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Unpacking the Network Processes and Outcomes of Online and Offline Humanitarian
Collaboration

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Abstract

Employing a bona fide network perspective, this study investigates the network processes and outcomes of organizational collaborative networks before and following Typhoon Haiyan, taking into account the influences of network factors, organizational attributes, and environmental exigencies. The analysis from an online survey with relief organizations and those organizations' Twitter data showed the consistent influence of past relationships on the formation of subsequent relationships after the disaster. In the on-the-ground network, a few highly active organizations stood out and engaging in multiple modes of communication with resource contacts were seen as an adaptive practice that helped organizations to build resource ties after the typhoon. In the online domain, organizations developed a post-typhoon network by means of becoming directly linked to one another and becoming equally resourceful in building their ties. Additionally, different forms of resilience were observed as outcomes of collaborative networks. Findings of this study present theoretical and practical implications by unveiling the network dynamics of contemporary humanitarian actions.

Keyword: organizational collaboration, network analysis, disaster response, social media, voluntary sector

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Disaster represents a condition under which both formal and informal methods of collaboration are likely to materialize. This is shown to be true for the voluntary sectors, which are part of the civil emergency response system for pre-disaster planning, disaster response, and post-disaster aid (Adger, Quinn, Lorenzoni, Murphy, & Sweeney, 2012). Voluntary sectors may include societal institutions (e.g., religious groups, professional associations), non-governmental organizations (NGOs), non-profit organizations (NPOs), media, and/or business communities (Taylor & Doerfel, 2011). Citizens may resort to humanitarian aid by voluntary sectors due to a lack of confidence in government support. In addition, online and social media have been an important foundation of various self-organized and voluntary emergency efforts in social movements and disaster contexts (Starbird & Palen, 2012). After Hurricane Katrina, for example, a wiki was used by people around the world to mobilize and coordinate rescue efforts (Majchrzak, Jarvenpaa, & Hollingshead, 2007). Similarly, NPOs and news organizations also adopted social media to disseminate information after the 2010 Haiti earthquake (Muralidharan, Rasmussen, Patterson, & Shin, 2011).

While these aforementioned studies have documented the usefulness of online and social media for collaborative emergency responses, most research on disaster and social media is focused on how individuals and relief organizations adopt new technologies for online emergency response (Landwehr & Carley, 2014). Little is known about the process of how these collective relief efforts come into being and change over time outside the online domain. Moreover, most studies on organized collaboration in the voluntary sector rely on one-time observations (e.g., Guo & Acar, 2005; Nolte & Boenigk, 2013), with a few exception such as

Schumate, Fulk and Monge (2005) and Lee and Monge (2011). A longitudinal and systematic understanding is imperative because it can identify whether and how the organized efforts are robust and sustainable beyond a one-time event, across both online and offline domains.

To address these gaps, the study examines the relief organizations involved in Typhoon Haiyan in the Philippines, with the aim of understanding the evolving processes of those relief organizations' different forms of collaborative networks across online and offline domains. Typhoon Haiyan hit the Philippines on November 8, 2013, causing physical devastation as well as 6,000 deaths; more than 16,000,000 people and 57 cities across the nation were affected (NDRRMC, 2014). In the disaster-prone Philippines, international or cross-geographic relief efforts are particularly salient (Luna, 2001). Following the 2011 Haiti earthquake and 2012 Hurricane Sandy, the use of social media has become an important source for organized relief efforts (Landwehr & Carley, 2014). Together, these facts establish Typhoon Haiyan as a solid case to investigate the contemporary form of organizational collaborative networks for humanitarian response actions.

This study aims to answer the following questions. First, what contributes to the formation of organizational collaborative networks in the disaster response context, and how are these collaborative networks sustained over time? Second, what are the consequences that result from sustained collaborative networks? Because of the study's consideration of both environmental exigencies and network factors in organizational collaboration, we used Cooper and Shumate's (2012) bona fide network perspective as the conceptual foundation to examine the network processes and outcomes of relief organizations' collaborative networks across online and offline domains, taking into account the influences of network factors, organizational attributes, and environmental exigencies. Specifically, in this study, we examined two types of

organizational collaborative networks in the disaster response context: the resource network constructed by the relief organizations following Haiyan, and those relief organizations' online humanitarian networks built and maintained on Twitter before and after Haiyan. In developing the hypotheses and research questions, we differentiated these two networks as *the resource network on the ground* and *online humanitarian networks*, respectively.

This study contributes to communication research and practice in the following ways. First, drawing on the bona fide network perspective and the concepts of embeddedness and homophily, this study examines both the structural and attribute-based influences on the formation and evolution of disaster relief networks across online and offline domains. Rather than focusing on the attribute-or geography-based enablers or constraints, findings of this study suggest the importance of relationship building in the organizing of post-disaster relief networks. Second, by integrating the bona fide network perspective and the theory of media multiplexity, this study enriches the conceptualization of multimodal communication as an emergent and robust practice enacted by relief organizations after a disaster. Findings of this study revealed that engaging in multimodal communication with external resource contacts facilitated connections to the same resource contact types. Third, this study proposes to examine resilience as a type of outcome for humanitarian collaborative networks, which is especially salient in disaster-prone regions and countries. Last, this study makes a major methodological contribution by using a mixed-methods approach and encompassing cross-sectional and longitudinal data in examining bona fide humanitarian organizing networks.

This paper first reviews the bona fide network perspective and related theories, then explains the development of hypotheses and research questions. Detailed procedures of how to obtain and process multiple sources of data are provided in the methods section. The results of

the analyses are presented, with the aim of enhancing theoretical and societal understandings about the evolving collaborative networks across online and offline domains in the context of disaster response.

Network Mechanisms and Outcomes of Humanitarian Collaboration

As an extension of the bona fide group perspective (Putnam & Stohl, 1990), the bona fide network perspective emphasizes the following characteristics: 1) network boundaries are blurred; 2) interorganizational networks are embedded in a complex environment; 3) interorganizational networks are multifaceted and multiplex, and different relationships influence one another; 4) networks are dynamically restructured over time; and 5) outcomes of networks occur at both individual organization and whole network levels. Essentially, the bona fide network perspective posits that interorganizational collaboration is influenced by environmental exigencies and network factors (Cooper & Shumate, 2012). Disaster can be a type of triggering event to affect these collaborations. Similar to the situation of social movements, in the disaster context, having access to tangible (e.g., goods, money, volunteers) and intangible (e.g., information) resources is necessary, and the ability to mobilize these resources usually comes in the form of connecting to pre-existing networks and reliance on the timely support from other organizations (McCarthy & Zald, 1977).

