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Tsunami early warnings via Twitter in government: Net-savvy citizens' co-production of time-critical public information services

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ABSTRACT

Governments aim to mitigate natural hazards' impacts through a disaster early warning system. Drawing on citizen co-production theory and resilient information infrastructures framework, we empirically examined government use of Twitter Tsunami Early Warning Civic Network and citizens' roles in co-providing timely and actionable information. The Indonesian government issued its tsunami early warning Tweet, which was "re-tweeted" without delay by its followers to their own followers to warn tsunami hazards during the 2012 earthquake. Within 15 min it reached over 4 million Twitter users. Based on our case study and social network analysis of Twitter information flows and exchanges within the network, we found that the speed and enormous reach of the government's Twitter tsunami early warnings would be significantly less without citizens' direct participation in re-tweeting, hence influencing greater control of the network. We present evidence for net-savvy citizens' co-production effects on increased government efficiency in providing time-critical public information services.

1. Introduction

In recent decades, the frequency and impact of catastrophic disasters (also known as extreme events) have dramatically increased. Extreme events (EE), such as the 2004 Indian Ocean Tsunami, 2005 Hurricane Katrina, 2010 Haiti Earthquake, 2011 East Japan Great Earthquake and Tsunami, and 2012 Hurricane Sandy, overwhelmed the response capacity of government agencies and profoundly affected communities in large areas. While EE cannot be prevented, governments aim to mitigate their impacts through a disaster early warning system. Timely and actionable information is critical for both disaster response agencies and affected communities to mobilize agile and adaptive responses (Scholl, Patin, & Chatfield, 2012). For the effective and efficient delivery of time-critical public information services, governments need to mobilize sufficient resources so that disaster early warnings can be issued in a timely manner and reach citizens in the predicted high-risk areas during EE. In reality, this often is a tall order for many governments with chronic budget deficits or facing budget cuts to prepare for and respond to unthinkable EE.

While in the past the role of citizens in disaster-related information provision was rather limited, more recently, social media have increasingly been used for information exchanges during EE. Government agencies responsible for emergency/disaster services used social media for early warnings (Chatfield & Brajawidagda, 2012, 2013; Starbird & Palen, 2010), search and rescue (Wei, Qingpu, We, & Lei, 2012), emergency relief (Goggins, Mascaro, & Mascaro, 2012) and recovery (Lu & Yang, 2011). However, the literature needs both empirical research and methodological rigor for developing a deeper and richer understanding of the government use of social media during EE. This research, therefore, is grounded in prior theoretical work on public administration theory on citizen co-production (Whitaker, 1980) and resilient information infrastructures (RII) framework under EE (Scholl & Patin, 2012, 2014) to address the following two research questions:

(RQ#1) How has government used social media to provide citizens with timely and actionable disaster information under the conditions of a rapidly evolving EE? And,
(RQ#2) How has government used (or can use) social media to engage citizens in co-providing time-critical public information services under the conditions of a rapidly evolving EE?

In order to answer the questions, we studied and analyzed the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) and its Twitter Tsunami Early Warning Civic Network as an integral part of the agency's RII. We used case study research and social network analysis of Twitter information flows and exchanges among the BMKG's Twitter followers in the civic network during the April 2012 Northern Sumatra Earthquake.

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The remainder of this paper is structured as follows: Section 2 reviews the literature on disaster early warning systems, government use of social media for disaster early warnings, citizen co-production theory and RII framework. Section 3 describes our research methodology which consists of case study research and social network analysis. Section 4 presents our case study results on Indonesia's disaster management reforms and the RII implementation, which includes a Twitter Tsunami Early Warning Civic Network for linking networked citizens and organizations with government for EE preparedness and response. Section 5 presents our social network analysis results. Section 6 discusses the enabling roles of net-savvy citizens in forwarding the government's tsunami early warning tweet, influencing greater control of the Twitter flows and exchanges within the network, and hence increasing government efficiency and creating public value in co-producing time-critical public information services under EE. Section 7 presents our conclusions, including a discussion of limitations of this research and our future research directions.

2. Literature review

2.1. Disaster early warning systems

While natural hazards cannot be prevented, governments aim to mitigate their impacts through a disaster early warning system. Disaster early warning systems provide timely and actionable information, through authorized government agencies, to enable citizens exposed to hazard to take effective action, avoid or reduce their risk, and prepare for effective response (UNEP, 2012). From an information perspective, early warning systems need to satisfy at least the following user information requirements:

- Speed of communication (Chatfield & Brajawidagda, 2013; Fortier & Dokas, 2008; Meissen & Voisard, 2008);
- Reach (Chatfield & Brajawidagda, 2012, 2013; Meissen & Voisard, 2008; Starbird & Palen, 2010);
- Information quality (Fortier & Dokas, 2008; Meissen & Voisard, 2008; Klischewski & Scholl, 2008).

In order to detect the likely occurrence of disasters, a prior research has focused on advancing sensor technologies and implementing decision support systems (DSS) to predict the disaster's likely scale, time of occurrence, location, potential impacts, and the need for mass evacuations. On the other hand, government communication of the predicted hazard to the intended audience in a timely and actionable manner is also critically important. Citizens in the hazardous areas need to know about the looming EE so as to prepare for evacuations or other protective measures. In other words, public information services in providing citizens with timely and actionable information are of critical importance in mitigating the impacts of natural hazards and building a resilient society.

2.2. Government use of social media for disaster early warnings

Social media technologies provide scale and 'reach' which can be defined as the capability to reach the intended audience. Social media technologies are by their very nature decentralized, distributed, and networked in form, with millions of users at multiple points of information production and consumption (Boyd & Ellison, 2008). Consequently, social media's speed of communication is fast, depending on the number of active users and followers who transmit the information without delay within their social media networks.

The use of social media channels in government for sharing time-critical information in disaster situations, especially via Twitter, has been emerging over the past five years (Chatfield & Brajawidagda, 2012, 2013; Starbird & Palen, 2010). Early social media-related research appeared in the context of the 2007 Southern California Wildfires (Sutton, Palen, & Shklovski, 2008). Table 1 lists a representative literature. It shows that social media use in government and non-government organizations for disaster management has been emerging in the recent years across different disaster agencies and emergency services in the developed and developing countries which frequently experienced disasters. So far empirical studies have focused on the use of social media for different disasters and different phases of the disaster management cycle, with the exception of the risk mitigation phase in which no prior research was found. While the type of social media use studied varies widely from Facebook, Twitter, blog, web forum, photo sharing, microblog and SharePoint, it appears that Twitter is the most frequently used social media channel in disaster situations.

