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Risk Communication Networks in South Korea: The Case of the 2017 Gangneung Wildfire

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Wildfires have become increasingly common and intense in South Korea because of climate change, but few have recognized the catastrophic level of the problem. Given the significant impact of wildfires, emergency management stakeholders must have effective risk communication structures for rapidly responding to such phenomena and overcoming geographical difficulties. Despite the country spending billions of dollars to build a big data-based early warning system, risk communication flow during the 2017 Gangneung wildfire was ineffective, thereby causing substantial economic, social, and environmental losses. To examine the patterns of information exchange in South Korea's risk communication networks and their structural characteristics during the wildfire, we conducted semantic and network analyses of real-time data collected from social media. The results showed that the inefficient flow of risk information prevented emergency responders from adequately assessing the emergency and protecting the population. This study provides new insights into effective risk communication responses to catastrophic events and methods of research on webometric approaches to emergency management.

Keywords: emergency response framework, Gangneung wildfire, interorganizational network, risk communication

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1. Introduction

Emergency evacuation is the last-minute, last-resort policy action that governments can take to prevent further casualties and damage to communities. Under time constraints and severe uncertainty, the decision on whether residents in affected areas should be compelled to evacuate needs to be made in a timely manner for them to survive unexpected catastrophic disasters for which response requirements exceed local capabilities. In making the right choice, exchanging or sharing risk information and resources across agents helps each relevant stakeholder conduct planned joint responses to adapt to the drastically changing and heterogeneous demands of disaster response (Kim, Yoon, & Jung, 2017). This interdependence, however, is confronted with critical challenges when the flow of information on risk and evacuation is disrupted or untailored to the needs of residents and emergency responders in terms of collective actions. Miscommunication or ineffective coordination among collaborators may create confusion that gives rise to considerable chaos among stakeholders and delays resident evacuation, further resulting in unnecessary and unintended consequences. Amid these challenges, studies on risk communication have identified the diverse immediate needs of multiple stakeholders in collaborative networks. The problem is that their approaches tend to arbitrarily revolve around policy supply and demand sides.

On May 6, 2017, a fire started on a small hill in Gangneung, approximately 230 kilometers east of Seoul. This occurrence resulted in substantial economic, social, and environmental losses, with over 2500 residents having had to be evacuated to nearby temporary shelters. South Korea has spent billions of dollars addressing the inefficient coordination of responses to unexpected disasters since the Sewol ferry accident in 2013. Nonetheless, as revealed by the Gangneung wildfire, the country's emergency management system was less prepared to deal with uncontrollable, catastrophic fires. Mountains cover almost two-thirds of South Korea, but relevant authorities and practitioners took a long time to recognize wildfires as natural disasters that pose ruinous consequences to the country. Other types of natural catastrophes, such as hurricanes and tsunamis, are often beyond our control, but wildfire causes can be eliminated through hazard operation, as implied by the term "firefighter" (Nowell et al., 2018). However, a dry or severely windy climate fuels the spread of wildfires in steep and rugged terrains, making it difficult to communicate with the local populations of affected communities and across emergency response agencies during mitigation in mountainous regions (Velez, Diaz, & Wall, 2017). This situation is particularly problematic when residents in regions suffering from disasters tend to wait for an official evacuation order by the central government, as is generally the case in the hierarchical or authoritarian emergency management networks of East Asian countries (Jung & Park, 2016).

Social media has been increasingly recognized as a major platform in which to exchange and disseminate risk information for both interorganizational and interpersonal coordination during disasters (Liu, Lai, & Xu, 2018; Jung & Park, 2014). This recognition stems from the fact that diverse risk information materials, such as pictures, audio files, and video clips, can be presented on the platform (Liu, Lai, & Xu, 2018; Jung & Park, 2014). Social media can be the closest avenue through which residents can engage in faster and easier information sharing in a network compared with traditional information channels. The real-time communication offered by such media can contribute to systematic disaster response that entails four emergency response functions that guarantee organized activities in the public sector: emergency assessment, hazard operation, population protection, and incident management (Lindell, Prater, & Perry, 2006). Considerable research has been devoted to risk communication networks (Yeo, Knox, & Jung, 2018; Reuter & Kaufhold, 2018; Olsson, 2014; Ressler, 2006), but few have involved developing comprehensive networks and integrated real-time information exchange among stakeholders into disaster response functions.

The effectiveness of response coordination is determined not only by resources for information sharing but also by the quality of information shared within emergency management networks (Kapucu, Arslan, & Demiroz, 2010). In South Korea, knowledge of what types of information are needed by emergency management networks or what issues they are required to address to respond to wildfire disasters remains underdeveloped. To fill this gap, this study examined the information exchange patterns of interorganizational networks in South Korea to determine how information flows in networks that respond to wildfires. It also looked into the structural characteristics of these networks to identify missing links in risk communication on social media. Finally, exploring risk information throughout a disaster response period, this study used a webometric network method to ascertain correspondence between the needs of multiple stakeholders and the information dissemination conducted in response to wildfires. This research extends knowledge of effective risk communication responses to potentially catastrophic events at both macro and micro levels by combining social media and semantic network analyses.