Applying this bona fide network perspective, Cooper and Shumate (2012) investigated the antecedents (types of NGOs), processes (environmental constraints, multiplex relationships), and outcomes of collaboration at organizational (centrality, offering more and varied services to clients) and network levels (gains in systemic capacity). Yet as much as the bona fide network perspective offers a flexible and systematic way of accounting for diverse forms of organizational collaboration, it does not delve into or provide theoretical reasons for the

underlying network processes of organizational collaborative networks. To fill the void, we draw on the concepts of embeddedness, homophily, and media multiplexity to explain the network factors that influence the formation of bona fide collaborative networks among disaster relief organizations. We follow this with the delineation of network outcomes as a result of collaboration.

Embeddedness and organizational collaboration networks. In the disaster context, prior network relationships among organizations help the mobilization of emergent disaster response networks even though those relationships are not emergency-related (Robinson, Berrett, & Stone, 2006). The influence of network relationships on social and organizational behaviors corresponds with the concept of embeddedness, which includes *relational, structural, and positional embeddedness* (Granovetter, 1992; Gulati, 1995; Gulati & Gargiulo, 1999). Essentially, embeddedness is closely linked to the notion of social capital, which refers to the resources inherent in social relationships that are accessed or mobilized for purposive actions (Lin, 1999). Similar to embeddedness, social capital may embody relational and structural dimensions of connections--how well organizations know each other and who organizations know and in what ways (Nahapiet & Ghoshal, 1998). Because of the lack of direct measures, we focus on structural and positional embeddedness in this study. We define these two types of embeddedness as follows, and make a theoretical linkage between each type of embeddedness and the relevant communicative and relational dynamics involved in organizational collaborative networks.

Operationally, *structural* embeddedness represents the extent to which an organization's structural position presents opportunities for new tie formation and this could take different forms. In response to a disaster event, organizations often tapped into their previous networks;

knowing that someone in the network was safe and ready to resume operations motivated them to rebuild their own operations as well (Doerfel, Lai, & Chewning, 2010). Research has shown consistent findings that organizations' past relationships are likely to predict the formation of future ties (Lee & Monge, 2011; Shumate et al., 2005). The first hypothesis thus examines the influence of relief organizations' structural embeddedness in the post-disaster network, or the influence of previously established relationships on subsequent relationship building.

H1: The relief organizations that have established ties with resource contacts on the ground are more likely to continue those resource ties in the later phase of disaster relief than change to new resource ties.

H2: The relief organizations that have connected to each other online are more likely to continue those connections online in the later phase of disaster relief than change to new connections.

Structural embeddedness is also observed through the dynamics of closure, that is, pair of organizations with shared partners from past ties became embedded and central in a densely clustered group (Granovetter, 1992; Gulati & Gargiulo, 1999). In particular, being embedded and central in a densely clustered group has been linked to corporate success and the ability of an organization to face crisis or uncertainty (Gabbay, Talmud, & Raz, 2001). Such a clustering network structure is also believed to help a focal organization guard against threats to survival (Wells, Lee, & Alexander, 2001). In disaster response, certain types of resources such as materials, volunteers, or money are often in high demand and a few entities are likely to fulfill the need for these resources. As such, relief organizations tend to be connected to those similar few entities for operations. We thus hypothesize that a small group of active relief organizations is likely to cluster together through their pattern of building connections to a few common

popular resource contact types.

H3: The relief organizations' resource network on the ground exhibits a structural tendency toward closure such that active relief organizations are more likely to be connected to a few popular resource contact types than would be predicted by chance alone.

When organizations decide who to connect with, they usually first resort to their current partners, which represents the dynamics of triadic closure. Atouba and Shumate (2010) showed that in the international development organization network, organizations tended to collaborate with their partners' partners. Shumate et al.'s (2005) study found that the patterns of the alliances of HIV-AIDS networks were predicted by common ties to intergovernmental organizations (IGOs) such as the United Nations, as well as prior relationships among organizations. The use of information and communication technologies (ICTs), especially social media, may create opportunities for NPOs and NGOs to go beyond their specific regions and easily engage in conversations with other organizations directly. But relatively little empirical evidence has been provided concerning whether and how the pattern of transitivity manifests in the online humanitarian networks. One of the few exceptions close to the topic of this research is Shumate (2012)'s work, which showed that NGOs tended to hyperlink to other NGOs that they connected through a common partner. In light of this, we hypothesize that the argument of triadic closure also applies to the online humanitarian network.

H4: The online humanitarian network exhibits a structural tendency toward triadic closure such that relief organizations with shared partners are more likely to be directly connected to one another than would be predicted by chance alone.

Organizational collaboration may also be driven by *positional* embeddedness, that is, the

positions or roles an organization may occupy in the network (Gulati & Gargiulo, 1999). For example, centrality is usually associated with informational benefits, because organizations having more connections are likely to have a better understanding of the network situation (Freeman, 1979). These central organizations are relatively visible, signalling their attractiveness as potential partners to others in the network (Gulati & Gargiulo, 1999). In fact, organizations with a higher level of centrality are likely to form different types of relationships with one another (Lee & Monge, 2011). Central organizations are perceived as more influential and important than peripheral organizations (Doerfel & Taylor, 2004). As the central players dominate the opportunities, the network may evolve into a core-periphery structure, where a few nodes are highly active and connected while the rest are loosely connected to one another.

In sum, when an organization decides who to follow in a network, they may look for the most central and popular organizations. Translating the principle of positional embeddedness into relief organizations' collaborative networks, it is possible that certain active relief organizations are more likely to seek out and acquire resources from more contacts, while others focus on a limited set of resource contacts. Moreover, a core-periphery network structure reflects the patterns of structural differentiation in a network, which was found to be useful for the formation of new interorganizational ties (Gulati & Gargiulo, 1999). In the disaster context, such core-periphery network structure is not uncommon. Emergent disaster relief networks tended to exhibit a two-tier system where a relatively core and stable sector (governmental organizations) coexisted with a relatively transient and peripheral sector (non-governmental, non-profit, and private organizations) (Robinson, Eller, Gall, & Gerber, 2013). Moore, Eng and Daniel (2003) studied NGOs involved in the flood relief operations in Mozambique and found that international NGOs tended to occupy more central positions in the interorganizational relief network while

local NGOs were relatively peripheral in the relief network. The following three hypotheses are developed to examine the resource and online humanitarian networks' tendency toward a core-periphery structure.

H5a: In the resource network on the ground, a few active relief organizations that have connections with different types of resource contacts are more likely to emerge than would be predicted by chance alone.

H5b: In the resource network on the ground, a few popular resource contact types that have connections with different relief organizations are more likely to emerge than would be predicted by chance alone.

