

# **CULTIVATING USER ENGAGEMENT IN MULTIMODAL CRISIS COMMUNICATION ON SOCIAL MEDIA**

**by**

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The Hong Kong University of Science and Technology  
in Partial Fulfillment of the Requirements for  
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in Computer Science and Engineering

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1 January 2024

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## **ABSTRACT**

Social media platforms have emerged as crucial information hubs during crises. Compared to mass media, social media enables two-way communication between citizens and government, and affords crowdsourced information creation and dissemination by the public. The advancement of social media has expanded crisis communication beyond text, embracing multiple modalities like images, videos, and audio.

Cultivating user engagement in crisis communication, including behavioral, cognitive, and emotional engagement, is of great significance in facilitating the development of citizens' situational awareness of crises, and enhancing resilience for crisis response. However, obstacles such as information overload, misinformation, and uncertainty hinder effective engagement. It remains unclear how multimodal crisis communication presents opportunities and challenges in engaging and informing the public. Understanding user engagement in multimodal crisis communication can inform effective communication strategies and design opportunities for social media platforms in crisis contexts.

In order to fill this gap, this dissertation examines user engagement under the (combinational) use of rich text, images, and videos in crisis communication, covering diverse significant crisis

communication objectives such as knowledge sharing, emotional connection, and help-seeking. This dissertation starts with the investigation of help-seeking posts during natural disasters as a representative case of crisis communication in rich text, capturing narrative strategies to facilitate effective help-seeking and overcome the overwhelm challenge. Then, focusing on image-embedded posts during a health crisis local outbreak, I adopt a mixed-methods approach to understanding themes, goals, and strategies of crisis imagery, highlighting the visual-text correlation for informational and emotional goals. Finally, by centering on crisis videos, my research answers how innovative video-creation strategies such as recreational elements and government-citizen collaboration play a role in engaging users, and how interactive video-commenting features such as asynchronous comments and synchronous danmaku supplement videos in crisis communication.

Collectively, this dissertation highlights the significance of multimodal crisis communication, encompassing rich text, images, and videos, in effectively engaging users on social media platforms during times of crisis. The findings offer valuable insights and design implications to cultivate user engagement, foster resilience, and ensure the dissemination of timely and accurate information during challenging circumstances.

# CHAPTER 1

## INTRODUCTION

Social media platforms have become crucial information hubs that millions gather during crises such as natural disasters and epidemics. Compared to mass media which largely relies on one-way and top-down communication from official agencies, social media platforms allow two-way communication between citizens and government, and afford crowdsourced information creation and dissemination by the public [43, 208, 58]. On social media, people spontaneously spread situational danger warnings and self-rescue knowledge [141, 140, 131], collectively make sense of the situation [31, 163, 93, 91], collaboratively debunk crisis-related misinformation [46, 73], and mutually provide assistance to facilitate post-disaster recovery [165]. Researchers have given increasing attention to how to support effective and efficient **crisis communication** in HCI and CSCW community [25, 103, 59].

Given the crucial role of social media-based crisis communication, cultivating **user engagement** in crisis-related messages on social media becomes a topic of concern. Scholars have highlighted the significance of not only *behavioral engagement* that manifests in likes, comments or shares when users consume crisis-related information [23], but also *cognitive engagement* when the public makes sense of complex crisis situations [91, 163] and *emotional engagement* when affected populations connect with each other online [99, 70]. Understanding how to foster user engagement during crises can help uncover communication and design opportunities to facilitate the development of citizens' situational awareness of crises, and enhance resilience for crisis response [52, 23, 167, 21]. Nonetheless, engaging social media users with timely and correct information during crises faces various obstacles. From the perspective of social media creators, some critical messages, such as help-seeking posts, may not get adequate attention from the intended target(s), as crisis-related posts typically emerge in a huge volume with diverse topics [86, 6]. From the perspective of social media consumers, the sensemaking process for crisis may be hindered by not only the proliferation of misinformation but also the spread of uncertainty and anxiety under non-routine situations, which may undermine decision-making for crisis response [?, 91].

With the advancement of mobile devices and high-speed Internet, crisis communication no longer solely relies on text, while developing the use of multiple modalities such as images, videos, and audio to convey crisis information [14, 124, 10]. Such **multimodal crisis communication** sheds light on new opportunities to engage and inform the public, and brings challenges as well. For instance, social media posts with images can leverage visual narratives to embody information and attract attention [134, 137], but also leads to potential risks of visual-based misinformation with visuals' power in information persuasion and emotional contagion [16]. Similarly, crisis videos with commenting features may facilitate the dialogue between viewers and video creators to promote engagement, yet unverified user-generated comments may distract viewers' attention and interfere with users' understanding of video content [63]. Therefore, understanding user engagement in multimodal crisis communication may provide insight into not only effective communication strategies for emergency management, but also design opportunities for social media platforms for crisis communication needs.

Motivated by this problem space, this dissertation focuses on understanding how to cultivate user engagement in multimodal crisis communication. By employing quantitative and qualitative studies on diverse social media platforms, this dissertation investigates the (combinational) use of rich text, images, and videos for diverse crisis communication objectives such as knowledge sharing, emotional connection and help-seeking. Based on the findings, this dissertation discusses how multimodal crisis communication intertwines with diverse engagement dimensions including behavioral engagement, cognitive engagement, emotional engagement, and collaborative engagement. This dissertation reveals computer-supported cooperative work for crisis responses in the new era of social media, and outlines the importance of the integration of AI in social media systems to support crisis management, the design needs to facilitate collaboration in crisis response, and new moderation mechanisms for multimodal crisis misinformation.

## 1.1 User engagement in rich text crisis communication

Posting help-seeking requests on social media has been broadly adopted by victims during natural disasters to look for urgent rescue and supplies. The help-seeking requests need to get sufficient public attention and be promptly routed to the intended target(s) for timely responses. However, the huge volume and diverse types of crisis-related posts on social media might limit help-seeking requests to receive adequate engagement and lead to their overwhelm. To under-

stand this problem, chapter 2 proposes a mixed-methods approach to figure out the overwhelm situation of help-seeking requests, and individuals' and online communities' strategies to cope. We focused on the 2021 Henan Floods in China and collected 141,674 help-seeking posts with the keyword "Henan Rainstorm Mutual Aid" on a popular Chinese social media platform Weibo. The findings indicate that help-seeking posts confront critical challenges of both external overwhelm (i.e., an enormous number of non-help-seeking posts with the help-seeking-related keyword distracting public attention) and internal overwhelm (i.e., attention inequality with 5% help-seeking posts receiving more than 95% likes, comments, and shares). We discover linguistic and non-linguistic help-seeking strategies that could help to prevent the overwhelm, such as including contact information, disclosing situational vulnerabilities, using subjective narratives, and structuring help-seeking posts to a normalized syntax. We also illustrate how community members spontaneously work to prevent the overwhelm with their collective wisdom (e.g., norm development through discussion) and collaborative work (e.g., cross-community support). We reflect on how the findings enrich the literature in crisis informatics and raise design implications that facilitate effective help-seeking on social media during natural disasters.

Transmitting crisis-related scientific information to social media users is a crucial step to arm the public with the necessary knowledge to respond to crisis situations. Discussing research-sensemaking questions on Community Question and Answering (CQA) platforms has been an increasingly common practice for the public to participate in science communication. Nonetheless, how users strategically craft research-sensemaking questions to engage public participation and facilitate knowledge construction is a significant yet less understood problem. To fill this gap, chapter TBD presents a mixed-methods study to explore user-developed strategies in proposing research-sensemaking questions, and their potential effects on public engagement and knowledge construction. We collected 837 science-related questions and 157,684 answers from Zhihu. Through open coding, we captured a comprehensive taxonomy of question-crafting strategies, such as eyecatching narratives with counter-intuitive claims and rigorous descriptions with data use. Regression analysis indicated that these strategies correlated with user engagement and answer construction in different ways (e.g., emotional questions attracted more views and answers), yet there existed a general divergence between wide participation and quality knowledge establishment, when most questioning strategies could not ensure both. Based on log analysis, we further found that collaborative editing afforded unique values in refining research-sensemaking questions regarding accuracy, rigor, comprehensiveness and attractiveness. We propose design

implications to facilitate accessible, accurate and engaging science communication on CQA platforms.

## **1.2 User engagement in text-visual crisis communication**

Social media images, curated or casual, have become a crucial component of communicating situational information and emotions during health crises. Despite its prevalence and significance in informational dissemination and emotional connection, there lacks a comprehensive understanding of visual crisis communication in the aftermath of a pandemic which is characterized by uncertain local situations and emotional fatigue. To fill this gap, chapter 3 collected 345,423 crisis-related posts and 65,376 original images during the Xi'an COVID-19 local outbreak in China, and adopted a mixed-methods approach to understanding themes, goals, and strategies of crisis imagery. Image clustering captured the diversity of visual themes during the outbreak, such as text images embedding authoritative guidelines and “visual diaries” recording and sharing the quarantine life. Through text classification of the post that visuals were situated in, we found that different visual themes highly correlated with the informational and emotional goals of the post text, such as adopting text images to convey the latest policies and sharing food images to express anxiety. We further unpacked nuanced strategies of crisis image use through inductive coding, such as signifying authority and triggering empathy. We discuss the opportunities and challenges of crisis imagery and provide design implications to facilitate effective visual crisis communication.

## **1.3 User engagement in text-video crisis communication**

Effectively engaging citizens during crises is critical for governments to disseminate timely information and help the public to adjust to the constantly changing conditions. In particular, promoting youth engagement not only enhances crisis awareness and resilience among the young generation, but also has a positive impact on youths’ social participation and responsibility. With the increasing popularity of online video services, leveraging online videos to disseminate authoritative information has become a method widely adopted by government. To enhance youth awareness and engagement, two new video-based crisis communication strategies have been utilized on a popular youth-targeted video platform Bilibili in China: creating recreational videos such as

animation and music videos, and collaborating with individual video-uploaders in video making. However, their impacts and results are largely unknown, which motivates our study. Guided by Entertainment Education (EE) and Collaborative Governance (CG), chapter TBD report the first systematic study on how recreational video category and government-citizen collaboration would influence youth engagement focusing on 3,347 COVID-19-related government-generated videos on Bilibili. This study reveals that recreational videos successfully promote youth engagement including interaction, feedback and sharing. Collaboration with individual uploaders in video making also has a substantially positive impact on youth engagement. Through an in-depth qualitative content analysis of user-generated commentaries, we further unpacked the unique values (e.g., trust work for youth participation) as well as latent limitations (e.g., imbalanced topic distribution) of the two new strategies. We discuss how the findings enrich EE and CG theoretically, and provide practical implications to effective and engaging communication strategies during crises.

Video commentary, synchronous or asynchronous, is indispensable in viewers' engagement and participation, and may in turn contribute to video with additional information and emotions. Yet, the roles of video commentary in crisis communications are largely unexplored, which we believe that an investigation not only provides timely feedback but also offers concrete guidelines for better information dissemination. Chapter 1 presents the study on two distinct commentary features of online videos: traditional asynchronous comments and emerging synchronous danmaku. We investigate how users utilize these two features to express their emotions and share information during a public health crisis. Through qualitative analysis and applying machine learning techniques on a large-scale danmaku and comment dataset of Chinese COVID-19-related videos, we uncover the distinctive roles of danmaku and comments in crisis communication, and propose comprehensive taxonomies for information themes and emotion categories of commentary. We also discover the unique patterns of crisis communications presented by danmaku, such as collective emotional resonance and style-based highlighting for emphasizing critical information. Our study captures the unique values and salient features of the emerging commentary interfaces, in particular danmaku, in the context of crisis videos, and further provides several design implications to enable more effective communications through online videos to engage and empower users during crises.

## **1.4 Research Contributions**

My dissertation adopts mixed-methods approaches to understand user engagement in multimodal crisis communication encompassing rich text, images, and videos, and proposes design implications to facilitate accurate, timely and effective crisis communication on social media. In summary, the dissertation makes the following contributions:

- (1) This dissertation highlights the significance of narrative strategies in crisis-related posts. The studies develop a comprehensive taxonomy of linguistic and non-linguistic strategies that influence public engagement on social media, and propose design implications to support the construction of crisis-related posts under information overload during crises;
- (2) This dissertation unpacks the dynamics of visual-language correlations in crisis communication. The studies capture informational and emotional correlations between text and images, enhancing crisis communication as an organic whole. Such visual-language correlations provide insight into the design for crisis information seeking and crisis information moderation;
- (3) This dissertation illuminates the values and limitations of innovative approaches in engaging users through video crisis communication, such as the incorporation of recreational visual elements and synchronous commenting. The studies shed light on how different modalities in crisis videos supplement each other in knowledge establishment and sentiment expression, and how to empower users to share, seek, and make sense of crisis information through video system design.

## CHAPTER 2

# NARRATIVE STRATEGIES IN PREVENTING HELP-SEEKING POSTS FROM BEING OVERWHELMED

### 2.1 INTRODUCTION

Among various crisis communication needs on social media, *seeking help*, through which victims post urgent help-seeking requests to ask for rescue, supplies or critical information, has become a topic of concern [57, 129, 161, 140, 141, 99, 27, 201]. Compared to directly seeking help from specific agencies (e.g., calling emergency numbers like 911 [28]), help-seeking posts on social media are broadcast to the public. This approach makes it possible to convey help-seeking requests to broad targets including government emergency offices [103, 83], non-governmental organizations [191] and civil volunteers [165] in disasters, who can not be reached through direct help-seeking without knowing their contact information.

The time sensitivity of post-disaster rescue raises a high demand for help-seeking posts to get sufficient public attention and be promptly routed to the intended target(s) [86]. However, crisis communication on social media is characterized by *a large volume* and *diversity* of posts [6]. For example, Qu et al. revealed that posts that requested help were mixed with many other types of posts that expressed personal feelings, updated situations or raised suggestions [140]. Such characteristics of crisis communication might lead to the critical challenge of **help-seeking overwhelm**, when help-seeking requests fail to receive sufficient public attention and responses and finally get submerged. Understanding this challenge and proposing corresponding strategies would be valuable to facilitate effective help-seeking through social media.

Consequently, this paper investigates how help-seeking posts are overwhelmed during a natural disaster from three perspectives. First, we look into the overwhelm situation of help-seeking posts, aiming to comprehensively uncover the nature of this challenge. Second, when how to express the help-seeking requests substantially influences the transmission of the posts [111, 101,

[100], unearthing the linguistic and non-linguistic strategies<sup>1</sup> of individuals in seeking help is of great significance. Third, as an indispensable component of crisis communication on social media [155, 163, 99, 165], how online communities respond to the help-seeking overwhelm challenge is also critical yet underexplored. Hence, we propose the following research questions in this work:

- **RQ1:** What is the overwhelm situation of help-seeking posts on social media during a natural disaster?
- **RQ2:** What are the strategies that individuals take to prevent help-seeking posts from being overwhelmed, and what are their effects?
- **RQ3:** What are the strategies that online communities use to prevent help-seeking posts from being overwhelmed?

To understand these research questions, we collected 141,674 posts from a popular Chinese social media platform Weibo that contained the “Henan Rainstorm Mutual Aid” keyword during the 2021 Henan Floods in China, and performed a mixed-methods study integrating machine-learning-assisted statistical analysis, regression analysis and qualitative content analysis. We find that help-seeking posts are not only overwhelmed by considerable other categories of posts that also contain the help-seeking-related keyword (we define it as *external overwhelm*), but also face the challenge of attention inequality, with less than 5% posts attracting more than 95% public attention (we define it as *internal overwhelm*). We identify a set of linguistic and non-linguistic user-developed strategies for help-seeking. Most of them succeed to promote public engagement (e.g., disclosing danger and vulnerabilities, using subjective narratives and structuring the post to a normalized syntax), yet some fail (e.g., tagging words signifying authenticity in the post). Finally, we reveal the community’s spontaneous effort to prevent the overwhelm, which involves both collective wisdom (e.g., norm development through discussion) and collaborative work (e.g., norm enforcement and cross-community support). The findings shed light on design implications to facilitate effective and efficient help-seeking behaviors online during natural disasters.

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<sup>1</sup>In this study, we define “linguistic strategies” as help-seeking strategies related to semantics (e.g., detailed description and emotional expression), and use “non-linguistic strategies” to represent the (typically technologized) strategical communication that are less relevant to semantics, such as mentioning others and embedding videos [179].

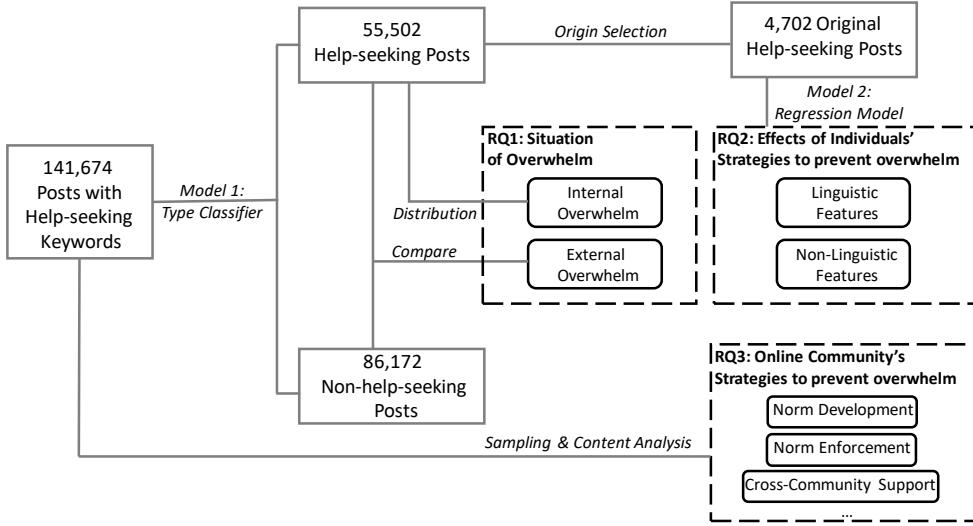


Figure 2.1: The overall analytical flow to understand how help-seeking posts are overwhelmed during the 2021 Henan Floods

This work thus enriches the crisis informatics venue in CHI and CSCW community mainly by: (1) revealing the external and internal overwhelm challenges of help-seeking posts during natural disasters; (2) developing a comprehensive taxonomy of linguistic and non-linguistic strategies that influence the public engagement of help-seeking posts; (3) unveiling the community’s collaborative work that affords the resilience in response to the help-seeking overwhelm. Under massive and miscellaneous posts on social media-based crisis communication, this work provides insights into future directions to promote the effectiveness of online help-seeking from the perspectives of social-media contexts, individuals and online communities.

## 2.2 METHOD

We adopted a mixed-methods study to systematically understand how help-seeking posts were overwhelmed during a natural disaster. We first described the study event (Section 2.2.1) and data selection and collection (Section 2.2.2) to contextualize the investigation. Then, we reported how we leveraged machine-learning-assisted statistical analysis to figure out the overwhelm situation (RQ1, Section 2.2.3), applied regression analysis to unveil the effects of individuals’ linguistic and non-linguistic strategies to prevent overwhelm (RQ2, Section 2.2.4), and used qualitative content analysis to understand the community’s overwhelm-prevention strategies (RQ3, Section 2.2.5). The overall analytical flow is shown in Figure 2.1.

### 2.2.1 Study Event: the 2021 Henan Floods

The 2021 Henan Floods occurred in Henan province, China throughout July 2021 [189]. A prolonged period of heavy rainfall was the cause of the event, where the peak of rainfall reached 201.9 millimeters (7.95 inches) within an hour. The floods caused widespread damage. As of 2 August 2021, about 14.5 million people were affected by the floods across 150 counties, cities and districts including Zhengzhou, Xinxiang and Weihui, and 815,000 residents were evacuated<sup>2</sup>. Provincial authorities reported 302 deaths, and over 50 were missing<sup>3</sup>.

Weibo, the largest Chinese microblogging website, has about 10 years' history and grew as one of the dominant sites for crisis communication in China [200, 25, 140]. Similar to Twitter, users could post content in text, picture or video, and others could interact through like, comment or share (retweet) interfaces. Posts with more likes, comments and shares have a higher popularity score on Weibo<sup>4</sup>. As such, they are intuitively more visible under the "TOP" recommendation mode similar to Twitter. These actively-interacted posts also have a higher chance to appear on the default "real-time microblog" of a specific topic or search, when posts are "*ranked by the latest share or like timestamp*" as indicated in the interface. Weibo played a crucial role in help-seeking information posting and transmission During the 2021 Henan Floods. As of November 2021, the posts with hashtag "#Henan Rainstorm Mutual Aid" had reached 24.6 million (including retweets and comments), receiving a total of 17 billion read<sup>5</sup>.

### 2.2.2 Data Selection and Collection

Before collecting the data, we went through posts regarding the 2021 Henan Floods on the Weibo platform to get a preliminary understanding of users' online help-seeking behavior in this context. We noticed that users developed diverse strategies to identify the help-seeking purpose of their posts: (1) use the hashtag "#Henan Rainstorm Mutual Aid#"; (2) contain the Super Topic "Henan Rainstorm Mutual Aid", through which interface users could follow specific topics and form long-lasting communities [192, 25]; (3) only include the plain text "Henan Rainstorm Mutual Aid". Consequently, to make the data comprehensive, we chose keyword-based collection ("Henan

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<sup>2</sup><https://www.henandaily.cn/content/2021/0802/312251.html>

<sup>3</sup><https://www.163.com/news/article/GGDLBVE0001899O.html>

<sup>4</sup><https://www.weibo.com/ttarticle/p/show?id=2309404007731978739654>

<sup>5</sup><https://s.weibo.com/weibo?q=%23%E6%B2%B3%E5%8D%97%E6%9A%B4%E9%9B%A8%E4%BA%92%E5%8A%A9%23>

*Rainstorm Mutual Aid*") to identify all help-seeking posts instead of the hashtag- or super-topic-based collection approach.

We performed the keyword-based data crawling assisted by the WeiboSuperSpider tool [76]. The date ranged from July 17, 2021, the beginning of the Henan heavy rain [189], to August 8, 2021, when the provincial emergency response of flood control reduced from level I to level III [9]. We collected the data on September 28, 2021, a sufficiently long time after the end of the date range. In this way, the social media engagement indexes (i.e., likes, comments and shares) [23, 18, 35] became steady for a relatively fair comparison between microblogs posted in different periods. However, it inevitably led to the loss of part of the data due to post deletion, especially when "*deleting posts after getting rescued*" was developed as a norm by the community to promote the visibility of less-noticed help-seeking posts (see Section 2.3.3).

In total, we retrieved 141,674 posts with the keyword "*Henan Rainstorm Mutual Aid*" contributed by 72,075 distinct users, including 13,591 original posts from 9,996 users.

### 2.2.3 RQ1: Understanding the Overwhelm Situation

The exploratory observation of help-seeking posts before data collection empirically indicated two types of overwhelm: (1) **external overwhelm**, the challenge of being overwhelmed by a large volume of *non-help-seeking* posts that also included the help-seeking-related keyword (i.e., "*Henan Rainstorm Mutual Aid*"); (2) **internal overwhelm**, the challenge of being overwhelmed by numerous other help-seeking posts. We designed specialized strategies to investigate the two overwhelm types.

#### External Overwhelm

To quantify different types of posts with the "*Henan Rainstorm Mutual Aid*" keyword, we manually generated a codebook through corpus annotation, and then built a multi-class text-classifier to assign the codes to the whole corpus.

We first tried to figure out the types of posts in our dataset and obtain a training dataset. We used inductive thematic analysis to annotate the data [45], letting codes naturally emerge. Specifically, two authors first independently read 200 samples and generated initial codes (e.g., "*rescue seeking*" and "*situational risk reminders*") that directly reflected the data. Through dis-

cussion and comparison, they merged the initial codes and concluded the final codebook with high-level types (e.g., "seeking help" and "offering help"). The agreement ratio (93.5%) and Cohen's Kappa ( $\kappa = 0.90$ ) indicated substantial agreement between the two coders [116]. Disagreement was resolved through another round of discussion. Finally, two annotators separately coded another 400 posts each, reaching a training dataset with a total of 1000 type-assigned samples. The codebook is shown in Table 2.1.

After building the training dataset, we developed the type classifier as follows:

- **Preprocessing:** We used the Jieba word segmentation tool to segment the Chinese text [169], and removed stopwords based on the HIT Chinese stopwords table [50]. Punctuations, numbers and URLs were also excluded.
- **Word Embedding:** We trained the Word2Vec word embedding model [120] on the whole dataset, representing each word as a 300-dimension vector.
- **Model Selection:** We tried both traditional machine learning models (e.g., SVM and xgboost) through averaging word vectors to vectorize posts, and deep learning models (GRU and LSTM). We finally chose LSTM [67] for its best performance. Specifically, under 10-fold cross-validation, the micro F1 score for the 4-class classification achieved 79.6%, which was substantially good to generalize the human annotations to the whole dataset. In the training, we used Adam as the optimizer, and added a dropout layer (rate=0.2) to prevent overfitting when our labeled data was limited [47].

We applied the classifier to assign codes to all posts. To explore the external overwhelm by *non-help-seeking* posts, we compared the volume and engagement indexes (likes, comments and shares) of *seeking help* posts to other three post types in the dataset.

## Internal Overwhelm

Based on the type classifier, we selected the pure *seeking help* posts to focus on the internal overwhelm, i.e., how they were overwhelmed by each other, as shown in Figure 2.1. We investigated the distribution of the user-engagement indexes to figure out the attention inequality [210] of

Table 2.1: The codebook of post types with the help-seeking-related keyword “*Henan Rainstorm Mutual Aid*” during the Henan Floods (the keyword is omitted in the examples)

Type	Definition	Example	Percentage in the Sample
Seeking Help	Posts requesting help especially rescue and supplies	<i>[The location] has at least 24 children (the youngest is less than half a year old) and 50 adults. No water, no power, no gas, poor signal. We need water and food, and if possible, getting evacuated. [phone number]</i>	33.9%
Offering Help	Posts about offering help to victims and rescue teams	<i>I am now in Zhengzhou, and plan to go to the disaster areas of Xinxiang and Weihui. I can lead the way for any official or civilian rescue team. I am very familiar with the disaster area! Contact me: [phone number]</i>	9.9%
Transmitting Critical Information	Posts sharing critical disaster-related information such as self-rescue knowledge, situational risk reminders and community norms	<i>Just received the information. Water short-circuiting happened in [location]. Three people died from the electric shock. Remind again: Never go out at random now. The Road is flooded. It is very dangerous!</i>	15.6%
Sharing Attitudes and Opinions	Posts sharing personal attitudes and opinions, such as blessing and raising attention	<i>Wish everyone safe and peaceful!</i>	40.6%

*seeking help* posts. In particular, we referenced the Pareto principle (80/20 rule) [41] and Gini Index [44] to measure the inequality, which were initially adopted in the social and economic area, and recently used to test inequality in social media [177, 210, 75].