2. Emergency Response to the 2017 Gangneung Wildfire

Destroying over 340 hectares of forestland in Gangwon Province in the northeastern region of the country (Korean Forest Service, 2017), the wildfires occurring on May 6, 2017 in Sangju, North Gyeongsang, Samcheok, and Gangneung blazed for 72 hours before they were finally quelled. The fires caused extensive damage to property, with 550 residents left homeless and thousands having had to evacuate. About 81% of the expanse of Gangwon Province is covered in mountains, where the climate is characterized by the dry air and intense winds that exacerbated the fires that initially started at around 11 a.m. on a small hill in Dogye-eup, Samcheok-si in Gangwon and at 3 p.m. in Seongsan-myeon in Gangneung. A few months before the disaster, specifically in January 2017, the Korean Forest Service (KFS) had released its *Comprehensive Wildfire Prevention Strategy in the Country*, which encompasses prevention and mitigation programs and the use of big data in emergency response systems. The gaps in this strategy were highlighted by the wildfire disaster.

In Gangwon, strong winds and abnormally dry weather conditions reignited the wildfires, which then escalated into a substantially larger forest fire, threatening nearby cities and prompting the Gangneung city government to announce the evacuation of residents in six cities on May 6 at 6 p.m. According to the KFS, 28 helicopters and about 10,000 individuals were mobilized to combat the fires at 5 p.m.; nevertheless, they failed to extinguish the fires. Even though the agency borrowed helicopters from the National Emergency Management Agency

(NEMA) and the Army, the central government raised the alert to the highest level, “red,” only at 9 p.m. Then, Acting President and Prime Minister Hwang Kyo-ahn urgently instructed the government to mobilize every resource available in the country, such as the Ministry of Public Safety and Security (MPSS), the Ministry of National Defense, and local governments, to extinguish the fires. In the early morning of May 7, the KFS and the MPSS used every resource available to establish an emergency response and support headquarters to facilitate the coordination of relief efforts. The KFS reported that the major fires had been extinguished at 10:40 a.m., but this report was amended less than two hours later, as winds reignited the coals. In the battle to suppress the wildfires, one member of a helicopter crew lost their life and two others were hospitalized.

Criticisms after the 2014 Sewol ferry disaster were aimed primarily at the lack of a centralized command center for coordinating the emergency response initiatives of emergency management stakeholders. In an effort to resolve the ineffective coordination between emergency networks in the emergency rescue debacle associated with the Sewol disaster, the MPSS was established as the hub for emergency response to natural and manmade disasters. The ministry is responsible for sending emergency alerts, but none of the residents received notifications from the agency during the Gangneung wildfire. The MPSS maintained that they were supposed to send text messages alerting the residents when the KFS, Gangwon Province, or the city of Gangneung requested warning texts from the central government. They sent out messages on May 8. Despite the rapid spread of the fires and the destruction of homes, no official announcements from any government agency were broadcast by the national public broadcasting system. As a result, unconfirmed information circulated on social media, fomenting confusion and chaos among residents. During the entire wildfire period, the social media platforms of government organizations responsible for emergency response posted content irrelevant to the disaster.

Table 1

Hazard Operations by Governmental Agency Responders

Date	Time	Responder	Operation
May 6	11:42	KFS	Fire started in Dogye-eup, Samcheok-si
	15:27		Fire initiated in Seongsan-myeon, Gangneung
	17:30		Dispatched 28 helicopters of KFS
	18:00	Gangneung City Government	Instructed residents in six towns of Gangneung to evacuate to shelters
	21:00	KFS	Lifted the alert level to the highest "red"
	23:00 (estimated)	Office for Government Policy Coordination	Prime Minister urgently ordering the government to carry out operations and mobilize every resource available in the country
May 7	04:30	KFS	Dispatched 59 helicopters from KFS (29), NEMA (5), and the Army (14); 40 sprinkler trucks; 73 fire engines
	06:00	KFS	Established the Central Headquarters for Disaster Relief
	08:00	MPSS	Established the Central Headquarters for Disaster Assistance
	10:40	KFS	Reported major fires in Gangneung and Sangju as extinguished
	19:00	KFS	Full alert activated because of wildfire recurrence at night
May 8	10:02	MPSS	Sent out Emergency Cell Broadcast messages about the disaster
	11:48	KFS	Lost a helicopter crew during firefighting operation
May 9	05:20	KFS	Dispatched 35 helicopters and over 6900 personnel
	11:20	KFS	Completely extinguished the wildfires

Source: adapted from Jung & Park (2016, p. 134)
* KFS = Korean Forest Service; MPSS = Ministry of Public Safety and Security; NEMA = National Emergency Management Agency

3. Theoretical Frameworks

3.1 Organizational emergency response function

As the dynamics of a hazard increase the complexity and uncertainty of emergency responses, a systematic framework for such a purpose can advance the provision of resources critical to collective operations and effectively ensure immediate response to a catastrophic event (Jung &

Park, 2016). To counteract deficiencies in resources or capabilities on the part of individual organizations, interorganizational collaboration is carried out not only among non-profit agencies but also between each department within a government or between local and federal governments. As emphasized by Lindell, Prater, and Perry (2006) and Jung and Park (2016), successful emergency response structures serve four functions—emergency assessment, hazard operation, population protection, and incident management—which shape the roles of individual organizations and guide effective coordination in disaster response and planning among multiple emergency response agencies on the basis of each entity's expertise. Given that collective responses begin with successfully detecting potential threats, emergency assessment should be deployed to determine the actions that diverse stakeholders should take in subsequent response procedures (Lutz & Lindell, 2008). Under unexpected and complex disasters, accurate emergency assessment reduces uncertainty by producing intelligence regarding the magnitudes and potential effects of these occurrences and the communities anticipated to be affected by them.