H6: In the online humanitarian network, there is a concentration of a few active relief organizations while others are more equally distributed.

Attribute-based and socio-technical homophily. In addition to relational factors, the homophily effect is salient in organizational collaboration because similarity in organizational attributes breeds connections (McPherson, Smith-Lovin, & Cook, 2001). For example, Atouba and Shumate (2014) examined homophily manifested in attribute-based (same status, similar founding dates), geography-based (headquartered in the same regions) and institutional/structural aspects (common funding partners), and studied how these influenced the formation of interorganizational collaborative ties among infectious diseases INGOs. Their study supported the principle of homophily because those INGOs tended to collaborate with one another when they shared the same status, had similar founding dates, were headquartered in the same geographic regions, and had common funding partners. Similarly, Kim and Barnett's (2000) study on the international telecommunications industry also showed the influence of geographic proximity on the formation of the international telecommunications system. Singer and Kegler

(2004) investigated the role of interorganizational collaboration networks in enhancing community capacity for community health intervention. They found that the intensity and density of interorganizational networks were high among organizations of similar types, yet decreased as the collaboration moved through stages.

In the meantime, a growing line of work attempts to draw connections between the online networks of voluntary sectors and their offline collective actions. For example, Gillan's (2009) study on the UK anti-war movement showed that the online network pattern tended to be collaborative and diverse, while the offline counterpart was more divided and limited. Further, international NGOs are usually divided into two groups: North NGOs and South NGOs. The former refers to those INGOs headquartered in developed countries (e.g., North America, Western Europe and Australia/New Zealand) while the latter represents those groups headquartered in developing countries (e.g., Africa, or Central and South America). Yet so far, no conclusive evidence shows that technology use overcomes the North/South divide (Shumate & Dewitt, 2008).

Moreover, most of these studies linking online and offline domains focus on the hyperlink network among NGOs' websites (e.g., Yang, 2013). It is expected that the organizing networks on social media may exhibit a different pattern of overcoming these existing divides among humanitarian organizations. For example, the feature of following other users on Twitter makes it easier to build connections despite organizational or geographic differences, which is social media's affordance of association (Treem & Leonardi, 2012). Due to the lack of conclusive claims about the effect of geographic or type similarity on online organizational collaborative networks, we developed a general research question.

RQ1: How does the principle of homophily in the form of similarity in organizational

type and geographic location affect the evolved online humanitarian network?

While the bona fide network perspective suggests that technology plays a critical role in facilitating the process of collaboration between organizations, no specific conceptualizations of how technology is related to the network processes are proposed. In this regard, the theory of media multiplexity helps explain the process of technology use in the organizing of bona fide networks. Extending the concept of relational multiplexity to technology use, the theory of media multiplexity suggests that the more frequently two people communicate, the stronger the tie, and the more types of media they use (e.g., face-to-face talk, email) (Haythornthwaite & Wellman, 1998). Instead of focusing on the attributes of media or individual characteristics, the framework of media multiplexity emphasizes the social context in which a medium is used (Haythornthwaite, 2002).

In this paper, the use of multiple technologies for communication is termed “multimodal communication.” In the disaster context, using multiple means of communication to create or maintain relationships can be seen as a type of adaptive relational behavior initiated by organizations in response to environmental exigencies. Because multimodal communication with resource contacts involves engagement in technology use and the social context, we consider organizations with similar levels of multimodal communication with external contacts as exhibiting *socio-technical homophily*. Specifically, because resource contacts have preferred modes of communication, in consideration of such preferences, relief organizations may adopt this practice of multimodal communication and exhibit similarity in the level of multimodal communication when connecting to similar types of resource contacts.

H7: Relief organizations on the ground that have similar levels of external multimodal communication are more likely to share similar resource contact types than organizations

that have different levels of external multimodal communication.

Along with relational factors, the bona fide network perspective emphasizes the environmental influences on organizational collaborative networks. In emergent and disaster contexts, organizations directly affected by the exigencies are likely to mobilize their accumulated social capital in order to receive resources (Doerfel et al., 2010). In particular, response organizations in the affected area are likely to reach out and be reached by organizations of different types (Kapucu, 2005). It is expected that relief organizations in the affected country are likely to build connections with resource contacts. Similarly, if organizations cover a wider scope of area for relief operations, they are inclined to seek out resource support. Furthermore, relief organizations located within the affected country may have similar resource needs and are thus likely to reach out to similar entities that can provide resources needed for relief operations.

H8a: Relief organizations operating in the affected country are more likely to engage in resource ties with other entities than those organizations operating outside of the country.

H8b Relief organizations covering a larger scope of relief operations on the ground are more likely to engage in resource ties with other entities than those organizations covering a smaller scope of operations.

H9: Relief organizations located within the affected country are more likely to have ties with similar resource contact types than those organizations operating outside of the country.

Outcomes of collaborative networks. The bona fide network perspective examines the outcomes of interorganizational collaboration realized at organizational and network levels (Cooper & Shumate, 2012). In the disaster context, Nolte and Boenigk (2013) proposed a

process model examining public-nonprofit collaborative networks as well as looking at operationalized network outcomes in forms ranging from stronger interorganizational relationships, expanded scope of services, and growth of the network. Moore et al. (2003) studied NGOs involved in the flood relief operations in Mozambique and found that international NGOs tended to have a higher impact in terms of having more beneficiaries, while local NGOs were relatively peripheral in the relief network and had a lower number of beneficiaries in the affected communities. Simo and Bies (2007) examined the usefulness of cross-sector collaborative relief efforts between nonprofits and other organizations (e.g., government, business, the public) in helping community recovery and rebuilding after disasters.

In this study, we focus on examining network outcomes in the form of resilience. Resilience refers to the ability of individual, organizations, and a system of organizations to communicate and reorganize when faced with disruptive challenges (Chewning, Lai, & Doerfel, 2013). Resilience is a suitable concept for observing network outcomes of organizational collaboration in the disaster context because organizations' sustainable collective relief actions may help the affected communities to respond and recover more effectively after a disaster (Simo & Bies, 2007). The last research question is developed to address the network outcomes of relief organizations across online and offline domains.

RQ2: What are the realized network outcomes of relief organizations' collaborative networks in the form of resilience across online and offline domains after a disaster?