Of the literature on disaster early warning systems, however, only Starbird and Palen (2010) and Chatfield and Brajawidagda (2012, 2013) focused on the use of social media technologies in government. Furthermore, of the social media-based disaster early warning systems, only Cheong and Cheong (2011) and Chatfield and Brajawidagda (2012) used social network analysis on Twitter data for in-depth understanding of information flows and exchanges within social networks.

2.3. Public administration theory on citizen co-production

Extant public administration theories on citizen co-production (Bovaird, 2007; Meijer, 2011; Whitaker, 1980) or even citizen (financial) co-provision (Ferris, 1984) in public services have been proposed and studied in different contexts. In contrast to prior research on citizen engagement and participation in influencing the formulation of public policy, Whitaker (1980) argues for *the new and emerging roles of citizens in influencing the execution of public services*. Citizens can co-produce public services in many different ways, *ranging from passive roles to active and enabling roles*. He identifies typologies for citizen co-production in public services: (1) requesting public services from government; (2) cooperating with government in executing public services, and (3) negotiating with government to change public service activities.

Table 1
Social media research for disaster management.

Disaster	Year	Country	Type of social media used	Disaster management cycle	Reference (s)
Southern California wildfires	2007	USA	Blogs, forum, Flickr, Twitter	Response, recovery	Sutton et al. (2008)
Wenchuan earthquake	2008	China	Baidu Bar	Response, recovery	Wei et al. (2012)
			Web forum	Recovery	Lu and Yang (2011)
Red River flooding	2009	USA	Twitter	Preparation, response	Starbird and Palen (2010)
Oklahoma fire	2009	USA	Twitter	Preparation, response	Starbird and Palen (2010)
Brisbane storm	2010	Australia	Twitter	Preparation, response	Yin, Lampert, Cameron, Robinson, and Power (2012)
Haiti earthquake	2010	Haiti	Forum	Response, Recovery	Goggins et al. (2012)
			MS SharePoint	Response, recovery	Wei et al. (2012)
			Twitter	Response	Caragea et al. (2011)
Queensland flood	2011	Australia	Twitter	Preparedness, response	Cheong and Cheong (2011)
Christchurch earthquake	2011	New Zealand	Twitter	Preparation, response	Yin et al. (2012)
Thai flood	2011	Thailand	Twitter	Preparedness, response	Kongthon, Haruechaiyasak, Pailai, and Kongyoung (2012)
Great East Japan tsunami	2011	Japan	Twitter	Preparedness, response, recovery	Ichiguchi (2011)
Sumatra earthquake	2012	Indonesia	Twitter	Response	Chatfield and Brajawidagda (2012, 2013)

In contrast, Ferris (1984, p. 324) uses the term, "citizen coprovision", which is defined as "the voluntary involvement of citizens in the provision (financing) of publicly provided goods and services or their close substitutes." He views citizen co-provision as an economic process and argues that this new definition aims to extend the existing conceptions of citizen co-production *by examining the efficiency and equity effects of voluntary behavior of citizens and identifying the conditions conducive to this alternative public services delivery approach*. In consequence, he argues that the key criteria in examining benefits realization from citizen co-provision are whether or not citizen time and money donations directly: (1) *reduce the amount of government resources required to sustaining a given service level*, or (2) *increase the service level achieved with a given amount of government resources*.

With public services provided by different government agencies and even by private-sector parties, voluntary citizen action including time donations can be complicated and require knowledge of a given public service. In the digital age of public administration, the new conceptions of networked citizen coproduction have been emerging to examine the role of the internet in citizen and community coproduction of public services (Bovaird, 2007; Meijer, 2011). Social media in the hands of networked citizens who have no hierarchical organization have facilitated the leaderless 'social media revolution' in the turbulent aftermath of the 2009 Iranian Presidential election (Chatfield, Akbari, Mirzayi, & Scholl, 2012).

2.4. Resilient information infrastructures

The framework for "Resilient Information Infrastructure" (RII) (Scholl & Patin, 2012, 2014) explains the nature and dimensions of information infrastructures that can continue in mobilizing adaptive capacities under circumstances of extreme duress to provide timely and actionable information before, during, and after an extreme event for effective response and recovery. In their extended and formalized definition, *an information infrastructure* (*II*) *encompasses not only physical/tangible components*, such as organization, information systems, information repositories, physical information channels, retrieval procedures, and transmission networks, *but also includes less tangible*, *soft components*, *such as the power of social capital*, *social grids*, *and social flows of time-critical* "*information*," which is not only understood as a "thing" or a "record," but also as a *process* and a *relationship of meaning* (*or shared sense making*) *between human actors*. Dimensions of a RII encompass its *redundancy* and its *resourcefulness*, which provide for its *robustness* and *rapidity* in support of an effective and efficient time-critical action. Therefore, the conception of RII, in contrast to 'national critical infrastructures,' encompass *organizational* (routines, rules, resources, and governance structures and processes), *social* (personal, group, interpersonal, and intergroup relationships), and *technological* (hardware, software, and embedded services) components. The conceptual framework for RII argues for the need to study the interplay between these components (Scholl & Patin, 2012, 2014).

The framework for RII postulates that the more resilient these information infrastructures the better they can serve as backbones for *information-driven decision-making in unpredictable and dynamically evolving environments and continued provision of essential services under any given circumstances*. Resiliency in IIs expands into the tangible/physical and the intangible/social/tacit knowledge/relational dimensions of information infrastructures. Among the key challenges when responding to an extreme event are the direction and coordination of response efforts requiring an up-to-date situational awareness and operational picture, which might not become available within the first 24 to 72 h of an extreme event (Chatfield, Wamba, & Tatano, 2010; Harrald, 2006; Kapucu, 2006; Kapucu, Arslan, & Collins, 2010). A reliable and functioning information infrastructure is the indispensable prerequisite for projecting a comprehensive operational picture based on *trustworthy*, *accurate*, *complete*, *and timely information* (Harrald, 2006; Marincioni, 2007). Such information has to be *timely and actionable*, and compiled to enable first-response leadership to immediately make informed decisions on priorities of response, deployment of responders, resource allocation, areas served, foci of response, and collaborative engagement.