Lindell, Prater, and Perry (2006) suggested that well-designed incident management specifies *internal direction* and *control with notification*, channels and mechanisms for notifying relevant stakeholders (first responders and affected populations), and *the manner by which physical and human resources*, such as volunteer firefighters or emergency facilities/equipment, *are mobilized* and *deployed* in a timely manner during analysis/planning. Because authorities and responsibilities are often fragmented government structures, collective action problems, such as work duplication, ineffective coordination, and inaction, arise from division in duties (Feiock, 2013; Jung, Song, & Park, 2017). To avoid blame under increasing uncertainty, risk-averse bureaucrats, who exercise relatively high degrees of discretion in decision making regarding hazard operation and incident management, may perform a defensive routine under a diffusion of responsibilities (Lutz & Lindell, 2008; Jung, Song, & Park, 2019). Thus, the incident management function defines authorities and responsibilities across relevant organizations in predetermined plans for preventing structural gaps in risk communication networks (Burt, 1992). *Channels and mechanisms* develop along with chains of internal direction and control.

A risk communication network alerts first responders to hazard operation operations and disseminates risk information to other support teams, such as technical support groups for the *analysis/planning* involved in incident management (Lindell, Prater, & Perry, 2006). Risk communication is especially important in terms of resource mobilization because resources and abilities to respond to a catastrophe vary across emergency response agencies and target populations in affected areas. Accurate emergency assessment identifies what each agency needs, thus enabling stakeholders to determine resource allocation and request further assistance from joint networks. Real-time communication allows updates to data on environmental conditions and characteristics of hazard agents that help modify what and how operations for hazard mitigations are conducted to remove wildfire hazards (Lindell, Prater, & Perry, 2006). The sharing of risk information and judgments concerning threats and hazards is underlain by the assumption that sources of information provided to emergency agencies are trustworthy; inaccurate assessment, miscommunication, or limited access to risk information due to poor incident management impedes rapid and effective resource mobilization and mitigation for the elimination of wildfire sources. These shortcomings also cause further devastation and negative effects on local communities (Kapuçu, Arslan, & Collins, 2010).

In terms of population protection, the population monitoring and assessment involved in emergency assessment includes understanding the motivations and behaviors of target populations (Lindell, Prater, & Perry, 2006). Even when detailed characteristics of a threat are identified, the lack of resources, risk perceptions, and low levels of trust in government-relayed information can influence the compliance of target populations with governments' protective measures, such as following hurricane evacuation orders, social distancing, and wearing a mask (Elder et al., 2007; Thompson, Garfin, & Silver, 2017). Sending warnings with accurate risk information is critical for emergency preparedness among residents, but an important task is to deliver tailored information. In particular, individuals with special needs, including the elderly, disabled individuals, and children, must be better informed regarding the timing and location of evacuation, emergency communication channels that track protective actions, and alternative ways to sustain resources, such as food, transportation support, and medicines (Lindell, Prater, & Perry, 2006). The research claimed that even as appropriate protective actions are implemented, the urgency of circumstances and dynamics of hazard agents call for effective mutual communication, which can help accommodate heterogeneous needs and prevent unnecessary damage to the aforementioned minority groups.

3.2 Interorganizational collaboration and risk communication

Wildfire disasters have called considerable attention to multidisciplinary approaches as the effects of these phenomena have become catastrophic (Smith et al., 2016; Ansell, Boin, & Keller, 2010). Sidle et al. (2013) urged the systematic assessment of both environmental and socioeconomic drivers to prevent the devastating consequences of natural disasters, while Reyers et al. (2015) analyzed how diverse actors form a knowledge community to disentangle interdependent social–ecological systems of wildfires in an urbanizing area. Evolutionary perspectives view fire as indispensable to living creatures on earth, and even wildfires were not included in policy agendas as disastrous issues until the early 2000s (Smith et al., 2016; Agee, 1993; Bond, Woodward, & Midgley, 2005). As wildfires intensify and occur more frequently because of climate change, the failure to address these phenomena has brought significant consequences to ecosystems and human communities (Bowman et al., 2009; Westerling et al., 2011). These negative effects may be exacerbated, and disproportionate outcomes for under-resourced communities may be generated under poor urban infrastructure, ineffective emergency management, and ineffective collaborative governance, especially in urban environments, where current public services—from water, electricity, housing, food, and education to transportation, business, and public safety—are highly interconnected (Wilson, McCaffrey, & Toman, 2017; Nowell et al., 2018).

