Nutrition & Dietetics, vol. 75, no. 5, pp. 509–519, 2018.

[165] S. Andreastuti, E. Paripurno, H. Gunawan, A. Budianto, D. Syahbana, and J. Pallister, "Character of community response to volcanic crises at sinabung and kelud volcanoes," Journal of Volcanology and Geothermal Research, 2017.

[166] H. Watson, R. L. Finn, and K. Wadhwa, "Organizational and societal impacts of big data in crisis management," Journal of Contingencies and Crisis Management, vol. 25, no. 1, pp. 15–22, 2017.

[167] T. Vihalemm, M. Kiisel, and H. Harro-Loit, "Citizens' response patterns to warning messages," Journal of Contingencies and Crisis Management, vol. 20, no. 1, pp. 13–25, 2012.

[168] P. Palttala, C. Boano, R. Lund, and M. Vos, "Communication gaps in disaster management: Perceptions by experts from governmental and non-governmental organizations," Journal of Contingencies and Crisis Management, vol. 20, no. 1, pp. 2–12, 2012.

[169] B. Smith and M. Taylor, "Empowering engagement: Understanding social media user sense of influence," International Journal of Strategic Communication, pp. 1–17, 02 2017.

IEEE Access®

[170] B. M. Alajmi and C. L. Al-Qallaf, "Crisis-management content in lis curricula: Developing a model for future improvement," Journal of Library Administration, vol. 58, no. 7, pp. 645–673, 2018.

[171] "Global social media ranking 2019." [Online]. Available: https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/

[172] M. Eriksson and E.-K. Olsson, "Facebook and twitter in crisis communication: A comparative study of crisis communication professionals and citizens," Journal of Contingencies and Crisis Management, vol. 24, no. 4, pp. 198–208, 2016.

[173] Y. Li, S. Yang, S. Zhang, and W. Zhang, "Mobile social media use intention in emergencies among gen y in china: An integrative framework of gratifications, task-technology fit, and media dependency," Telematics and Informatics, vol. 42, p. 101244, 2019.

[174] A. Whiting and D. Williams, "Why people use social media: a uses and gratifications approach," Qualitative Market Research: An International Journal, 2013.

[175] C. A. Wynd, B. Schmidt, and M. A. Schaefer, "Two quantitative approaches for estimating content validity," Western journal of nursing research, vol. 25, no. 5, pp. 508–518, 2003.

[176] D. F. Polit, C. T. Beck, and S. V. Owen, "Is the cvi an acceptable indicator of content validity? appraisal and recommendations," Research in nursing & health, vol. 30, no. 4, pp. 459–467, 2007.

[177] D. F. Polit and C. T. Beck, "The content validity index: are you sure you know what's being reported? critique and recommendations," Research in nursing & health, vol. 29, no. 5, pp. 489–497, 2006.

[178] B. F. Liu and S. Kim, "How organizations framed the 2009 h1n1 pandemic via social and traditional media: Implications for us health communicators," Public Relations Review, vol. 37, no. 3, pp. 233–244, 2011.

FATIMA SIDI received her Bachelor of Computer Science (1988), Master of Science (2002) and her PhD in Management Information System from Universiti Putra Malaysia, Malaysia (UPM). Fatima is currently working as an Associate Professor in the discipline of Computer Science, at the Department of Computer Science, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia (UPM). Her current research interests are Knowledge and Information Management Systems, Data and Knowledge Engineering, Database and Data Warehouse.

UA BUKAR received his BSc. in Business Information Technology with concentration in e-commerce research and strategy from Greenwich University UK, as well as MSc. in Computer Network Management from Middlesex University Dubai. He is currently pursuing his Ph.D. degree with the Department of Software Engineering and Information Systems, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia, Malaysia. His contributions have been published in prestigious peer-reviewed journals and international conferences. His research interests include crisis informatics, data analytics, machine learning and the use of quantitative methods in information systems research. His IT career has included work as several niche projects, with responsibilities ranging from teaching, research and analysis.

ROZI NOR HAIZAN NOR received her PhD in Computer Science from Universiti Teknologi Malaysia (UTM), Malaysia. Rozi Nor Haizan is currently a Senior Lecturer in the Department of Software Engineering and Information System. She holds over a tenth of experience as a lecturer in the area of Information Systems. Her current research interests are in Software Engineering, Knowledge Management, Information System Management and Web Application. To date, Rozi Nor Haizan is the Principal Investigator for 3 research grants valued RM500,000 and has published her work in more than 50 articles in journals, conferences proceedings, seminars, technical reports. Additionally, Rozi Nor Haizan has about 5 copyrights to her name.

MARZANAH A. JABAR received her PhD in Management Information System from Universiti Putra Malaysia, Malaysia. She is currently an Associate Professor in the Department of Software Engineering and Information System. Marzanah has over twenty years of experience as a System Analyst in the area of Enterprise System Development and has been appointed as consultant to several software development projects in UPM and other agencies. Her current research interests are in Software Engineering, Knowledge Management, Information Management Systems and Enterprise Software Development. To date, Marzanah is the Principal Investigator for 35 research grants valued at RM2 millions, consultation work worth RM300,000 and has published more than 200 articles in journals, conferences proceedings, seminars and technical reports. Additionally, Dr. Marzanah has 53 copyrights and 2 patents to her name. She has also successfully commercialized 1 product from her own research.

SALFARINA ABDULLAH received her PhD in Knowledge Management from Universiti Putra Malaysia, Malaysia. Salfarina is currently a Senior Lecturer in the Department of Software Engineering and Information System. She has served almost twenty years of teaching in the faculty for various undergraduate and postgraduate courses mostly in the area of Information Systems. She has been appointed as a consultant and expert subject matter to several software development projects in UPM and other higher learning institutions. Her current research interests are in Knowledge Management in Software Engineering and Information Management Systems. Salfarina has led couple of research grants as the Principal Investigator and as a research committee for several other research grants. She has published more than 40 articles in journals and conferences proceedings and seminars. In addition to that, she also has over 10 copyrights and 1 patent to her name.

MOHAMED OTHMAN received his Ph.D. degree (Hons.) from the National University of Malaysia. He is currently a professor in computer science with the Department of Communication Technology and Network, Universiti Putra Malaysia (UPM). Prior to that, he was a Deputy Director of the Information Development and Communication Center, where he was in charge of UMPNet network campus, uSport Wireless Communication Project and the UPM Data Center. He is also an Associate Researcher and a coordinator of high-speed machines with the Laboratory of Computational Science and Informatics, institute of Mathematical Science, UPM. In 2017, he received an Honourable Professor from Silkway International University (SWIU), Shyrrikent, Kazakhstan, and was also a visiting professor with South Kazakhstan State University, Shymkent, and L. N. Gumilyov Eurasian National University, Astana, Kazakhstan. He has published in more than 300 International journals and 330 proceeding papers. His main research interests are in the fields of computer networks, parallel and distributed computing, high-speed interconnection networks, network design and management (network security, wireless and traffic monitoring), consensus in IoT, and mathematical modeling in scientific computing. He is a senior member of IEEE, and a life member of the Malaysian National Computer Confederation, and Malaysian Mathematical Society. He was the recipient of the Best PhD Thesis in 2000 by Sime Darby Malaysia and Malaysian Mathematical Science Society. He has also filed six Malaysian, one Japanese, one South Korean, and three U.S. patents.

. . .