3. Research methodology

3.1. Case study research

A case study research for theory building (Eisenhardt, 1989) was adopted for this research as it appropriately guides us to address the research questions. This approach enables us to effectively investigate and capture the dynamics among key stakeholders involved in the development, implementation and use of the system (Eisenhardt, 1989). Moreover, the case study is considered as a suitable approach when answering research questions such as "why" and "how" things are done (Lee, 1989). Prior to the case interviews, we examined Indonesian e-government websites of the central disaster management agencies to identify the key disaster management policies that are relevant to the operation of disaster early warnings. Policy analysis was conducted to help us better understand the relationships among the agencies, the division of labor, shared resources, and the line of authority with regard to the sharing and flows of disaster information among Indonesia's disaster management agencies.

We then conducted two semi-structured case study interviews with Executive Secretary of the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) and Senor IT Manager, the National Disaster Management Agency of Indonesia (BNPB) in Jakarta, Indonesia. Both interviews (although they were guided by a written interview protocol in English) were conducted in Indonesian for active participation from interviewees and lasted more than 90 min per interview. The BMKG information infrastructures and social media use in government are our focal research interests. So while the number of interviews was limited, we accessed the most informed of the public policy reforms and RII development and implementation in Indonesia with regard to its social media use for national disaster management.

3.2. Social network analysis

In order to address the research questions, we also conducted a series of social network analysis (SNA) of Twitter information flows and exchanges within the BMKG's Twitter Tsunami Early Warning Civic Network during the April 11, 2011 earthquake. As Fig. 1 shows, this earthquake with a magnitude 8.6 occurred off Aceh, Indonesia — the same location of the 2004 Indian Ocean Tsunami disaster. While the earthquake did not result in another devastating tsunami, it killed 7 people and severely affected 107 residents.

In SNA, a social network graph is used to model a social network composed by nodes and links. While nodes represent individual actors within a social network, links represent social ties, relationships, connections, exchanges, or interactions among the actors. A graph enables us to visualize a vast amount of large data and complex information flows for a general overview. With software tools, salient metrics of the social network can be generated from the existing nodes and links for further analysis.

Table 2 shows salient metrics of BMKG Twitter Tsunami Early Warning Civic Network. *The number of nodes determines the size of the BMKG civic network*. The strength (or weakness) of social ties between the nodes is represented by the number of the links. The density of this civic network refers to the degree of dyadic connections in the network, indicating how fully the network is inter-connected. The network diameter is the largest distance of any dyadic pair of nodes in the network. The average degree represents quantifications of average actor tendencies in connections to others in the network. While the weakly connected component represents the number of one-way communications among

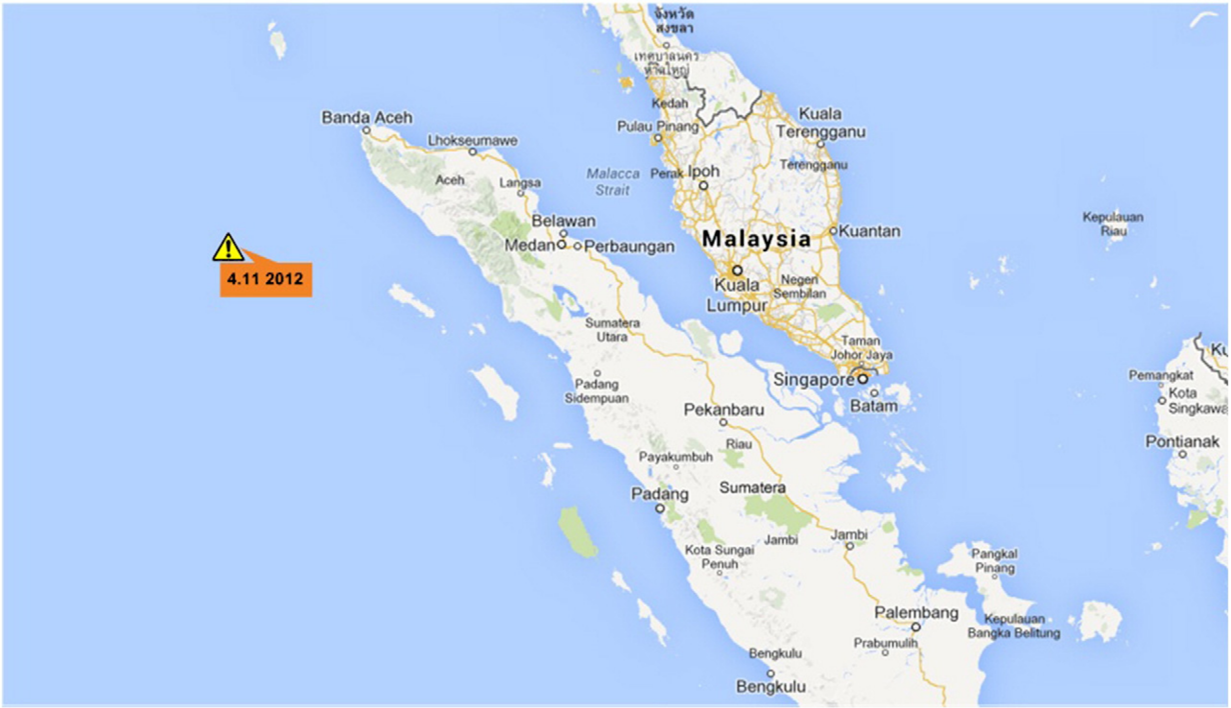

Fig. 1. Location of April 11, 2012 Indonesia earthquake (M 8.6).

the nodes, the strongly connected component represents the number of the nodes with two-way communications.

In our SNA, BMKG-issued Tweets and BMKG Twitter followers' retweets (or the government Tweet forwarded by its Twitter followers) represent a linked civic network of information flows and exchanges which were triggered by the BMKG's first tsunami warning Tweet issued to its Twitter followers on April 11, 2012. According to the Twitter archives, this BMKG's first Tweet was retweeted ("RT") for 7781 times. However, Twitter.com limits the REST API user access for searching a specific tweet. Therefore, we used a third party data provider, Topsy.com, for searching the tweets. We collected the tweet data for the period of 16 days (June 18–July 3) in 2012. The search identified 6383 retweets (or 82%) of all the tweets generated by the followers of the BMKG Twitter Tsunami Early Warning Network. Of the 6383 retweets, we eliminated 137 duplicate retweets. Therefore, we traced 6246 retweets to the Twitter.com website to collect metadata such as the time of a retweet, Twitter user name, the number of followers the user has, and importantly, user location information. We then conducted a SNA of the 6246 retweets by the BMKG's followers during the EE period.