Wildfire disaster management involves a broad range of policy areas, such as environmental protection, sustainable development, land use management, emergency management with collective actions across government agencies, and private property rights. The physical dimensions of wildfire disaster management cover how fire affects the ecosystem, whereas its societal components entail considering how rapid urbanization places human habitation at risk of fire. Policy interventions in one area can affect related fields or the well-being of other communities (Vespignani, 2010). Working with multiple stakeholders, organizations in a fragmented network of relevant fields are often unsure about identifying suitable partners in developing the quality of information or acquiring resources that reinforce local capabilities. These issues were evident in the impact of Hurricane Katrina, which revealed the ineffective coordination of interorganizational collaboration responses and conflicts in resource allocation that arose from decision making on priorities across stakeholders or jurisdictions; the conflicts were due to the fact that the effects of disasters often transcend geographical jurisdictional boundaries (Ansell, Boin, & Keller, 2010). Under extreme uncertainty and resource shortage, humans are less likely to be cooperative or prosocial, that is, feel safe and comfortable when surrounded by individuals whom they trust or with whom they share similarities (homophily) (McPherson, Smith-Lovin, & Cook, 2001). Strong ties in effective communication structures help reduce potential collaboration risks or address coordination problems, thus facilitating a collaborative response to disasters (Jung, 2017; Nowell & Steelman, 2014).

Whereas centralization may fail to adapt to local demands for collaborative emergency management in addressing disasters such as Hurricane Katrina, bridging among actors is pivotal in facilitating information flow across organizational, sectoral, and geographical boundaries (Faas et al., 2017; Waugh & Streib, 2006). For population protection, trust and homophily among residents of affected areas are critical elements when undertaking an evacuation during large wildfires. Faas et al. (2017) argued that residents tend to rely on risk information from trusted and familiar sources, even if they know little about the quality of these sources (Fitzpatrick & Mileti, 1991; Steelman et al., 2014; Velez, Diaz, & Wall, 2017). Such interactions entail resource- (Demiroz, Kapucu, & Dodson, 2013) and task-interdependent networks (Bodin & Nohrstedt, 2016), reciprocal rather than unilateral cooperation structures (Jung, Song, & Park, 2019), bonding strategies for collaborative networks (Jung & Song, 2015), and resource seeking from centralized actors (Choi & Brower, 2006; Andrew & Carr, 2013). Hu, Knox, and Kapucu (2014) found that central players were part of a joint network that responded to the Boston Marathon bombing. Moreover, dissimilar actors can be connected for resource redundancy under wildfire disasters with complex characteristics (Jung, Song, & Feiock, 2017; Faas et al., 2017).

Risk communication can occur in three ways: between emergency response organizations, between residents/citizens, and between organizations and residents/citizens. Kim, Yoon, and Jung (2017) found that in national government-oriented networks, the response to transboundary infectious diseases involves local agencies actively seeking information by communicating with neighboring jurisdictions when action from the national government is constrained. This limitation may result from bureaucratic rigidity—the same one that drove the Korean government's failure to send warning messages to victims during the Gangneung wildfire (Jung, Song, & Park, 2017). During the tragedy of the World Trade Center, non-formal actors could coordinate within radio communication networks (Petrescu-Prahova & Butts, 2005). Previous studies on interorganizational collaboration in emergency management examined how organizations work together and share information across networks, what patterns typify such collaborative interactions and what structural characteristics underlie risk communication, and how actors are driven to ensure effective information exchange across multiple organizations (Jung & Park, 2016). However, little attention has been paid to the content of information or messages that are constructed for information exchange in centralized wildfire disaster management, balance between diverse interests, and resolution to conflicts during the response phrase.

3.3 Social media and semantic networks in emergency management

Risk communication networks involve not only government agencies—local and central emergency management—but also populations in affected and potentially affected areas (Aldoory, Kim, & Tindall, 2010; Aldoory & Sha, 2007; Binder et al., 2011; Grunig, 2003); this means "an interactive process of exchange of information and opinion on risk among individuals, groups, and institutions" (The National Research Council, 1989, p. 12). The diversity of stakeholders in risk communication networks translates into differences in the ethical principles, organizational cultures, and religious customs that affect emergency response coordination (Yeo, Knox, & Jung, 2018). An insufficient understanding of these differences can cause conflicts of interest; thus, further research on effective risk communication strategies is needed to address the barriers to effective coordination in the aforementioned networks (Andrew, 2009; Jung, 2013; Jung, 2017).

During disasters, a useful task is to identify what the public needs and infer what problems are missed in the disaster response phase. Semantic network analysis uncovers what key issues or concerns about ongoing hazards should be addressed by emergency responders and how these salient frames of messages are associated among multiple stakeholders in risk communication related to coping with disasters (Jung & Park, 2015; Liu, Lai, & Xu, 2018). One way of communicating risk is through social media platforms, such as Twitter and Facebook, as these allow an individual user to interact with government agencies during a catastrophic event. In the transmission of real-time information, social media provides various stakeholders with critical details about hazard operation, population protection, and locations that aid the search and rescue of underrepresented residents (Bird, Ling, & Haynes, 2011). Recent cases demonstrated the effectiveness of social media as a risk communication tool; examples are the 2010 Haiti earthquake and the 2011 Fukushima nuclear accident, during which hazard-related information was rapidly disseminated, thereby minimizing casualties (Cho, Jung, & Park, 2013; Jung & Park, 2014; Spong, 2011). Given that disasters destroy telecommunications infrastructure, it is challenging for leading government agencies to maintain real-time updates. They have access to various other risk communication channels, such as text messaging, mobile apps, and online websites, but some of these platforms can be poorly maintained amid unanticipated catastrophes.