#### 2.2.4 RQ2: Investigating Effects of Individuals' Strategies to Prevent Overwhelm

In this section, we described how we identified individuals' linguistic and non-linguistic strategies to prevent overwhelm, and leveraged regression analysis to comprehensively figure out their effects.

##### Dataset Consideration

We selected original help-seeking posts as the research target for RQ2, as (1) they were representative to capture individuals' linguistic and non-linguistic strategies, and (2) the origin selection helped to avoid the influence of repetitive content in shared posts to regression analysis. To achieve so, we first filtered out non-help-seeking posts based on the type classifier developed in Section 2.2.3, and selected the original ones, as shown in Figure 2.1. This step yielded 4,702 original help-seeking posts for further analysis.

##### Identifying Individuals' Linguistic and Non-linguistic Strategies

Linguistic patterns, such as emotions, proximity and information completeness, directly affected how people perceived and responded to crisis information [111, 103, 100]. Recently, non-linguistic strategies, such as enhancing media richness (e.g., using images and videos) [23] and structuring the post to a fixed format [165], were also discovered in crisis informatics literature. Thus, we performed a grounded-theory-based approach [144] to identify which linguistic and non-linguistic strategies were adopted by individuals when drafting seeking-help requests to attract public engagement. Note that many strategies were unconsciously used by help-seekers when they described the situations, such as disclosing the vulnerability and severity of disasters to draw attention. Specifically, two authors coded 200 samples to abstract potential linguistic and non-linguistic strategies separately (saturation was reached after coding 80-100 posts). They merged similar

codes and resolved the disagreement through discussion, and iterated for several rounds to reach a consensus.

After identifying the strategies, we then focused on their patterns for further automatic extraction, which was a prerequisite step for building the regression model. Based on the nature of each linguistic and non-linguistic pattern, we either chose regular expression matching or existing extraction tools. We iteratively (1) derived patterns from the data, (2) designed corresponding regular expressions or searched for suitable tools, (3) applied regular expression or tools to extract the feature, and (4) manually validated a set of samples to ensure the accuracy of our extraction. Finally, all strategy-extraction approaches reached an accuracy rate above 80% based on our manual validation on 100 random samples, with most of them higher than 95%, indicating sufficiently precise feature extraction.

We provide the description as well as the extraction method for each strategy as follows. A typical example of our feature extraction of linguistic and non-linguistic strategies is shown in Figure 2.2.

- **Linguistic Features**

- **Authenticity** (binary): The strategy of explicitly tagging the seeking-help post with keywords signifying authenticity. It was extracted from keyword matching, e.g., "verified".
- **Information Detailedness**. Providing adequately detailed information (*phone\_number*, *address* and *time*) to facilitate the rescue.
  - \* *phone\_number* (binary): Whether a post contained the phone number of the contact person. It was extracted by 11-digit-number regex matching.
  - \* *address* (binary): Whether a post contained the specific location to perform the rescue. It was identified by cocoNLP<sup>6</sup>, a tool with good performance to match time and addresses in Chinese.
  - \* *time* (binary): Whether a post described the exact time of help-seeking. It was extracted by cocoNLP.

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<sup>6</sup><https://github.com/fighting41love/cocoNLP>

- **Danger.** The strategy of disclosing situational danger (*vulnerability*, *supply\_shortage*, *disaster\_severity*, *population\_size* and *lose\_communication*) to draw attention from the public. If not specified, the feature was extracted through regex matching.
  - \* *vulnerability* (binary): Whether a post disclosed vulnerable groups, such as children, seniors, patients and pregnant women.
  - \* *supply\_shortage* (binary): Whether a post indicated supply shortage, including lack of water, electricity, gas and food.
  - \* *disaster\_severity* (binary): Whether a post directly described the flood situation (i.e., rising, retreating, the depth of water, etc). It was extracted by keywords (e.g., "rising") or number matching (for water level) supported by Sinan<sup>7</sup>.
  - \* *population\_size* (numeric): The size of affected population extracted by Sinan (in a logarithmic scale).
  - \* *lose\_communication* (binary): Whether a post showed the potential danger of losing communication, e.g., mobile phones out of charge or signal.
- **Emotion.** Disclosing negative emotions. The negativity bias theory suggests that negative emotions have a stronger impact on a person's behavior and cognition [147]. *Anger*, *anxiety* and *sadness* well captured the negative emotional disclosure in our context, which also echoed prior work [111, 101]. We applied Jingdong Chinese Sentiment API<sup>8</sup> to generate the emotion score.
  - \* *anger* (numeric): The level of anger in the post.
  - \* *anxiety* (numeric): The level of anxiety in the post.
  - \* *sadness* (numeric): The level of sadness in the post.
- **Subjectivity** (numeric): Using subjective narratives to ask for help. It was calculated by TextBlob<sup>9</sup>, an effective tool of subjectivity inference, after Chinese-English translation.

### • Non-linguistic Features

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<sup>7</sup><https://github.com/yiyujianghu/sinan>

<sup>8</sup><https://neuhub.jd.com/ai/api/nlp/sentiment>

<sup>9</sup><https://textblob.readthedocs.io/en/dev/quickstart.html#sentiment-analysis>

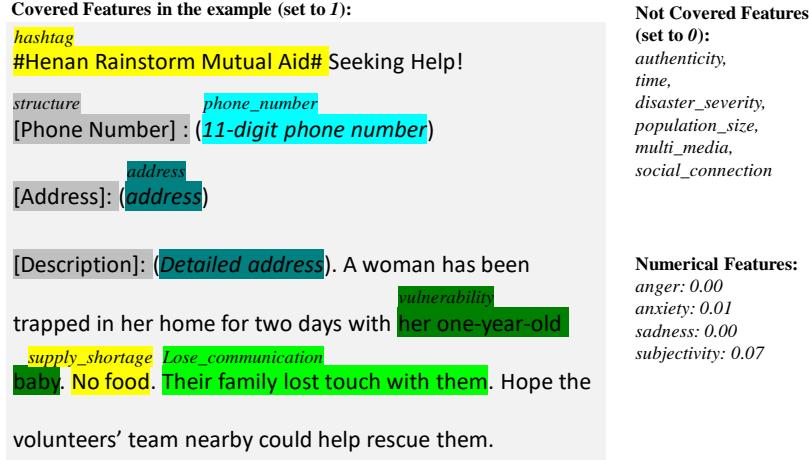


Figure 2.2: A help-seeking post example that illustrates the feature extraction of linguistic and non-linguistic strategies.

- *structure* (binary): Whether structuring the post to a normalized syntax to facilitate information extraction [165, 166]. The normalized syntax, proposed by digital volunteers, encouraged help-seekers to structure the details of help-seeking information (e.g., phone number, address, help-seeking time, help-seeker’s name and situation description) line by line, and use brackets to enclose detail labels for clarity, as shown in Figure 2.2. It was identified by regex matching (combining bracket and keyword pairing).
- *multi\_media* (binary): Whether using images or videos to describe the disaster situation. It was an intrinsic feature in our crawled data.
- *hashtag* (binary): Whether using hashtag(s) to identify the help-seeking requests (extracted by hashtag matching).
- *social\_connection* (binary): Whether mentioning others (extracted by matching "@").

## Developing Regression Model

We developed regression models to understand the effects of the identified linguistic and non-linguistic strategies, i.e., whether they successfully promoted public engagement and prevented the overwhelm. We took likes, comments, shares and their sum as dependent variables to measure the social media engagement [18, 89, 23]. The distributions of these indexes were over-dispersed (likes: M=26.53, SD=404.43; comments: M=6.87, SD=58.97; shares: M=46.55, SD=709.41), when the

conditional variance exceeds the conditional mean. Therefore, we applied the negative binomial regression [66], the appropriate regression model to process over-dispersed count data, to analyse how the strategies influenced public engagement.

We also considered *post type* and *contextual features*, which were proved influential to public engagement during disasters [111, 100], as two categories of control variables in the regression models.

- **Type:** Whether the help-seeking post was used to *seek rescue* or *seek supply*. The method to establish the classification criteria was similar to the pattern-extraction approach in Section 2.2.4. Specifically, as we observed that most *seek supply* posts explicitly used "need/badly need (something)" keywords (e.g., "need pumps") to describe what they lacked, while *seek rescue* posts did not (and typically made strong requests such as "asking for help" or "seeking help"), we identified the post type using need-relevant keywords. This classification approach was proved practical when the accuracy reached 81% on the 100 manual-validation sample. Note that different from public health crises in which people frequently asked for situational information due to the high uncertainty [55, 111], *seeking information* was barely discovered in our data samples.
- **Contextual Features:** Number of *follower* and *following* of the help-seeker, and the number of help-seeking posts in the post date (*information\_density*). These features naturally defined the context of crisis communication [103].

## 2.2.5 RQ3: Exploring the Online Community's Strategies to Prevent Overwhelm

We performed qualitative content analysis to understand the online community's strategies to prevent help-seeking posts from being overwhelmed. Particularly, we focused on both (1) the *strategy practices*, which were perceived in interactions that directly reflected the community's support; and (2) the *strategy development*, which were identified from discussions among community members, especially when some users realized the problem of help-seeking overwhelm and tried to think out community-based support. We focused on the two aspects instead of only strategy practices considering some community's work was invisible, e.g., the coordination of

digital volunteers. As such, we sampled the posts for content analysis from the whole dataset instead of the filtered help-seeking posts as shown in Figure 2.1, when *strategy development* largely came from non-help-seeking posts (e.g., sharing attitudes). Posts with heated discussion in replies, which well captured the community’s collaborative work, were more focused. Two authors independently coded 100 random posts and their comments to generate initial codes. Then, they discussed and compared the codes to reach a consensus, and went back to code additional data, iterating for several rounds till no new codes emerged. In total, they coded 220 posts with 1423 replies.

## 2.3 FINDINGS

In this section, we reported the findings on the overwhelm challenge of help-seeking posts during a natural disaster. In Section 2.3.1, we uncovered the overwhelm situation of help-seeking posts, showing that the engagement of help-seeking requests was not only affected by enormous non-help-seeking posts which also contained the help-seeking-related keyword, but also threatened by the attention inequality with very few help-seeking posts receiving most responses. In Section 2.3.2, we described how individuals’ linguistic and non-linguistic strategies to prevent overwhelm influenced public engagement. In Section 2.3.3, we illustrated the strategies that were spontaneously developed by the online community to prevent the overwhelm supported by its collective wisdom and collaborative work. The findings revealed the rich nuances of the overwhelm challenge of seeking help on social media during a natural disaster, and shed light on potential countermeasures from social-media contextual (RQ1), individual (RQ2) and community (RQ3) perspectives.

### 2.3.1 RQ1: Overwhelm Situation

#### External Overwhelm

The comparison between *seeking help* posts and the other three post categories in volume, likes, comments and shares is shown in Figure 2.3. For all engagement indexes (likes, comments and shares), the null hypotheses of the one-way ANOVA test (i.e., all post types had the same means) [90] were rejected ( $p < 0.05$ ), indicating there existed substantial inter-category differences.

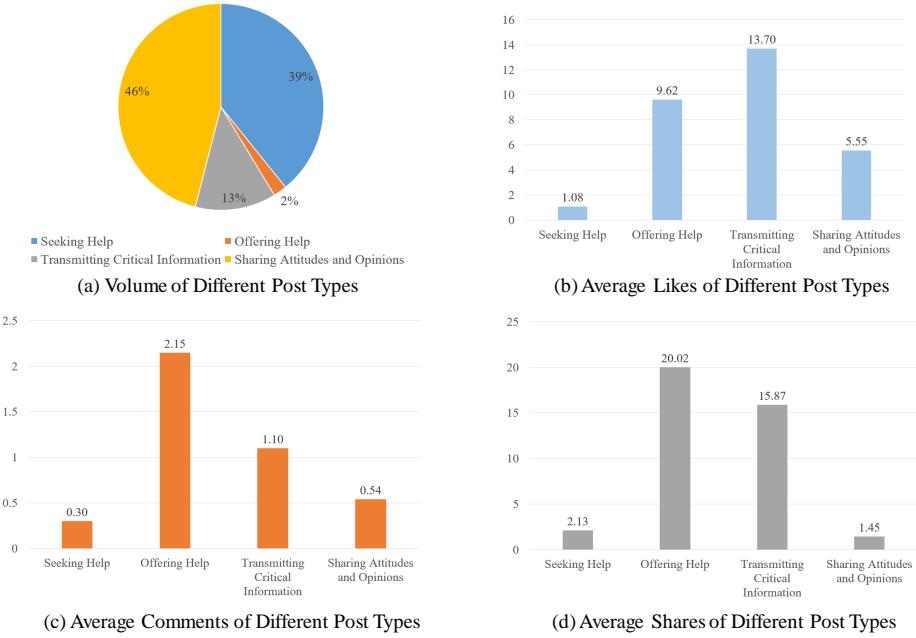


Figure 2.3: The comparison of different post types in (a) Volume, (b) Likes, (c) Comments, and (d) Shares.

The comparison yielded several significant findings: (1) The *seeking help* posts received the fewest likes and comments, and were shared much less than posts *offering help* or *transmitting critical information*, even though the keyword for data collection "Henan Rainstorm Mutual Aid" was mainly designed for helping those in need during crises [188]; (2) The *seeking help* posts were also not the dominant category in amount (39.2%, N = 55,502), which was less than posts *sharing attitudes and opinions*; (3) The *offering help* posts, though not large in volume (2.1%, N = 3,003), received the most average comments and shares, exhibiting people's particular engagement on this category of posts; (4) The *transmitting critical information* posts were liked most, showing public's acceptance and gratitude toward such kind of posts.

Note that the comparison of help-seeking posts with the other three post categories did not hint that the other three post categories were less important. Indeed, posts that offered help (e.g., providing the phone number of the rescue teams) and transmitted critical information (e.g., which areas were dangerous during the crisis) were a crucial component of crisis communication [140]. The *sharing attitudes and opinions* posts would also help to attract people's attention from the whole microblogging platform. However, our findings revealed the risk of the overwhelm of individual's online help-seeking by miscellaneous information during the natural disaster, especially when no interface helped to select the pure help-seeking posts.

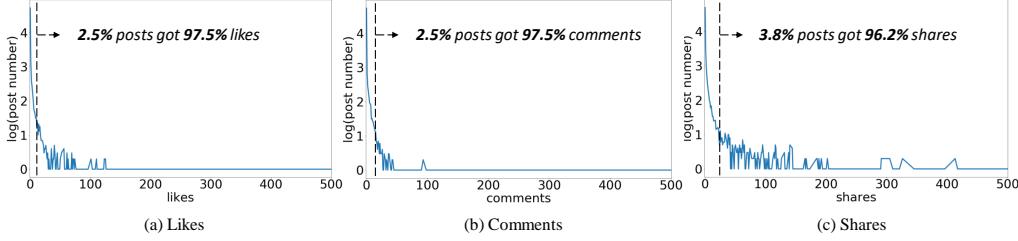


Figure 2.4: The distribution of *seeking help* posts (after a logarithmic scale of the post volume) in (a) Likes, (b) Comments, and (c) Shares. For all three engagement indexes, less than 5% posts got more than 95% attention, indicating extreme imbalance and the high chance of being overwhelmed for individuals' help-seeking.

### Internal Overwhelm

Figure 2.4 demonstrated the distribution of pure *seeking help* posts in likes, comments, and shares after a logarithmic scale of the post volume. The results signified extreme imbalance of user attention: 2.5% posts got 97.5% likes and comments, and 3.8% posts got 96.2% shares, which was more imbalanced than the Pareto principle (80/20 rule) [41] and previous findings on general Twitter posts [210]. In particular, 94.9%, 96.7%, and 43.3% *seeking help* posts got 0 like, comment and share respectively, and 41.8% among all posts received 0 in all three indexes, indicating the high proportion of help-seeking posts with little or zero attention. The Gini indexes for likes, comments, and shares of help-seeking posts were 0.995, 0.992, and 0.989, which also indicated the extreme engagement inequality.

These findings largely revealed the nature of attention inequality for *seeking help* posts during the natural disaster. Based on that, the following sections 2.3.2 and 2.3.3 demonstrated individuals' and the online community's effort to prevent overwhelm.

### 2.3.2 RQ2: Effects of Individuals' Linguistic and Non-linguistic Strategies

We implemented negative binomial regression models to explore how *linguistic* and *non-linguistic* strategies affected public engagement of help-seeking posts in the natural disaster. The results of the negative binomial regression are shown in Table 2.2.

Table 2.2: Results of negative binomial regressions for social media engagement. IRR (Incidence Rate Ratio) indicates the ratio change of the dependent variable when increasing an independent variable by one unit. For a specific feature, if IRRs across all engagement dimensions (likes, comments, shares and their sum) are great than 1, we italicize the feature to denote its strong promotion effect. \*\*\* $p<0.001$ ; \*\* $p<0.01$ ; \* $p<0.05$ .

		Likes		Comments		Shares		Sum		
		IRR	Std. Err.	IRR	Std. Err.	IRR	Std. Err.	IRR	Std. Err.	IRR
<b>Linguistic Strategies</b>										
Authenticity	<i>authenticity</i>	0.91***	0.017	0.94***	0.018	0.96*	0.017	0.92***	0.017	
	<i>phone_number</i>	1.16***	0.018	1.14***	0.019	1.33***	0.018	1.31***	0.018	
Detailedness	address	0.96*	0.016	1.07***	0.017	1.03	0.016	0.97	0.016	
	<i>time</i>	1.07***	0.016	1.04*	0.017	1.18***	0.015	1.07***	0.015	
	vulnerability	0.93***	0.016	1.13***	0.017	1.10***	0.016	1.01	0.016	
	<i>supply_shortage</i>	0.91***	0.019	0.95**	0.019	0.73***	0.018	0.87***	0.018	
Danger	<i>disaster_severity</i>	1.10***	0.017	1.12***	0.017	1.18***	0.016	1.12***	0.016	
	<i>population_size</i>	0.95**	0.017	0.95**	0.017	1.14***	0.016	1.04*	0.016	
	<i>lose_communication</i>	1.16***	0.018	1.13***	0.018	1.43***	0.017	1.23***	0.017	
	anger	0.96**	0.017	0.96*	0.018	0.73***	0.018	0.87***	0.017	
Emotion	anxiety	0.95**	0.017	0.99	0.018	1.05**	0.017	1.05**	0.017	
	sadness	0.94**	0.02	1.02	0.019	0.99	0.023	0.96*	0.018	
Subjectivity	<i>subjectivity</i>	1.13***	0.016	1.06***	0.016	1.09***	0.015	1.13***	0.015	
<b>Non-linguistic Strategies</b>										
Non-linguistic	<i>structure</i>	1.07***	0.016	1.01	0.017	1.10***	0.016	1.06***	0.016	
features	<i>multi_media</i>	1.36***	0.016	1.31***	0.016	1.62***	0.015	1.39***	0.015	
	<i>hashtag</i>	1.51***	0.016	1.04*	0.017	1.35***	0.015	1.39***	0.015	
	<i>social_connection</i>	0.91***	0.016	0.96*	0.017	0.95***	0.015	0.93***	0.015	
<b>Control Variables</b>										
Type	seeking_supply (reference group: seek- ing_rescue)	0.78***	0.018	0.84***	0.019	0.85*	0.017	0.79***	0.017	
Contextual	<i>follower</i>	3.00***	0.015	1.58***	0.015	2.59***	0.015	2.57***	0.015	
features	<i>following</i>	1.22***	0.015	1.22***	0.015	1.39***	0.015	1.29***	0.015	
	information_density	0.66***	0.016	0.75***	0.017	0.85***	0.015	0.75***	0.015	

## Linguistic Strategies

The investigation on the five linguistic strategies (*tagging authenticity, providing detailed rescue-relevant information, disclosing danger, expressing negative emotions* and *using subjective narratives*) indicated their substantial influences on how people responded to the help-seeking requests. Specifically, we concluded the following findings: (1) Manually tagging the *authenticity* in the post had no promotion of public attention; (2) How users perceived and responded to help-seeking posts were contingent upon the *detailedness* of the provided information. In particular, disclosing the phone number was very effective to attract public engagement which increased likes by 16%, comments by 14%, and shares by 33%; (3) Elucidating the *danger* that victims faced was beneficial to receive more public attention. Specifically, disclosing victims' vulnerability (e.g., children and seniors getting affected), describing the disaster severity (e.g., rising water level), mentioning the affected population size, and showing the possibility of losing communication all contributed to a higher chance of being shared. One exception was the supply shortage which reduced public engagement. A possible reason was that many posts indicating supply shortage asked for supply support instead of rescue; (4) The *subjectivity* when expressing help-seeking requests could arouse public attention. However, three types of negative *emotions* (anger, anxiety and sadness) surprisingly did not promote public engagement, which contradicted prior findings focusing on the health crisis [111].

## Non-linguistic Strategies

Structuring the posts with a normalized syntax (*structure*, IRR=1.06, p<0.001), adopting figures or videos (*multi\_media*, IRR=1.39, p<0.001) and adding disaster-specific hashtags (*hashtag*, IRR=1.39, p<0.001) all enhanced the engagement and spread of help-seeking posts, which indicated these strategies' effectiveness in attracting public attention. On the contrary, the effort of mentioning others (*social\_connection*, IRR=0.93, p<0.001) failed to promote the public engagement.

## Control Variables

Apart from how the linguistic and non-linguistic strategies, the intrinsic needs and contexts of help-seeking naturally influenced public engagement. Compared to the posts seeking supply, people were engaged more in posts seeking rescue. Users with stronger social ties received more

attention when looking for help, when having one more follower brought a 157% increase of the total engagement index. *Information density* (IRR=0.75, p<0.001) negatively predicted social media engagement. As such, the findings on contextual features largely distinguished seeking help via broadcasting from seeking help via specific targeting (i.e., asking for help from authoritative sources), when the latter was barely impacted by the social ties of the help seekers and the level of busyness [103].

### 2.3.3 RQ3: Community's Work to Prevent Help-Seeking Overwhelm

In this section, we describe how users in the community collaboratively made an effort to prevent help-seeking posts from being overwhelmed. Such community's work included *norm development*, *norm broadcast*, *norm enforcement*, *raising attention for less-noticed posts* and *cross-community support*.

#### Norm Development

When a specific post raised the concern on the help-seeking overwhelm, community members spontaneously initiated discussions in the comment, aiming to reach a consensus on norms that could promote the visibility of individuals' help-seeking posts. They raised negative consequences when help-seeking requests were not properly conveyed, put forward possible solutions, and complemented each other to make norms comprehensive. Here is an example:

**Poster:** #Henan Rainstorm Mutual Aid# The help-seeking information is too repetitive and mixed. It increases the workload to the staff who gather rescue information, and makes the front line hard to rescue... Please forward the original post instead of copying the content to your microblog. I know everyone is worried, but don't spoil things with good intentions.

**U1:** Agree. Only when you or your family need help, or someone clearly asks you to post it, you can post the original help-seeking information in the (Henan Rainstorm mutual help) Super Topic.

**U2:** And after being rescued, please delete the microblog and leave the help-seeking channel for others.

In this example, the origin poster raised the concern about repetitive help-seeking posts, and initiated the norm to avoid copying and sharing. U1 better clarified the norm under the specific context, and U2 supplemented it with another possible solution that argued deleting the microblog after being rescued. Such processes, under the wisdom of the crowd, helped to generate inclusive norms to maximally prevent help-seeking information from being overwhelmed under the current design of the microblogging platform.

## Norm Broadcast

We observed that a set of norms were generated and broadcast to enhance the visibility of help-seeking posts as shown in Table 2.3. They involved suggestions for help-seekers (e.g., structure help-seeking information), sharers (e.g., keep the originality when sharing) and other community members (e.g., ban irrelevant comments), and covered both before-posting and after-posting periods. Some norms emerged through the discussion of community members as mentioned in Section 2.3.3, and some norms were developed based on the work of digital volunteers. For instance, the example for the norm "*include critical details*" in Table 2.3 was concluded when digital volunteers found that some help-seekers did not disclose phone numbers, which might lead to the failure of getting responses.

## Norm Enforcement

Community members, including some digital volunteers, collaboratively worked to enforce norms through commenting under non-standard help-seeking posts, and thus promoted their chance of being responded instead of getting neglected. Here is an example:

**Poster:** #Henan Rainstorm Mutual Aid# Need urgent help!

(detailed address) in Sizhuangding Village, Xinxiang. Here are several families. A total of 11 people, including one suffering from heart disease! A lady has collapsed!