The BMKG concurrently uses two Twitter accounts: @BMKGnews (the old account) and @infoBMKG (the new and preferred account), both of which have different citizens and organizations as followers. @BMKGnews issued its first tsunami warning at 8:46:36 UTC, 1 min, 41 s earlier than @infoBMKG did. The BMKG uses the same standardized Tweet structure for the two accounts. Fig. 2 shows the BMKG's first Tweet issued through @infoBMKG. Its content states (in English translation): "Tsunami Early Warning in Bengkulu, Lampung, Aceh, West Sumatra, North Sumatra, Earthquake Mag: 8.9 SR, April 11 2012 15:38:29 West Indonesian Time, Location 2.31 LU,9 twitpic.com/98fdwn View photo." The Tweet has an embedded photo image link through which the followers can view a hazard map.

Table 2
Salient metrics of the BMKG Twitter Tsunami Warning Civic Network.

Metric	The 4.11 2012 tsunami warning tweet network
Number of nodes	6246
Number of links	16,145
Network density	0.001
Network diameter	24
Weakly connected component	1210
Strongly connected component	3868
Average degree	2.585
Average path length	7.001

4. Case study results: Indonesia's disaster management reforms

As a central disaster agency, Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) in Jakarta is positioned as the lead upstream supplier of Indonesia's disaster information value chains. The BMKG Twitter Tsunami Early Warning Civic Network is an integral part of the agency's RII developed through the Indonesian government's disaster management reforms.

4.1. Public policy reforms on disaster early warning and response

On December 26, 2004, the Indian Ocean Tsunami, which was caused by a magnitude 9.1 earthquake off Aceh, Indonesia, recorded human deaths of 165,708 in Indonesia alone and 227,898 in the region and resulted in estimated damage cost of US$10 billion (US $12 billion today) (EM-DAT, 2013). It was a brutal wake-up call for Indonesian government and citizens alike about the urgent need to reform the nation's disaster preparedness and disaster response. In order to mitigate natural hazards' impacts, especially the number of disaster casualties, Indonesian government adopted a series of legal reforms that were in alignment with the Hyogo Framework for Action 2005–2015, which emphasized the national priority for building strong institutional and

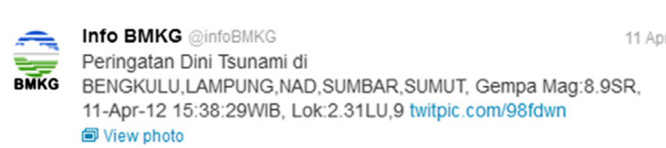

Fig. 2. BMKG first Tweet of the 4.11 2012 tsunami warning.

technological infrastructures for better disaster preparedness and response (UNISDR, 2005).

The Parliament passed the Law 24/2007 on Disaster Management (Government of Indonesia, 2007), which explicitly states that the government of Indonesia is responsible for disaster response, including mitigating disaster risks and protecting the society from natural hazards. In 2008, Badan Nasional Penanggulangan Bencana (BNPB) was established as a new National Disaster Management Agency responsible for disaster coordination and management of all natural hazards. The BNPB is charged to coordinate other government agencies responsible for specific disaster response functions and operations. Other existing disaster agencies were also institutionally empowered. For example, the two legal bases for the BMKG — Presidential Decree 61/2008 (Government of Indonesia, 2008) and Law 31/2009 on Meteorology, Climatology and Geophysics (Government of Indonesia, 2009) — now clearly state that one of the BMKG's main responsibilities is to provide early warnings on natural hazards to government agencies and the mass media. The series of legal reforms have led to public information service reforms. The Head of BMKG Decree mandates that the first early tsunami warning must be issued within 5 min after an earthquake. While this new mandate for the BMKG is to warn other government agencies and the mass media of the tsunami hazards (BMKG, 2012), the BMKG is *not mandated to warn citizens directly* within 5 min of an earthquake. This was confirmed during our case interviews with the BMKG and its standard operating manual.

4.2. Indonesia tsunami early warning system

As an integral part of the national disaster management reforms, Indonesia launched a large-scale information infrastructure project, which included the development of a comprehensive Tsunami Early Warning System (known as InaTEWS). The BMKG operates the InaTEWS to detect, analyze, simulate and issue disaster early warnings on extreme weather, earthquake and tsunami. Fig. 3 shows an overview of Indonesia's RII that support the InaTEWS. The InaTEWS receives seismic data from the BMKG, the crustal deformation from National Coordinating Agency for Surveys and Mapping (Bakosurtanal), and sea wave level monitoring information both from Bakosurtanal and the Agency for the Assessment and Application of Technology (BPPT) (Harjadi, 2008; Harjono & Pariatmono, 2012).

Fig. 4 shows the BMKG's InaTEWS decision support system (DSS) and its Tsunami warning information flows through the BMKG upstream and downstream information value chains. The InaTEWS supports the BMKG's data-driven decision-making processes through the following four sub-systems: (1) situation assessment system for creating earthquake maps and running simulations; (2) real-time monitoring system that is integrated with GPS, buoys and tide gages; (3) decision system for suggesting the appropriate type of warnings; and (4) production system for disseminating tsunami early warnings to the list of government agencies and approved mass media.

The Executive Secretary of the BMKG during his interview for this research pointedly observed: "Although tsunami warning should be issued within 5 min after an earthquake (according to the Head of BMKG Decree 1/2012), the InaTEWS ideally needs additional 500 accelerometers (devices that measure proper acceleration of tsunami waves) all around the Indonesian coasts in order to predict tsunami within 2 min after an earthquake. This is because the earthquake epicenter, on average, is located from 250 to 400 km away from the nearest coast of Indonesia. This actually reduces the amount of time we have to warn citizens living near the coast of tsunami hazards and give them less time to evacuate themselves."

4.3. Twitter tsunami early warning network

Whereas the InaTEWS was designed to issue early tsunami warnings largely to government agencies and mass media, the BMKG's Twitter Tsunami Early Warning Civic Network is a citizen-centric disaster communication channel used by the BMKG to warn net-savvy citizens directly of predicted tsunami hazards. As of July 2, 2012, the BMKG Twitter Tsunami Early Warning Civic Network issued a total of 6223 Tweets and built a total of 339,871 followers. The BMKG network further increased its followers to 456,197 as of December 9, 2012.