Methods

This study uses a mixed-methods approach, consisting of an online survey with relief organizations and the organizations' longitudinal Twitter data before and after Typhoon Haiyan. Organizations were chosen mainly based on a news article by CNN which listed all the

organizations involved in the relief action of Typhoon Haiyan, as well as the United Nations Office for Coordination of Humanitarian Affairs (OCHA)'s website, which provides a complete list of organizations involved in Haiyan relief efforts (N = 264).¹ After receiving the IRB approval from the first author's affiliated institution, we filtered out duplicate organizations and sent out email invitations to all 180 organizations on the OCHA list to participate in the survey from March to May 2014. In OCHA's directory, details about an organization's contact person (e.g., email, job title) were provided. To ensure the reliability and validity of the response, we intentionally selected the organizational contacts who were in charge of the relief efforts on the ground (e.g., country director, humanitarian aid coordinator, emergency coordinator) to fill out the survey. In the invitation email, we provided the scope and the type of the questions covered in the survey and asked the contact to forward it to appropriate personnel if he/she was not directly in charge of the emergency management and community engagement on the ground.

Among the 180 invitations sent out, 41 organizations responded (response rate = 22.8 %).² The Twitter data of these 41 organizations were also retrieved. Using the additional organizational contacts mentioned by these participating organizations in the survey,³ the scope of the Twitter data was expanded accordingly. After this adjustment, the final Twitter dataset consisted of 70 organizations. Table 1 presents the details about the organizations under study for both the survey and Twitter data.

Online survey with relief organizations. All 41 participating organizations were asked whether they received resources of any type (e.g., informational, financial, physical) from the following ten sources in each of the two phases of their relief and recovery support with the community (0= No, 1= Yes,): individuals from the affected community, non-profit organizations from the affected community, individuals outside of the affected community, non-profit

organizations outside of the affected community, businesses from the affected community, businesses outside of the affected community, local government or public agencies, provincial government or public agencies, news media from the Philippines, and news media from outside of the Philippines. These ten resource contact types were developed by adapting existing research (e.g., Doerfel et al., 2010; Lai & Chewning, 2014). Based on the responses, two rectangular two-mode matrices were created where the rows represented the 41 relief organizations and the columns were the ten resource contact types. The matrices were to examine the relief organizations' resource network immediately after Haiyan (Time 1) and within three months after Haiyan (Time 2). We chose to focus on resource receipt in this study because for relief organizations, receiving resources from both inside and outside the affected area is particularly important for relief operations on the ground (Shepherd & Williams, 2014). Table 2 presents the descriptive statistics of the ten resource contact types.

Four endogenous and attribute factors were measured in the following ways. *The two-mode network at Time 1* was considered as a dyadic attribute to assess the effect of the resource network at an earlier time on the network at a later time. In measuring the binary variable of *geographic location*, organizations whose headquarters are in the Philippines were coded 1 (n = 17); those not in the Philippines were coded 0 (n = 24). For categorical estimation, we recoded the variable of geographic location, where those organizations with headquarters in the Philippines were coded 1 and others coded 2. In creating the binary variable of *scope of relief action*, two steps of data processing were implemented. Typhoon Haiyan mainly affected five regions of the Philippines (Regions 4-8). In the survey, organizations were asked to report the region(s) where they provided relief support. The identified regions were counted, and classified organizations whose operations covered only one judiciary region were coded 0 (n = 24) and

organizations covering two or more regions were coded 1 ($n = 16$).

Organizations' external coordination was measured by the use the following means of communication: face-to-face, email, texting, voice phone calls, social media, websites, and other (e.g., bank transfers, Skype) (0 = No, 1 = Yes). A summed scale of level of external multimodal communication was created, ranging from 1 to 7 at Time 1 ($M = 4.81$, $SD = 1.94$) and Time 2 ($M = 4.83$, $SD = 1.86$). The variable of multimodal communication was then dichotomized where code 1 described the organizations with a lower level of multimodal communication (those using five or fewer modes of communication with external contacts) (Time 1, $n = 15$; Time 2, $n = 14$) and code 2 represented those with a higher level of multimodal communication (using more than five modes of communication) (Time 1, $n = 22$; Time 2, $n = 17$). Two categorical attributes, *external multimodal communication at Time 1 and Time 2*, were created.

Collection and processing of Twitter data. To examine the evolution of organizations' network on social media, the official Twitter pages of these 70 organizations for a four-month period starting one month before the typhoon to three months after (October 12, 2013 to January 31, 2014) were crawled and downloaded (total messages = 44,280). This study measures two types of organizing network relationships on Twitter through the features of mentions and hashtags. Twitter users can mention other users in a message (tweet) by adding the "@" symbol before the other user's username. Mentions can be used to indicate connections and conversational dynamics between Twitter users (Highfield, Harrington, & Bruns, 2013). The other type of network structure was based on the shared hashtags between users. Hashtags represent Twitter users' common practice of organizing the information in a tweet with the pound sign or hash mark (#) followed by a keyword (e.g., #TyphoonHaiyan). Use of hashtags represents the intention to follow the discussion related to the marked topic within the Twitter

community (Larsson & Moe, 2012). Accordingly, two Twitter users are deemed connected by virtue of their use of common hashtags.

In generating network matrices, the following four steps were performed. First, the raw data were processed using regular expression in Python to generate the contacts mentioned in the tweets and hashtags used by these 70 organizations. Second, the dataset was broken into eight sub-datasets, with each representing a two-week observation of activity (e.g., T1=10/12-10/25/2013). Third, for each time point, two two-mode binary matrices were generated. The first one was developed to measure the “mentioned” network, where the rows represented the 70 focal organizations and the columns were populated by the 15,634 contacts mentioned by these organizations in the tweets. The other matrix was created to measure the shared hashtag network, where the rows represented the 70 organizations and the columns were the 5,983 hashtags used by these organizations. In both matrices, a “1” was entered in the cell when the focal organization mentioned the particular contact or used a particular hashtag in the tweet during that period, regardless of the number of mentions or the number of hashtag uses.

Fourth, the two binary matrices created in the earlier step were converted into four square one-mode valued matrices (70 x 70 and 15,634 x 15,634; 70 x 70 and 5,983 x 5,983). In total, 48 matrices were created (2*8 time points + 4*8 time points = 48). For the purpose of this paper, only the one-mode org-by-org matrices were used for analysis. These org-by-org matrices represent the common connections between two organizations as they are linked to the same entities or topics. This is similar to the concept of the affiliation network, where two persons are considered connected when they both belong to the same group (Borgatti & Halgin, 2011).

Two categorical attributes were created for the Twitter data, including organizational type and geographic location. All of the 70 organizations were coded using the following six

categories: business, government agency, NPO (e.g., a group for Filipino students overseas, a volunteer group for Haiyan), NGO (e.g. Red Cross National Societies, CARE), IGO (e.g., United Nations), and coalition (e.g., national response network). Unlike NGOs, NPOs usually engage in a smaller scope of services contributing to the well-being of a community or a society, and they do not engage in the distribution of surplus of funds to their members or stakeholders (Bromideh, 2011). It is important to distinguish NPOs and NGOs in this study because of the emergent and adaptive practices often carried out by the NPOs in response to disasters (Atkinson, 2014). These practices include leveraging different types of communication channels and social relationships, which corresponds to the variable of multimodal communication examined in this study. The region where organizations are headquartered was used to measure similarity in geographic location (see Table 1). Additionally, two attribute files (geographic and type similarity) were converted into matrix formats using the “Attribute to matrix” option available in UCINET (Borgatti, Everett, & Freeman, 2002).