**U1:** Phone Number please.

**U2:** Please provide the name and contact telephone number!

**Poster:** Contact: (Phone Number)

**U3 (Volunteer):** Reported to the rescue team by online volunteers.

Table 2.3: Norms built by the community to prevent help-seeking posts from being overwhelmed

Period	Norm Type	Target	Example
Before Posting	Use the hashtag and super topic to seek help	Help-seekers	<i>Compatriots in Henan who are affected by the storm and have difficulties can post help-seeking microblogs on Weibo *with the topic included*. Volunteers will collect the information based on the topic.</i>
	Structure help-seeking information	Help-seekers	<i>...You can use the #Henan Rainstorm Mutual Aid# topic to request help. It is recommended to structure your posts with [address:], [contact information:], and [description of your difficulty:].</i>
	Include text description	Help-seekers	<i>Please include the text version of your help-seeking request, instead of only in the image, so that people in network-affected areas can load and see.</i>
	Include critical details	Help-seekers	<i>My friends, when you request for help and supplies, please include your phone number. Otherwise, we can not report it to the rescue team.</i>
	Keep the originality when sharing	Sharers	<i>When you want to spread the help-seeking information, please forward the original microblog, instead of copying and posting by yourself. Otherwise it will lead to the repetitive rescue. Thanks for your collaboration.</i>
After Posting	Delete posts after getting rescued	Help-seekers and sharers	<i>I hope that those who have been rescued can report safety and delete their microblogs to leave more resources for people who are still waiting for help.</i>
Anytime	Ban irrelevant comments (e.g., insult and conspiracy talk)	All community members	<i>Never be a troll. You are occupying the public space on this topic and influencing others who need help!</i>
	Raise attention on help-seeking posts in less represented areas	All community members	<i>Now the focus here is still Zhengzhou. Actually the situation in Zhengzhou is stable now, while many people in Xinxiang need help. Please do not ignore their request for help!</i>

In this example, when the poster requested urgent help without providing contact information, community members repeatedly reminded the poster till the digital volunteers were able to report the complete help-seeking information. Another typical example showed how users tried to enforce the norm "*delete posts after getting rescued*" (though their effort failed in this case as we collected this post after the disaster):

**Poster:** #Henan Rainstorm Mutual Aid# *The whole Qimen Village in Xinzheng Town, Xun County is surrounded by water. The embankment is about to break down. Now villagers have to perform self-rescue. There is no rescue team, and we can not reach them. Please help us!!! There are 8000 people in our village, with many old people and children.*  
(Name), (Phone Number), 8:36

**U1:** *Troops have been there. They arrived at about 1:00 this morning.*

**U2:** *Rescue workers are already there. If you are safe now, please delete the post.*

## Raising Attention for Less-Noticed Posts

Community members voluntarily left supportive comments under unsolved or unanswered help-seeking posts to bring public attention to them. The most common example was "*up!*", when community members simply aimed to keep the activity level of specific posts which were about to be submerged. More elaborate strategies were also perceived. For instance, some community members copied and pasted less-noticed posts in the comment of some popular posts to attract attention. In another case, community members collaboratively leveraged the "@" interface to mention rescue teams and digital volunteers that they knew in the comment of less-noticed posts to increase the chance of being noticed.

## Cross-Community Support

A surprising type of community's work to prevent help-seeking overwhelm is the cross-community support. Specifically, when some users retweeted or commented on the help-seeking posts, they added hashtags or super topics of other popular communities, typically regarding celebrities with a large number of followers, to attract attention from these communities. Here is an example:

**Poster (Sharer):** # Super Topic of (A Celebrity's Name) # My friends following the (celebrity's name), please help me forward it! In a hurry, but still not responded. // #Henan Rain-

*storm Mutual Aid# SOS! (A list of village names and addresses.) All villages are badly flooded. No food, no power, no signal. The flood dikes are all broken, and people are staying on the roof. We need rescue troops!!! Civilian rescue teams are not suggested to come here. It is too dangerous.*

*A list of replies: Forwarded!*

In this example, the sharer added a super topic with about 10 million followers and aimed to get support from that community. The post was then widely spread. However, whether this strategy led to another cause of imbalanced attention was still unclear.

## 2.4 DISCUSSION

In this work, we comprehensively investigated the challenge of help-seeking overwhelm during a natural disaster, and uncovered strategies developed by individuals and communities for the overwhelm prevention. This section discusses how our findings expand the understanding of help-seeking during natural disasters and shed light on implications to support more effective and efficient help-seeking behaviors. We first reflect on the visibility challenges of help-seeking requests under massive and miscellaneous crisis communication in Section 2.4.1, proposing design implications to hinder external and internal overwhelm at the system level. Then, in Section 2.4.2, we highlight the essential role of individuals' help-seeking patterns, which enlightens practices to facilitate efficacious help-seeking requests and warns of the disastrous consequences of exaggeration. In Section 2.4.3, we think over how to better leverage the power of online communities to afford the resilience of help-seeking overwhelm.

### 2.4.1 Under Massive and Miscellaneous Posts: Reflecting on the Visibility of Help-Seeking Requests

Prior work has emphasized the significance of help-seeking posts during natural disasters to efficiently acquire victims' urgent needs and better organize the rescue [27, 99, 86, 129, 161]. Nevertheless, under the "information explosion" on social media after disasters, the visibility of help-seeking posts is not optimistic [129]. By showing evidence of both internal and external overwhelm of help-seeking posts, this work not only enriches the understanding of help-seeking requests online, but also raises design implications to create a better environment for help-seeking.

First, this work found that even in posts containing the keyword related to help-seeking (#*Henan Rainstorm Mutual Aid*# in this case), information was still **miscellaneous**, and the pure help-seeking content was not the majority. As shown in Section 2.3.1, *help-seeking* posts only accounted for about 40% in the dataset, which were fewer than posts *sharing attitudes and opinions*. That dovetails with previous work which indicated that most posts with the rescue-related hashtag during disasters were actually NOT for help-seeking [129]. Indeed, rich nuances are added to specific topics when people gather on social media during natural disasters [136], whose crisis communication needs vary extensively [141, 140]. Meanwhile, our findings further warned of the inadequate attention and engagement of *help-seeking* posts compared to other categories like *offering help* or *transmitting critical information*. For instance, the *help-seeking* posts received the fewest likes and comments among the four identified categories. Though other categories of posts could satisfy other information needs during crises, the miscellaneous information largely hindered help-seeking posts from promptly reaching the intended audience. In this regard, assigning subcategories to posts that contain help-seeking-related keywords, whether human-generated through crowdsourced tagging or machine-generated via automatic text classification, would be promising to help online and offline volunteers find those in need more efficiently. Also, it is important for future work to comprehend why *help-seeking* posts fail to get sufficient attention compared to other types of information. As prior work indicated, how people reacted to information during crises was shaped by a complex emotional, perceptive, and cognitive process [101, 12, 81]. Understanding information receivers' perceptions that guide their behaviors when processing help-seeking requests information would be beneficial to draw practical implications with more effective and engaging help-seeking strategies.

Second, this work also uncovered how help-seeking on social media might fail under the **massive** volume of help-seeking posts in a short period. As exhibited in Section 2.3.1, more than 95% of help-seeking posts shared less than 5% user engagement (likes, comments and shares), and about 40% posts received no response. This finding provided the new evidence of *attention inequality* in social media [210, 177] in the setting of crisis communication, which was even worse compared to the general case [210]. Though it is natural given the varied social capital of help-seekers, we warn of the catastrophic consequences of such attention inequality. Some popular help-seeking posts are disseminated broadly even after the rescue, while the unsolved help-seeking requests remain neglected. Also, challenges of filtering and retrieving are raised for digital volunteers' self-organized work on collecting and routing information in crisis [85, 72]. Thus, we urge for re-

flections on how online help-seeking systems can be specially designed to make the overwhelmed posts more visible. For instance, typical ranking and recommendation algorithms might lead to popularity bias (i.e., popular items are ranked highly and recommended frequently) and amplify attention inequality [1, 7]. On this note, specialized recommendation systems, giving a higher priority to less noticed help-seeking posts, shall be considered and tested by researchers and designers.

#### 2.4.2 Help-Seeking Strategies Matter: Implications and Warnings

Effectively expressing the help-seeking needs and requests is regarded as an essential approach to attract attention from the public and facilitate the information extraction for digital volunteers [100, 165]. Driven by communication theories (e.g., negativity bias theory [147] and social support theory [178]), prior work broadly investigated the impact of content and creator factors on the response and dissemination of help-seeking posts [100, 111, 101]. However, when nuanced strategies are developed and adopted by individuals for help-seeking, a deeper understanding of the strategies, beyond the high-level content type and emotion category [100, 101, 103], is warranted. This work establishes a comprehensive taxonomy of linguistic and non-linguistic strategies that influences the public engagement of help-seeking posts. We reflect on the effective help-seeking practices and how platforms shall support the articulation of help-seeking needs, and warn of the exaggeration and misrepresentation when help-seeking strategies matter.

This work well demonstrated the “power of language” [127] in the scenario of help-seeking. As shown in Section 2.3.2, including sufficient rescue-relevant details (e.g., phone number), disclosing danger (e.g., population vulnerability and potential of losing communication), and using subjective narratives all contributed to a higher chance of getting responded and spread. However, not every victim managed to leverage these strategies to explain their danger and needs, which might aggravate the attention inequality. Recall that community-developed norms urged for “*including critical details*” when many victims forgot to attach their phone number in the post. Additional labor was taken by the community or digital volunteers to achieve situational awareness and acquire sufficient rescue-relevant details, which reduced the efficiency of crisis communication. Consequently, future researchers and designers shall think over and investigate how help-seeking-specific interfaces can support valuable information disclosure in the *drafting and posting* stage of help-seeking, supporting efficient information extraction and expediting the

rescue plan making.

Under the current design of social media platforms, non-linguistic strategies also had substantial influences on public engagement. For instance, structuring posts to a normalized syntax, similar to the effort of Tweak the Tweet [166, 165], positively predicted the number of likes, comments, and shares. The promotion effects also held for attaching hashtags to signify the help-seeking purpose, and adopting figures and videos to vividly describe the disaster situation. These findings empirically validated the effectiveness of the naturally developed crisis communication principles (e.g., hashtag use) from a quantitative perspective [131]. To this end, system-facilitated construction of help-seeking posts, e.g., providing an elaborately-designed template for post structuring, shall be considered by future researchers and practitioners. Meanwhile, we suggest more in-depth investigations on the non-linguistic patterns which are less understood in the existing literature. For example, when video content and forms intrinsically influence public engagement in crises [60, 22], understanding which videos are shared in help-seeking posts and how they influence the public response is a promising research direction.

We finally warn of the disastrous consequences of exaggeration or misrepresentation when specific help-seeking strategies work. For instance, Section 2.3.2 indicated that emphasizing situational vulnerability and disaster severity was effective to draw public attention. As such, maliciously misusing such strategies to distract engagement from those in real need would be catastrophic and shall be particularly focused on for future researchers. When misinformation has been a significant topic in crisis communication [200, 70, 205], we call for more research attention into how to cope with misinformation in the help-seeking context.

#### **2.4.3 Community's Effort for Overwhelm Prevention: Insights and Facilitation**

How online communities facilitate crisis communication is gaining growing attention in HCI and CSCW [198, 141, 140, 70, 163]. In the specific setting of help-seeking, we revealed that community members also collectively developed countermeasures and collaboratively worked to prevent the help-seeking posts from being overwhelmed. This section discusses (1) how the community's effort for overwhelm prevention provides insights into the design for effective help-seeking, and (2) how the design can be in turn improved to facilitate the community's collaborative work.

“The wisdom of the crowd” plays a crucial role in crisis communication such as debunking misinformation and conspiracy [170, 200, 59, 5]. Our findings contribute to this line of work by showing how the public collaboratively came up with strategies for overwhelm prevention and put them into practice. For example, through a process of discussion and negotiation, community members thought out a set of norms such as *keeping the originality when sharing* and *deleting posts after getting rescued*, and further disseminated and enforced the norms under the current design of Weibo. These crowd-developed norms were surprisingly comprehensive, which covered different periods (before and after posting) and different targets (help-seekers, sharers, or all community members). Generally, these norms reflected the essential needs of help-seekers and digital volunteers to cope with the information overwhelm, and provided significant insights into the design of help-seeking communities. When community norms are increasingly valued to help the community achieve its goals [88, 19], future designers and researchers shall actively reflect on the insights of crowd-developed norms and propose corresponding interfaces to provide system-level support. For instance, automatic reminders for help-seeking post deletion after successful rescue could potentially complement the current user-initiated norm enforcement and make the overwhelmed posts surface.

In return, we underscore the necessity of better situating the community’s collaborative work in the help-seeking community’s original function, instead of letting them evolve as two processes interfering with each other. For instance, as indicated in Section 2.3.3, current collective brainstorming on norms regarding help-seeking typically tagged the posts with help-seeking-related keywords to attract community members for discussion. However, when such discussion was mixed with help-seeking posts, users’ attention was dispersed, i.e., users needed to pay additional effort to distinguish and trace either norm discussion or help-seeking requests. Another typical example was that with the community’s effort to raise attention for the ignored help-seeking requests (see Section 2.3.3), a large volume of repetitive and less meaningful posts and replies were generated (e.g., “*up!*”), which also complicated the fulfillment of communities’ original purpose of help-seeking. In this regard, future designers are recommended to bridge the gap between *the community’s natural countermeasures to prevent overwhelm* and *insufficient support to facilitate effective cooperation*. For example, a separate zone for norm discussion is warranted to avoid entanglements between pure help-seeking requests and norm developing effort.

#### 2.4.4 Limitations and Future Work

This work performed a mixed-methods approach to investigate the overwhelm situation and individuals' and communities' corresponding strategies of help-seeking during a natural disaster, shedding light on considerations for efficient and effective help-seeking behaviors online. However, this work suffered from the following limitations: (1) as we focused on help-seeking posts after one recent natural disaster in a Chinese social media platform, the findings may not be generalized to other platforms with different designs or other disasters with different situational conditions; (2) the community-developed norm for *deleting posts after getting rescued* reduced a portion of data, which might introduce a bias into the study and slightly influence the results; (3) due to the difficulty to quantitatively measure the online communities' strategies, we did not investigate their effects on the overwhelm prevention.

When the help-seeking overwhelm is a critical issue in crisis communication yet related work is still limited, we call for more in-depth investigations into this topic. Future work shall compare help-seeking behaviors across different platforms to understand how the platform design may influence the help-seeking process, and raise proof-of-concept interfaces to thoroughly evaluate the design implications. Also, a qualitative study on how users perceive different help-seeking strategies and make corresponding responses would be beneficial to draw valuable guidelines for effective help-seeking.

### 2.5 CONCLUSION

This work adopts a mixed-methods approach to investigate the situation of help-seeking overwhelm on a popular Chinese social media platform Weibo during 2021 Henan Floods, and how individuals and communities develop countermeasures to cope with it. We find that help-seeking posts face critical challenges to get adequate public engagement. They might not only be overwhelmed by massive non-help-seeking posts that also include the help-seeking-related keyword, but also be submerged under the attention inequality of help-seeking posts (less than 5% help-seeking posts attracting more than 95% likes, comments and shares). We extract a comprehensive taxonomy of linguistic and non-linguistic strategies of help-seekers to promote public attention, and explore their influences using negative binomial regression models. The results indicate that including contact information, describing danger and vulnerability, adopting subjective narra-

tives, structuring the post to a normalized syntax, and adopting hashtags and multi-media all help to enhance the engagement of help-seeking requests, while expressing negative emotions and mentioning others have no promotion. Finally, a qualitative content analysis uncovers the community's spontaneous effort to prevent the overwhelm, which involves both collective wisdom (e.g., norm development through discussion) and collaborative work (e.g., norm broadcast and enforcement). Based on the findings, we propose design implications that support effective help-seeking during natural disasters.

## CHAPTER 3

# VISUAL USE IN CONNECTING CITIZENS DURING A LOCAL OUTBREAK

### 3.1 INTRODUCTION

Social media has become a crucial information channel during crises. Characterized by de-centralized communication and crowdsourced information creation, social media affords a prominent place where people gather to cultivate situational awareness [91, 94, 31], route help-seeking requests [165, 201, 58] and provide mutual emotional support [59, 203, 70]. As the development of camera-embedded smartphones and high-speed internet eases the creation and sharing of images online, **social media imagery** is an increasingly substantial component in crisis communication. Millions of images are generated across different disasters [4] and transmit informative crisis-related messages [159].

Among different modalities in crisis communication, imagery has manifested a unique capability in delivering certain kinds of knowledge, sentiments, and experiences during crises [137, 13, 14, 102, 208, 162, 154]. For example, crisis images in COVID-19, whether formal visualizations [208] or non-formal memes [137], could effectively engage viewers with crisis information such as disease prevalence, and facilitate public decision making. Through specific visual elements, crisis imagery can also have an emotional impact on the audience [137, 82], with the power of emotional persuasion [82] or emotional connection establishment [14, 138]. A visual representation is also helpful for reaching and engaging the audience with relatively low literacy levels [56] and could facilitate their sensemaking under crises. Nonetheless, the majority of work in crisis communication has exclusively focused on textual content for analysis. The understanding of visual crisis communication through social media imagery, and the interplay between crisis text and images, are still limited.

The informational and emotional richness of crisis imagery has great potential in supporting crisis response during *local outbreaks in the aftermath of the pandemic* which are local situation-centered and emotionally fatigued [193, 17, 2]. In the aftermath of the pandemic, local outbreaks

are common [130, 186], unpredictable, and affect local policies and residents' daily life [17], which poses new challenges for crisis response. People not only need to cultivate situational awareness of the rapidly shifting local policies [2, 194], but also have to retract to more constrained everyday behaviors and potentially suffer from crisis fatigue [193]. Further, local outbreaks are characterized by the information barrier, with segregated perceptions of crises between the affected local populations and the general public [174], which demands persuasive crisis communication to get attention from the outside world. Given the unique value of social media crisis imagery in information persuasion and emotional contagion, understanding the use of crisis imagery may shed light on how people utilize visual narratives to cope with these specific challenges of crisis communication in local outbreaks. In particular, unpacking which visual themes are presented in local outbreaks, and how people strategically adopt them to share situational information and vent emotions beyond textual narratives, may provide insight into efficient and effective multimodal crisis communication in the aftermath of the pandemic.

To fill this significant research gap, we propose the following research questions:

- **RQ1:** *What* themes of images do users share on social media during a COVID-19 local outbreak? (**Crisis Visual Themes**)
- **RQ2:** *For what* crisis communication goals do users share crisis images during the local outbreak? (**Crisis Visual Goals**)
- **RQ3:** *How* does the use of crisis images strategically facilitate crisis communication during the local outbreak? (**Crisis Visual Strategies**)

To answer the research questions, we adopted mixed-methods and multimodal analysis, incorporating image clustering, text classification, and inductive coding, to uncover themes, goals, and strategies of crisis imagery. We focused on the event of COVID-19 outbreak in Xi'an City in China, and collected 345,423 crisis-related posts and 65,376 original images from Weibo, a popular Chinese social media platform. We first used image clustering to distinguish diverse crisis visual themes such as text images and posters. By identifying information and emotions of crisis-related posts with images, we then revealed how the use of different visual themes significantly correlated with the informational and emotional goals in text, such as the proliferation of text images in disseminating the latest policies and the association between food image and anxiety in lockdown.

Through the inductive coding of image-attached posts, we further identified four types of strategic use of crisis images to facilitate crisis communication, including images as signs of authority, visual-based information enhancement, evidence to improve credibility, and triggers for empathy. We discuss opportunities (e.g., establishing emotional connections) and challenges (e.g., image-enhanced misinformation) of image-based crisis communication, reflect on the complementary roles of crisis images and language, and propose design implications to promote effective and accurate crisis communication through social media crisis images.

In summary, the contribution of this work to crisis communication literature in HCI and CSCW includes: (1) we propose an effective analytical structure to identify diverse crisis image themes, and capture a comprehensive taxonomy of visual representations in a COVID-19 local outbreak; (2) we uncover inter-modality correlations between text and images, demonstrating that crisis images of different types serve different informational and emotional goals; (3) we unveil nuanced and unique strategic use of social media crisis images to supplement or augment textual narratives, enhancing crisis communication as a whole; and (4) we provide design implications to facilitate accurate, efficient and effective visual crisis communication. This work sheds light on opportunities and challenges of visual-based crisis communication, and highlights the significance of understanding multimodal crisis communication as an organic whole.

## 3.2 METHOD

We adopted a mixed-methods approach to examine the characteristics of social media crisis imagery in a COVID-19 local outbreak. To systematically unpack crisis visual themes (RQ1, Section 3.2.3), we used image clustering to discern different visual elements in crisis imagery. To understand their crisis communication goals (RQ2, Section 3.2.4), we developed text classifiers to extract information and sentiments from original posts of crisis images, and made comparisons among different crisis visual themes. To further figure out the strategic use of images for these crisis communication goals (RQ3, Section 3.2.5), we conducted inductive coding of crisis image samples in the post context, unearthing its unique values in enhancing crisis communication. The overall analytic flow of this study is described in Figure 3.1.

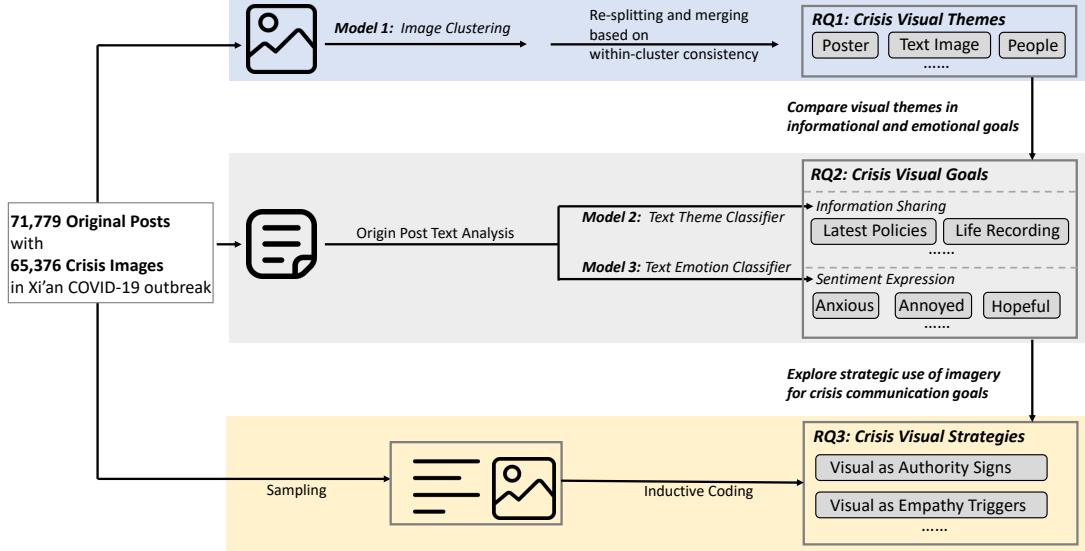


Figure 3.1: The analytic flow to understand visual crisis communication during a COVID-19 local outbreak.

### 3.2.1 Study Event: Xi'an COVID-19 Local Outbreak

The Xi'an COVID-19 local outbreak, caused mainly by SARS-CoV-2 Delta variant [126], is regarded as the most severe COVID-19 local outbreak in China after Wuhan outbreak as of January 2022 [190]. The first COVID-19 case of this event was reported on December 9, 2021 [190], at which time COVID-19 had infected more than 260 million people worldwide and caused more than 5 million deaths [133]. Following a dynamic zero-COVID strategy, the local government imposed a lockdown on December 23, 2021, which lasted for about one month till January 24, 2022 [190]. The lockdown implemented a stay-at-home order, in which citizens needed permission to leave residential compounds or the city, affecting 13 million local residents [207]. A total of 2053 cases were reported in Xi'an during this event [190]. We focus on visual crisis communication in this event as a typical example of a COVID-19 local outbreak with lockdown management, which might contribute to the understanding of civic response in similar health crisis events with highly contagious viruses, varied and strict management measures, and uncertain local situations.

### 3.2.2 Data Collection

We chose Weibo as the research site, which is the largest Chinese microblogging website and a significant social media platform for crisis communication in China [200, 25, 140]. To determine

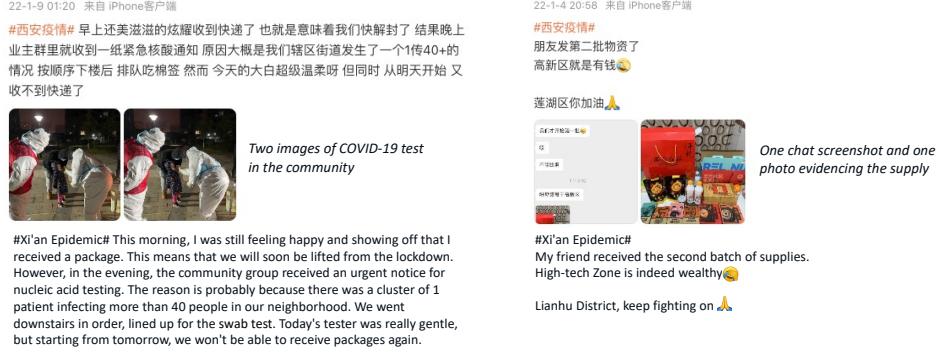


Figure 3.2: Two examples with visual use in the dataset of crisis-related posts during the Xi'an local outbreak.

the data inclusion criteria, we first randomly browsed posts related to the Xi'an COVID-19 Local Outbreak. We finally chose the most frequent keyword “*Xi'an epidemic*” (which sometimes appeared as a hashtag) for data collection. Applying the WeiboSuperSpider tool [76], we crawled posts whose text included the “*Xi'an epidemic*” keyword and collected all the images within them. The data covered the period from December 9, 2021, when the first COVID-19 case was reported in this event, to January 24, 2022, the date when the Xi'an government lifted the lockdown. In total, we retrieved 345,423 relevant posts, and kept the 71,779 *original* posts contributed by 39,866 distinct users as the target dataset. Among them, 29,075 posts (40.5%) had one or more images, and the total image number was 66,183. We kept 65,376 images after excluding GIFs, which contained multiple frames and may produce unreliable results for static visual analysis.

Generally, posts in the collected dataset received an average of 48.5 likes ( $SD=2093.0$ ), 7.2 comments ( $SD=130.7$ ), and 2.9 shares ( $SD=59.5$ ). On average, posts with images received slightly higher user engagement, with an average of 54.4 likes ( $SD=2007.8$ ), 8.7 comments ( $SD=131.2$ ), and 3.2 shares ( $SD=45.1$ ), compared to posts without images which received an average of 44.5 likes ( $SD=2149.0$ ), 6.1 comments ( $SD=130.4$ ), and 2.6 shares ( $SD=67.6$ ). The average post length was 164.6 ( $SD=246.5$ ). In addition to the de-facto hashtag “#*Xi'an epidemic*#” in the event ( $N=20,144$ , also as the keyword for collection), the other 5 most frequent hashtags included “#*Xi'an*#” ( $N=2028$ ), “#Come on *Xi'an*#” ( $N=1605$ ), “#Diary of Fighting Against the Epidemic in *Xi'an*#” ( $N=861$ ), “#Epidemic prevention and control#” ( $N=560$ ) and “#*Xi'an* Epidemic Updates#” ( $N=501$ ). We provide two example posts with visuals in Figure 3.2 to familiarize readers with the dataset.