The growing salience of a given issue can exert social pressure on governments to respond to public opinion and disseminate formal risk information to local communities in a timely manner. During the 2017 Gangneung wildfire, the formal risk communication networks between emergency responders and target populations appeared relatively closed because of the elections occurring that year. In such a case, semantic network analysis can help detect whether public awareness is raised through tactics such as pinpointing relevant discussions and amplifying the emotions of victims or residents to attract the attention of elected officials (Song et al., 2019). Moreover, because wildfire disasters have been minimally highlighted in South Korea, semantic analysis can identify relevant stakeholders' collective cognitive structures that help reveal how these disasters are framed or how the public perceive them (Jung, Song, & Park, 2017; Jurgens & Helsloot, 2018; Yeo, Comfort, & Jung, 2018). This task is critical, as it advances the design of policy tools or intervention that best guarantees compliance and mutual understanding between policymakers and policy beneficiaries. This advancement, in turn, is advantageous to both hazard operation and population protection.

4. Research Design

4.1 Methods

This research investigated the patterns of risk communication among emergency response networks on social media during the 2017 Gangneung wildfire. From a macro perspective, we explored collaborative networks to identify the major stakeholders of such systems and the structural characteristics of wildfire risk communication, such as vertices, edges, and edges with duplicates on social media. Collecting real-time data from social media, we delved into whether public safety was effectively secured through principal emergency response functions. Considering all active organizations with a social media presence, the analysis enabled us to capture multi-level interactions between emergency response stakeholders and key actors. The social network analysis treated each social media user as a stakeholder and reported subgroup structures as a cluster in the risk communication networks of interest (Jung & Park, 2016; Sams, Lim, & Park, 2011). Users who posted tweets that included a keyword and responded to posts were regarded as part of a node in a network matrix. We documented not only original tweets but also retweets and Twitter mentions containing a keyword to measure the edges (or links) among users as interactions in the risk communication networks (Yeo, Knox, & Jung, 2018). The interactions occurring via retweets or responses to original tweets were assigned a code of 1 (Jung & Park, 2014).

A semantic network analysis is useful for capturing thematic frames in strategic approaches to emergency response (Diesner & Carley, 2011; Jung et al., 2015). This method involves constructing a network matrix and recognizing a word as a node; basically, interaction is used as grounding for measuring the co-occurrence of a keyword in a tweet. Given that the quality of information flows in a network determines successful emergency response, this research shed light on whether risk communication during the Gangneung wildfire encompassed the four emergency response functions. The approach enabled us to detect semantic patterns of information exchange under the dynamics of the risk communication networks with comprehensive cognitive structures of key issues (Jung & Park, 2016). Taking potential selection bias on social media platforms into account, this study scrutinized social media keyword content related to the disaster as well as news articles from online media outlets and official documents.

4.2 Data collection

In the collection of real-time social media data during disasters, a widely used technology is NodeXL, which allows observations of network structures and patterns of communication between diverse actors on Twitter (Hansen, Shneiderman, & Smith, 2011). Social media data were collected from Twitter from May 6 to 11, 2017 to identify the risk communication networks at play during the disaster; the keyword used for such a purpose was “wildfire” (in Korean). Drawing on only tweets written in Korean, we examined each URL attached to such posts to identify information sources, that is, whether the tweets were extracted from government or individual social media accounts, as well as what types of actors responded in real time to the wildfires, as identified in the dataset, during the disaster period. NodeXL was also used to import datasets into Excel, enabling the visualization of “reply-to” or “mentions” in tweets between actors in the risk communication networks. The method also enabled the examination of the structural attributes of a Twitter network, such as one-way or mutual interactions (Jung & Park, 2014).

For the semantic analysis, this study used a big data solution called *Textom* to collect textual data from online news articles that mentioned the keywords of interest over the analysis period. The textual data from Twitter were also imported into Textom. Eliminating special characters and the postposition of nouns, Textom measures the frequencies and distances of word co-occurrence (Jung & Park, 2014). For example, the keyword “Gangneung-si” was modified into “Gangneung,” as *-si* is simply a denotation for “city” in Korean. For visualization, we selected the 20 most frequently appearing words and word pairs on the basis of the descriptive statistics obtained using Textom. Two of the major search engines in Korea, Naver and Daum (equivalent to Google), were used to extract words and estimate relational meanings of co-occurring words within texts. Textom calculates centralities of network connections on the basis of eigenvector values (Cha, Rhee, & Chung, 2017). High values of eigenvector centrality reflect the extent to which a word is positioned at the center of a semantic network structure. It is assumed that a central word is more influential than other words (Cha & Kweon, 2015).

5. Findings
5.1 Macro-network analysis: risk communication

Table 2 shows the May 6 to 11 descriptive statistics of the risk communication networks. Overall, there were 14,569 vertices and 18,282 edges in the connected components from the time the fire started to the end of the incident management period. A total of 17,738 unique edges indicated that users communicated without duplicating their interactions.