Data analysis. Hypothesis testing and research questions were answered using exponential random graph modeling (ERGM) and Multiple-Regression Quadratic Assignment Procedure (MR-QAP). The ERGM method is suitable for this study because it permits the simultaneous examination of attributes, network factors, and other relations on the formation of a network relationship (Shumate & Palazzolo, 2010). PNet is a program used for ERGM analysis through Monte Carlo Markov Chain likelihood estimation to maximize the probability of generating the network that fit the observed network by producing convergent estimates (Robins, Snijders, Wang, Handcock, & Pattison, 2007). Each hypothesized parameter is estimated and parameter estimates more than twice their standard errors are considered significantly different from zero (Robins et al., 2007). Positive and significant parameter estimates indicate that the

tested structural or attribute effects happen more than by chance alone. Negative and significant parameters indicate that the hypothesized structural or attribute effects occur less than would be expected by chance.

In a well-fitting model, the convergence t-ratio for each parameter should be less than 0.1 in absolute value (Robins et al., 2007). After the model converges (with all t-ratios less than 0.1), the goodness-of-fit estimates are then obtained by comparing the observed network to the simulated models using the estimated parameter values (Goodreau, 2007). The goodness-of-fit indicates the degree to which the estimated model provides a plausible or good explanation for the observed network as well as for additional network dimensions not included in the model. The convergence statistics for the estimated parameters should be less than 0.1. For non-estimated parameters, if the convergence statistic values are between 1 and 2, it indicates a plausible fit, and a good fit if the statistics are less than 1.0 (Shumate & Palazzolo, 2010).

BPNet and LPNet are the two extensions of PNet. BPNet, which allows the examination of the other two-mode network simultaneously into the model, was used to analyze the two-mode resource network (Wang, Sharpe, Robins, & Pattison, 2009). The edge (density) is commonly used as a control variable in the two-mode network (Zhu, Huang, & Contractor, 2013). H1 was tested using the estimation of the EdgeAB parameter (see Figure 1). A significant and positive EdgeAB would suggest that the earlier relief network predicts the formation of the subsequent network. H3 tested the effect of potential closure with the L3 parameter. A significant and positive L3 would suggest that active relief organizations are connected to multiple resource contacts and one of those resource contacts is also tapped by other relief organizations. In other words, active relief organizations and popular resource contacts show the tendency of forming a potential cluster. H5a and H5b were tested with star parameters (Sa2, Sp2,

Sa3, Sp3). Because models with higher-order alternating star parameters did not converge, only the lower-order degree distribution effects (2-stars, 3-stars) were included in the model.

Significant and positive Sp2 and Sp3 would suggest a certain level of concentration among a few active relief organizations, and significant and positive Sa2 and Sa3 would suggest a certain level of centralization among a few popular resource contact types. H7 examined the effects of similarities in levels of multimodal communication on sharing similar resource contact types at two time points with the Attr_match_2pP parameters. H8a and H8b suggested the effects of relief organizations' attributes, including the headquartered location and the scope of operations, on the formation of resource ties. The Attr_rP parameters were estimated; significant and positive Attr_rP parameters suggest the tendency of relief organizations to construct resource ties if they operate in the affected country and cover a wider scope of relief areas. H9 examined the similarities in resource contact types by organizations located in the affected country, using the Attr_match_2pP parameter.

LPNet was used to analyze the longitudinal evolution of the Twitter networks because it allows the examination of the effects of endogenous factors and attributes on the evolved networks. Edge is often used as a control variable. H4 examined the closure effects with the triangle and alternating 2-path parameters. The triangle and alternating 2-path parameters represent the degree of closure and the pattern of multiple connectivity, respectively (Snijders, Pattison, Robins, & Handcock, 2006). H6 was tested using the estimation of both the lower-order star parameters (2-star, 3-star) and the higher-order alternating star parameter. The former measure the level of degree distribution (centralization) and the latter captures the spread of the degree distribution (variance between degrees) (Robins et al., 2007). MR-QAP was used to test the predictive effects among network relationships, specifically the effects of earlier Twitter

networks on the later ones (H2). Similar to multiple regression analyses, MR-QAP tests the effects and explanatory power of predictors (attributes, relational factors) on a dependent variable (i.e., network relationship). But it uses the random permutations method to account for the interdependency of network observations.

Results

The BPNet model of the resource network had a good fit, with the absolute values of the convergence statistics for estimated parameters below 0.1, and for additional parameters less than 2 (see Table 3).⁴ The network ties with resource contacts immediately after the typhoon predicted the tie structure later on. Hence, H1 was supported. That means the relief organizations tended to continue their ties with the same resource contact types in a later phase of disaster relief. That also means, if these ties were not established at earlier time, it was less likely that they were able to be made later. The insignificant three-path parameter indicates lack of potential closure, as active relief organizations who were connected with diverse resource contact types did not show a tendency of connecting to the popular resource contact types. H3 was thus not supported. Several central and active relief organizations stood out with multiple links to resource contacts, as indicated in the positive and significant relief-org 2-star parameter. H5a was supported. But it is worth noticing that having ties with too many resource contact types was not observed, which was shown in the negative relief-org 3-star parameter. No particular resource contact type was identified as more popular than others, which were shown in the insignificant resource contact 2-star and 3-star parameters. H5b was not supported.

A significant homophily effect was observed in the variable of external multimodal communication. Similarities in the level of multimodal communication with external actors at different times had an effect on organizations' connections. Hence, H7 was supported.

Interestingly, organizations with similar levels of external multimodal communication immediately after the typhoon were less likely to have connections to the same resource contact types. Yet, this similarity had a positive effect on the connections that took place weeks or months after the typhoon. Whether relief organizations were headquartered in the Philippines and the scope of relief actions covering multiple affected regions did not make a difference in terms of having external resource ties. Hence, H8a and H8b were not supported. Being headquartered in the affected country (the Philippines) did not reflect the preference of building ties to common resource contact types; thus H9 was not supported.

Twitter networks. The results of MR-QAP analyses suggested that in the Twitter mention network, four out of seven networks at earlier points predicted the network at the last point of observation (T8) (see Table 4). By comparison, all of the seven earlier networks of organizations built on shared hashtags significantly predicted the network at T8. In both mention and shared hashtag networks, the network structure at T8 was strongly influenced by the immediate period preceding that time point (T7). Together, H2 was supported, indicating that organizations were embedded in their prior relationships and participation in these online humanitarian networks could garner expeditious benefits in terms of being integrated into the network.