5. Social network analysis results

The BMKG Twitter network is a social network whose speed and reach are largely determined by the number and the action (or inaction) of the government agency's Twitter followers. They form weak ties and establish online connectedness through their actions of sending, receiving and forwarding tweets within the network. In our case, the followers' direct actions to forward (retweet) the BMKG's tsunami warning Tweet created positive network externalities since they had positive effects on increasing the speed and reach of the network. The BMKG can reach a greater number of citizens with its tsunami early warning Tweet if its followers act without delay, forwarding it to their

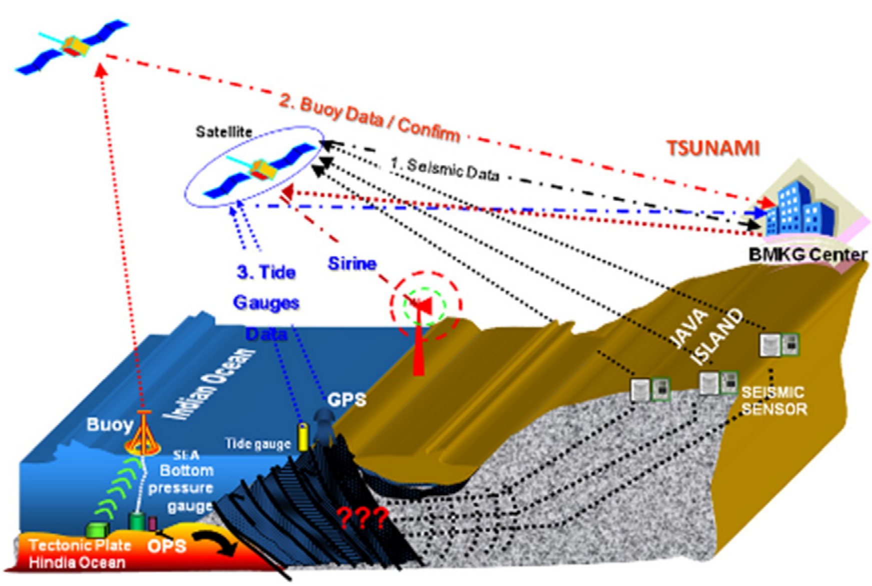

Fig. 3. An overview of Indonesia's information infrastructures for InaTEWS. Source: Indonesian Institute of Science (Harjadi, 2008).

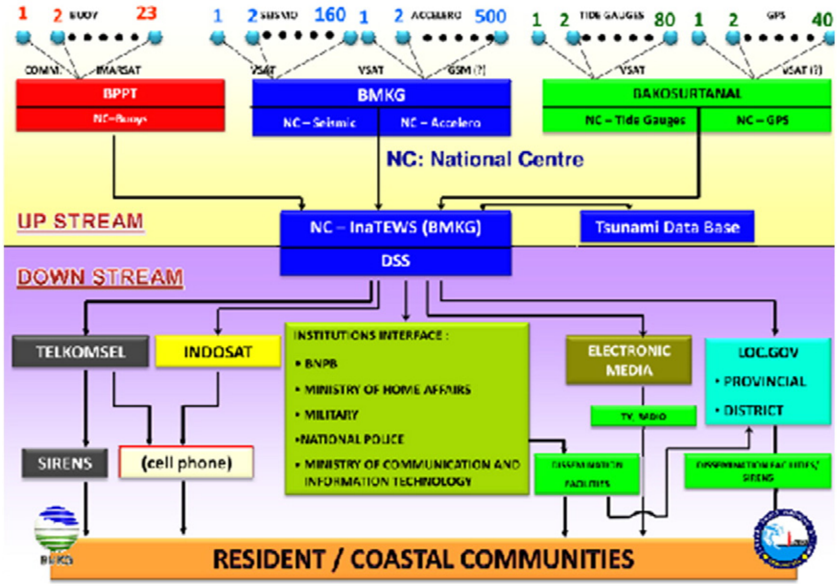

Fig. 4. Tsunami early warning information flows (Harjono & Pariatmono, 2012).

own followers, and directly participate in its Twitter-enabled public information services.

5.1. The speed and reach of the BMKG Twitter tsunami early warning civic network

The 2012 Northern Sumatra (Magnitude 8.6) Earthquake occurred at 8:38:29 UTC on April 11, 2012. As we discussed in the previous section, the BMKG is mandated by the law to issue an early tsunami warning within 5 min of an earthquake to the government agencies and the mass media (BMKG, 2012). The BMKG e-government website has posted its first tsunami warning at 15:43:25 (West Indonesian Time or 8:43:15 UTC). This demonstrates that *extant RII enabled the BMKG to issue a timely early warning only 4 min, 46 s after the earthquake* (within the mandatory "within 5 min" policy guidelines).

Fig. 5 shows a timeline for the BMKG Tweet and re-tweets sent by its followers within the network on April 11, 2012. The BMKG issued the first tsunami warning at 8:46:17 UTC through @infoBMKG (its new Twitter account), which shows the time delay of 7 min, 48 s after the earthquake. So, against the e-government website information, *there was a delay of 3 min, 2 s before the BMKG warned citizens of the tsunami hazards through the Twitter Tsunami Early Warning Network*. Our SNA results show that 200 retweets were issued concurrently by the BMKG's followers, which created the network's tweet traffic peak at 8:48 UTC. The information flows and exchanges peaked 6 min prior to the predicted tsunami arrival time. Since the predicted tsunami was not eventuated, the BMKG revoked its tsunami warnings at 13:07.

Table 3 shows the first ten followers who "RT" within the BMKG network: 7 citizens and 2 organizations (@Metro_TV and BMKG through its two different Twitter accounts). The @BMKGnews's first tsunami warning Tweet was sent to its 10,995 followers at 8:44:36. The BMKG Tweet was "RT" by 10 of its followers to their own followers. One of the 10,995 BMKG Twitter followers is @Metro_TV, a leading national television station with its own followers of 2,492,811. Of the Metro_TV followers, 2182 (or 0.09%) "RT" the tsunami early warning Tweet to their own followers. Table 3 also shows that the seven citizens also had their own followers, ranging from 2159 (@Silvyams) to 522 (@SNUGSTR). Finally, it shows *a total of 2,845,301 Twitter followers* within the civic network who received the first tsunami warning Tweet *within 2 min after the government agency issued its Tweet*.

We found that the BMKG issued its first tsunami early waning Tweet through the two different Twitter accounts, which have different followers. While these two Tweets were issued at different times, they had the same Tweet message content and the same standard message structure. For some reason, however, the first tsunami warning Tweet was issued through the old account (@BMKGnews) 1 min, 41 s earlier than another Tweet through the new account (@infoBMKG).