There were several considerations regarding the limitation of the dataset. First, we only used one most widely-adopted keyword “*Xi'an epidemic*” for data collection. As also the de-facto

hashtag/super-topic [25] of this local outbreak on Weibo, this keyword was representative to collect a sufficiently large dataset for quantitative analysis and capture different themes of user-generated posts regarding the event. We did not include other keywords such as “*Xi'an quarantine life*” or “*Xi'an epidemic updates*” that might introduce a bias towards specific aspects of the outbreak. However, this keyword could not ensure the comprehensiveness of data collection, as some pertinent posts might be omitted. Second, we collected data on March 14, 2022, i.e., 50 days after the event, so that the engagement indexes of posts (e.g., likes and shares) stabilized for a fair comparison. Nonetheless, it inevitably led to the loss of some posts, especially under factors such as self-deleting outdated crisis-related posts [58]. Finally, different from Twitter, Weibo adopts a more flexible setting on post visibility, including “public”, “followers”, “social circle (mutual followers)”, “selected friends” and “private” [187]. We only managed to collect the public posts, which limited the dataset size to some extent and was potentially skewed towards more public disclosure.

### 3.2.3 RQ1: Uncovering Visual Content Themes with an Image Clustering Approach

To have a preliminary understanding of what users disclosed and shared through images during the COVID-19 local outbreak, we first aimed to unpack the themes of social media crisis images. We chose unsupervised image clustering with transfer learning for feature extraction [206] to categorize the data. Compared to the widely-adopted image content analysis of manually coding images and assigning theme labels [137, 208, 13], image clustering can scale image analysis to larger datasets and is less subject to reproducibility concerns. Also, in contrast to supervised image classification, image clustering is not restricted by the size and quality of the human-labeled training dataset. The recent development of transfer learning and deep neural networks further brings great potential for image clustering, especially in categorizing miscellaneous social media images [206]. Therefore, image clustering is well applicable for identifying visual themes of crisis imagery in the context of this work.

As our ultimate goal was to generate coherent clusters with pure and explainable content themes, we adopted *within-cluster consistency* [206] as a quantitative measure of whether our clusters were internally consistent. Specifically, *within-cluster consistency* denoted the proportion of the most common theme in a human-annotated sample for a given cluster (similar to “semantic

validity” in unsupervised topic modeling [53]). We averaged *within-cluster consistency* of all clusters to evaluate the performance of each image clustering approach and selected models based on it.

## Transfer Learning for Low-Dimensional Feature Extraction

We adopted transfer learning [173] to extract low-dimensional features of high-dimensional pixel representations of images, which is the bottleneck of unsupervised image clustering [206]. It outperforms visual-element-based extraction approaches such as bag-of-visual-words models [206, 158, 108], and achieves good performances in a variety of imagery analysis tasks [206, 128].

To find a suitable pretrained model, we performed a pilot experiment on 1000 image samples and tried various popular pretrained deep learning models, including VGG16 [156], VGG19 [156], ResNet [61], MobileNet [68] and MobileNetV2 [151], for feature extraction. All models were pretrained on ImageNet [33], a large image database covering 1000 general categories, and thus had the generalizability to fit into our dataset. Specifically, we first resized images to  $224 \times 224$  pixel with RGB color mode, fed images into each candidate model with pre-trained weights on the ImageNet [33], and generated the last layer as the low-dimensional representations of images [206]. Then, we applied a basic clustering method (K-means [106]) to the extracted features. We also experimented with a traditional feature extraction approach for comparison, i.e., the bag-of-visual-words model extracting scale-invariant visual features [158]. When varying the value of K, we found 5 clusters generally yielded a high silhouette score (a metric measuring clustering quality [146]) as well as meaningful results across different feature extraction models. Therefore, we set  $K = 5$  for a fair comparison. After clustering, two coders manually coded visual themes of 100 samples ( $5 \text{ clusters} \times 20 \text{ samples in each cluster}$ ) for each candidate model, compared labels, and discussed to reach a consensus. They examined the performance with *within-cluster consistency* (Table 3.1). The evaluation indicated that different pretrained models all outperformed the bag-of-visual-words model and did not exhibit substantially different performance among them. As such, we finally chose MobileNetV2 [151] with the highest feature extraction speed to facilitate further experiments when scaling up to the whole dataset. Assisted by MobileNetV2, we represented each image in the dataset ( $224 \times 224 \times 3$ ) as a 1280-dimension vector, which was the last hidden layer (global average pooling layer [151]).

## Image Clustering

After converting images to low-dimensional representations, we adopted clustering to uncover visual content themes that were accurate and interpretable.

Table 3.1: Image Clustering Model Performance based on Within-cluster Consistency.

Experiment	Feature Extraction Model	Clustering Model	Splitting and Merging	Averaged Within-Cluster Consistency
Determining Feature Extraction Model	bag-of-visual-words [158]	K-Means [106]	No	0.64
	VGG16 [156]	K-Means [106]	No	0.71
	VGG19 [156]	K-Means [106]	No	0.70
	ResNet [61]	K-Means [106]	No	0.72
	MobileNet [68]	K-Means [106]	No	0.67
Determining Clustering Model	MobileNetV2 [151]	K-Means [106]	No	0.72
	MobileNetV2 [151]	DBSCAN [87]	No	0.65
	MobileNetV2 [151]	Gaussian Mixture Model [143]	No	0.69
Final Model	<b>MobileNetV2 [151]</b>	<b>K-Means [106]</b>	<b>Yes</b>	<b>0.80</b>

First, we tried different types of clustering methods, including centroid-based (i.e., K-means [106]), density-based (i.e., DBSCAN [87]) and distribution-based (i.e., Gaussian Mixture Model [143]) approaches. Following a similar approach in determining the feature extraction model, we compared different clustering methods based on *within-cluster consistency* and found that there was no substantial difference between them (Table 3.1). Therefore, we chose K-means to categorize crisis images for simplicity. To determine an optimal K value, we defined the search space of K in a range of 5 to 20, and computed silhouette scores [146] for each candidate; K = 6 was finally adopted with a maximal silhouette score. We noticed that most generated clusters were surprisingly pure and clear (e.g., text images) but two clusters were a mixture of sub-themes (i.e., diverse types of photos). Therefore, we performed a re-splitting and merging step as detailed below.

1. **Sampling:** Randomly sampling 50 images for each cluster to measure the within-cluster

consistency. It yields 300 image samples (50 images  $\times$  6 clusters) in total.

2. **Coding:** Two coders independently coded images and assigned theme labels  $l_j^i$  for image  $i$  in cluster  $j$ . In particular, the coders first followed a descriptive coding process to analyze visual content [149], focusing on visual types (e.g., chat screenshots and in-situ photos) and visual elements (e.g., medical staff and food). They then conducted pattern coding [149] to connect fine-grained codes and identify larger visual themes that potentially captured image clusters (e.g., assigning the high-level theme label “text images” for relevant codes such as “chat screenshots” and “document photos”). They reached a consensus on theme labels through several rounds of meetings, comparisons, and discussions.
3. **Measuring Consistency:** For each theme  $t$  that appeared in Cluster  $C_j$ , we computed its prevalence  $P_t = \frac{\sum_{i \in C_j} l_j^i = t}{|C_j|}$ , i.e., the percentage of images belonging to this theme in the cluster. We defined a cluster as “*consistent*” when it had a dominant theme  $t$  whose prevalence was larger than a dominance threshold  $thld_d$ , i.e.,  $P_t > thld_d$ . A larger dominance threshold  $thld_d$  denotes stricter consistency when the dominant theme is required to have a higher proportion in the cluster. In this work, we set  $thld_d$  as 60%.
4. **Splitting:** For each inconsistent cluster, we re-split it according to how many significant themes it contained. Specifically, we selected significant themes  $T_s$  whose prevalence  $P_t$  was greater than a significance threshold  $thld_s$  (We set  $thld_s$  as 20% in this work). Then, we set  $K = |T_s|$  (number of significant themes) to separate the inconsistent cluster into  $K$  sub-clusters using K-means.
5. **Merging:** After splitting the inconsistent clusters, we repeated sampling, coding, measuring consistency, and finding the dominant theme for each sub-cluster. No inconsistent sub-cluster was detected in this round. We merged all clusters and sub-clusters with the same dominant theme.

In total, the image clustering yielded six clusters with distinct visual themes<sup>1</sup>, including *posters*, *text images*, *indoor objects*, *outdoor scenes*, *people*, and *food*, which will be detailed in Section 3.3.1. Two coders independently annotated themes of 600 label-assigned samples (100 samples  $\times$  6

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<sup>1</sup>Note that it is a coincidence that the number of clusters (six) equaled the initial  $K$  value after the splitting and merging steps

clusters) as *true* or *false* (i.e., whether the actual theme of each image corresponded to the label assigned by image clustering) to evaluate the final performance. After annotation, the authors adopted Cohen’s kappa to validate inter-rater reliability [116]. The high Cohen’s kappa ( $\kappa = 0.86$ ) suggested strong agreement between the two coders and strengthened the validity of the manual evaluation. The evaluation generated an average recall of 79.5%, indicating the substantially good performance of image clustering in uncovering visual themes.

Within all image clusters, we noticed that *indoor objects* and *outdoor scenes* were two relatively general categories, which communicated diverse indoor and outdoor activities valuable in the event (e.g., community nucleic acid test), and thus could benefit from a fine-grained classification to generate more meaningful results. Therefore, we applied deep learning models fine-tuned on specific scene-based datasets to predict scenes or items. To identify *indoor objects*, we chose MIT Indoor Scenes dataset as one of the benchmark datasets for indoor scene recognition [142]. To discern *outdoor scenes*, we chose Places365 database as one of the authoritative datasets for scene classification [209]. We adopted Vision Transformer (ViT) model [39] fine-tuned on MIT Indoor Scenes dataset and VGG16 [156] fine-tuned on Places365 database, both of which achieved good performance in the specific task [181, 84].

### 3.2.4 RQ2: Investigating Visual Crisis Communication Goals with Text Analysis of Original Posts

RQ1 focused on visual features and generated a comprehensive taxonomy of crisis image themes during a COVID-19 local outbreak. It captured the substantial diversity of crisis imagery, ranging from text-embedded images with the latest policies to photos recording daily quarantine life. This led to a further question: *which goals do these diverse types of images serve for crisis communication*, and more importantly, *how different visual themes are adopted for different crisis communication goals*? To investigate this question, we (1) performed quantitative text analysis of original posts to unpack crisis communication goals, and (2) compared different visual themes in the informational and emotional objectives. The quantitative text analysis and inter-image comparison particularly focused on *information sharing* and *sentiment expression*, two significant communication objectives in crisis settings [59, 204, 180, 141, 140].

## Text Analysis of Original Posts

We developed information and emotion classifiers for original post analysis as a preliminary step to figure out the visual goals, i.e., how different types of crisis images were used to fulfill different crisis communication needs.

**Information Theme Classifier:** To identify which types of information were disseminated in the local outbreak-related posts, we developed a codebook through inductive thematic analysis, and leveraged a text classifier to generalize the information themes to the whole corpus.

To establish the codebook of information themes, we used inductive thematic analysis to code a sample of posts [45], capturing the codes naturally reflecting the topics of crisis-related posts. Specifically, two coders carefully read through 200 post samples independently, and generated codes of information themes (e.g., “*latest policies and measures*”) that described the data. Through several rounds of discussions and comparisons, they reached a consensus on the theme codes of crisis-related posts as shown in Table 3.2, and returned to annotating every post in the 200 samples based on the four type labels. The Cohen’s Kappa ( $\kappa = 0.91$ ) suggested substantial inter-rater agreement between the two coders [116]. Finally, the two coders separately annotated another 400 posts each, generating 1,000 theme-assigned samples as the training dataset. An additional sample of 200 posts was further labeled as the test dataset. The annotation process also helped the two coders validate that the four information types were inclusive to describe user-generated posts during the event with no new code emerging. Generally, the information themes aligned with the public response on Chinese social media during the early COVID-19 outbreak such as the discussion on management measures [183, 59, 97]. However, as a COVID-19 resurgence, little discourse focused on the causative agent, prevention knowledge, and epidemiological characteristics [97, 197]. Meanwhile, *life recording during lockdown* characterized the event with prolonged abnormal living conditions.

We applied Bidirectional Encoder Representations from Transformers (BERT) [36] to classify the local-outbreak-related posts for its good performance and generalizability in text classification tasks. Specifically, we adopted BERT-wwm, a Chinese BERT model pretrained on Chinese Wikipedia [30], and fine-tuned it with our training dataset (N=1000) to adjust it to our specific tasks. The micro f1-score achieved 82.1% in the test dataset (N=200), indicating its substantially good performance. Finally, we leveraged the information theme classifier to assign theme labels

Table 3.2: The codebook of information themes of Weibo posts related to the Xi'an COVID-19 local outbreak.

Type	Definition	Example	Percentage in the Sample
Situational Information	Posts communicating situational COVID-19-related information, such as recent cases, social events, and scientific suggestions on new variants	<i>Up to now, a total of 1,451 cases have been diagnosed in Xi'an, including 2 critical illness cases and 11 serious illness cases. The critical illness rate was 0.14%, and the serious illness rate was 0.76%.</i>	34.9%
Attitude Disclosure	Expressing attitudes towards the COVID-19 local outbreak and relevant issues	<i>I'm not in the mood to eat meals and go to class. I want to go home... I beg COVID-19 to stop troubling Xi'an. Don't let Xi'an people be unable to go back hometown.</i>	29.8%
Life Recording under Lockdown	Recording personal life, status, and challenges under lockdown	<i>This is the first time I feel that the epidemic is so close to me... The community downstairs of my company has raised a cordon.</i>	23.4%
Latest Policies and Measures	Announcement or adjustment of the COVID-19 management policies and measures	<i>[IMPORTANT! Xi'an starts a new round of nucleic acid screening on December 27th] According to the news from the Xi'an Epidemic Prevention and Control Headquarters: From 12:00 on December 27th, Xi'an will start a new round of COVID-19 nucleic acid screening. Reminder: Keep social distance and protect yourself.</i>	11.9%

to the whole dataset of original posts (N=71,779).

**Emotional Type Classifier:** To identify emotional types of text posts, we first tried some widely-adopted Chinese emotion prediction models (e.g., Jingdong Sentiment API<sup>2</sup> and SnowNLP<sup>3</sup>), yet we noticed that these models were not well-applicable to our context through manual evaluation. Therefore, we followed an emotion identification method similar to our information theme classification approach, including (1) codebook establishment through open coding [29] on 100 samples by two authors, capturing emotions in this specific scenario (five emotion types shown below); (2) validation of inter-rater reliability on assigning the five emotion types with Cohen's Kappa (N=100,  $\kappa = 0.91$ ); (3) annotation on training dataset (N=1000) and test dataset (N=200); and (4) BERT-based emotional type classification (micro f1-score = 78.6% on 5-class emotion classification). The open coding indicated that a single label could well represent each post, and five emotion classes were identified to effectively describe emotions in our samples:

- **Positive - Hopeful (19.9%)<sup>4</sup>:** Mutual encouragement and wishes to overcome the difficulty;
- **Positive - Appreciative (4.3%)**: Gratitude to medical staff, community workers, and other social connections in the local outbreak;
- **Neutral (52.2%)**: Neutral posts such as news, latest policies, and unemotional life recording;
- **Negative - Annoyed (11.9%)**: Feeling of annoyance when normal life was disturbed by the local outbreak and relevant measures;
- **Negative - Anxious (11.7%)**: The nervousness and worry due to the uncertainty during the local outbreak (e.g., uncertain lockdown time and food supply).

## Comparison of Crisis Visual Goals

After identifying the information theme and emotion type of each post, we extracted the crisis image category of the post established in RQ1 (or the dominant category based on frequency if the post contained more than one image). We investigated how the transmitted information themes

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<sup>2</sup><https://neuhub.jd.com/ai/api/nlp/sentiment>

<sup>3</sup><https://github.com/isnowfy/snownlp>

<sup>4</sup>Percentage of each emotion denotes its proportion in the 1000 training dataset.

and emotions correlated with (1) whether crisis images were used or not, and (2) which types of crisis images were used. Particularly, we compared different image types on the information or emotion categories of posts to investigate their differences in informational and emotional goals. We also performed chi-square tests [117] to validate the statistical significance of such differences, i.e., whether different image types had significantly different information and emotion distributions.

### 3.2.5 RQ3: Understanding Strategies of Crisis Images with Inductive Coding

RQ1 and RQ2 leveraged computational approaches across visual and linguistic modalities to comprehensively unpack the rich *themes* and the nuanced informational and emotional *goals* of crisis imagery. The comparison of crisis communication goals among visual themes helped to statistically depict the *inter-modality correlation* between visual and text. Moving a further step, a more in-depth investigation of such inter-modality correlation, especially the strategic use of visuals to enhance crisis communication as a whole, could deepen the understanding of crisis image use. Therefore, we applied inductive coding to qualitatively look into the *visual strategies* in crisis communication, i.e., how crisis images *facilitated* information sharing and sentiment expression in the specific context.

Specifically, we sampled 1200 distinct images ( $200 \text{ images} \times 6 \text{ visual theme categories}$ ) identified in Section 3.2.3, and situated them within the original posts. We conducted inductive thematic analysis [45] and inductive emotion coding [137] on the data. Two authors (1) inductively coded the information themes and emotions expressed in both the image samples and corresponding post text; (2) compared visual-based and language-based information and emotions; (3) figured out *how they were related*; and finally (4) recorded how crisis visuals strategically *facilitated* the information and emotion sharing. Two coders took an iterative process of coding, comparing, and discussing to resolve the difference and finalize the codebook. The coding reached saturation given the sample size, so we did not code more data. This step of qualitative analysis helped to unpack how visual narratives manifested unique values and complemented text in crisis communication. After qualitatively identifying specific visual strategies, we also presented relevant quantitative evidence to illustrate their prevalence and potential correlations with user engagement, affording a more thorough understanding of the result.

### 3.3 FINDINGS

This work provides a comprehensive description of the themes, goals, and strategies of crisis imagery during a COVID-19 local outbreak, promoting the understanding of *visual crisis communication* in general social media crisis images. In Section 3.3.1, we describe the taxonomy of crisis visual themes obtained from image clustering, showing distinct features of different visuals in the event. We further demonstrate how these crisis image themes were substantially correlated with different informational and emotional objectives in Section 3.3.2, unearthing the specialized use of crisis images in crisis communication. In Section 3.3.3, we depict several unique strategies of visuals that contributed to effective crisis communication. Overall, these findings uncover not only the rich features of social media crisis imagery, but also its special values in promoting situational awareness and establishing emotional connections.

#### 3.3.1 RQ1: Visual Themes

The image clustering yielded six representative visual themes as shown in Figure 3.3, including two text-embedded image categories [114]: *posters* and *text images*; and four “visual diary” image categories that recorded life during the outbreak: *indoor objects*, *outdoor scenes*, *people*, and *food*. These crisis image themes communicated distinct visual elements in the local outbreak to enhance situational awareness and establish emotional connections. We detailed descriptive analysis of different visual themes, and started with two text-embedded image categories:

- **Posters** (22.7%, N=14,836): Images embedding some big-character text, especially with a solid-color background. Different from images with rich text about crisis information (*text images*), posters generally only had meta information (e.g., “latest news” in Figure 3.3 *Posters, B*) of the post. Some poster-style photos, especially photos of COVID-19-related press conferences with the agency name embedded in a solid-color background (e.g., Figure 3.3 *Posters, A and E*), also characterized this category. The highlighted text information of posters helped to convey the core message and catch users’ eyes at a glance. In a similar visual style, text-embedded visualizations and memes (e.g., Figure 3.3 *Posters, H*) were also categorized into this visual theme though not in a great amount.
- **Text images** (16.0%, N=10,434): Images with plentiful embedded text. We noticed that

plenty of authoritative regulations (e.g., the lockdown measures of the city) and community guidelines (e.g., communities' COVID-19 test notice) were shared by local residents in the form of images such as screenshots of government-posted articles, potentially due to the convenience of forwarding images in and outside the Weibo platform. Screenshots of chat messages (e.g., Figure 3.3 *Text Images*, *J*) were another type of text image that provided situational information with original sources, such as the latest suggestions posted by community officers in a community group chat. Meanwhile, text images were also observed to convey some sensitive messages, such as conflicts with supply providers and rumors faked as chat logs with "political insiders", to circumvent moderation.

Below are the four "visual diary" image categories:

- **Indoor objects** (17.6%, N=11,480): Images capturing indoor objects that recorded everyday life during the lockdown. This category reflected people's resilience during this isolated lifestyle, such as making handicrafts (Figure 3.3 *Indoor Objects*, *I*) and decorations (Figure 3.3 *Indoor Objects*, *A*). Self-disclosure of mental status in quarantine such as anxiety or hopefulness was typical along with this type of visual diary, which is further demonstrated in Section 3.3.2. According to the model pretrained on specific indoor scenes [181], the top 5 most frequent indoor items include (1) *buffet* (9.4%, N=1082): Food supply and cooking<sup>5</sup>; (2) *artstudio* (9.3%, N=1072): Handicrafts, paintings, calligraphy, and homework; (3) *inside\_subway* (7.8%, N=894): Actually as close-range photos of indoor family activities (e.g., playing with pets); (4) *airport\_inside* (4.8%, N=553): Actually as spacious lobbies (sometimes with people queuing for the nucleic acid test); (5) *greenhouse* (4.8%, N=550): Potted plants, vegetables, fruits.
- **Outdoor scenes** (17.2%, N=11,234): Outdoor photos such as streets, parks and attractions. Many images in this category demonstrated the emptiness of the city during the COVID-19 lockdown (e.g., Figure 3.3 *Outdoor Scenes*, *C*), expressing the wish for a normal life. Also, some outdoor photos served as real-time proof of situations in the local community, such as the location of checkpoints of movement pass (Figure 3.3 *Outdoor Scenes*, *D*) and the crowdedness of a specific COVID-19 test point that reminded community members to come later (Figure *Outdoor Scenes*, *J*). According to the scene-based pre-trained model [84], the

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<sup>5</sup>We note the contextual interpretations of each category after observing a series of examples with the given label.

top 5 most frequent outdoor items are (1) *staircase* (16.0%, N=1795): Actually as Chinese buildings especially ancient towers with storeyed shapes, such as Figure 3.11 B; (2) *artstudio* (14.0%, N=1574): Supply distribution points; (3) *ice\_cream\_parlor* (7.7%, N=868): Actually as the lockdown checkpoints or COVID-19 test points; (4) *campus* (5.1%, N=576): (empty) campus grounds and buildings; (5) *hospital* (4.0%, N=447): Outdoor scenes with doctors or workers in biohazard suites.

- **People** (16.9%, N=11,040): Images of humans in the outbreak. Two important sub-themes of this category were (1) selfies and photos of families (e.g., Figure 3.3 *People, A and I*), notable types of social media images to show their lives to others and connect with audiences [114, 69, 115], which might be valuable for social connections during lockdown; and (2) photos of medical staff and community workers, some recording and appreciating their contributions and sacrifices during the crisis (e.g., Figure 3.3 *People, F*), and some showing conflicts between community workers and residents and criticizing specific workers on their abuse of power during the lockdown (e.g., Figure 3.3 *People, H*). Note that the theme *People* did not necessarily contradict with *indoor objects* or *outdoor themes*; both the two categories also contained a noteworthy proportion of photos with humans. However, we noticed that compared to *people*, human images categorized into *outdoor scenes* typically suggested significant environmental knowledge (e.g., surroundings of the lockdown checkpoint and COVID-19 test queue in Figure 3.3 *Outdoor Scenes, D & J*), while those classified as *indoor objects* often “spotlighted” items of quarantine life (e.g., Christmas tree in Figure 3.3 *Indoor Objects, A* and supply in Figure 3.3 *Indoor Objects, G*). Such subtle differences captured by the model were meaningful in distinguishing different crisis-related messages in the event.
- **Food** (9.7%, N=6,532): plated food and drinks. In addition to recording everyday dishes, these food images also communicated information about the food supply of the local community during the lockdown to other affected citizens in the city.

Different visual themes exhibited substantial differences in public engagement indexes (i.e., likes, comments, and shares) as shown in Figure 3.4. The differences in average comments and shares between visual themes were statistically significant under the one-way ANOVA test ( $p < 0.05$ ). Generally, users were most engaged in posts with *posters* images which received the most

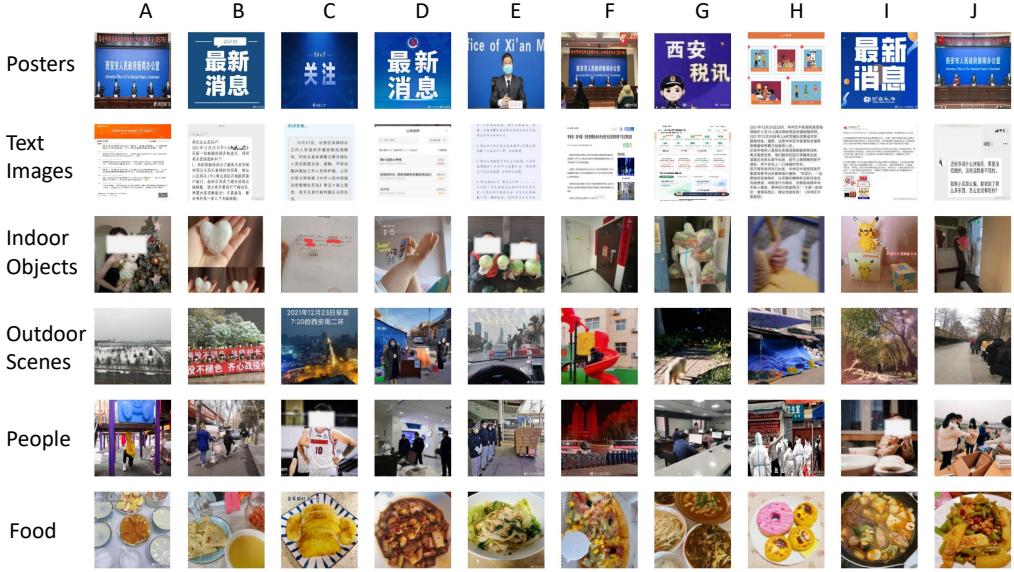


Figure 3.3: Image content themes during the Xi'an COVID-19 local outbreak based on image clustering (each row represents one image cluster). The image examples of each cluster ( $N=10$ ) were picked from random samples ( $N=20$ ), instead of crisis images nearest to cluster centers, to demonstrate the in-cluster diversity.