The LPNet models for both mention and shared hashtag networks had a good fit, with the absolute values of the convergence statistics for estimated parameters below 0.1, and for additional parameters less than 2 (see Table 5). In both mention and shared hashtag networks, the positive effects of the triangle parameter suggest that organizations tended to interact in clique forms. The negative and significant alternating 2-path parameter indicates that the situation where organizations with shared partners but without direct connection is rare. Over time,

organizations were less likely to form ties that only resulted in multiple short indirect paths between them. Combining positive triangle and negative alternating 2-path parameters implies that organizations with multiple partners were likely to form ties with each other and exhibited a preference for forming direct ties in the Twitter network. H4 was thus supported.

In both of the mention and shared hashtag networks, insignificant 2-star and 3-star effects suggested a lack of highly connected relief organizations. Furthermore, there was no evidence indicating an equal distribution of degrees among relatively unconnected relief organizations, as shown by the insignificant effects of the alternating star parameter in both networks. Hence, H6 was not supported.

To answer RQ1 regarding the homophily effect in the online humanitarian network, the effect of type similarity was positively significant in the shared hashtag network, suggesting that the social selection process was in place because organizations of similar type were likely to form ties with one another. Yet in the mention network, similarity in organizational type and geographic location was not salient in the formation of network ties. In sum, the results of the longitudinal network analysis showed the consistent strength of the structural processes in network evolution, controlling for the effect of homophily factors in the Twitter networks.

In answering RQ2 regarding the network outcomes of collaborative relief networks, visualization of the network structures is used to identify different forms of resilience as manifested in the resource network and the online network. Due to space limitations, the visualization of the resource network on the ground is available upon request. First, instead of a few resources contact types, multiple resource contact types (including local and provincial government agencies, non-profit organizations, news media, businesses, and individuals from outside the Philippines) served as suppliers in the resource network on the ground after Haiyan.

Second, a clear pattern of cross-sector and cross-geographic collaboration was discerned as relief organizations at national and international levels were involved in relief actions in different phases of disaster relief. For example, local NPOs and NGOs worked with businesses from outside the Philippines, local and provincial government agencies, and other international non-profit organizations.

As in the disaster response situation, a higher level of cohesion and coordination within the disaster response network was often observed in successful cases of disaster response (Kapucu, & Garayev, 2013). In fact, comparing the network within three months after Haiyan with the network immediately after, relief organizations exhibited a decline of average resource ties from 4.46 to 4.02 and resource contact types received a decrease of nominating organizations from 18.3 to 16.5. Despite these decreases of activity in the resource network, it was observed that the network consisting of multiple organizational actors within the affected country working in concert with resource contacts from outside has established a resilient structure over time.

Figures 2a-d provide the visualization of popular hashtags and corresponding shared hashtag networks before and during Typhoon Haiyan. In particular, Figures 2e and 2f illustrate the popular hashtags and the network at the last point of observation. The typhoon appeared to serve as a force to assemble the network focusing on this particular topic. The network was relatively dense and active immediately after Haiyan. Three month after Haiyan, the network resumed its looser network structure constructed on a group of other common topics, which resembled the pre-Haiyan network. Together, this indicates that the humanitarian organizations within the Twitter network exhibited resilient capacity to respond and adapt to environmental changes in the form of self-sustaining network over time.

Discussion

Following the bona fide network perspective, this study treated a natural disaster (Typhoon Haiyan) as an antecedent that facilitated organizational collaborative networks involved in relief operations, and examined the network processes and outcomes of these networks across online and offline domains. The results from the survey data supported the hypotheses about structural and positional embeddedness. The resource network immediately after the typhoon predicted the network structure at a later time point. The resource network were also concentrated in a few highly connected organizations, yet with a cap in terms of the number of possible resource contact types. Moreover, having socio-technical similarity (that is, those having similar levels of multimodal communication with resource contacts) immediately and months after the typhoon helped the formation of common resource ties. Similar to the survey data, the analysis of the organizations' Twitter data supported the hypothesis about structural embeddedness. As early as one month before the typhoon and as well as two weeks before the final period of observation, the network ties at those points significantly predicted the network ties at the latest point of observation. As the interorganizational networks evolved, they tended to interact with one another in the form of a closure structure. Yet in the online networks, these organizations exhibited a relatively equal distribution of connections, with a lack of popular central organizations or preferred connections with those central organizations.

Online and Offline Bona Fide Collaborative Humanitarian Networks

This study examined disaster response networks on the ground and online, which offers an important way to conceptualize bona fide networks by considering organizing and collaborative behaviors in different forms across online and offline domains (Lai, 2014). Despite the observed significance of structural embeddedness, the resource network on the ground and online humanitarian networks exhibited different network processes and outcomes. In the

resource network on the ground, while positional embeddedness in the form of a core-periphery network structure mattered, structural embeddedness in the form of closure and attribute- and geography-based homophily merely exerted weak effects on the formation of collaborative networks following the disaster. In contrast, the online humanitarian networks presented a different picture because with the reduced influence of central players and elimination of bridges, organizations were likely to engage in direct connections with one another and form a closure structure.

Together, these findings enrich the literature on organizational collaborative networks, especially in the emergency response context. Specifically, the domination of a few organizations in the relief resource network is prevalent (Abbasi & Kapucu, 2012). Yet instead of a few popular resource contact types, several entities such as government agencies, non-profit organizations, businesses, and individuals from outside the affected area stood out as solid resource contacts in different phases of disaster relief, which indicates the resilience of the network in response to rapid changes such as a natural disaster. Moreover, unlike previous studies where local NGOs were usually relatively peripheral in the relief network (Morre et al., 2003), this study found evidence of the active role played by local NGOs and NPOs in the cross-sector and cross-geographic collaboration in the resource network after Haiyan. These findings echo the previous research, which suggests that self-organizing networks of organizations consisting of the public, non-profit, and private sectors is deemed an optimal approach to deal with various complex challenges imposed on communities around the world, especially for disaster management (Comfort, Oh, & Ertan; 2009; Luna, 2001).

On the other hand, the lack of support for hypotheses regarding the influences of geographic proximity to the affected area and scope of geographic coverage on resource ties

indicates the possibility that relief operations may require little engagement in the external resource network. For example, the well-established international humanitarian organizations covering wider affected areas might be seen as “isolates” in the external resource network because they may mostly tap into their own internal network of country offices for resources and support. As a matter of fact, half of the isolates in the resource network at different time points were international NGOs and NPOs. Another interpretation is that regardless of their headquartered or covering location, some organizations focused on a particular type of emergency response (e.g., child safety, health issues, online crowdsourcing) and were thus less involved in the external resource network.