We also found that the BMKG tsunami early warning Tweet provided *short but valuable lead times of 8 min, 53 s* for citizens in the hazardous coastal zones to evacuate themselves, should a catastrophic tsunami

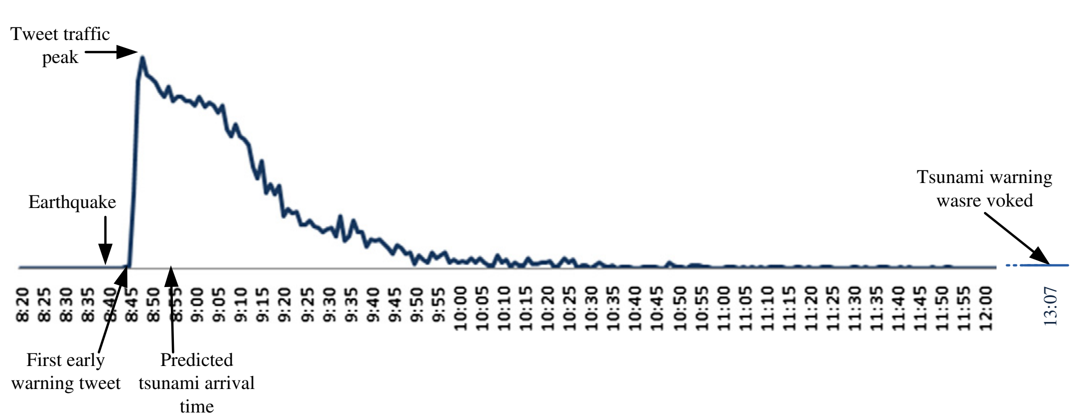

Fig. 5. Timeline for tsunami early warning tweets' flows and exchanges.

Table 3
The first 10 tweets and retweets sent within the BMKG civic network.

No	Timestamp	Tweet sent by	RT by	Number of followers	Number of follower retweets
1	8:44:36	BMKGnews		**10,995**	**10**
2	8:45:06		And1aZharR	305	1
3	8:45:41		Metro_TV	2,492,811	2182
4	8:45:45		Sigantengkalem	1549	9
5	8:46:17	infoBMKG		**333,289**	**1796**
6	8:46:35		hiYano	665	3
7	8:46:36		Silvyams	2159	4
8	8:46:36		RezkySy	918	0
9	8:46:37		Umenumen	2088	11
10	8:46:37		SNUGSTR	522	2
	Total			2,845,301	

be eventuated. Two underlying assumptions for computing the lead times are: (1) the earlier time stamp (8:44:36) for the @BMKGnews Tweet and (2) the 15 minute latency between the earthquake and the estimated tsunami arrival time. While the actual arrival times of tsunami waves often vary even within the same coastal region, depending on many factors, prior empirical research on tsunami estimated that the 2010 Mentawai Tsunami off Indonesia arrived at the nearest coast in 15 min after the earthquake occurred on October 25, 2010 (Newman, Hayes, Wei, & Convers, 2011).

Fig. 6 shows graphically the speed and reach of the BMKG Twitter Tsunami Early Warning Network. The line graph shows the number of Twitter followers within the agency's Twitter Tsunami Early Warning Civic Network who can be potentially reached and warned by the BMKG Tweet. The x-axis on this line graph shows time (in minute), whereas the y-axis shows the number of Twitter account holders within the network. Using 15 min (or until 8:53:39 UTC) as a lead time for the BMKG to warn citizens of tsunami hazards, the line graph shows that *the agency's first early tsunami warning Tweet can reach potentially as many as 4,115,164 Twitter followers within the network in 15 min*. The line graph also shows that the number of Twitter followers who can be reached increases sharply within the first minute and continues to increase throughout the tsunami warning period. *The rapid and sharp increase observed immediately after the first Tweet is explained by the number of followers and the actions of Metro_TV without delay in forwarding the BMKG Tweet to its own 2,492,811 followers*, greatly contributed to the civic network's speed and enormous reach. With the voluntary actions of other big nodes; @infojakarta, @infobandung, @r_djangkaru, @hediyunus, @infobdg and @aagym, the BMKG Twitter Tsunami Early Warning Civic Network could potentially reach as many as 6,470,136 within 30 min (or 9:08:29) and 8,280,030 Twitter followers within the BMKG Twitter network within 60 min (or 9:38:29).

5.2. BMKG followers with social influence (big nodes) within the network

Table 4 shows the ten largest nodes within the BMKG Twitter Tsunami Early Warning Network. It also shows the number of retweets sent by their own followers. @Metro_TV not only issued the first retweet of the BMKG early tsunami warning Tweet but also had the largest followers, making @Metro_TV as the biggest node in the civic network. Of its nearly 2.5 million followers, 2182 of them also directly forwarded the Metro_TV retweet (which was the original BMKG Tweet) in propagating and increasing the size of the BMKG Twitter Tsunami Early Warning Network. Other three big nodes are local city information channels: infobdg, infojakarta and infobandung. In contrast, four of the top ten retweeters are well-known citizens with the power of social influence on other citizens in society. Of the four citizens, the third biggest node is one of the most well-known Moslem preacher with 334,070 followers. His followers also forwarded 694 retweets. On average, however, only 0.1% of all the followers in the government agency's network forwarded the big nodes' tweet.

The ten big nodes are central and active hubs of the BMKG network. Fig. 7 is a magnification of the dense center of the BMKG network, showing the ten big nodes.

Finally, Fig. 8 shows the ten major locations of the BMKG Twitter followers on the map of the west coast of Sumatra, the small islands off the west coast of Sumatra, and the south west coast of Java. The map was part of the 4 11 2012 first tsunami warning Tweet issued by the @infoBMKG, which was shown earlier in Fig. 2. Fig. 8 shows the epicenter of the earthquake (marked by a red circle) and the projected tsunami high-impact areas (marked by red and yellow lines). While the red line on the map indicates the expected severe impacts of the tsunami, the yellow line shows the expected strong impacts. Using the BMKG map, we show a wide distribution of the BMKG Twitter followers in the tsunami high-risk areas. As shown on the map, we were able to identify the locations of 2908 Twitter followers (or 47%) out of our data set of 6246 Twitter followers in the BMKG network. However, the remaining 3338 (or 53%) failed to provide their location information. Of the identified locations, a total of 312 retweets were sent by the BMKG followers living in the most threatened areas by the predicted tsunami: Aceh (21), North Sumatra (146), West Sumatra (78), Bengkulu (18) and Lampung (49).