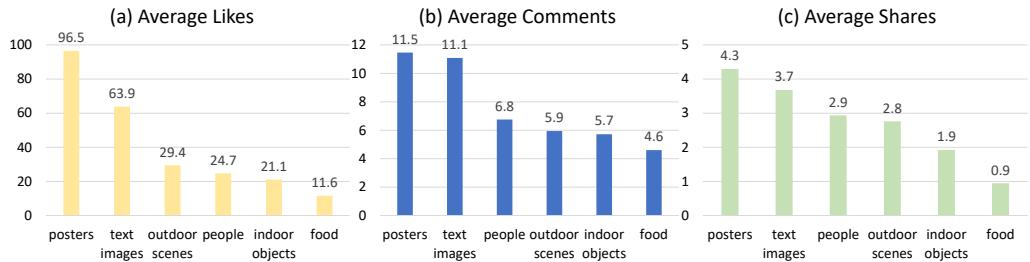


Figure 3.4: Comparison of different visual themes in public engagement indexes: (a) likes, (b) comments, and (c) shares.

likes, comments, and shares, followed by *text images*. In comparison, users were less engaged in the other four “visual diary” categories. One potential reason might be that visual messages passed through posters and text images (e.g., screenshots of government-posted articles) were more likely to be generalized to different settings and useful to other citizens, while photos recording daily life might be more personal and related to specific scenarios.

**RQ1 Summary:** Through image clustering, we captured a comprehensive taxonomy of crisis visual themes during a COVID-19 local outbreak, including *posters* and *text images* as two text-embedded categories, and four “visual diary” types presenting life in lockdown. These visual themes attracted different levels of user engagement (e.g., *posters* and *text images* received more

likes, comments, and shares). It demonstrated **the diversity of visual communication** during a local outbreak in Chinese social media, and implicitly reflected some specialized use of crisis images, such as the prevalence of *posters* relating to the latest and authoritative information. In the next section, we explicitly described how these diverse visual themes were adopted for different informational and emotional goals, providing a quantitative view of visual-text correlation.

### 3.3.2 RQ2: Visual Goals

Through text analysis of the posts that contained crisis images, we unveiled how different themes of crisis images were adopted for different objectives in information sharing and emotional expression during the COVID-19 outbreak. These findings provided a comprehensive picture of the crisis communication *goals* of crisis images.

#### Descriptive Statistics

Using the information theme classifier described in Section 3.2.4, we captured the proportion of four information themes in crisis-related posts during the local outbreak. Specifically, *situational information* ( $N=26,963$ , 37.6%) and *attitude disclosure* ( $N=25,291$ , 35.2%) were the two most popular information categories. The prevalence of these two categories echoes prior works on crisis response [58, 140, 141]. *Life recording under lockdown* accounted for 20.0% crisis-related posts ( $N=14,389$ ), and information about the *latest policies and measures* had the smallest proportion ( $N=7.2\%$ ,  $N=5,136$ ).

The text emotion analysis revealed that in addition to the *neutral* category, two negative emotions (i.e., *annoyed* and *anxious*) and two positive emotions (i.e., *hopeful* and *appreciative*) characterized emotions that users disclosed during the local outbreak. In the whole dataset, the total proportion of negative emotions (22.5%, with  $P_{\text{anxious}} = 12.4\%$  and  $P_{\text{annoyed}} = 10.1\%$ ) was close to the total proportion of positive emotions (23.4%,  $P_{\text{hopeful}} = 20.0\%$  and  $P_{\text{appreciative}} = 3.4\%$ ). Therefore, there was an upsurge in negative emotions in the aftermath of the pandemic compared to the initial COVID-19 outbreak in Wuhan in Chinese social media [184]. It highlighted the prevalence of anxiety and annoyance, serving as a warning of unhealthy mental well-being that might be due to COVID-19 fatigue [193, 34] under repetitive and uncertain outbreaks.

Figure 3.5 described the temporal trends of post volume, information themes and emotion

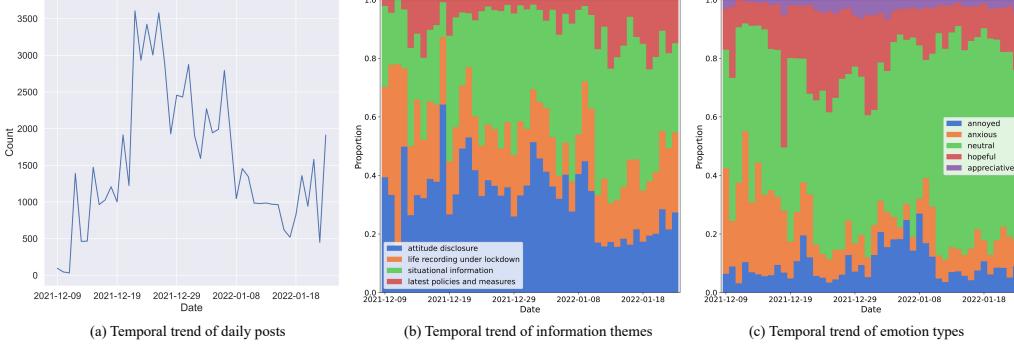


Figure 3.5: Temporal trend of the volume, information themes, and emotion types of crisis-related posts during Xi'an COVID-19 local outbreak.

types during the event. The number of posts gradually increased at the early stage of the outbreak, and reached the first peak on Dec. 22, 2021 with the announcement of lockdown [190]. The discourse gradually tapered off around Jan. 10, 2022 when the social transmission was controlled with no new cases [190]. The information themes and emotion types exhibited notable temporal patterns along with the development of the local outbreak. Specifically, *latest policies and measures* accounted for a significant proportion during the initial and final phases of the event. *Situational information* gradually grew at the onset of the outbreak and became stable since the lockdown. Besides, *attitude disclosure* was prevalent until the outbreak was brought under basic control. For emotion types, *anxious* prevailed at the outset of the outbreak, and *annoyed* manifested two peaks, one during the initial lockdown period and another after the lockdown had been in effect for some time. Meanwhile, *hopeful* posts remained in a great amount during the lockdown period with the decrease of cases.

These descriptive statistics helped to contextualize the crisis imagery regarding information sharing and sentiment expression in the corpus. Next, we focused on how different types of crisis images were adopted for different informational and emotional goals.

## Information Sharing

Figure 3.6 demonstrates the proportions of crisis information themes in different types of crisis images. Through a chi-square test, we revealed that there was a **statistically significant difference in shared information among different crisis image types** ( $p < 0.001$ ). It suggests that the types of images used in a post largely correlated with the messages the post aimed to target. We underscore the following critical findings: (1) Compared to crisis-related posts with-

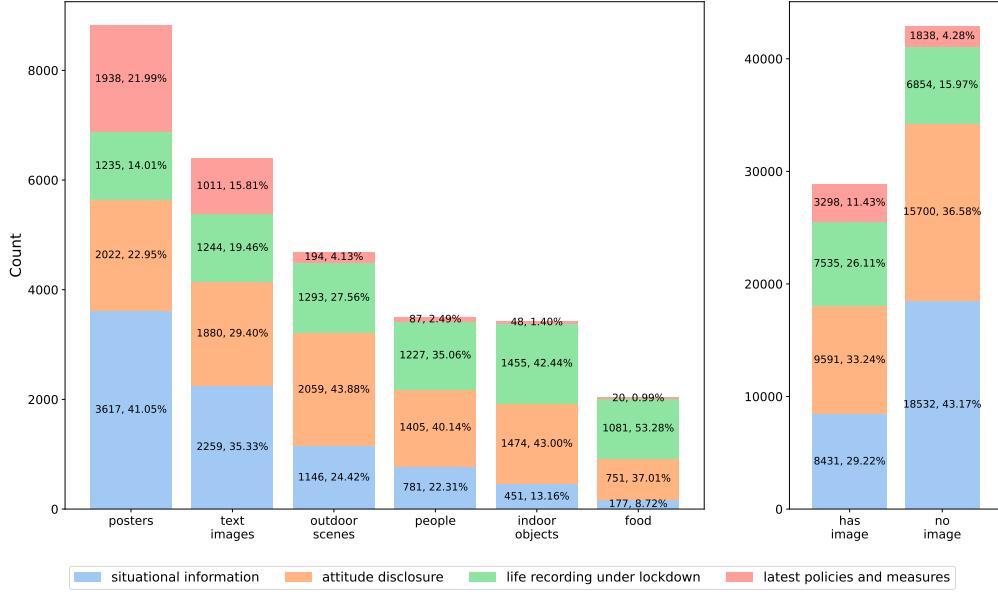


Figure 3.6: Distribution of crisis-related information themes in different types of crisis images. The chi-square test indicates a statistically significant difference in shared information among different crisis image types ( $p < 0.001$ ).

out images, image-attached posts were far more widely adopted to share the *latest policies and measures*. It indicates that images were widely leveraged to signify or demonstrate formal and official information, which will be further illustrated in Section 3.3.3; (2) *posters* contained the highest proportion of *situational information* (41.05%, N=3617) and the *latest policies and measures* (21.99%, N=1938), followed by *text images*. In comparison, all remaining categories had less than 25% *situational information* and less than 5% *latest policies and measures*. This finding indicates that *posters* and *text images* had been broadly used to transmit policies and other situational information that were crucial in crisis response; (3) *People*, *outdoor scenes*, *indoor objects* and *food* all had a high proportion (greater than 70%) of posts for *life recording under lockdown* and *attitude disclosure*. Therefore, these four crisis image categories largely captured and embodied the public livelihood and mentality, which is crucial when strict lockdown measures are enforced [150, 3].

## Sentiment Expression

Figure 3.7 demonstrates the proportions of crisis-related emotions in different types of crisis images. The chi-square test denoted that there was a **statistically significant difference in expressed emotions among different crisis image types** ( $p < 0.001$ ). We note the following important findings: (1) crisis-related posts containing images were generally more positive than

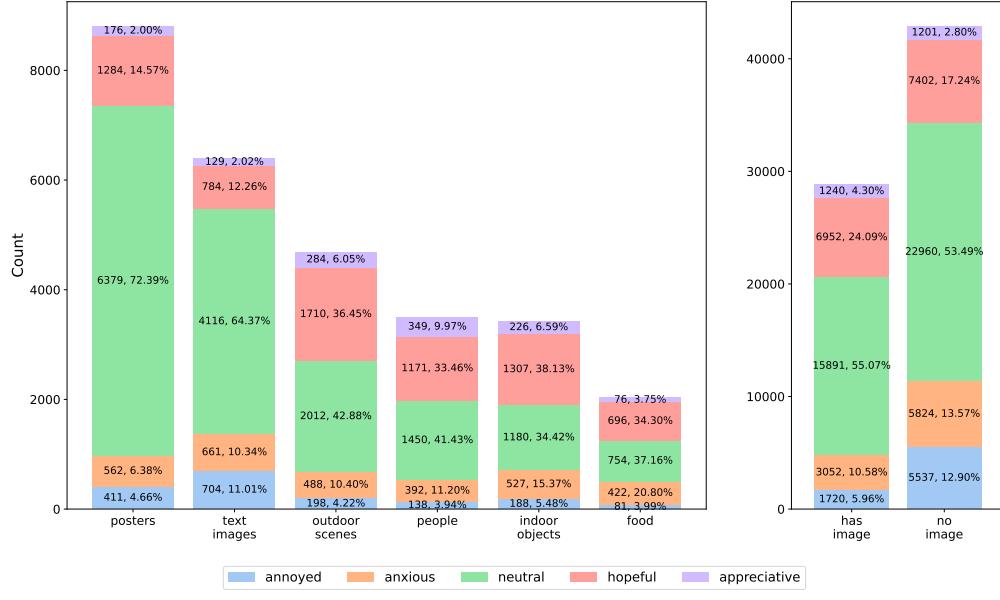


Figure 3.7: Distribution of crisis-related emotion categories in different types of crisis images. The chi-square test indicates a statistically significant difference in vented emotions among different crisis image types ( $p < 0.001$ ).

posts without images; (2) *posters* was the most emotionally-neutral category containing 72.4% neutral posts (N=6379), followed by *text images*, which might be related to their nature for illustrating or signifying crisis-related information. Nevertheless, *text images* contained a notable proportion of negative emotions. After manually reviewing a set of samples, we realized that users frequently posted screenshots (as *text images*) to disclose their anxiety when the COVID-19 situation got worse (e.g., screenshots of an authoritative article on newly confirmed cases), or annoyance at the negligence of some staff (e.g., screenshots of chat revealing some staff's abuse of power); (3) *outdoor scenes* and *people* were strongly correlated with positive emotions, e.g., using outdoor scenery to express the wish for a normal life. In particular, the *people* category had the highest proportion of *appreciative* emotion, when some users posted photos of medical staff to express their gratitude; (4) *food* was surprisingly the most negative category, especially with the highest *anxiety* percentage. We observed that some users posted *food* images to express their worry about food shortages or dissatisfaction with the food supply under lockdown; (5) *indoor objects*, recording the isolated quarantine life, was the most emotional category with high volumes of both positive and negative emotions.

**RQ2 Summary:** Through text classification, we unveiled four dominant information types (i.e., *Situational Information*, *Attitude Disclosure*, *Life Recording under Lockdown*, and *Latest Policies*

*and Measures*) and five emotion categories (*Hopeful, Appreciative, Neutral, Annoyed, and Anxious*) in the corpus, and quantified their correlations with crisis visual themes. Results indicated statistically significant differences in shared information and expressed emotions among different crisis image types, e.g., the wide use of *posters* in disseminating the *latest policies and measures*, and the prevalence of *anxious* emotions regarding *food* images. These findings demonstrate **inter-modality correlations** in crisis communication. In the next section, we provide more nuances on such inter-modality correlation, revealing how the strategic use of visuals complemented text narratives and contributed to effective crisis communication.

### 3.3.3 RQ3: Visual Strategies

In this section, we demonstrate representative strategies of social media images to facilitate crisis communication, including *images as signs of authority*, *images as visual-based information enhancement*, *images as evidence to improve credibility*, and *images as triggers for empathy*.

#### Images as Signs of Authority

Adopting crisis images to signify authority surprisingly characterized visual crisis communication during the local outbreak in China as shown in Figure 3.8. These signposting images, typically as *posters* or *text images*, might not contain rich authoritative information in themselves, yet helped to capture public attention, and attracted users to read the post text with authoritative situation updates or guidelines. Typical examples of this strategy are *posters* with some big-character text (e.g., “*authoritative statement*” in Figure 3.8a, and “*pandemic latest updates*” in Figure 3.8b) embedded in a solid-color background, a clear indicator of official information in Chinese social media. *Poster-style* photos of officials in the epidemic prevention press conference (Figure 3.8c) were another kind of sign that implied an authoritative message in the text. Some users also forwarded *text images* of government documents in COVID-19 management (Figure 3.8d) to signify the authority of the transmitted text. Original posts along with this crisis image type mostly communicated the *latest policies and measures*. As the quantitative evidence, about 90% image-attached posts of *latest policies and measures* had dominant visual types as *posters* (58.8%) and *text images* (30.7%), accounting for also about 60% of all *latest policies and measures* posts. Besides, *latest policies and measures* posts using *posters* or *text images*, typically as authority signs, also attracted more likes ( $\bar{X}_{\text{likes}}=45.2$ ), comments ( $\bar{X}_{\text{comments}}=6.8$ ) and shares ( $\bar{X}_{\text{shares}}=3.0$ ) on aver-



Figure 3.8: Crisis visual strategy 1: images signifying authority. Images with this strategy can be (1) big-character text embedded in a solid-color background, e.g., “*authoritative statement*” in A and “*pandemic latest updates*” in B; (2) photos of officials such as C, or (3) government documents such as D. They might not contain rich authoritative information within visual representations, but attract attention to and signify the authority of the post.

age compared to those with other visuals ( $\bar{X}_{\text{likes}}=14.2$ ,  $\bar{X}_{\text{comments}}=4.4$ ,  $\bar{X}_{\text{shares}}=2.5$ ) or without images ( $\bar{X}_{\text{likes}}=29.6$ ,  $\bar{X}_{\text{comments}}=4.6$ ,  $\bar{X}_{\text{shares}}=1.2$ ). These images shed light on how official, organizational, and individual users leveraged visuals to denote and strengthen the authority of posts, and thus promote the transmission and acceptance of the communicated crisis information during the local outbreak.

### Images as Visual-based Information Enhancement

How experts and citizens use data visualization language (e.g., chart-based temporal visualization and map-based geospatial visualization) to better present crisis information has been a focus in crisis informatics literature [137, 208, 13]. This work revealed that users leveraged diverse visual representations, as “visualizations” in a broad sense, to convey what was difficult or obscure to express through plain language. Such crisis images well supplemented and enhanced situational crisis information in the post text. For example, Figure 3.9a applied a diagram to elucidate the relationship and location of the infected population through epidemiological investigation, and Figure 3.9b used a table to clearly summarize helplines in different districts during the local outbreak. QR codes, a special pattern to condense and route useful crisis information, were also frequently observed to achieve information augmentation, such as in Figure 3.9c (public transport update during lockdown) and Figure 3.9d (helplines during lockdown). These visualizations were mostly classified into *posters* with a text-embedded visual style, which comprised 42.9% visual use in *situational information*. Indeed, *posters* were not only more likely to be adopted in *situational information* posts (compared to the 30.5% *posters* use among all posts), but also achieved higher user engagement in *situational information* ( $\bar{X}_{\text{likes}}=189.9$ ,  $\bar{X}_{\text{comments}}=18.7$ ,  $\bar{X}_{\text{shares}}=7.0$ ) than other visuals ( $\bar{X}_{\text{likes}}=79.7$ ,  $\bar{X}_{\text{comments}}=11.9$ ,  $\bar{X}_{\text{shares}}=6.7$ ). These examples point to ways in which mul-



Figure 3.9: Crisis visual strategy 2: images as visual-based information enhancement. Images with this strategy can be (a) a diagram demonstrating epidemiological investigation, (b) a table summarizing helplines, (c) a colored table updating public transport information with a QR code, or (d) a QR code linking to helplines. These images, as “visualization” in a broad sense, efficiently convey situational information extending beyond textual narratives.

timodal communication with crisis images could enrich the presented situational knowledge in local outbreaks, going beyond what plain language could capture.

### Images as Evidence to Improve Credibility

Information credibility on social media has been a concern during health crises when rumors, conspiracy, and misinformation abound [205, 160, 91]. We found that social media users widely took images as evidence to improve the credibility of the shared information during the local break. Such visual evidence can either be physical photos (e.g., Figure 3.10a proving the crowdedness of COVID-19 test in a local community), digital pictures (e.g., Figure 3.10b proving poster’s donation), or screenshots of mobile applications (e.g., Figure 3.10c and Figure 3.10d). Such visual evidence was a powerful way to demonstrate one’s difficulties and challenges, especially when social media users in non-affected areas had no concrete idea of the local outbreak situation. For example, Figure 3.10c used a chat screenshot to reveal the price gouging during the local outbreak, and Figure 3.10d used a screenshot of an online shopping and ordering platform to give evidence of the supply shortage, both of which were persuasive ways to deliver particular challenges in the crisis. These images provide empirical evidence of how users took advantage of crisis images to convince others on social media. Nevertheless, we warn that visual-enhanced persuasion might potentially be more detrimental when containing unverified information, which is detailed in Section 3.4.1.



Figure 3.10: Crisis visual strategy 3: images as evidence to improve credibility. Images with this strategy can be (a) a physical photo proving the crowdedness of the COVID-19 test venues, (b) a digital picture proving donation, (c) a chat screenshot proving price gouging (“*high price is normal during hard times*”), and (d) a screenshot of an online ordering platform (every item “*sold out*”) proving supply challenges. With visuals as evidence, these images manage to improve credibility and convince others when communicating situational information.

### Images as Triggers for Empathy

Through inductive coding, we identified that images were widely used as triggers to gain empathy and build emotional connections during the outbreak. Such images typically contained cultural, societal, or situational visual constructs that captured the sharing experience of the affected local population. For instance, Figure 3.11a and Figure 3.11b represent Terracotta Warriors and ancient buildings respectively, which were cultural symbols of the Xi'an city. The cultural symbols were integrated into the local challenge of the COVID-19 crisis, serving a role to call for unity and courage to overcome the difficulty. Figure 3.11c and Figure 3.11d used field photos of an empty street and a COVID-19 test at night to raise empathy among local residents under quarantine, expressing the wish for normal life and admiration of medical staff. In particular, we also found that visual use was more prevalent among *positive* (*hopeful, appreciative*) posts (48.8%) rather than *neutral* (40.9%) or *negative* (*annoyed, anxious*) ones (29.6%), potentially indicating the wider adoption of affective visuals in triggering and transmitting *positive energy* [110]. Besides, when both *neutral* or *negative* posts had *text images* and *posters* as the two most popular visual themes, *hopeful* posts were mostly characterized by *outdoor scenes* (24.6%), potentially due to their use as symbols building emotional proximity; similarly, *appreciative* posts had *people* as the most dominant visual theme (28.1%), when photos of medical staffs were given emotional values in collectively expressing gratitude. These examples shed light on how users exploited the power of



Figure 3.11: Crisis visual strategy 4: images as triggers for empathy. Images with this strategy can be local cultural symbols (Terracotta Warriors in A and ancient buildings in B) and local field photos (an empty street in C and a COVID-19 test at night in D). These visual elements could raise empathy among affected citizens with a common ground and transmit specific emotions such as encouragement.

the emotional contagion of visual symbols for collective emoting during a crisis.

**RQ3 Summary:** In this section, we described rich and nuanced strategies of crisis image use in contributing to effective crisis communication, including *images as signs of authority*, *images as visual-based information enhancement*, *images as evidence to improve credibility*, and *images as triggers for empathy*. These findings not only revealed the unique values of visual narratives in engaging, persuasion, and emoting, but also reflected how the strategic use of crisis images supplemented and enhanced text narratives to fulfill informational and emotional needs.

## 3.4 DISCUSSION

By investigating themes, goals, and strategies of crisis images in a COVID-19 local outbreak, this work enriches the understanding of the unique patterns and values of social media crisis imagery. In this section, we discuss the opportunities and challenges along with the proliferation of crisis imagery, and rethink the complementary roles of crisis images and language in crisis communication. We finally provide design implications for image-based searching and image-combined moderation to facilitate accurate and effective visual crisis communication.

### 3.4.1 Unpacking Visual Crisis Communication on Social Media: Opportunities and Challenges

Existing work largely focuses on textual crisis communication to comprehend how people collaboratively cultivate situational awareness, develop risk perceptions, and provide informational and emotional support on social media under health crises (e.g., [91, 54, 174]). This work contributes to the literature on crisis communication by comprehensively unpacking the visual use on social media during a COVID-19 local outbreak. We reveal how crisis imagery could be rich and nuanced in themes, goals, and strategies, and play a significant role in fulfilling diverse communication needs in crises. In this section, we situate our findings within the existing literature, uncovering opportunities and challenges of visual communication.

Users developed diverse crisis visual use to adapt to specific needs during local outbreaks. For example, *text images* embedded rich situational information in a single image, providing a convenient way for cross-platform sharing; in comparison, *posters* strengthened the timeliness and credibility with highlighted meta information, managing to capture the audience’s attention to the post text. Even different visual symbols of “visual diary” such as selfies and food, common in general social media for self-disclosure and social connection [114, 69], could convey crisis-specific information that visually enhances mutual understanding, cultivates situational awareness, and facilitates decision making (e.g., photos of long queues waiting for COVID-19 tests implying the crowdedness, and food images indicating community supply). These findings reflect the *diversity and malleability of crisis imagery in conveying situational information with public wisdom*. It provides new evidence of self-organized civic participation and collective intelligence for crisis response [135, 31] through social media images, and adds nuances to the understanding of strategic communication in collectively cultivating risk perceptions and assessments [32, 55]. In addition, these findings demonstrate that images could be a rich resource for public health researchers to *uncover public understanding and attitudes towards health crises and crisis-related policies*, which resonates with prior work [62, 48]. When images carry significant crisis communication roles, excluding image-based information could potentially lead to biases in understanding public opinions.

This work also revealed simple yet powerful emotional narratives [185, 137] in crisis images that could raise empathy among those sharing similar experiences and identities as described in Section 3.3.3. A photo of an empty fridge might express more anxiety than a large paragraph

describing the food shortage, and a motivational poster integrating local cultural symbols might evoke more unity and courage than one thousand words. To this end, visual cues would not only serve as *a vehicle for emotional disclosure* [114], but also *establish emotional connections and stimulate solidarity* among the affected populations in the crisis. It provides a new perspective on how visual narratives manage to build collective memory [138] through cultural, societal, and situational constructs to transmit specific emotions during crises. We also discovered the strong correlation between visual cues and the expressed emotions given the specific context in Section 3.3.2 (e.g., the prevalence of anxiety in *food* images). These findings provided empirical evidence on how different visual symbols might be given different emotional values in the crisis setting, shedding light on the potential of *affective visualization for crisis response* [137].

On the other hand, given that crisis response and politics are tightly intertwined [79], we warn that such emotion-embedded crisis images might be exploited to *weaponize emotion for political purposes* [15, 154] or *conspiracy theories* [91]. When particular emotions like fear or anger may influence people's crisis assessment and response [32, 104], weaponized emotion may lead to biased perceptions and even exacerbate rumors and conflicts during crises. Such a hidden danger was particularly notable when prioritizing information valence over veracity characterizes crisis communication in Chinese social media [110]. As such, it is significant for future work to situate crisis images in the sociopolitical context and examine the dynamics of affective visual narratives surrounding political objectives, persuasive communication, and information credibility.

This work also enriches the understanding of how *visual-based misinformation* [16] may go viral during local outbreaks. The information gap between local and non-local populations (or even different local communities during lockdown) naturally characterizes local outbreaks [174], in which crisis images shared by local stakeholders can be particularly persuasive. Section 3.3.3 indicates that images, whether field photos or digital screenshots, were frequently used as evidence to improve credibility when “pictures don't lie”. It vastly increases the misinformation risk when pictures do lie - for example, rumors expressed in faked screenshots of chat history [125], or appropriated photos from other scenarios [14]. The emotions embedded in visual narratives may further promote the spread of visual-based misinformation. Therefore, we suggest future researchers look into the dynamics of how image-based misinformation affects local/non-local user perceptions and online/offline crisis response [16, 37, 172], pay attention to the debunking effort of individuals and communities, and develop AI-supported or crowdsourcing-based countermea-

sures to cope.

### 3.4.2 Multimodal Crisis Communication: Rethinking the Complementary Roles of Crisis Images and Language

Images and language, two common modalities in social media, have been considered as two supplementary vehicles for communication and jointly provide affecting and persuasive narratives [114]. Nonetheless, how visual and linguistic elements complement each other to fulfill informational and emotional needs in crisis communication has been less investigated. This work reveals the nuances of the complementary roles of the two modalities in crisis communication.