Table 2

Descriptive Statistics of Risk Communication During the Disaster

Graph Metric	Statistics
Vertices	14569
Unique Edges	17738
Edges with Duplicates	545
Total Edges	18283
Reciprocated Vertex Pair Ratio	.0001
Reciprocated Edge Ratio	.0002
Connected Components	174
Single-Vertex Connected Components	111
Maximum Vertices in a Connected Component	14184
Maximum Edges in a Connected Component	17739
Maximum Geodesic Distance (diameter)	12
Average Geodesic Distance	3.596691
Graph Density	.00008

Figure 1 illustrates the periodic changes in total interactions over the risk communication networks on Twitter. The vertex parameter decreased from 187 (from May 6 to 7, 2017) to 54 (from May 8 to 9, 2017) but grew exponentially from May 10 to 11, 2017. Because of inaccurate hazard assessment, the KFS had prematurely reported that the wildfires had been extinguished on May 7. Many individuals and organizations had also become less interested in the disaster and were not maintaining risk communication with emergency response networks via Twitter; these developments were prompted by the presidential elections slated on May 9 following the impeachment of former President Park Geun-hye. After the presidential inauguration on May 10, newly elected President Moon Jae-in instructed the government to assume a pivotal role in disaster management, after which the indices rose again from May 10 to 11, with people refocusing on disaster risk communication.

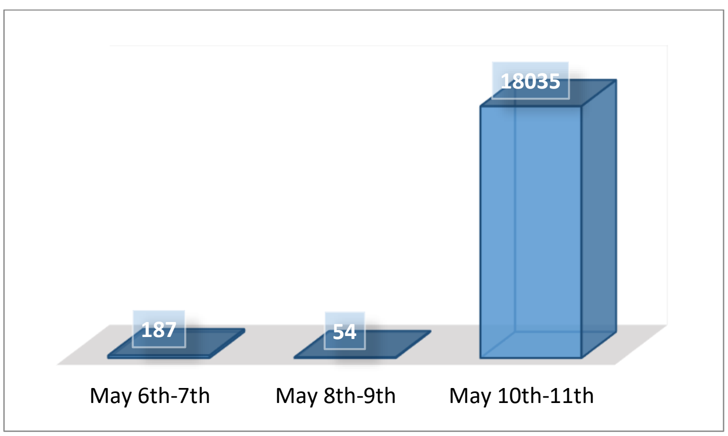

Figure 1. Changes in risk communication network: keyword for “Wildfire” in Korean

Figure 2 presents the risk communication structure in operation during the emergency response. Communications within Groups 1 to 3 dominated in the networks, but few multiple interactions occurred between two vertices. Group 1 transmitted information primarily about the volunteer firefighters at Gangneung Fire Station who were combatting the blaze throughout the disaster period. By law, the firefighters should serve for a maximum of four hours a day, but they were relentlessly engaged in the operations with little additional reimbursement and poor equipment. As part of incident management, the local Gangwon government mobilized the volunteer firefighters available to them to mitigate the hazard, but they could have been in considerable danger.