6. Discussion

Sections 4 and 5 presented the key findings from the case study and the social network analysis, respectively, in order to answer the first research question (RQ#1):

> *How has government used social media to provide citizens with timely and actionable disaster information under the conditions of a rapidly evolving EE?*

When assuming 15 min (or, until 8:53:39 UTC) as an acceptable lead-time for BMKG to warn citizens of tsunami hazards, the SNA results clearly showed that the Indonesian government quite effectively warned its Twitter followers of the predicted tsunami hazards through @BMKGnews within 6 min, 7 s of the occurrence of the 8.6 magnitude

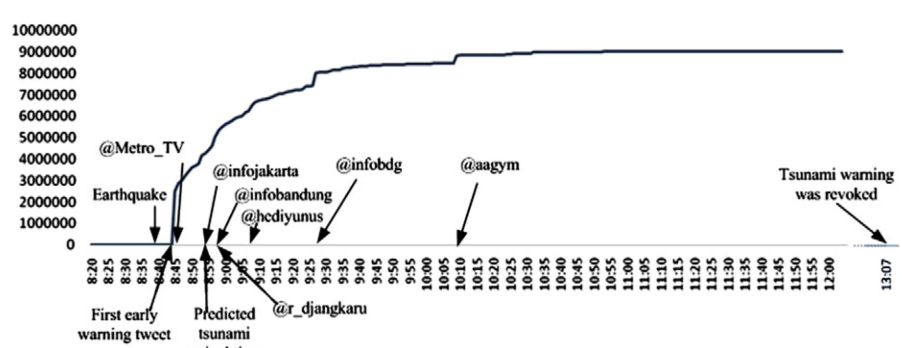

Fig. 6. Number of Twitter followers who can be warned during the tsunami warning period.

Table 4
Top 10 retweeters by the number of followers.

No	Twitter account	Description	Number of followers	Number of followers' retweets
1	Metro_TV	National television channel	2,492,811	2182
2	infobdg	Local city information channel	561,194	508
3	aagym	Citizen (Indonesia Moslem preacher)	334,070	694
4	infojakarta	Local city information channel	237,950	692
5	infobandung	Local city information channel	232,450	360
6	HediYunus	Citizen (Indonesia's famous singer)	156,955	122
7	r_djangkaru	Citizen (Indonesia's famous actress)	124,422	223
8	RadioElshinta	National radio channel	119,173	219
9	evansanders_id	Citizen (Indonesia's famous actor)	88,520	61
10	bolanewscom	National online sport magazine	81,319	158

earthquake on April 11, 2012. Other SNA results clearly showed that BMKG's early tsunami warnings potentially reached as many as 4,115,164 Twitter followers within the 15 min acceptable lead-time. However, these results should not be interpreted as evidence for the power of social media per se. On the contrary, the SNA results also showed that without voluntary and collaborative efforts of Twitter followers, including individual citizens and organizations, the speed and enormous reach of the BMKG Tsunami Early Warning Civic Network would not have had the dynamic and enabling effects that it finally achieved. These individuals and organizations represent the networked and computer-literate population of the Indonesian society. The followers of BMKG's Twitter network were interested in being warned of tsunami hazards in a timely manner. They served as network nodes and hence largely determined the size of the civic network. However, had the network followers remained inactive, for example, by not reading BMKG's early tsunami warning without delay, and had they decided to not "RT" the warning message to their own followers and friends, BMKG's Twitter-based Tsunami Early Warning Civic Network would not have achieved the speed and enormous reach this research has demonstrated. The BMKG needed both the effective use of Twitter technology tools and active engagement of networked and comprehending citizens to warn their own followers of tsunami hazards in a timely manner when the magnitude 8.6 earthquake occurred on April 11, 2012.

However, we find that BMKG has some room for improvement. As we discussed earlier, the BMKG concurrently uses both the old and the new Twitter accounts. For some reason, another tsunami warning Tweet with the exactly identical content and structure was issued through @infoBMKG, lagging 1 min, 41 s behind the @BMKGnews tweet, which means the early tsunami warning through this new Twitter account was issued 7 min, 48 s after the earthquake. Furthermore, BMKG's e-government website posted its earthquake reporting and first tsunami warning at 8:43:15 UTC, which demonstrates the government agency's capacity to issue a timely early warning within

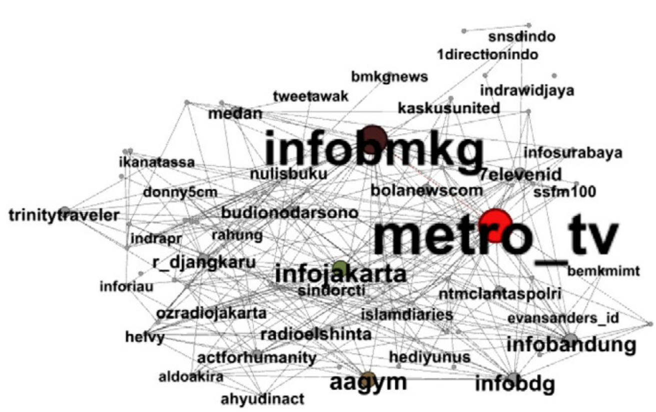

Fig. 7. BMKG Twitter followers with social influence (big nodes).

only 4 min, 46 s after the earthquake (within the mandatory "within 5 min" policy guideline). These time delays suggest institutional factors such as the need to reduce the time to manually feed its Twitter civic network rather than technological factors.

In summary, despite the agile response and alert, government resources and warnings alone did not comprehensively inform potentially affected communities in April 2012; however, through the extended civic network relying on retweets and sub-networks that had formed via Twitter in an ad-hoc fashion, populations were informed that otherwise would have been exposed to the hazards without warning. In other words, the combined collaborative efforts of government and networked citizens had a substantial effect and potentially saved many lives.

The second research question (RQ#2) reads:

How has government used (or can use) social media to engage citizens in co-providing time-critical public information services under the conditions of a rapidly evolving EE?

Citizen co-production (Bovaird, 2007; Meijer, 2011; Whitaker, 1980) of public services has been studied and discussed for some decades. This research shows how and to what extent the followers of BMKG's early tsunami warnings influenced the information flows and exchanges within the agency's civic network and beyond. Whitaker (1980) argued that citizens can co-produce public services in many different ways, *ranging from passive roles to active and enabling roles*. The followers of the BMKG civic network cooperated with government through direct participation in providing time-critical public information services. However, the followers of the BMKG civic network did not engage in negotiating with the BMKG to change public information services. During the case interview with the Executive Secretary of the BMKG, the interviewee indicated that the InaTEWS ideally needed additional 500 accelerometers (devices that measure proper acceleration of tsunami waves) all around the Indonesian coastline in order to predict tsunamis *within 2 min* after an earthquake, which would provide citizens with longer lead times for evacuations. We hold that BMKG could crowdsource information from its Twitter followers located in coastal areas to identify and communicate the arrival of tsunami waves to the nearest coast, hence increasing the BMKG capacity to detect tsunamis earlier with or without the additional accelerometers.