Through qualitative analysis of crisis images within the context of a post, we revealed the distinct strategies of images to spotlight, enhance, and enrich situational information in the text. Images could either serve as simple yet powerful signs of authority (Section 3.3.3), catching public attention on the text-based authoritative guidelines; work as an auxiliary component to support and verify the linguistic argument (Section 3.3.3), visually improving the information credibility; or embody rich situational information within images themselves through various visualization approaches (Section 3.3.3), thus breaking the limit that text can express. These findings enrich the understanding of multimodal information sharing [134] by **unpacking dynamics of visual-language correlations in crises**. Crisis images are more than a standalone component with visualized information, but connect with text and enhance the entire information through attention attraction, credibility indication [134] and information embodiment [137]. These visual-language correlations exhibit the potential to correspondingly alleviate the critical challenges in *heterogeneity, credibility, and quality* of crisis information on social media [135]. Moreover, the inter-modality correlations also afford user empowerment with evolving user-developed strategies for effective crisis communication, which resonates with prior work [139, 59]. To this end, we call for more fine-grained investigations of public strategies in establishing visual-language correlations to cope with specific challenges in crisis communication (e.g., attracting attention to critical posts among heterogeneous crisis information [58]), and how they influence risk perceptions and emergency responses.

Social media images also play an irreplaceable role that complements language in communicating emotions during crises. On the one hand, visual elements afford particular values in emotion expression through emotion embodiment [137] and emotion contagion through constructing

collective memory [14, 138], which extend beyond linguistic narratives. On the other hand, when image-based emotion venting might suffer from ambiguity and subjectivity in interpretation [14], language is critical for contextualizing the visual constructs and facilitating emotion comprehension, achieving complementarity in emotional communication. On this note, it is warranted for future work to examine the strategic use and misuse of inter-modality emotional connections in crisis settings. For example, it is significant in understanding how conspiracy theorists may build malicious inter-modality connections [119], e.g., situating unrelated but emotional crisis images within misinformation, to promote the spread of crisis-related rumors.

Generally, this work enriches the understanding of inter-modality correlation that empowers users for strategic crisis communication. Unpacking such inter-modality correlation would be as important as understanding information in each modality. Therefore, we suggest *a holistic view* that takes the text and visual as an organic whole for further researchers to get a comprehensive understanding of multimodal crisis communication [175], focusing on not only the uniqueness of one modality, but also the correlation and complementarity between modalities.

### 3.4.3 Design Implications

#### Implications for Crisis Information Seeking

This work unpacks the significant role of crisis imagery, from authoritative guidelines through text images to situation descriptions through on-site photos, in communicating situational crisis information. Such public-generated visual knowledge, as supplements to textual information, is meaningful for both local victims who may be subject to movement restrictions and non-local people who may lack a comprehensive understanding of crisis [13]. That warrants an overarching design goal in *supporting multimodal crisis information seeking*.

First, this work indicated the feasibility of automatic algorithms in classifying diverse crisis visuals, which were correlated with different informational and emotional goals. It sheds light on the potential of *AI-supported visual categorization* to enhance crisis visual seeking. For example, the affordance of filtering based on AI-generated crisis visual categories could empower users to navigate all visuals categorized as “text images” to quickly find authoritative documents in crisis management.

Besides, we suggest designers broadly *leverage the natural connection of multimodal data* to

help users sift through crisis information. For instance, during crises with movement restrictions (e.g., lockdowns or natural disasters), the navigation of crisis visuals could largely benefit from the incorporation of geolocation information. This work revealed users' wide adoption of in-situ photos, such as outdoor scenes of COVID-19 test queues or supply locations, in spreading situational information. Nonetheless, other users may not easily capture such context-specific visual information under the overwhelming amount of crisis-related data [74]. In this scenario, allowing users to view the "outdoor" visual category and sort based on location proximity could empower them to easily acquire situations in the local community.

Finally, we suggest designers actively *situate crisis information systems within the sociocultural and sociopolitical context* to propose specific interfaces for crisis communication. For example, when it is a norm to deliver authoritative guidelines along with visual authority signs in Chinese social media (as shown in Section 3.3.3), automatically identifying authority signs and affording the interface to browse relevant posts could support the seeking of authoritative crisis information.

### Implications for Crisis Information Moderation

The findings on crisis visual strategies in Section 3.3.3 indicated that crisis images were often endowed with additional roles for crisis communication such as signifying authority, enhancing information, or triggering public emotions. Such visual use was typically correlated with higher public engagement indexes. These visual strategies could enhance crisis communication when properly delivered, but might also contribute to the spread of misinformation if the veracity was unchecked. Therefore, we suggest design interventions particularly pay attention to such critical visual use in crisis communication. For example, an AI-supported tool that *prioritizes images with critical roles (e.g., images signifying authority) in fact-checking* might help capture high-risk misinformation before its wide dissemination. Also, such *visual-role reminders* could be embedded into before-posting nudges [78] or during-exposure warnings [80] (e.g., remind sharers by "This image indicates the authority of the post text. Please double-check the content").

#### 3.4.4 Technical Implications

This study also revealed the limitations of current methodologies that would be valuable to note for further multimodal analysis of crisis communication. First, this work reflected how a lack

of *cross-cultural and in-domain datasets* may bring unexpected algorithmic misinterpretations for multimodal analysis in the crisis setting. For example, deep learning models pretrained on scene-specific datasets wrongly categorized COVID-19 lockdown checkpoints in China as ice cream parlors. Such constraints also naturally limited the generalization of more fine-grained crisis-related types through image clustering. Therefore, it warrants the development of large-scale multimodal datasets for specific crisis settings, which echoed prior work [74, 4]. A more high-level challenge was that mainstream object-centered analytic tools (e.g., image classification and object detection) may fail to unpack the nuanced roles of multimodal crisis communication. For example, recognizing an image as a “chat screenshot” might be less meaningful compared to revealing its actual goal as “evidencing challenges mentioned in the post”. Therefore, content analysis might be only the starting point in understanding multimodal crisis communication rather than the ultimate goal.

On the other hand, the analytical approach employed in this study has highlighted potential avenues for conducting multimodal analyses of crisis-related data. We provide empirical evidence on the feasibility of transfer learning in understanding multimodal crisis communication, which could largely reduce the burden of manually curating labels. Also, this work integrated CV-based visual analysis and NLP-based text analysis to unpack the visual-language correlations for crisis communication. It enlightens a promising direction to adopt multimodal deep learning models [196] to process multimodal crisis data as an organic whole.

### 3.4.5 Limitations

This work investigated the themes, goals, and strategies of social media crisis images during a COVID-19 local outbreak, deepening the understanding of visual crisis communication in HCI and CSCW. Nonetheless, this work has the following limitations: (1) this work focuses on a COVID-19 local outbreak in China in the aftermath of the pandemic. Therefore, some findings may not be generalized to other health crisis settings; (2) the image clustering method managed to capture visual elements such as people and objects in crisis images, but was still limited in discerning detailed visual themes, such as topics of text image; (3) as a secondary analysis, we did not investigate how the affected population perceived crisis images, and understanding users’ perceptions on crisis images might provide more in-depth findings of the crisis visual strategies. When multimodal crisis communication has been an increasingly prevalent practice, we call for

broad investigations into different crisis communication settings to reveal the full potential of crisis imagery. As a further step, it is also of great significance for future work to propose and evaluate proof-of-concept interfaces to facilitate and enhance visual crisis communication as well as maximally reduce visual-based misinformation.

### 3.5 CONCLUSION

This work makes the first investigation into how crisis communication is characterized and facilitated by social media crisis images during a COVID-19 local outbreak. Focusing on the Xi'an local outbreak in China, we collected 345,423 crisis-related posts and 65,376 original images on a popular Chinese social media platform Weibo, and conducted a mixed-methods study to understand visual themes, goals, and strategies in crisis communication. Through an image clustering approach, we unpacked the diversity of crisis imagery with two text-embedded visual categories (i.e., posters and text images) and four “visual diary” types that recorded life during the event (e.g., outdoor scenes during quarantine). We demonstrated how different visual types were leveraged to fulfill various informational and emotional communication goals, e.g., using text-highlighted posters to signify the latest policies and embedding anxiety into visual diaries of quarantine life. Users developed strategic use of crisis images as signs of authority, visual-based information enhancement, evidence to improve credibility, and triggers for empathy. We discuss opportunities and challenges of visual crisis communication, reflect on the inter-modality correlation and complementarity, and propose design implications to facilitate effective and accurate visual crisis communication.

# CHAPTER 4

## SYNCHRONOUS VIDEO COMMENTING IN COLLECTIVE KNOWLEDGE CONSTRUCTION AND SENTIMENT EXPRESSION

### 4.1 INTRODUCTION

In recent years, we have witnessed the increasing popularity of online video websites as an information source to engage the general public in creating and disseminating video information. Online video websites are distinctive from traditional social media platforms such as Twitter and Facebook by exclusively using audio and video content for information dissemination, and generally more accessible to all demographic backgrounds [96]. During crises when timely, accurate, and situated information is crucial for a wide audience, online crisis videos are increasingly used in addition to traditional social media platforms due to their high interactivity and the ability in providing richer and real-time information dissemination. For instance, during the H1N1 influenza pandemic, Centers for Disease Control and Prevention (CDC) in the United States adopted a strategic use of videos posted on YouTube to deliver information to the public, garnering millions of views on YouTube [182].

Video commentary interface<sup>1</sup> is an indispensable component in online video platforms for viewers to communicate with others, share relevant information [122], express emotions [152], and build connections [92]. Conventional video commentary interface is often placed in a comment box under videos, making watching videos and accessing video comments two separate and asynchronous procedures. As such, the immediacy of communications through commentary is limited, which might lead to a decline in users' sharing intention and the ignorance of other viewers' responses [113]. Recently, new synchronous commentary features are emerging. Among them, danmaku has gained increasing popularity especially in Japan and China and received growing attention in the HCI and CSCW community [195, 26, 113, 105, 98]. Unlike traditional video comments, danmaku floats above videos and flies by from right to left for several

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<sup>1</sup>In this paper, we use "commentary" to represent all forms of user commenting during or after watching the video, instead of the narrow sense of commenting box below the video.



Figure 4.1: Interface of Danmaku Commenting on Bilibili. Viewers contribute to video content synchronously through danmaku and directly influence what others may see in the video, which brings potential values in crisis communication. For example, the danmaku in the white box corrects the misbehavior of the video character by pointing out "You should cover your nose when wearing the mask".

seconds. It has two distinct features: (1) anonymous posting [195] and (2) fixed showing period on the video timeline assigned by the commenter regardless of the actual post time [113]. Such a design allows viewers to synchronously contribute to video content and directly influence how others may view and perceive the video, as shown in Figure 4.1.

With live and synchronized danmaku, the video content that viewers see is collectively composed by the original video creator(s) and collaborative contributions of danmaku posts. Most prior works on danmaku examined its role in engaging and entertaining viewers, while how viewers contribute to videos through danmaku and what influence it imposes on information dissemination largely remain unknown. Such video content "co-creation" by viewers, beyond entertainment, have significant implications on the timely information dissemination as well as viewer perception in crisis videos, where accurate, timely and situational information is required while misinformation is rampant [96, 123]. A rich stream of research in HCI and CSCW has examined crisis communication in traditional social media like Facebook and Twitter (e.g., [136, 165, 65, 71, 55]). Such crisis communication is characterized by the collaborative work in creating and disseminating situational information [118, 180, 204] and offering emotional support [140, 141, 38]. On the other hand, though online crisis videos have received increasingly more attention in crisis informatics and communication [124, 182, 10, 11], the existing literature generally considers the video creators as the sole source of information and disregards the viewers' participation. No previous

work, to the best of our knowledge, has examined the collaborative contributions of viewers to crisis videos through commentary especially danmaku, which directly influence what others may view and perceive in watching the video. The unique features of danmaku compared to traditional comments, such as anonymity, synchronicity and diverse styles, may further characterize crisis communication in danmaku with special patterns.

This work is the first attempt to explore how users utilize danmaku and comments to contribute to crisis videos. We investigate users' contribution from the perspectives of **information sharing** and **sentiment expression**, which are two core components in crisis communication [64, 141, 140] and two dominant aspects that capture all the danmaku and comments as revealed in our iterative qualitative data coding. We aim to understand how different commentary designs influence such behaviors, and how to better design commentary interface to support public collaborative contribution to videos. Specifically, we propose the following research questions:

- **RQ1:** How prevalent is information sharing and sentiment expression in danmaku compared to comments in crisis videos?
- **RQ2:** What emotions and information themes have emerged in danmaku and comments of crisis videos?
- **RQ3:** What are the unique patterns of danmaku-based and comment-based information sharing and sentiment expression in crisis videos?

To answer these questions, we collect 777,865 danmaku and 1,539,629 reviews from top 1,000 viewed COVID-19-related videos on bilibili.com, the largest danmaku video websites in China, and apply a mixed-methods approach to analyze the data by leveraging natural language processing techniques and qualitative analysis. We discover that sentiment expression is more prevalent in danmaku, while information sharing is more common in video comments. By building taxonomies of hierarchical information themes and fine-grained emotion categories, we reveal that video viewers rely on danmaku more to collectively express positive emotions (e.g., admiration and encouragement), and utilize comments more to individually vent their negative emotions such as criticisms. In addition, we find that viewers share more domain knowledge as well as information that is specifically related to certain sections of videos through danmaku, while information

on the major topic of video is more commonly observed in comments. Several unique sentiment expression and information sharing patterns emerge in danmaku, such as *interactive emotion communication* and *style-based highlighting* to emphasize critical crisis information. Based on the findings, we further discuss the potential of synchronous commentary in crisis videos to more effectively engage and empower the public.

In conclusion, this work contributes to the HCI and CSCW community mainly by: (1) understanding viewers' contributions to crisis videos through commentary instead of only being engaged; (2) proposing comprehensive taxonomies for information themes and emotion categories of commentary in crisis videos; (3) discovering unique hypertext patterns of crisis communication in danmaku and comments; and (4) highlighting design implications for video commentary to facilitate crisis communication. Our study reveals the unique benefits of synchronous commentary interface in crisis videos, and sheds light on richer and more intelligent commentary interfaces that satisfy variant sentiment expression and information sharing needs of viewers during crises.

## 4.2 METHOD

This paper reports an in-depth investigation into danmaku and comments' role of information sharing and sentiment expression in crisis videos. We adopted a mixed-methods approach, incorporating natural language processing and qualitative analysis. To answer RQ1, We built two machine learning classifiers to quantify the prevalence of information sharing and sentiment expression in danmaku and comments. To address RQ2, we applied qualitative thematic analysis to uncover information themes and built a quantitative emotion classifier to identify the emotion categories. To solve RQ3, we systematically reviewed danmaku and comments in 50 crisis video samples across different topics combined with corresponding video context, and assisted with quantitative analysis to validate the empirical findings. The overall analytical flow is illustrated in Figure 4.2. Based on this framework, we seek to unpack the information sharing and sentiment expression behavior in danmaku and comments in crisis videos, and understand the potential of them as building blocks within online video platforms to facilitate crisis communication.

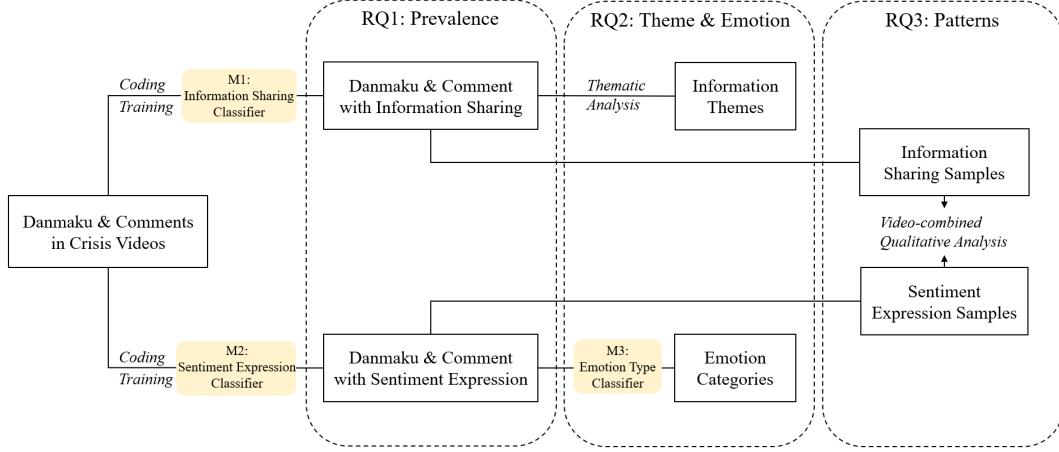


Figure 4.2: Overall Analytical Flow

#### 4.2.1 Data Collection and Processing

Among all video websites with the danmaku feature, we collected data from bilibili.com, the largest danmaku video website in China, because it included a large number of COVID-19-related videos created by both the government and the general public, and had received numerous user-generated danmaku and video comments. Using the Bilibili official API, we crawled the top 1,000 most-viewed potentially COVID-19-related videos as the initial dataset through keyword search "新冠肺炎" (Chinese expression for "COVID-19") on bilibili. The data collection was conducted on March 14, 2020, one week after new cases in China per day dropped below 100 [132]. Consequently, the collected dataset was representative to cover nearly all significant COVID-19-related events from outbreak, peak to gradual control of COVID-19 in China, and combined videos generated by both government and civic video uploaders.

To eliminate irrelevant data and get a deeper understanding of the context of danmaku and comments, we manually viewed, filtered, and coded the themes of the 1,000 videos. Two coders whose native language is Chinese separately watched 100 video clips first and determined whether the videos were related to COVID-19. Videos whose titles or descriptions contained COVID-19 yet with irrelevant content, e.g., videos unrelated to COVID-19 but claiming "*all proceeds will be donated to COVID-19*" in the video description, were excluded. The agreement ratio was 0.95, indicating substantial agreement. The disagreement was resolved with the help of a third coder following the majority rule. Then, the two annotators used grounded theory [20] to generate a codebook of video themes. Using the 100 video samples, they assessed the video content, refer-

enced the video titles and descriptions, separately developed theme codes and finally confirmed the codebook together through several rounds of discussion. Based on the codebook, each of the two authors further coded 450 remaining videos on relevance and themes, through which all videos in the dataset were assigned with relevance and theme labels. No new theme code appeared in this process. This step excluded 121 unrelated videos, leaving 879 COVID-19-related videos categorized into five themes.

According to the video IDs of the 879 COVID-related video clips, we obtained the corresponding danmaku and comments data. The metadata of danmaku included *text*, *the timestamp of posting*, *time of the appearance in the video*, *font size*, *font color*, *scrolling mode*, *category*, and *virtual user ID* (hashed to keep the anonymity of danmaku). The metadata of comments included *text*, *user ID*, *poster ID*, *the timestamp of posting*, *the number of likes and replies*, and *the top 3 hot-replies*.

#### 4.2.2 RQ1: Predicting the Prevalence of Information Sharing and Sentiment Expression

To answer RQ1 (the prevalence of sentiment expression and information sharing), codes of whether a danmaku or comment expressed emotion and/or shared information were to be assigned. Therefore, we first generated a training dataset through manually annotating the corpus as illustrated in Section 4.2.2, and then built reliable information sharing and sentiment expression text classifiers to generalize the human-assigned codes to the whole dataset as described in Section 4.2.2.

##### Corpus Annotation

Initially, two annotators read 100 danmaku and 100 comment samples to get a general sense of the data, and annotated them separately on (1) whether the post shared information, and (2) whether the post expressed sentiment. Though there are several definitions of "information" with similar core concepts, we followed Losee's definition of information as "statements or facts that are received by a human and that have some form of worth to the recipient" [107]. The posts identified with emotion sharing can be either sharing explicit sentiment (e.g., "*I feel relaxed after watching this video.*") or implicit sentiment inferred from statements (e.g., "*Come on, Wuhan!*"). Two coder's agreement ratio of annotation was high (0.91 on average), and the differences were resolved through discussion. Then, the two annotators continued to code another 400 danmaku

and 400 comments, yielding an annotated dataset with 500 danmaku and 500 comments in total.

## Machine Learning Model Building

Using the manual annotations of 1,000 danmaku and comments, we built machine learning models to predict whether a danmaku or comment post shared information or expressed sentiments (*M1: Information Sharing Classifier* and *M2: Sentiment Expression Classifier* in Figure 4.2). Note that we developed two independent models for information sharing and sentiment expression instead of building a 4-class classifier. The major reason is that we aimed to reveal the prevalence of each variable and make comparisons between danmaku and comments instead of investigating the correlation between information sharing and sentiment expression. Also, the performance of a combined classifier was not good (f1 score ; 65%).

We first processed the danmaku and comments text data in preparation for text classification. Before normal text preprocessing procedures, we designed several extra processing steps for danmaku that accounted for the unique characteristics of danmaku, including: (1) normalizing the reduplicated characters that had special meaning in danmaku (e.g., "hhhhhhh" for laughing) [195] by only keeping 3 characters as the length did not influence the meaning; (2) transferring emoticons (e.g., "(-\_-;) for "nervous") to corresponding meaning by referencing *Bilibili Danmaku Emoticon Set*<sup>2</sup>; (3) replacing pointers such as "←", which were used to reference addressees in communication [113], with the corresponding directions in words. As emoticons and pointers rarely occurred in video comments, we normalized reduplicated characters and translated emoji with their corresponding meaning for video comments instead.

The following steps transferred the processed text into the vector representation. We first conducted text segmentation using Jieba, a widely-adopted Chinese word segmentation module in python [168]. Stopwords were removed based on HIT Chinese stopwords table [51]. Then, we trained Word2Vec word embedding model with 300 dimensions for danmaku and comments separately [120], and adopted average word vectors to represent document-level vectors, which have been adopted in a wide range of tasks and proved to be effective for short text [199, 171].

Taking the 300-dimension danmaku / comment vector as the input feature, we compared multiple classification algorithms such as SVM, KNN and Logistic Regression, aiming to find the model

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<sup>2</sup><https://www.bilibili.com/read/cv3312482/>

with the best performance. We finally selected XGBoost [24] for its highest F1 score among all algorithms. We tuned two hyperparameters to optimize classifiers, which were maximum depth of trees and minimum sum of instance weights in a child.

#### 4.2.3 RQ2: Generating Information Themes and Emotion Categories

To explore what information themes and emotion categories emerged in danmaku and comments in crisis videos, we first read 100 danmaku and 100 comment posts to get a general sense of the data. We noticed that the emotions in the posts were semantically intuitive, while information themes were more complicated with much hidden information beyond text feature, especially for danmaku data. As an interactive communication channel, demonstrative and personal pronouns were commonly used and represented part of the information, e.g., "You (*refer to the video character*) wear the mask improperly", or "This (*refer to the link given in the video*) is not reliable". Further, given the co-watching simulation, danmaku-based information sharing often required prior knowledge given by video context, e.g., "(*The mechanism introduced in the video that the coronavirus developed a membrane outside their protein*) helps the virus enter cells more easily". As such, though video watchers could easily get the meaning of danmaku under the specific context, it was hard to identify information themes directly from plain text without joint analysis of video content. This challenge was much less observed in sentiment expression. Consequently, we designed different processing strategies, using qualitative thematic analysis to identify information themes and quantitative emotion type classifier to predict emotion categories.

#### Qualitative Thematic Analysis

We randomly sampled 500 danmaku and 500 comments from those predicted with information sharing in Section 4.2.2 for qualitative thematic analysis. Two investigators separately identified the information themes, and merged the codes through discussion. We used grounded theory [20] to code the data. For each danmaku post, we assigned theme codes through joint analysis of video context by locating the timestamp of the danmaku's appearance in the video and watching a short period to get the context of the post. For each comment post, we also read the video title and description, referenced the video topic codebook and watched a short period of video to get the sense of commenting context before assigning theme codes.

## **Building Emotion Classifiers**

To identify the emotion types, two researchers read 100 danmaku and 100 reviews which were identified with sentiment expression in Section 4.2.2 and generated a set of initial codes independently. After discussion of the disagreement, establishment of the uniform criteria and re-coding, we finally built the codebook of sentiment types which emerged naturally to describe the content. During the coding, we noticed that very few viewers conveyed mixed-type emotions in a single post. Therefore, we assigned a single sentiment label to each danmaku or comment. Based on the codebook, two coders continued to annotate and generated 1,000 label-assigned posts (500 reviews and 500 danmaku) for sentiment types. Same processing steps, text features and machine learning models were adopted as Section 4.2.2 except for adapting the task as a multi-class classification problem, building *M3: Emotion Type Classifier* in Figure 4.2. After testing its performance, we utilized it to generalize the emotion category to all danmaku and comments which were identified with sentiment expression.

### **4.2.4 RQ3: Unpacking the Unique Patterns of Information Sharing and Sentiment Expression in Danmaku and Comments**

With danmaku's nature of anchoring at a specific video timestamp and different appearing styles (e.g., positions, colors and scrolling modes), the patterns of information sharing and sentiment expression in danmaku were far beyond the semantic meaning. As such, to systematically unpack the hypertext unique patterns of information sharing and sentiment expression in danmaku and comments, we conducted novel video-combined qualitative analysis on danmaku and comment posts. Specifically, instead of only reading the post text, two authors first separately viewed 50 videos samples (5 video topics  $\times$  10 videos per topic). Then, they interpreted the displayed danmaku, evaluated top-100 voted comments and their replies for each video, and focused on the following features of information sharing and sentiment expression in danmaku and comment posts:

- **Commentary-Video Association:** How the information shared in comments and danmaku was associated with video content, and how the sentiment expression in commentary was triggered by the video?

- **Inter-Commentary Interaction:** The information and emotions conveyed by referring to, augmenting, or refuting other danmaku and comments. Such interaction was explicitly supported through the reply interface for video comment and achieved through the use of colors, positions and content reference for danmaku [113].
- **Style-Communication Relationship (danmaku only):** The relationship between the behavior of information sharing and sentiment expression and danmaku displaying styles (i.e., font size, color and the display mode)

To validate the empirical findings obtained from qualitative analysis, we also assisted with quantitative analysis, e.g., investigating the proportion of information sharing in danmaku of different displaying styles.