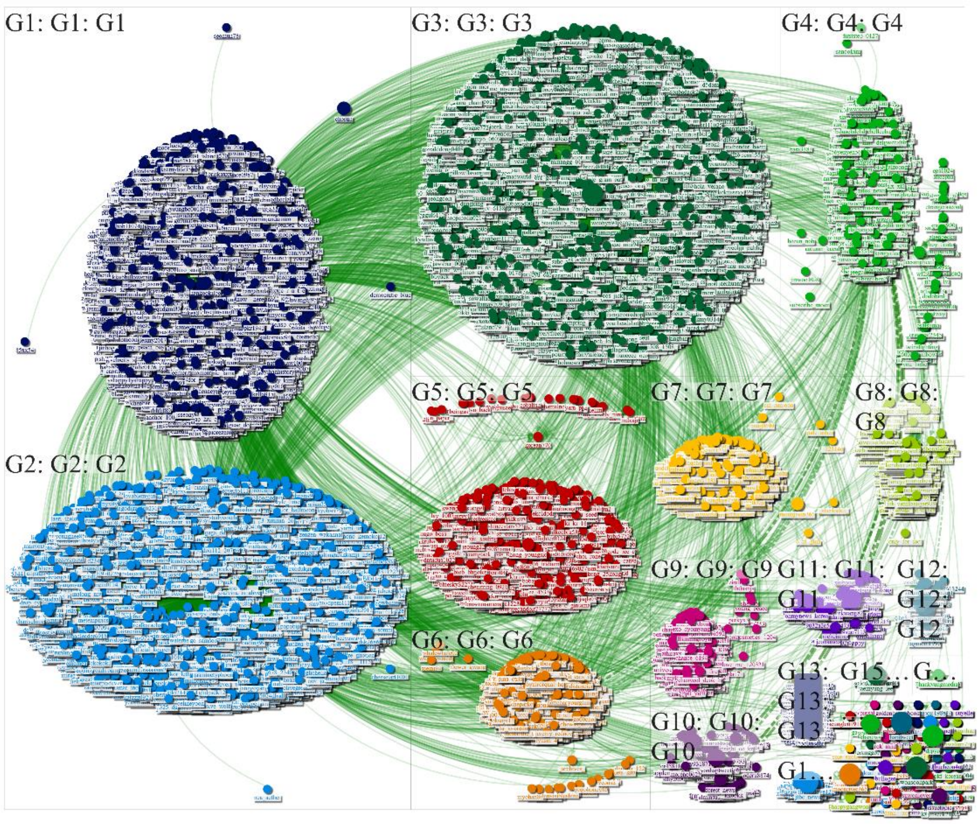

Figure 2. Risk communication structure for the 2017 Gangneung Wildfires

One of the most active URLs in the Group 2 interactions was related to fundraising for residents, whereas the majority of the most active URLs in Group 3 revolved around reports about the funeral of a helicopter crew who was killed during the firefighting operation. Similar to Group 1, these groups tended to center on disseminating information that was irrelevant to hazard agents, mitigation operation, or evacuation. The National Institute of Forest Science was the most frequently mentioned Twitter account in Group 4, but none of the most frequently mentioned formal emergency response agencies appeared in Groups 2 and 3. None of the official government agencies were identified as top Twitter users across the three groups.

Group 4 exhibited 163 edges with duplicates, which was the most frequently occurring index among all the groups. In terms of hazard operation, the stakeholders in Group 4 actively communicated within the group, exchanging information about fire extinguishing operations. These social media network visualizations demonstrated that each individual was sensitively interacting with others by sharing hazard information during the emergency response phase (Table 3).

Table 3

Wildfire Disaster Response Network by Subgroups

Clusters	Vertices	Edges with Duplicates	Total Edges
G1	3390	13	3406
G2	2774	14	2791
G3	2578	2	2580
G4	1278	163	1383
G5	1120	3	1126
G6	836	0	841
G7	682	2	685
G8	370	0	424
G9	365	0	368
G10	247	19	268
G11	228	12	246
G12	132	206	401
G13	117	166	262
G14	64	3	67
G15	53	0	55

5.2 Micro-network analysis: semantic analysis

Figure 3 reports the semantic interconnections within the wildfire risk communication networks on social media during the disaster response. Responses to the hazard that were relevant to the central government contained the words “Moon Jae-in” (recently elected president), “president,” and “government,” as well as words associated with local leadership, such as “Choi Moon-soon” (Gangwon governor) and “Gangwon governor.” The MPSS is the national government agency that serves as the control center in the emergency management system of Korea. As previously stated, one of its main tasks is to send out emergency alerts and coordinate responses with local governments. In the Gangneung wildfire event, the KFS, which is also a central government agency, managed the emergency response in coordination with the Gangwon local government. However, as Figure 3 indicates, no attention was paid to population protection or evacuation in risk communication. These deficiencies pointed to a persistent missing link in emergency response functions in South Korea, despite its tremendous emphasis on population protection since the Sewol ferry accident, during which a significant number of passengers could not be rescued. In terms of incident management, the MPSS failed to send out emergency alerts to residents and the public in the initial emergency response phase; no disaster service was established at the Korean Broadcasting System, Korea's main disaster broadcasting station, and no information about the hazard were provided by government emergency response agencies on their social media feeds. This lack of attention to public information aggravated the situation by creating confusion and chaos in communities; more individuals could have fallen victim to the disaster because of the shortfall in risk communication to the public.

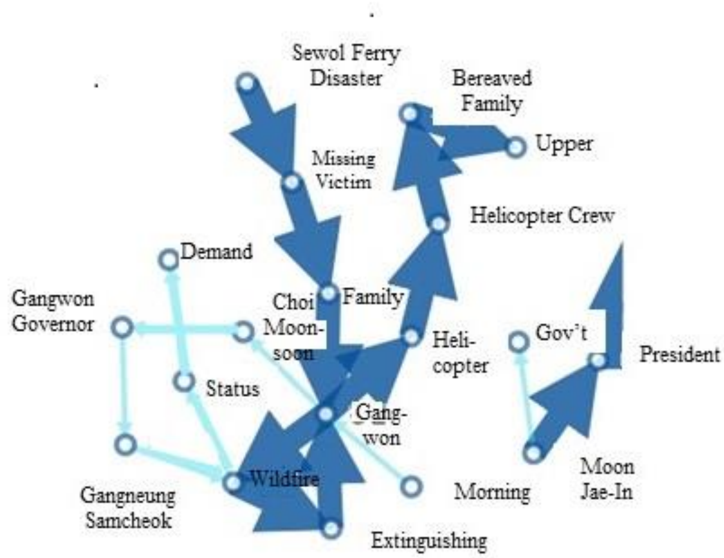

Figure 3. Social media risk communication semantic analysis

Figure 4 shows the characteristics of the semantic network risk communication occurring during the disaster; these characteristics were determined on the basis of the data derived from online news media articles that featured the keyword "wildfire" (in Korean). As discussed in the preceding paragraphs, the core risk communication content was the volunteer firefighters from the Gangneung Fire Station. In South Korea, each local government employs its own firefighters, so access to human resources, facilities, and equipment for responding to hazards varies depending on local government finances. In particular, the Gangwon Fire Department tends to rely on civilian volunteer firefighters because of a shortage in paid firefighters. In the 2017 wildfire, the volunteers were instrumental to firefighting efforts, even though they were overworked and lacked adequate resources. Because they could render service for only four hours, as mandated by law, they were reimbursed for only this period per day (about $11 per hour), despite being compelled to work longer hours to ensure public safety. Because of this situation, the public started lobbying to amend policy to improve quality of life among firefighters. This situation also cast light on another missing link in incident management in South Korea.