In the online humanitarian networks, the network mechanisms of embeddedness are constructed based on communication relationships. Organizations’ use of the features of mentions and hashtags on Twitter represent communicative behaviors either through publicizing other contacts’ names or engaging in topic-focused conversations, which requires actors to know and practice the common norms of using these keywords. Interorganizational collaboration entails positive links being initiated and maintained. As such, the findings about structural embeddedness of the online humanitarian networks provide important empirical evidence for the research on digital organizing, which suggests that the positional embeddedness (skewed degree distribution) tends to relate to negatively connoted links (e.g., aggressive actions) whereas structural embeddedness (clustering) relates to positive links (e.g. friendship, communication) (Szell, Lambiotte, & Thurner, 2010).

Emergent and sustained communicative practices. The framework of media multiplexity implies that media use is embedded into and interacts with a social collective’s existing communicative practices. The context of disaster necessitates the enactment of a set of

communicative practices that might be especially suitable for post-disaster action. During the process of adapting to this situational demand, organizations build norms and learn about ways to enrich the relationship by exchanging a wide scope of resources, and also to reach others by using different modes of communication. The results of negative and positive effects of similarity in multimodal communication (immediately and months after the typhoon, respectively) are evidence of this learning process. Organizations adapted to the chaotic and uncertain environment immediately after the typhoon, and they engaged in modes at varying levels to reach out or be reached by resource contacts. This variation became part of the learning process, which helped relief organizations find common connections to certain resource contacts later on. When the triage was over, relief organizations with similar levels of multimodal external communication tended to select common resource contacts. Multimodal communication thus represents an enactment of adaptability by organizations in carrying out relief support work. This study extends the bona fide network perspective to a disaster relief context, and offers empirical evidence highlighting the importance of considering emergent and robust communicative practices adopted by organizations in evolving interorganizational collaboration following a disaster.

Compared to the significant effects of earlier relationships and socio-technical similarity, attribute- and geography-based factors are not salient in post-disaster relief networks, as indicated by the insignificant effects of geographic and organizational type similarities in the evolved networks on Twitter, and by the insignificant effect of geographic proximity for operations in the resource network on the ground. Although this finding fails to support the existing research linking similarities of organizational attributes and geography to network formation, this study evidences the argument that social media has the capacity to foster collaboration and

mobilization beyond geographic limitations and expand the scope of participation (Penney & Dadas, 2014). Specifically, it appears that what matters more for post-disaster organizational collaborative networks online is whether and how the relationships are built and evolve over time, rather than attribute-based or geography-based enablers or constraints such as organizational type or geographic location.

The bona fide network perspective emphasizes the fuzzy boundaries of collaboration as a network is formed revolving around a specific issue (Cooper & Shumate, 2012). The survey data show the evolving and consistent cross-sector and cross-geographic resource network constructed by relief organizations revolving around Haiyan. The online data suggest that interactions and relationships on Twitter helped relief organizations explore different types of foci that sustained the loosely connected network relationships. In other words, the bona fide organizing networks on Twitter are enacted in a temporally dynamic way because the common social issues that connect those humanitarian organizations together are subject to change over time. Combining these two sources of data, it is clear that although this online network may not necessarily translate into physical humanitarian aid operations, it offers the practical insights of creating and maintaining a socio-technical system where humanitarian organizations operating on the ground can restructure their focused activity and articulate connections, which potentially can be activated when needed.

This study examined resilience as a type of network outcome of organizational collaboration, especially in the disaster relief context. Despite having no direct measures, resilience was observed through the consistent presence of particular resource contact types and the diversity of partnering organizations in the resource network, as well as the existence of topic-centered self-sustaining activities in the online network. Future research should investigate

different types of resilience as network outcomes of humanitarian collaborative efforts. In countries with resource limitations such as the Philippines, it has been a growing trend that humanitarian aid organizations engage in broader community development initiatives, beyond disaster response (Luna, 2001). It is possible that organizations from outside the affected country are able to tap into the local network after a particular disaster, which helps them engage in other initiatives related to the community in the long run.

This study makes a major methodological contribution to the existing research on organizational and communication technology by using a mixed-methods approach and encompassing cross-sectional and longitudinal data in examining bona fide humanitarian organizing networks. Using social media data offers a more economical way of obtaining data on different types of organizations (IGOs, INGOs, national NGOs and NPOs), which addresses the limitation of current research focusing on only one category of organizations per study (e.g., Atouba & Shumate, 2010; Shumate et al., 2005). It also enables longitudinal observations of the interactions among organizations of different types, which helps yield more accurate insights into the process of organizing networks.

Conclusion

This study has three limitations. First, the online network data relied on 70 organizations' Twitter data. Undoubtedly, detailed analysis on the features and content available on Twitter and other social media systems is necessary to enrich social understandings about the role of social media in humanitarian organizing. Second, this study relies on multiple sources to extract a partial list of humanitarian organizations involved in Haiyan relief. Yet convenience and snowball sampling is a common approach in disaster-related research (Norris, 2006). Last, the online survey had a relatively low response rate and resulting small sample size. The mixed-

methods approach incorporating Twitter data, however, helped mitigate the potential bias associated with only getting insight from the organizations responding to the survey. Specifically, the Twitter data were retrieved from the organizations who responded to the survey as well as those identified by the survey respondents as their network contacts. Accordingly, the Twitter data of those 15 organizations who did not respond to the survey invitation were included and analyzed.

Using a mixed-methods and longitudinal approach, this study answers two questions, the first of which is how collaborative response networks that take different forms across online and offline domains are sustained over time. Findings of this study revealed that the resource network on the ground corroborates the hypothesis about structural embeddedness and positional embeddedness, whereas the online networks exemplify the patterns of structural embeddedness in the form of triadic closure. By conceptualizing technology use as organizations' adaptive relational behavior, this study showed that organizations with similar levels of multimodal communication are likely to engage with similar resource ties. Nonetheless, similarities in organizational type and geographic locations are not salient in both the resource network on the ground and the Twitter networks, which further reinforce the importance of investing in emergent relationships that evolve over time. This study also answers the second question about the network outcomes of these collaborative networks in terms of resilience, which is manifested through the consistent presence of multiple key players and cross-sectional and cross-geographic collaboration among organizations on the ground and the topic-centered self-sustaining network online. With more empirical research expanding the scope of inquiry, more knowledge will be obtained as to how to better implement effective adaptive methods to cope with environmental threats and changes.