## 4.3 FINDINGS

Our findings provided insights into the role of danmaku and comments in supporting information sharing and sentiment expression in crisis videos. First, we comprehensively reported the descriptive statistics of COVID-19-related videos as well as danmaku and comments in Section 4.3.1. In Section 4.3.2, we described the prevalence of information sharing and sentiment expression in danmaku compared to conventional comments in crisis videos. In Section 4.3.3, we unpacked rich and multifaceted information themes and emotion categories conveyed through danmaku and comments under crisis videos, and compared their differences. In Section 4.3.4, we revealed the unique hypertext patterns of danmaku-based/comment-based information sharing and sentiment expression through qualitative video-combined analysis.

### 4.3.1 Descriptive Statistics

The preprocessed dataset included 879 COVID-19-related videos. The average length of videos was 4.4 minutes ( $SD=5.5$ ), and the average viewed times were 851163.9 ( $SD=1042845.0$ ). There were 9 videos disabling both danmaku and comments, and 8 videos disabling danmaku only. A number of 296 videos (33.7%) were published by government accounts, and the remaining were published by civic accounts held by individuals or non-state agencies. Generally, the videos published by government accounts were shorter (~3 minutes compared to ~5 minutes of civic-generated videos)

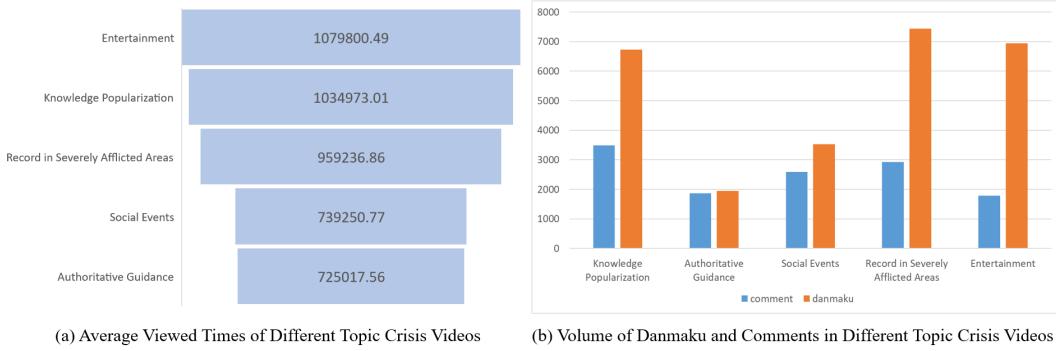


Figure 4.3: Descriptive Statistics on (a) Average Viewed Times and (b) Volume of Danmaku and Comments in Different Topic Crisis Videos

and viewed less (~672k viewers compared to ~942k viewers in civic-generated videos) on average. The average danmaku volume was 4828.6 ( $SD=13070.5$ ), and the average comment volume was 2538.4 ( $SD=3069.5$ ).

Through manual annotation of 879 COVID-19-related videos in our dataset, we identified five video themes naturally describing the video data including **Social Events**, **Entertainment**, **Record in Severely Afflicted Areas**, **Knowledge Popularization**, and **Authoritative Guidance**, whose definitions, examples and proportions are exhibited in Table 4.1. Among them, videos about Social Events were most frequent (52.2%), followed by Entertainment (15.5%), Recording in Severely Afflicted Areas (14.9%), Knowledge Popularization (9.3%) and Authoritative Guidance (8.1%). Most of videos on Authoritative Guidance (77.5%) were contributed by government accounts, while most of Entertainment videos (90.4%) were posted by civic accounts, which reflected the nature of the two types of video uploaders.

As Figure 4.3 (a) shows, Videos on Entertainment and Knowledge Popularization were most viewed with more than 1 million viewed times on average, while videos about Social Events and Authoritative Guidance had relatively fewer viewed times. Figure 4.3 (b) illustrates the volume of danmaku and comments in crisis videos of different themes. The volume of danmaku was larger than the volume of comments in crisis videos of all themes, indicating the wide usage of the danmaku feature. Such volume differences between danmaku and comments reached the highest in Entertainment videos, where the average number of danmaku was 3.89 times higher than the average number of comments, while the volumes of danmaku and comments were nearly the same in the more formal Authoritative Guidance videos.

Table 4.1: Content Themes of COVID-19-related Videos on Bilibili

Theme	Definition	Example	Proportion
Social Events	Videos focusing on social events triggered by or related to COVID-19 (e.g., donation, discrimination and mask production)	<i>A young man dropped 500 masks in the police office and ran away, the police said: your "escape" looks really handsome!</i>	52.2%
Entertainment	Videos exhibiting COVID-19 related issues in recreational forms (e.g., animation, music video and auto-tune remix-themed content)	<i>Understand attitudes towards coronavirus in different provinces in the way of Tom and Jerry</i>	15.5%
Record in Severely Afflicted Areas	On-spot record showing the epidemic situation in severely afflicted areas	<i>The seventh day of the lockdown in Wuhan by Wuhanese video uploader: The status of fever clinics in Wuhan</i>	14.9%
Knowledge Popularization	Videos Popularizing scientific knowledge related to COVID-19 (e.g., transmission mechanism of virus)	<i>What is the coronavirus? How does it make people sick in Wuhan?</i>	9.3%
Authoritative Guidance	Videos on epidemic-related information released by authoritative organizations or persons	<i>Epidemiologist Zhong Nanshan: The inflection point of the epidemic has not come yet. Early detection and early isolation is the key</i>	8.1%

Table 4.2: F1 Scores and Parameters (MD: Maximum Depth; MWC: Minimum Weights in a Child) of Machine Learning Models. There is only one model for M3, as it achieved better performance when merging danmaku and comment training dataset in training the multi-class emotion type classifier.

	M1: Information Sharing Classifier (Binary)	M2: Sentiment Expression Classifier (Binary)	M3: Emotion Type Classifier (Multi-class)
Danmaku	81.1% (MD=3, MWC=1)	87.8% (MD=7, MWC=3)	(MD=7, 69.3% (MD=1, MWC=3)
Comments	86.3% (MD=7, MWC=1)	83.7% (MD=4, MWC=1)	

777,865 danmaku posted by 449,729 unique users and 1,539,629 video comments posted by 950,896 unique users were collected from 879 COVID-19-related videos. The volume of collected danmaku was smaller than the volume of comments because of the upper limit of 1,000 danmaku for each video based on Bilibili official API. The average length by Chinese characters was 8.0 for danmaku ( $SD=7.9$ ) and 24.3 for video comment ( $SD=49.1$ ), which validated the short length nature of danmaku [113].

### 4.3.2 RQ1: How prevalent is information sharing and sentiment expression in danmaku compared to comments in crisis videos?

Among 500 annotated danmaku and 500 annotated comments in the training dataset, 190 (38.0%) danmaku and 201 (40.2%) comments were identified with having sentiment expression, and 124 (24.8%) danmaku and 221 (44.2%) comments were labeled with having information sharing. Through training on the annotated data, the F1 scores of Information Sharing Classifier (M1) and Sentiment Expression Classifier (M2) both achieved higher than 80% under 10-fold cross-validation as shown in Table 4.2, which was substantially good to generalize the annotated codes to the whole danmaku and comment datasets.

According to the codes assigned by the text classification model, the proportion of sentiment expression was 38.6% ( $N=300,053$ ) for danmaku and 32.7% ( $N=503,734$ ) for video comments. For information sharing, only 24.8% ( $N=192,865$ ) danmaku were predicted as sharing information, while the percentage in video comments reached 60.1% ( $N=925,691$ ). The differences of danmaku and comments were both statistically significant for sentiment expression ( $p < 0.001$ ) and in-

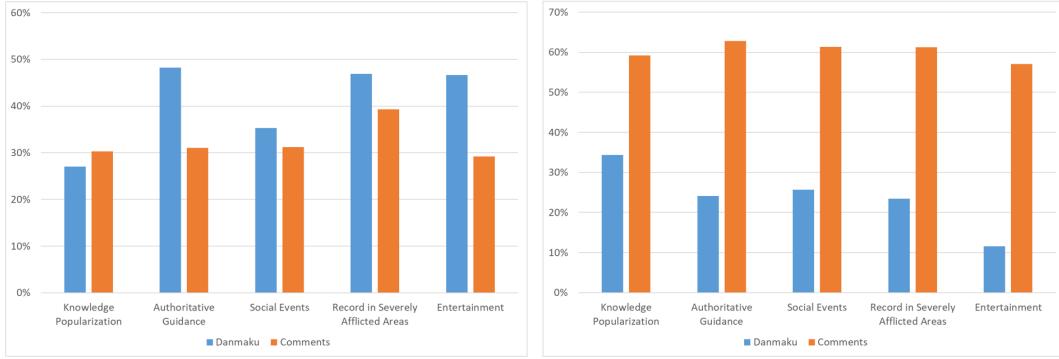


Figure 4.4: The proportion of (a) Sentiment Expression and (b) Information Sharing of Danmaku and Comments in Different Topic Crisis Videos

formation sharing ( $p < 0.001$ ) under chi-square test, which was applicable for binary variable with large volume. The results indicated that **sentiment expression was more prevalent in danmaku, while information sharing was much more prevailing in video comments**.

Figure 4.4 illustrates the proportion of sentiment expression and information sharing of danmaku and video comments in crisis videos with different topics. The differences between danmaku and comments of all video topics were statistically significant ( $p < 0.001$ ) under chi-square test. The results indicated that danmaku generally had a higher sentiment expression proportion and a lower information sharing proportion compared to video comments across different video topics, except for Knowledge Popularization videos in which comments had a slightly higher sentiment expression proportion. Besides, there were significant disparities in information sharing and sentiment expression proportions of danmaku between different topic videos, while such inter-topic differences were much smaller for video comments.

### 4.3.3 RQ2: What emotions and information themes have emerged in danmaku and comments of crisis videos?

In this section, we addressed RQ2 by identifying the fine-grained emotions vented in danmaku of crisis-related videos through quantitative sentiment analysis and hierarchical information themes derived from qualitative thematic analysis.

## Beyond Positive and Negative: Fine-grained Emotion Types of Danmaku in Crisis Videos

Fine-grained emotions are regarded with great significance to further understanding of public reactions and the specific functions that users' emotional states may reflect during crisis [49]. Eleven emotion types across positive and negative categories were identified in the training data, and substantially good performance (macro averaged F1 score=69.3%) of emotion type classifier was achieved through training compared to previous work [121, 8]. The emotions, examples, and the proportions in all danmaku and comment posts after generalization are shown in Table 4.3. Positive emotions included **Admiration**, **Encouragement**, **Gratitude**, **Joy**, **Empathy**, **Moved** and **Relieved**. Negative emotions included **Criticism**, **Worry**, **Shocked** and **Recollecting**. Emotions were grouped into positive or negative mainly referring to Robinson's emotion theory [145]. We found that: (1) Compared to video comments, danmaku had higher proportions of positive emotions and lower proportions of negative emotions. (2) Under positive emotions shared in danmaku, **Encouragement**, through which users mutually transmitted courage and confidence, and **Admiration**, through which users expressed the adoration to specialists and staffs aiding in Wuhan, accounted for the highest proportion, both reaching nearly 20% among all danmaku and comment posts with emotion venting. (3) **Criticism** was the dominant negative emotion with a proportion higher than 30%, through which users criticized misbehaviors in crisis. The common target misbehavior included (i) individual behaviors related to the suspected epidemic origin and virus spread such as eating wild animals and refusing mask-wearing; (ii) factories, organizations and agencies failing to perform their duties such as factories that made substandard masks and organizations that embezzled donations; (iii) epidemic-related adverse social phenomena including racial discrimination, regional discrimination and price gouging; (iv) other meaningless, toxic or malicious commentaries.

## Hierarchical Information Themes

Through qualitative thematic analysis on 1,000 danmaku and video comments with information sharing, we built a hierarchical information topic taxonomy by grouping 17 themes into 5 high-level categories (i.e., domain knowledge, situated knowledge, opinions, video-relevant information, and external sources) as shown in Table 4.4. **Domain Knowledge** denoted information based on users' expertise. In the crisis videos we studied, the themes of domain knowledge mainly included *the characteristics of virus, personal protection suggestion, COVID-19 pandemic situations*

Table 4.3: Emotion Types of Commentary in Crisis Videos. The significance of differences between danmaku and comments in emotion proportions was tested through chi-square test (\*\* p<0.001; \*\* p<0.01; \* p<0.05), which was applicable for binary variable with large volume.

Category	Emotion	Example	Danmaku Proportion	Comment Proportion
Positive	Admiration***	<i>Salute to all the staff working in the anti-epidemic front line!</i>	20.94%	19.73%
	Encouragement*	<i>Come on, Wuhan!</i>	19.33%	17.59%
	Gratitude***	<i>Thank you for your hard work and sacrifice!</i>	7.22%	3.21%
	Joy***	<i>Hahahaha. The anti-virus propagation accent is so funny.</i>	5.32%	1.54%
	Empathy***	<i>My dear, protect yourself in the epidemic! It will be fine!</i>	5.51%	5.01%
	Moved***	<i>Moved with tears.</i>	3.46%	2.81%
	Relieved	<i>After hearing uploader's explanation, I feel relieved.</i>	1.05%	1.03%
Negative	Criticism***	<i>Weakness and ignorance are not barriers to survival, but arrogance is.</i>	31.73%	42.11%
	Worry***	<i>The saddest thing is that now we have no solutions to defeat the virus!</i>	2.93%	4.48%
	Shocked***	<i>Oh my god. That is to say, as long as there is no radical cure, school would never reopen.</i>	1.34%	0.27%
	Recollecting***	<i>So Deserted. I miss the days when I can't get on the crowded subway.</i>	1.17%	2.22%

*and influences, and governmental and social responses.* Some other kinds of domain knowledge, such as the research progress of vaccine, the discussion of effects of traditional Chinese medicine, and knowledge about routine tracking technologies, though rare, were also observed and delivered potentially useful information. We thus grouped them into *other scientific information*. **Situated Knowledge** represented the information based on evidence from users' own experiences. Four typical themes emerged under situated knowledge, which were *Personal and Family Response*, *Cases and Responses in Community*, *Daily Live in Pandemic*, and *Supplies during Pandemic*. Some danmaku and comments shared unproven personal opinions, such as *opinions to individuals' responses, governmental and social responses*, as well as *crisis-related social events* (e.g., regional and racial discrimination, potential virus origin and mask shortage). We categorized them as **Personal Opinions**, which were subjective yet potentially had values to other viewers for reference. With regards to **Video Information** category, users explicitly or implicitly referenced *Video Characters*, *Video Sections*, or *Video Major Topics*, and provided information related to it. In addition, users may also convey information about *Video Meta Information*, which was not directly related to video content but provided additional video information such as the total viewed times, the volume of comments, or the observation that the video was forwarded by authoritative accounts. Finally, **External Sources** denoted information with links to external websites.

The comparison of the danmaku and comment fine-grained information theme proportion yields some interesting findings. First, more domain knowledge was shared in danmaku compared to video comments, indicating the intention of sharers to make the shared domain knowledge co-presented with video content as a synchronous procedure. There was no substantial difference in situated knowledge and personal opinions in proportion between danmaku and video comments. Opinions to social events accounted for a relatively high percentage in both danmaku (14.8%) and video comments (15.8%). Much danmaku-based information sharing focused on video sections (e.g., an event happened in recording or a given URL appearing in a specific section), while comment-based information sharing was more about video major topics as well as video meta information. Also, it is worth noting that external source sharing was only found in video comments. In the following sections, we will validate this empirical finding that external sources were rarely shared in danmaku through a comprehensive comparison in the whole danmaku and video comment dataset.

Table 4.4: Information Themes of Commentary in Crisis Videos. The significance of differences between danmaku and comments in theme proportions was tested through Fisher exact test (\*\* p < 0.001; \*\* p < 0.01; \* p < 0.05), which was applicable for relatively small datasets (N=1000).

Category	Theme	Example	Danmaku Proportion	Comment Proportion
Domain Knowledge	the Characteristics of Virus***	<i>This is an RNA virus, so if it doesn't mutate, that would be strange.</i>	6.80%	1.00%
	Personal Protection Suggestion*	<i>Ordinary medical masks would work for general public, Zhong Nanshan has said.</i>	6.20%	3.80%
	COVID-19 Pandemic Situations and Influences***	<i>There have also been confirmed cases in Tibet.</i>	3.40%	0.80%
	Governmental and Social Responses**	<i>Both companies BYD and Foxconn have started making masks.</i>	9.00%	5.20%
	Other Scientific Information*	<i>The accuracy of thermometer is limited.</i>	2.20%	1.00%
Situated Knowledge	Personal and Family Response	<i>I am lucky that my parents will take the initiative to buy masks, ask about the epidemic and learn about the virus.</i>	3.80%	4.40%
	Cases and Responses in Community	<i>There is also a case in my community. Scared.</i>	1.40%	1.80%
	Daily Live in Pandemic	<i>The fifth day in quarantine. If school doesn't reopen soon, I would die.</i>	5.80%	4.40%
	Supplies during Pandemic***	<i>It's cheaper than ours. There are no cases in my city, but the price of masks is still 35 yuan each.</i>	2.40%	5.40%
Personal Opinions	Opinions to Individuals' Responses***	<i>The best way to eliminate fear is to face it!</i>	3.00%	0.60%
	Opinions to Governmental and Social Responses***	<i>In my opinion, Henan Province is making great efforts to control the virus.</i>	9.00%	4.40%
	Opinions to Social Events	<i>Whether the contractors would donate masks is their freedom. No moral kidnapping.</i>	14.80%	15.80%
Video Information	Video Characters	<i>Uploader, are you OK? Your mask seems of no use.</i>	12.00%	11.60%
	Video Sections***	<i>The given URL in the video is invalid???</i>	17.40%	3.60%
	Video Major Topics***	<i>This video is objective and saturated with useful information.</i>	1.60%	17.0%
	Video Meta Information***	<i>This video has been recommended by China Central Television.</i>	1.20%	18.40%
External Sources	External Sources**	<i>You can get the latest epidemic situation from here: URL</i>	0.00%	0.80%

#### **4.3.4 RQ3: What are the unique patterns of danmaku-based and comment-based information sharing and sentiment expression in crisis videos?**

Previous sections have systematically examined the prevalence of information sharing and sentiment expression (RQ1), emotion types and information themes (RQ2) of danmaku and comments in crisis videos, revealing the distinct roles of danmaku and comments in crisis communication. Yet, as a communication channel featured by collectivity, interactivity, style-diversity and transiency, information sharing and sentiment expression in danmaku is far beyond the semantic value. In this section, through video-combined qualitative analysis, we moved on to the hyper-semantic level and focused on the unique patterns of danmaku-based and comment-based information sharing and sentiment expression. Specifically, we introduced two special sentiment expression patterns (*Collective Emotion Resonance* and *Interactive Emotion Communication*) and two information sharing patterns (*Style-Based Highlighting*, *Timely Information Supplement and Regulation*) observed in danmaku. Further, we revealed three unique patterns of comment-based information sharing (*External Sources*, *Comprehensively Integrated and Summarized Information* and *Information of Particular Users*), discussing how video comments supplemented the information sharing features that were not suitable for danmaku posts.

##### **Collective Emotion Resonance**

In crisis videos, video commenters leveraged danmaku as a channel of collective emotion resonance especially admiration and encouragement, which cultivated an intense emotional atmosphere of video watching in the way of screen flooding as shown in Figure 4.5 (a). For instance, in the video "Wuhan Real-time Record: The living conditions of hospitals, doctors and citizens in Wuhan" revealing the situation and response in Wuhan at the early stage of the epidemic, there was screen flooding of encouraging danmaku "*Come on, Wuhan!*"; in the video "Medical aid teams from four best hospitals have arrived in Wuhan: We will win the war against coronavirus!" recording the medical aid to Wuhan, there emerged screen flooding of admiring danmaku "*Salute!*". Such short yet powerful danmaku-based emotion venting, similar to a slogan, was infectious, which effectively communicated courage and positive energy and built public confidence in the video-viewing community during crises. Another typical case was that users utilized different but fixed-formed danmaku to create the screen flooding, e.g., "[Local specialty] (e.g., Peking duck) is supporting Hot Sesame Paste Noodles! (Wuhan specialty)", which appeared in multiple COVID-

19-related videos. Such danmaku not only raised viewers' interest in commenting by forming small groups with the same demographics, but also created the collective emotion resonance in the large video-viewing group with the same sentiment expression intention. In contrast, more individual emotion venting appeared in video comments.

## Interactive Emotion Communication

In danmaku, people interactively expressed emotions, especially empathy and gratitude to: (1) video uploader, e.g., *"Uploader, you must be careful! Remember always wear masks."* to a vlogger recording Wuhan situation; (2) characters, who could be either a key actor, one anonym showing up transiently or a group, e.g., *"Academician Zhong Nanshan, appreciate your work! Please take care of yourself"* to the Chinese COVID-19 guidance provider Zhong Nanshan, *"Guarding parking lot now must be lonely. Take care."* to a parking guard in a Wuhan recording video, *"You are really angels. Salute!"* to a medical group aiding in Wuhan; (3) other viewers, e.g., *"Guys watching this video, you don't deserve to have this disease!"*. It is worth noting that actually such emotional communication was hard to reach the target objects as the processes of video recording and video watching were asynchronous, yet viewers were still keen to initiate the simulative emotional dialogue, creating the interactive viewing experience.

## Style-Based Highlighting

Before posting danmaku, users can adjust the display settings including displaying mode, font size, and color, which diversifies danmaku. In our danmaku dataset, there were 95.02% shown in the way of normal "flying", 4.34% fixed at the top of video, 0.61% fixed at the bottom of video, and 0.03% advanced danmaku with specialized style. The majority of danmaku (99.82%) had normal font size, with 0.15% with smaller font size and 0.03% with bigger font size. There were 174 different colors in the danmaku dataset, in which white danmaku accounted for the highest proportion (91.70%), followed by red (5.01%), yellow (1.36%) and blue (0.04%).

We found that danmaku with unique display styles had a higher information sharing proportion. Specifically, normal "flying" danmaku only had 24.3% sharing information, while the percentage was 29.2% and 29.5% for fixed-at-the-top and fixed-at-the-bottom danmaku separately. Danmaku with color had a higher information sharing percentage (27.1%) compared to default

white danmaku (24.3%), and yellow danmaku held the highest information sharing proportion (35.3%). Also, larger font size indicated a higher chance of information sharing, with the information sharing proportion of 31.4% for danmaku larger than the normal font size, 24.6% for danmaku with normal size, and 19.7% for danmaku smaller than the normal font size. All aforementioned differences were statistically significant ( $p < 0.001$ ) under chi-square test. The combinations of display styles endowed additional displaying information to danmaku in addition to plain text, which elicited the strategic use of the style-based expression, especially highlighting, and thus facilitated crisis-related information sharing. For instance, in Figure 4.5 (b), under the context in which the vlogger mentioned mask and brought out a heated discussion about mask usage in danmaku, a user posted fixed-at-the-top red danmaku, which was distinct among all danmaku posts in style, to provide an authoritative explanation to mask usage:

*First of all, don't say that masks are useless. There is no doubt that wearing masks is better than no protection, because one function of the mask is to prevent people from transmitting droplets that carry viruses. Another problem is which masks are to be selected. N95 masks are better but not necessary. If you cannot distinguish the differences between different types of masks, just choose a surgical mask if there is no N95. (Appear at 3'30" of video "Real-time record in Wuhan: under the coronavirus, what is the situation of supermarkets, business districts and companies now?")*

Such information highlighted by special danmaku patterns gained the attention of a wide audience and received other users' gratitude in danmaku, e.g., "*Thanks to the red words for sharing the information*". We also observed that users tended to cite the information source in highlighted danmaku to enhance authority, such as "*Nanshan Zhong has confirmed that there is human-to-human transmission of coronavirus*".

### **Timely Information Supplement and Regulation**

Section 4.3.3 has revealed that danmaku had a much higher proportion of information sharing about video sections (17.4%) compared to comments (3.6%). This section moved a further step about the information sharing about video sections in danmaku and introduced its unique pattern: Timely Information Supplement and Regulation.

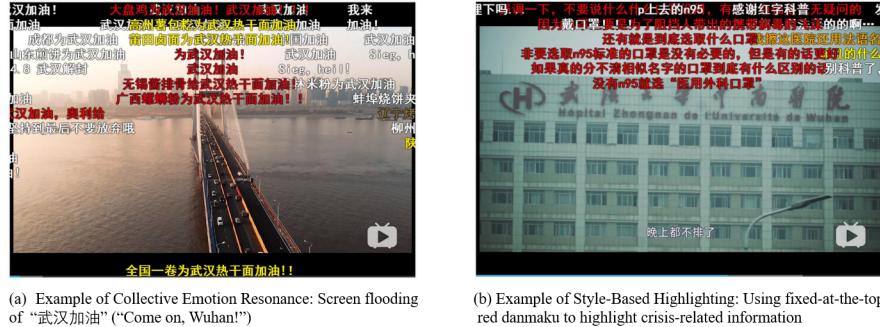


Figure 4.5: Examples of Unique Patterns in Danmaku-Based Sentiment Expression and Information Sharing: (a) Collective Emotion Resonance; (b) Style-Based Highlighting.

With the characteristic of appearing at a fixed time period, information sharing in danmaku exhibited a close correlation on the video context, which might provide detailed explanations and information extensions focusing on a specific video period. As such, danmaku-based information sharing could play the role of furnishing a timely information supplement to the video content. For instance, in a video related to community epidemic control, a section described the scenario that the community staff used an infrared frontal thermometer to measure the temperature of visitors. Danmaku popping up under this section provided further descriptions about the infrared thermometer, such as "*the infrared thermometer may not be accurate*" and "*the accuracy of the infrared thermometer is affected by the environment*". In another example, when the vlogger recorded the real-time situation in Wuhan and interviewed citizens, danmaku reminded that "*uploader wore the mask (nose not covered) in an inappropriate way*", which aimed to timely rectify the misinformation conveyed in the video. Danmaku immediately following the corresponding scene could effectively reveal misbehavior in videos, supplement relevant knowledge for confusing points and explain interesting scene details as shown in Figure 4.6, which could be substantially beneficial in crisis videos. In comparison, video comments failed to build such a strong correlation to video sections. Recently, some video platforms adopt the clickable timestamp [202] as an additional commentary function. Users could add a timestamp in comments, and others could click the timestamp and jump to the referenced video section. However, such behavior often asynchronously happened after video watching, and users might need to make a second effort to understand the video context, which limits the timely information supplement.