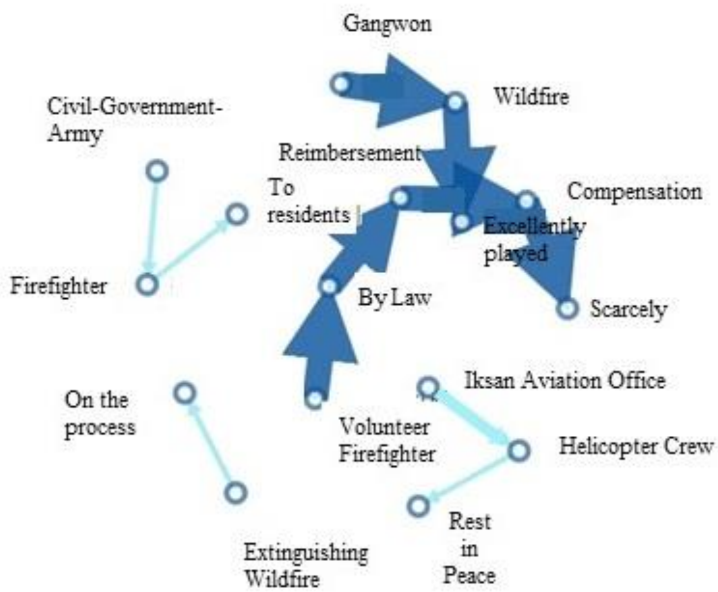

Figure 4. Semantic analysis on risk communication from online new media

6. Conclusions and Implications

This research explains the patterns and structural characteristics of the risk communication network during the response to the 2017 Gangneung wildfire. Effective communication in interorganizational collaboration networks has been recognized as a critical aspect of coping with natural disasters, but insufficient effort has been devoted to addressing how risk information is exchanged and how it aligns with local demands, along with how stakeholders manage the four emergency response functions (FEMA, 2013; Purpura, 2007; Ressler, 2006; Jung & Park, 2014). Capturing the dynamics of emergency responses by collecting real-time data and documenting other types of information, this study identified missing links between the risk communication and emergency response functions served by various stakeholders during the wildfire crisis.

The analysis of the risk communication networks on social media showed that inaccurate hazard assessment led people to overlook the severity of the disaster and that there was minimal information flow among stakeholders. The inefficient information dissemination created confusion among affected residents, who were relying on risk information from social media. The small number of multiple connections within subgroups suggested that each actor in the networks merely transmitted information rather than satisfying the needs of the community in the affected areas. Despite the urgency of the wildfires, the information disseminated online heavily dealt with non-hazard-related information, such as fundraising. Furthermore, although emergency response became centralized and social media usage by the government increased, formal emergency agencies failed to capitalize on such platforms for risk communication. Changes in risk communication networks over time imply that when other salient issues, such as presidential elections occurring in conjunction with disaster response, social media may not be able to help elicit attention from policymakers, even when public disclosure online is facilitated for risk communication. This possibility indicated that emergency assessment, communication in incident management, and population protection functions were insufficiently incorporated into the Gangneung wildfire disaster response.

The semantic network analysis contributed to the matching of risk information with the needs of potential victims. The results suggested that despite the many efforts expended after the Sewol ferry accident, hazard operation operations continue to inadequately address population protection. The findings also revealed that emergency responders in the public sector have failed to perform agency notification, as part of the incident management function, even as the capacity of social networks for emergency response has been growing (Jung & Park, 2014). Notwithstanding the promise held by the introduction of social media to emergency management networks in aiding coping with wildfire disasters, the use of these platforms have been confronted with numerous problems because of poor utilization and maintenance (Andrew, 2009; Jung, 2013; Jung & Song, 2015; Kapuçu, Arslan, & Collins, 2010). Lacking effective risk communication systems, the newly founded MPSS was unsuccessful in coordinating with the KFS and Gangwon local government, resulting in the initial failure to extinguish the fire and ineffective interorganizational emergency response. The semantic network analysis also indicated that the facilitation of self-organized networks can help governments overcome limitations in local capabilities during disaster response (Fedorowicz et al., 2014).

Employing data from social media helps illuminate real-time interactions in risk communication networks (Jung & Park, 2014). The social network analysis conducted in this research reflected that authorities were met with difficulties in limiting the geographical boundaries of the risk communication networks to within the affected areas; thus, the failed emergency alerts drove the residents to rely on external communication through social media.

The main limitations of this study include the fact that the social media analysis did not specify geographical information about information senders and receivers, which prevented us from inferring whether risk information successfully flowed from outside to the local communities in the affected areas. Future studies on risk communication networks will also need to address the digital divide confronting marginalized groups, who lack access to a device and may therefore be unable to access risk information in the first place. Risk communication networks based on webometric data may fail to identify actors who do not use predetermined keywords and exclude stakeholders who have no access to or do not use social media. Finally, although this research approached risk communication patterns using two lenses, drawing a causal inference was challenging because no experimental research designs were employed. In conclusion, more studies should be conducted to develop the methodology introduced in the current work to clear the way for examining implications for the development of effective risk communication networks through the construction of more extensive networks or the resolution of structural gaps.

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