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Notes

1. See <http://www.cnn.com/2013/11/09/world/iyw-how-to-help-typhoon-haiyan/> and <http://www.humanitarianresponse.info>.
2. Non-response bias analysis was conducted comparing 41 responding organizations and 139 non-responding organizations. While the results showed significant differences between responding and non-responding organizations in terms of headquartered region (Philippines, Asia Pacific, Europe, North America, Africa) (χ^2 (4, N=178) = 27.26, $p < .001$, 2 missing) and scope of operations (international, national, local) (χ^2 (2, N=178) = 28.10, $p < .001$, 2 missing), there was no significant age difference ($t(164) = .41$, $p = .68$, 14 missing). The differences were partly due to the fact that we had relatively more participating organizations from the Philippines. Yet this sampling pool essentially was aligned well with the objective of this study, which is to understand the humanitarian networks from the broader perspective encompassing both the international and the local humanitarian organizations from the affected country.
3. This study is part of a larger project. In the other section of the survey, organizations were asked to nominate the organizations they were in contact for the Haiyan relief operations. This list of nominated organizations, along with other sources, was used to generate the Twitter data used for this study.
4. The goodness-of-fit results are available from the authors.

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*Table 1**Information about the Organizations for Survey and Twitter Data*

Type	Survey	Twitter
Government agency	1	1
Business	1	3
NPO	9	14
NGO	29	45
Intergovernmental organization (IGO)	1	6
Coalition	-	1
Location		
Philippines	17	17
Asia Pacific region	3	1
Europe	10	16
North America	11	36
Total #	41	70

*Table 2**Descriptive Statistics of the Ten Resource Contact Types*

<i>Frequency distribution of the resource contact types</i>	Time 1	Time 2
Individuals from the affected community	19	18
Non-profit organizations from the affected community	13	12
Individuals outside of the affected community	22	18
Non-profit organizations outside of the affected community	23	20
Businesses from the affected community	9	12
Businesses outside of the affected community	16	16
Local government or public agencies	26	23
Provincial government or public agencies	21	22
News media from the Philippines	15	11
News media from outside of the Philippines	19	13
<i>Mean</i>	18.3	16.5
<i>Standard deviation</i>	5.10	4.38
# of resource contact each organization had		
<i>Mean</i>	4.46	4.02
<i>Standard deviation</i>	3.27	3.81

Table 3

Results of BPNet Estimation

	Hypothesis	Estimate	t-Ratio
Density (edge) (L)	Control	-4.932 (1.497)*	-0.038
Relief org's resource network (1 st period) (EdgeAB) ^a	H1	0.762 (0.202)*	0.038
Three path (L3)	H3	-0.006 (0.006)	-0.041
Relief org 2-star (Sp2)	H5a	1.186 (0.268)*	-0.032
Resource contact 2-star (Sa2)	H5b	0.175 (0.189)	-0.022
Relief org 2-star (Sp3)	H5a	-0.123 (0.045)*	-0.055
Resource contact 2-star (Sa3)	H5b	-0.002 (0.010)	-0.000
Relief orgs' multimodal communication 2-star (1 st period) (Attr_match_2pP)	H7	-0.181 (0.080)*	-0.037
Relief orgs' multimodal communication 2-star (2 nd period) (Attr_match_2pP) ^b	H7	0.069 (0.023)*	0.001
Relief orgs' HQ location density (Attr_rP)	H8a	-0.091 (0.136)	-0.055
Relief orgs' scope of operation density (Attr_rP)	H8b	-0.034 (0.128)	0.060
Relief orgs' HQ location 2-star (Attr_match_2pP)	H9	0.011 (0.023)	-0.095

Note. Parameter estimates (standard error). The hypotheses in bold were supported. ^a1st period: immediately after the typhoon.

^b2nd period: within three months following the typhoon.

*Significant effect ($p < .05$)

Table 4

Results of MR-QAP on Twitter Organizing Networks

	Hypothesis	Model 1	Model 2
		Post-Haiyan network (mention contacts)	Post-Haiyan network (shared hashtag contacts)
Intercept		.000 (-.001)***	.000 (.004)***
Organizational type similarity		-.015(-.031)	.010 (.048)
Geographic proximity		-.008(-.016)	-.019 (-.096)
T1	H2	.184 (.237)***	.176(.237)***
T2	H2	-.025 (-.030)	.073(.089)**
T3	H2	.052 (.024)*	-.048 (-.040)*
T4	H2	-.023 (-.020)	.119 (.097)**
T5	H2	.196 (.192)***	.062 (.068)*
T6	H2	.001 (.002)	.205 (.314)***
T7	H2	.488 (.383)***	.412(.437)***
Adjusted R ²		.580	.778
Significance level		.000	.000
Number of observation		4830	4830

Note. Coefficients in parentheses are unstandardized regression coefficients. The hypotheses in bold were supported. Post-Haiyan network (T8) refers to the network ties measured from January 18 to 31, 2014. Each of the time point represents the ties captured in the following: T1: 10/12-10/25/2013; T2: 10/26-11/8/2013; T3: 11/9-11/22/2013; T4: 11/23-12/06/2013; T5: 12/07-12/20/2013; T6: 12/21/2013-1/3/2014; T7: 1/4-1/17/2014. Typhoon Haiyan occurred during T3.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5

Results of LPNet Estimation

	Hypothesis	Mention network		Shared hashtag network	
		Estimate	t-Ratio	Estimate	t-Ratio
Edge	Control	-3.219 (0.879)*	-0.074	-2.155 (1.008)*	-0.039
Triangle	H4	0.271 (0.107)*	-0.013	0.095(0.032)*	0.039
Alternating 2-path	H4	-0.076 (0.036)*	-0.013	-0.129(0.025)*	0.023
2-star	H6	0.036 (0.101)	0.041	0.016(0.054)	0.008
3-star	H6	0.0002 (0.007)	-0.010	0.001(0.002)	-0.027
Alternating star	H6	0.016 (0.282)	0.069	-0.156(0.509)	0.008
Organizational type homophily	RQ1	0.041 (0.199)	0.003	0.431 (0.195)*	-0.003
Geographic homophily	RQ1	-0.295 (0.172)	0.016	-0.410(0.214)	0.004

Note. Parameter estimates (standard error). The analysis compared the network structures at T1 and T8 and the hypotheses in bold were supported.

*Significant effect ($p < .05$)

Figure 1(a). Summary of network graph statistics included in BPNet estimation.

Figure 1(b). Summary of network graph statistics included in LPNet estimation.

Figure 2. Popular hashtags used at three specific time points and the corresponding networks. The nodes on the left in (b), (d), and (f) are isolates without any shared hashtags with other organizations at that particular time.