In the following three subsections, we revealed three unique patterns of comment-based infor-

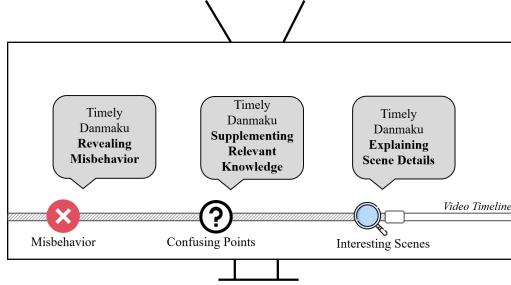


Figure 4.6: Timely Information Supplement and Regulation of Danmaku: Danmaku immediately following the corresponding scene could effectively reveal misbehavior in videos, supplement relevant knowledge for confusing points and explain interesting scene details.

mation sharing that were not suitable for danmaku.

## External Sources

Sharing external sources is a common behavior in video comments. Users may add external uniform resource locators (URLs) in comments to provide supportive evidence or information extensions that may link to other information hubs, social media sites, relevant videos, news outlets or authoritative guidelines [157], and others could directly click or copy and paste to go to the shared websites if interested. For instance, some video comments shared "*(Here records) the real-time situation of the new coronavirus epidemic in China: URL*", and some introduced "*Here is the paper mentioned in the video which has been published in Lancet: URL*". Such information was particularly valuable during crises in spreading more accurate and reliable information sources. However, URL sharing was seldom observed in danmaku. The major reason was that danmaku could only show for several seconds, and the transitory appearance limited other users to remember or copy the shared URL. In addition, going to other websites would interrupt the video-viewing process. Based on URL regular expression matching, we observed that only 7 (0.0012%) danmaku contained URLs, while 2497 (0.41%) video comments contained URLs.

## Comprehensively Integrated and Summarized Information

Integrated and summarized information is defined as the combination and summarization of multiple information sources or knowledge points in a single commentary. Such information was prevalent under video comments and gained a large number of likes, spreading to a wide audience. For instance, the following video comment under authoritative guidance video "Zhong

Nanshan: It is certain that the COVID-19 can be transmitted human-to-human. The virus is most likely from wild animals.", receiving 26,171 likes, concluded the main knowledge points in the video:

*Summary of academician Zhong Nanshan's speech: 1. Confirm the human-to-human transmission 2. The intensity is lower than SARS temporarily 3. The epidemic is currently in a climbing stage 4. The source has not been determined, but it is suspected to be wild animals. 5. Some medical workers have been infected 6. Public should be vigilant that the epidemic has escalated 7. N95 is out of stock, and ordinary masks are effective to some extent 8. Fever is the first suspected symptom 9. Do not go to Wuhan in the near future if unnecessary (video "Zhong Nanshan: It is certain that the COVID-19 can be transmitted human-to-human. The virus is most likely from wild animals.")*

In addition to the integrated video information summary, users may also collect useful external links relevant to the crisis and combined them in one post. For instance, the following video comment integrated external websites including complaint management platform, debunking websites, situation tracking websites, reminder and donation platforms:

*Complaint management platform: URL; Real-time debunking science website: URL; Real-time situation tracking: 1. The spread of the new coronavirus: URL; 2. Baidu version (including migration map, recommended): URL; 3. NetEase version (including detailed news reports): URL; 4. Tencent version (including a list of fever clinics): URL; ... Remind parents to wear mask: URL; Donation: URL. (video "What is the current situation of the epidemic? Here comes the authoritative analysis!")*

This kind of integrated information sharing was also only available in video comments instead of danmaku. As introduced in Section 4.3.1, The average length by Chinese character was only 8.0 for danmaku. The short-time appearance and the large volume of concurrent danmaku limited the time spent on a single danmaku, leading to its short text-length nature and thus the inappropriateness of integrated and summarized information sharing.

## **Information of Particular Users**

Danmaku provides a novel anonymous information sharing channel. However, in some scenarios, user identities of commentary would endow additional reliability, authority or popularity to the shared information, such as comments posted by video content curators, social media influencers or government accounts, which would further influence the broadness and acceptance of such information in crises. For instance, the creator of auto-tune remix-themed video "[Anti-coronavirus] Village head hardcore radio trap: Cheap" commented, "*Within 7 days of this video, the incentive proceeds will be donated to Wuhan! Thank you all!*", which obtained a high exposure and received more than 80 thousand likes. Another case was the comment posted by government account "Zhejiang Communist Youth League", "*Article 330 of the Criminal Law of the People's Republic of China stipulates that whoever, in violation of the provisions of the Law on the Prevention and Treatment of Infectious Diseases, commits any of the following acts, thereby causing the spread of a class infectious diseases or causing serious danger of their spread, shall be sentenced to fixed-term imprisonment of not more than three years or criminal detention...*". This government-generated comment also received wide attention, with more than 10,000 likes and more than 100 replies.

## **4.4 DISCUSSION**

Through a mixed-methods approach integrating machine learning and qualitative analysis, this work systematically investigated how users shared information and expressed emotions in danmaku and comments in crisis videos with regard to prevalence (RQ1), information themes and emotion categories (RQ2), and unique patterns (RQ3). In this section, we reflect on the findings, discuss the potential of synchronous commentary in crisis videos, and propose implications for designing improved commentary interfaces to facilitate effective and engaging crisis communication.

### **4.4.1 Complementary Role of Danmaku and Comments in Information Sharing and Sentiment Expression**

This work largely reveals the complementary roles of danmaku and comments in information sharing and sentiment expression in crisis videos. In general, information sharing was more prevalent in video comments, while sentiment expression was more prevailing in danmaku. For

sentiment expression, danmaku was more used to collectively vent the positive emotions, and appeared to be more interactive; in contrast, comments were more used to individually vent the negative criticisms, and appeared to be more dissociated. For information sharing, danmaku provided synchronous information supplement for video sections, while comments initiated asynchronous discussions focusing on video major topics. In addition, video comments supported specific information-sharing functions that were not practically suitable for danmaku, such as external URLs and comprehensively integrated and summarized information.

As Durkheim's theory of "collective effervescence" suggests, synchronization with shared symbols and emotions can increase emotional intensity [42]. The collective positive emotion expression in danmaku, especially the Admiration and Encouragement vented in the form of screen flooding, reflected such emotional valence increase. Also, the prevalence of "Positive Energy" largely echoed with previous findings on crisis response in Chinese social media [110]. The "Positive Energy" dissemination would be beneficial to establish public confidence, but may also influence how people perceive the veracity of information [110]. On the other hand, video comments provided a more calm and rational environment for information sharing, credibility assessment and discussion, which largely complemented the role of danmaku.

With the development of online videos and live streaming, it is a growing trend to support more than one alternative commentary channels for video platforms. For instance, both live comments through Internet Relay Chat (IRC) and retrospective comments through commenting box are available in YouTube Live [112]. Our finding contributes to a large body of research on video commenting interfaces that when two characteristics-distinct commenting channels (e.g., synchronous vs. asynchronous) are concurrently accessible to users, nuanced and complementary roles would develop based on their temporal, spatial, and style nature and collaboratively facilitate interaction by satisfying different aspects of user needs. On this note, unilaterally focusing on one channel would lead to bias and fail to get the full picture of user behavior. Future HCI and CSCW researchers are suggested to critically compare the behavior patterns in different commentary channels and design specialized commenting features to satisfy users' communication needs.

#### 4.4.2 The Particularity of Commentary in Crisis Videos

During time of crisis, online crisis videos typically exhibit an exponential increase within a short period (e.g., "infodemic" in COVID-19 [205]). Such crisis videos often show a varied quality with a not small proportion of misinformation [96], and rapidly evolve as the crisis situation changes [77]. As such, users may spontaneously leverage video commentary to correct misinformation, update the latest information and express emotions in the crisis. The features and uses of commentary in crisis videos are largely distinctive compared to commentary in other video genres such as music, movie and animation, which renews the demands to understand the commentary in this special video genre.

Our findings uncovered comprehensive taxonomies for granular emotion categories and information themes in danmaku and comments of crisis videos, which revealed the particularity of crisis video commentary. *Admiration* and *Encouragement* accounted for the majority of positive emotions, and *Criticism* was the most prevalent negative emotions. The emotion categories, as well as their proportions, reflected public emotional status during COVID-19 pandemic and were largely different from previous emotion models (e.g., circumplex model [148]). Particularly, the prevalent emotional support towards governmental disposition and collective contributions to pandemic control (e.g., government-led cross-region medical aid), reflected the patriotism and nationalism of specific groups in Chinese social media context [109]. As for user-generated information, a not negligible proportion of danmaku and comments shared situated knowledge such as *Cases and Responses in Community* to increase situational awareness among viewers. Also, numerous video commentary especially danmaku spontaneously shared domain knowledge about the video content, such as the scientific knowledge about the *Characteristics of Virus* and the latest authoritative *Personal Protection Suggestion*. In other words, the commentary in crisis videos was knowledge-intensive focusing on the crisis. Online videos are gradually becoming an irreplaceable information source for public, and government agencies are also increasingly taking online videos to release crisis communication [182, 11]. Mining how public are engaged in crisis videos and how they react to video information through video commentary, e.g., what public concerns are conveyed through negative criticisms and what information (and misinformation) are most widely disseminated in commentary, is of great importance for government agencies to design better crisis communication strategies. Future work will be required to take advantage of the rich data of crisis video commentary to discover public awareness, concerns and reactions in crisis.

### 4.4.3 Potential of Synchronous Commentary in Crisis Communication

Section 4.3.4 revealed the unique patterns of danmaku-based sentiment expression and information sharing, including *Collective Emotion Resonance*, *Interactive Emotion Communication*, *Style-Based Highlighting*, and *Timely Information Supplement and Regulation*. In this section, we critically discuss how these patterns differentiate danmaku from traditional video commentary and how viewers leverage danmaku to contribute to videos, and highlight the potential of synchronous commentary in crisis communication.

#### Collaborative Misinformation Correction

Prevalence of misinformation is a critical problem of crisis communication on social media, including crisis videos. For instance, previous work has identified more than a quarter of top-viewed Youtube videos about COVID-19 contained misinformation such as misleading protective recommendations for the general public [96]. In this light, danmaku provides a potentially effective way to synchronously identify and correct misinformation in crisis videos. This study revealed that danmaku distinguished from video comments for its *Timely Information Supplement and Regulation*. Viewers spontaneously moderated the video content and collaboratively provided correction when noticing misleading information in videos. Recall the example that when the vlogger left the nose outside the mask in a video recorded in Wuhan, a large number of danmaku rectified the improper behavior by pointing out "*Uploader wore the mask in an inappropriate way*" or "*Please cover your nose*". With part of such information assisted with *Style-Based Highlighting*, other viewers could immediately notice the collaborative correction of misinformation. In addition, the crowdsourcing way of information assessment endows danmaku with the ability of self-correction, which somehow inhibits the misinformation dissemination through danmaku. For instance, when a danmaku claimed that "*Don't worry, young people are less likely to be infected*", a following danmaku immediately replied, "*(Reply to) the foregoing danmaku, the authority has said that there is no less vulnerable population*". These observations extend previous research in understanding crisis misinformation correction on social media [176, 164]. Compared to video comments, danmaku-based misinformation correction co-appears with the misleading video section, making it easier to target the content with misinformation and get other viewers' attention. How to further support such collaborative misinformation correction, e.g., how to better distinguish valuable user-generated correction among danmaku stream, and how to improve the quality of

such spontaneous and unproven correction, are the questions that future CSCW researchers and practitioners shall critically think about. Meanwhile, more robust misinformation auto-detection and reporting mechanism should be considered to complement the current crowdsourcing way of self-misinformation-correction, so as to maximally hinder the misinformation creation and dissemination through danmaku.

### **Knowledge Co-construction and Augmentation**

Existing literature has revealed that in scientific video clips, video comments reached a higher-level of knowledge construction beyond the information of video content [40]. In this section, we argue that danmaku also facilitates such knowledge co-construction, and achieves synchronous information augmentation in both width and depth. As described in Figure 4.6, *Timely Information Supplement and Regulation* is a significant feature of danmaku. Such information sharing can either be triggered by video content, providing detailed explanations of different aspects of the corresponding scene, and thus broadening the width of video knowledge system; or triggered by danmaku discussion, correcting other danmaku's mistakes and supplementing relevant information, and thus deepening the depth of video knowledge system. As such, the video knowledge system with danmaku could be analogous to a tree structure with video content as the trunk and viewer-generated information as the branches, though there is no de-facto frameworks such as reply threads in Reddit. Such co-constructed knowledge structure is more robust and comprehensive than traditional crisis videos with the video creator as the only contributor. Besides, though the "trunk" of the video information system (i.e., pure video content) remains static, the "branches" (i.e., information in danmaku) are dynamic, in which danmaku with latest information provided by new viewers would cover old ones that may be out of date. As such, the video knowledge system also evolves with time when scientific information and authoritative guidance changes, which brings great values to crisis videos.

#### **4.4.4 Design Implications**

##### **Optimization of Style-based Highlighting**

Users leveraged unique displaying styles of danmaku (i.e., font, color and displaying mode) to highlight the danmaku, and the findings revealed that information sharing was more prevalent in

such danmaku, indicating the strategical use of style-based information highlighting to emphasize critical information. However, we also noticed that some users misused this function to abuse others or transmit misinformation. Though moderation in the community could mitigate the damage of such behaviors to some extent, the misuse of style-based highlighting would still degrade the video-viewing experience and mislead those who seek crisis information. On the other hand, some danmaku which provided high-quality information but had normal styles just "flew away" without getting much attention. This suggests a design implication for optimizing style-based highlighting, which could be either AI-facilitated (i.e., automatically measure the quality of danmaku and modify the styles to highlight those with higher quality), or feedback-facilitated (i.e., allow users to vote for danmaku with useful and high-quality information and highlight those with higher votes in style).

### **Design Improvement for Better Section Information Sharing**

In our study, nearly 30% of danmaku-based information sharing focused on events, objects, or characters in particular sections of the video (12.0% for video characters and 17.4% for content in video sections). As introduced in previous sections, such kind of information sharing serves as a timely information supplement and regulation, and might contribute to misinformation correction and knowledge augmentation. However, we noticed difficulties in referencing specific elements in sections when sharing corresponding information. To reference a character or object, viewers usually used position pointers like "↓" or described the referenced target like "the nurse with short hair". As such, other viewers took the extra effort to find the referenced target by following pointers or digesting descriptions, which might cause distraction or confusion. Thus, developing advanced referencing interfaces for danmaku is recommended. For instance, users could have the option to fix the danmaku at a specific area with the referenced target.

### **User Empowerment in Commentary Interface**

Empowering people through technology is of increasing concern in the HCI community [153]. Online videos have always been considered as the sole products of video creators and uploaders, while the contribution of viewers, who often complement the video content through commenting, is largely ignored. Through danmaku, users are empowered to create a text-based "floating screen" and endow additional user-generated information to the video content, influencing other

viewers' watching experience. Unlike video comments, users can choose to anchor danmaku posts at a specific video period and adapt the displaying styles. As revealed in the results, unique communication patterns were developed and adopted by users such as style-based highlighting, and further provided special benefits to crisis videos, e.g., collaborative misinformation correction. In this light, we propose a general design implication to video commentary designers to broadly empower viewers by providing more choices to tie their comments to video content temporally and spatially, and thus allow users to collaboratively and interactively contribute to videos. Note that the unique communication patterns brought by user empowerment were not limited to crisis videos and might be generalized to other video genres. For example, the collective emotion resonance might help to create a strong emotional atmosphere in some recreational videos, and the timely information supplement and regulation might be applied to other knowledge-intensive videos like scientific and educational videos. On this note, we suggest investigations on how different empowerment designs bring new user behavior patterns, and how they provide unique values to different video genres. On the other hand, viewers shall not only be empowered to co-create "what others could view" through commentary interface, but also have more options to choose "what they are willing to see". For instance, the collective emotion resonance in a form of screen flooding of danmaku might be appealing to some viewers, but may also be distracting to those who want to watch the pure video content. Consequently, more specialized filter options, e.g., merging similar danmaku, should be designed as compensation.

#### 4.4.5 Limitations and Future Work

Our work has some limitations. First, we only focused on one video platform, bilibili, which might have introduced biases into our analysis. Second, the demographics of viewers are missing because we could only access the virtual hashed user ID of danmaku, which is designed to be anonymous, based on Bilibili official API. Therefore, we are unable to trace back to users' demographic information through actual user ID. Third, though the text classifiers achieved substantially good performance, a larger annotated sample size and a more detailed feature engineering might lead to a more accurate generalization result. Fourth, though we conducted an in-depth analysis of danmaku and comments in crisis videos, a comparison study on other video genres might help highlight the distinct features of crisis communication through danmaku and comments. Finally, a proof-of-concept interface would be beneficial to get a thorough evaluation of

design implications. Future work will need to address these limitations, as well as explore additional opportunities of diverse commenting interfaces in video and live streaming. Also, a further investigation and comparison on the commentary pattern differences in different crisis video types (e.g., videos with different themes and purposes, videos generated by government or individuals), would deepen the understanding of crisis communication through video commentary and shed light on more effective crisis management.

## 4.5 CONCLUSION

In this paper, we studied the roles of danmaku and video comments in information sharing and sentiment expression in crisis videos through a mixed-method approach incorporating machine learning and qualitative video-combined content analysis. By investigating a large danmaku and comment dataset collected from COVID-19 videos, we revealed that danmaku had a higher proportion of sentiment expression, while comments had a higher proportion of information sharing. Viewers leveraged danmaku more to collectively vent positive emotions, and relied on comments more to individually disclose negative criticisms. In addition, more domain knowledge as well as information focusing on specific video sections was observed in danmaku, while more information on general video topics was found in comments. Several unique sentiment expression and information sharing patterns were identified in danmaku, such as collective emotional resonance and timely information supplement and regulation. Based on the findings, we discussed the potential of synchronous commentary in crisis videos including collaborative misinformation correction and knowledge co-construction and augmentation, and highlighted several design implications for commentary in promoting effective and engaging crisis communication.

# CHAPTER 5

## CONCLUSION AND FUTURE WORK

This dissertation makes a comprehensive investigation to understand user engagement in multi-modal crisis communication including rich text, images, and videos. Based on the findings, this dissertation proposes design implications to facilitate accurate, timely, and effective crisis communication on social media.

To navigate user engagement through crisis communication in rich text, we use a mixed-methods approach to examine how help-seeking posts on the popular Chinese social media platform Weibo were affected by the 2021 Henan Floods, and how individuals and communities developed strategies to cope with the overwhelming situation. The research reveals that help-seeking posts faced significant challenges in gaining sufficient public engagement. They were not only inundated by numerous non-help-seeking posts that contained relevant keywords, but also experienced attention inequality, with less than 5% of help-seeking posts receiving over 95% of likes, comments, and shares. The study identifies various linguistic and non-linguistic strategies employed by help-seekers to attract public attention and investigates their impact using negative binomial regression models. The findings indicate that including contact information, describing danger and vulnerability, adopting subjective narratives, using a normalized syntax structure, and utilizing hashtags and multimedia content all contribute to enhancing the engagement of help-seeking requests. However, expressing negative emotions and mentioning others do not have the same promotional effect. Additionally, a qualitative content analysis highlights the spontaneous efforts of the community to prevent overwhelm, involving collective wisdom through norm development discussions and collaborative work such as norm broadcasting and enforcement. Based on these findings, the study proposes design implications to support effective help-seeking during natural disasters.

To unpack how users were engaged in visual crisis communication, we investigate how social media crisis images contribute to crisis communication during a local COVID-19 outbreak, focusing on the Xi'an outbreak in China. We collected 345,423 crisis-related posts and 65,376 original images from Weibo, a popular Chinese social media platform. Using a mixed-methods approach,

we analyze visual themes, goals, and strategies in crisis communication. Through image clustering, we identify two categories: text-embedded posters and text images, as well as four "visual diary" types depicting life during the event, such as scenes during quarantine. We demonstrate how these visual types are used to convey information and evoke emotions, such as using posters to highlight policies and embedding anxiety in visual diaries. Users strategically leverage crisis images to establish authority, enhance information, improve credibility, and evoke empathy. We discuss the opportunities and challenges of visual crisis communication, the correlation and complementarity between different modes of communication, and propose design implications to facilitate effective and accurate visual crisis communication.

Finally, centering on crisis videos, my research looks into how innovative video-creation strategies and video-interaction interfaces play a role in engaging users. We first systematically investigate the factors influencing youth engagement in government-generated crisis videos on the Bilibili platform. Using a mixed-methods approach, we examine how video content (topic and emotion) and new engaging strategies (recreational video category and government-citizen collaboration) impact youth engagement dimensions (interaction, feedback, and sharing). Findings show that recreational videos such as music and animation significantly enhance youth engagement compared to traditional records and talks. Collaboration with civil video uploaders positively influences interaction, feedback, and sharing among youths. The study discusses the values and limitations of these engaging strategies, and their theoretical contributions to Entertainment Education and Collaborative Governance in crisis communication. The findings can inform effective and engaging crisis communication to youths in practice. Further, using a mixed-method approach, we examined the roles of danmaku and video comments in crisis videos. We discovered that danmaku predominantly expressed sentiment, while comments focused more on information sharing. Danmaku served as a channel for collective expression of positive emotions, whereas comments were used to individually express negative criticisms. Danmaku contained more domain knowledge and specific information related to video sections, while comments provided more general information about video topics. We identified unique patterns in sentiment expression and information sharing in danmaku, such as collective emotional resonance and timely information supplementation and regulation. Based on our findings, we discussed the potential of synchronous commentary in crisis videos, such as collaborative misinformation correction and knowledge co-construction. We also presented design implications for commentary to enhance effective and engaging crisis communication.

## 5.1 Future Directions

### 5.1.1 Multimodal Crisis Misinformation

Most previous work aimed to understand text-based misinformation and many design interventions also overlooked misinformation in other modalities (especially figures and videos), even though such visual-based misinformation also exists in a large volume and might be even more challenging to discern. For example, images, whether field photos or digital screenshots, were frequently used as evidence to improve credibility during crises when “pictures don’t lie” [14, 13]. It vastly increases the misinformation risk when pictures do lie - for example, rumors expressed in faked screenshots of chat history, or appropriated photos from a different scenario [14]. The emotions embedded in visual narratives may further raise empathy among people during crises and promote the spread of visual-based misinformation. One important research direction that I will pay attention to is to answer: in which way does misinformation exist in images and videos on social media during crises? how do people perceive (and perhaps identify) them, and how do they spread and influence people? and finally, how to develop suitable design interventions to mitigate the harm of visual-based misinformation during crises?

### 5.1.2 Opportunities and Risks of AI in Multimodal Crisis Communication

AI can play a significant role in supporting multimodal crisis communication by providing automated and personalized responses. For example, AI-driven chatbots and virtual assistants can provide real-time information, answer frequently asked questions, and offer guidance during a crisis, and provide responses in specific modalities based on users’ needs. These automated systems can alleviate the burden on human operators, handle a large volume of inquiries simultaneously, and provide consistent and accurate responses to the public. On the other hand, with the help of advanced algorithms, AI-powered systems can create and disseminate false or misleading information that appears legitimate and can easily deceive people. Furthermore, AI algorithms can identify and target vulnerable individuals and communities by analyzing user behavior, amplifying their existing beliefs and reinforcing their biases. This challenge of AI-generated misinforma-

tion needs particular attention during times of crisis when AI-generated misinformation might be used for nefarious purposes, such as using for political propaganda or triggering social unrest. Therefore, I am interested in understanding how AI-generated misinformation spreads on social media during crises. Meanwhile, with the development of large language models, people are increasingly relying on AI chatbots such as ChatGPT to get everyday advice. It can be foreseen that a growing body of users seeks AI chatbots for practical suggestions during crises. How might AI-generated crisis information introduce bias or even misleading content in this setting? I am also eager to explore this problem.

### **5.1.3 Crisis Communication for Vulnerable Populations**

During times of crisis, it is significant to enhance the accessibility of crisis informatics technologies so that they could also benefit some marginalized or underrepresented groups [?]. For example, Zhang et al. interviewed 16 older adults and revealed that even though most of them acknowledged the usefulness of crisis apps, there was a lack of awareness and engagement with such crisis informatics technologies [?]. Therefore, the inclusive and accessible design necessitates particular design considerations on these populations' specific preferences and vulnerabilities to fully satisfy their needs in crisis response. Unfortunately, misinformation on social media during crises, which is in a great amount, with rich modalities and hard to perceive in narratives, might make these underrepresented groups even more vulnerable. Existing literature has indicates the challenges of some underrepresented groups (e.g., older adults, low-income populations, and people in ethnic minorities) in assessing the credibility of online information such as the difficulty in distinguishing misleading content [?, ?]. Generally, how vulnerable populations face and combat crisis misinformation and how to develop supportive technology to assist them is a less understood area. I am particularly interested in the problem setting for older adults living in rural China. Which types of crisis-related online misinformation do rural older adults face, and how do they get exposed to it (from social networks, short video platforms, or other recommendation systems)? How do they identify (or fail to identify) and react to it, and what are their strategies when facing challenges in assessing the credibility of online information? For example, would they seek help from the local community, online groups, and younger generations? I plan to conduct a qualitative analysis with interviews to answer these questions and draw design implications for crisis informatics technologies from it.

#### **5.1.4 Science Communication in Crisis Response**

Due to the uncertainty and complexity of crises (especially health crises), it is necessary to communicate authoritative scientific knowledge when trying to guide and convince the public with correct and practical information during crises. Also, there is sometimes rapid scientific progress for crisis response (e.g., the COVID-19 vaccine), under which scientists and agencies may need to update the latest research to the public [?]. Such kind of science communication under crises becomes important information to combat misinformation. Unfortunately, science-related discussions intrinsically correlate with specialized linguistic use (e.g., terminologies and hedge words), which may become barriers to public understanding and participation [?]. To this end, how to engage the public with practical scientific knowledge to accurately respond to emergencies and fight against crisis misinformation is a significant yet underexplored topic. On the other hand, Section ?? has noted that public science discussion may exploit research outputs for conspiracy theories and extremist ideology during times of crisis, which is “misinformation in orthodox rhetorics” [?, 95]. Such misinformation is more difficult to identify for the public and may cause greater harm than “obviously misleading” content. More investigations are warranted to understand the public’s wisdom and effort in debunking misinformation in orthodox rhetorics, and it is also important to propose design interventions to arm users with more targeted information and advanced skills to distinguish them. For example, only nudging users to check whether misleading posts in orthodox rhetorics have credible information sources may even make people believe the misinformation (because they do have). In contrast, affording targeted debunking posts generated by experts may work better in refuting such well-crafted misleading content.

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