In summary, the social network analysis results presented here provide evidence that through the active and direct participation of BMKG Twitter followers in the Tsunami Early Warning Network, the overall service level increased beyond levels possible based on BKMG's own resources under the conditions of the rapidly evolving EE — the InaTEWS, Twitter Tsunami Early Warning Civic Network, and human resources. Therefore, the followers of the BMKG civic network co-produced time-critical public information services.

Finally, we need to highlight the critical importance of the Indonesian government's disaster management reforms, which empowered the BMKG institutionally and provided the BMKG with new information infrastructure. In their extended and formalized definition, Scholl and

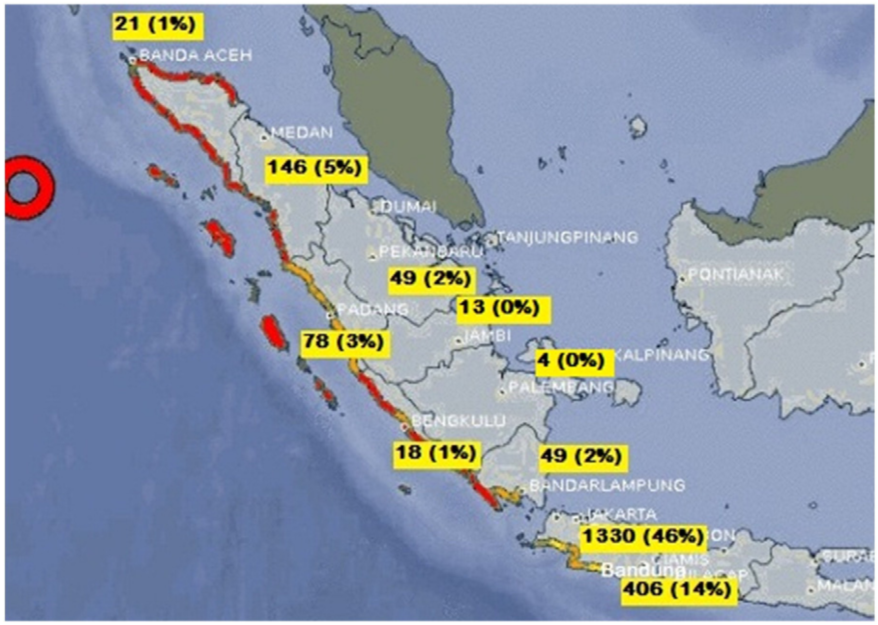

Fig. 8. Locations of BMKG Twitter followers.

Patin (2014) state that an information infrastructure (II) encompasses not only *physical/tangible* components, such as organization, information systems, information repositories, physical information channels, retrieval procedures, and transmission networks, but also includes *less tangible*, *soft components*, such as *the power of social capital*, *social grids*, *and social flows of time-critical* "*information*," which is not only understood as a "thing" or a "record," but also as a *process* and a *relationship of meaning (or shared sense making) between human actors*. Our case study research results clearly showed that the BMKG's new II critically consists of not only *physical/tangible components* such as InaTEWS and Twitter-based tsunami early warning system but also *less tangible*, *soft components* such as the power of social capital as shown by the big nodes with great social influence (Metro_TV and the popular Moslem preacher) and the social flows of time-critical Twitter tsunami early warnings which are driven by the followers who decide to forward the BMKG Tweet. The BMKG Tsunami Early Warning Civic Network has shown the dimensions of the government agency's II: *robustness* by the distributed locations of its followers throughout Indonesia and *rapidity* by the speed at which the BMKG civic network can reach over 4 million net-savvy citizens within 15 min of the earthquake. The BMKG II also shows its *redundancy* in multiple communication channels through which the public can be warned of tsunami hazards directly or indirectly and its *resourcefulness*, which is best exemplified by the effective use of resources to execute its key responsibilities which this research has captured and communicated.

Our research has clear public policy implications. In order for government to realize public value from social media in government in a specific context of EE such as we presented in this research — government use of social media to communicate disaster early warnings directly to citizens, government not only needs to harness effective use of social media technologies and tools but also need to have effective disaster management reforms and citizen engagement policies. Government needs to launch a citizen engagement strategy aimed at driving more value from social media in government, including a culture of close collaboration with net-savvy citizens with the power of social influence on their fellow citizens. The net-savvy citizens with social influence can contribute to increase the size of the government Twitter civic network, hence improving the speed and reach of the network in informing citizens about natural hazards. Finally, based on the citizen co-provision theory (Ferris, 1984), public policy needs to measure the citizen co-provision effects in reducing government resources or increasing the level of government efficiency in providing time-critical public information services.

7. Conclusions

In this empirical research, we addressed the two central research questions on the utility of social media in government and enabling roles of citizens in co-producing public information services under circumstances of extreme duress. Guided by a prior theoretical work on public administration theory on citizen co-production (Whitaker, 1980) in public services and resilient information infrastructures framework (Scholl & Patin, 2012, 2014), we studied and analyzed the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), the central disaster agency and the upstream supplier of Indonesia's disaster information value chains, and its Twitter Tsunami Early Warning Civic Network as an integral part of the agency's RII. In this research we used both case study research and social network analyses on the BMKG Twitter information flows and exchanges among its Twitter followers during the April 2012 Northern Sumatra Earthquake.

This research found clear evidence that the BMKG Twitter Tsunami Early Warning Civic Network provides an effective mechanism for direct participation of net-savvy citizens in co-producing time-critical public information services. Our social network analysis results show a strong evidence for the enabling roles of net-savvy citizens in forwarding the government agency's tsunami early warnings, which influenced greater control of information flows and exchanges within the BMKG's civic network and hence increased government efficiency in reaching over 4 million followers within 15 min of the earthquake. Our empirical findings have important public safety communication policy implications for realizing social media benefits in government. Government not only needs to harness the effective use of social media technologies and tools but also need to have effective disaster management reforms and citizen engagement policies. However, our research has inherent research limitations because we only focused on Twitter use in a single government agency in Indonesia and in a specific context of Twitter-based tsunami early warnings. Our future research directions include a survey research on the BMKG Twitter followers on their motivations to join the network and key drivers for their direct participation in executing time-critical public information services. They also include case study research and social network analysis of another government organization which uses Twitter for disaster management.

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