Creating a Taxonomy of Earthquake Disaster Response and Recovery for Online Earthquake Information Management

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Abstract: The goal of this study is to develop a taxonomy of earthquake response and recovery using online information resources for organizing and sharing earthquake-related online information resources. A constructivist/interpretivist research paradigm was used in the study. A combination of top-down and bottom-up approaches was used to build the taxonomy. Facet analysis of disaster management, the timeframe of disaster management, and modular design were performed when designing the taxonomy. Two case studies were done to demonstrate the usefulness of the taxonomy for organizing and sharing information. The facet-based taxonomy can be used to organize online information for browsing and navigation. It can also be used to index and tag online information resources to support searching. It creates a common language for earthquake management stakeholders to share knowledge. The top three level categories of the taxonomy can be applied to the management of other types of disasters. The taxonomy has implications for earthquake online information management, knowledge management and disaster management. The approach can be used to build taxonomies for managing online information resources on other topics (including various types of time-sensitive disaster responses). We propose a common language for sharing information on disasters, which has great social relevance.

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1.0 Introduction

Internet was reported as the preferred source of information and the most reliable source for news by a majority of American adults in 2009. Disaster communication increasingly occurs via social media for up-to-date information. For example, after the 2011 Japanese tsunami, there were more than 5,500 tweets per second about the disaster (Fraustino et al. 2012). Within the first nine hours after Ya'an Earthquake in 2013 in China, the number of tweets about the earthquake from *Weibo* (a Chinese microblogging website) totaled 64,000,000 (Chen and Fu 2013). Many of the posts were about help-seeking. Sixty-three percent of Canadians said emergency responders should be prepared to respond to calls for help posted on social media (Canadian Red Cross 2012). Online information sources, especially those from social media, have been used for emergency response and recovery.

Earthquake is one of the most common hazards. In the last ten years, 20,351 earthquakes above magnitude 5 hit the Earth with an estimated total of more than 350,000 deaths (USGS 2019). The earthquake and the aftershocks may take severe tolls in casualty and cause severe economic loss. As acute events, earthquake disasters require quick response and relief services (Marianti 2007). Organizing, mapping, disseminating, and communicating information adequately and swiftly are essential to prompt and effective response, especially in the first seventy-two prime hours, by supporting critical rescue decisions, such as where are the worst-hit areas, what are the needs of the victims, what to do for vulnerable groups, and how to cooperate among volunteers.

The capacity of collecting, organizing, and disseminating information is critical to disaster response and recovery, especially to the rapid-onset events with immediate destruction and death (OCHA-ROAP 2017; Marianti 2007). However, stakeholders of disasters use various technologies and protocols for communication, which makes information exchange difficult or even not possible between various organizations and countries (Knezić et al. 2015). Under extraordinary emergencies, they probably do not have uniform platforms and standards for information exchange, especially for the influx of information from domestic and overseas online sources. Furthermore, the contents and structures of online disaster information vary from each other. News agencies and portals tend to have a full coverage of catastrophes. Government authorities and non-government organizations are prone to publicize what has been done and what resources are available. Social media sites mainly reveal concerns of the general public, the needs of victims, and are also the places to express emotion. The online information in respect to disaster response and recovery is organized more often simply and casually rather than structurally and systematically. A taxonomy can be used to describe and organize information, providing a relationship structure and a common context of data, processes and management tools for cooperation and then facilitate information sharing and exchanging for disaster response and recovery (Knezić et al. 2015).

The goal of this study is to develop a faceted taxonomy using online information resources for managing online information with respect to earthquake disaster response and recovery. The vocabularies in the taxonomy were extracted from online information resources. The reason why we chose online information other than other sources (e.g., TV media and printed media) is that online information increases promptly and dramatically after an earthquake happens. The information that indicates the stakeholders' demand, reflects the disaster situation and implies the priorities of disaster response activities is critical to disaster management. The taxonomy was built using information resources about past earthquakes and is expected to support indexing and mapping, assisting retrieval and browsing, and exchanging and sharing information for future earthquakes. In this methodological paper, we focus on the process of constructing a taxonomy of earthquake disaster response and recovery by using online information from the earthquake-related websites and social media sites.

The paper is organized as follows: in the research background, several tools and methods of information management in disaster management domain and related viewpoints are introduced. The methodology is presented subsequently, followed by the procedure of developing the taxonomy, and a discussion of difficult problems and compromised solutions. Two case studies of using the taxonomy for organizing and sharing online earthquake-related information resources are presented afterwards, followed by a summary of findings and implications. The taxonomy can be viewed at http://www.swpu.edu.cn/system/_content/download.jsp?urltype=news.DownloadAttachUrl&owner=1459835785&wbfileid=2539518). The last section concludes the paper and points out future work.

2.0 Research background

Timely, reliable, and accurate information is critical to decision making for disaster management. In intra- and inter-agency interactions, multiple stakeholders collect, collate, and communicate information to coordinate response to, and relief of, human suffering. Accessing high-quality information and sharing it with partners is essential for improving the effectiveness of responses (UNCHA 2002; Dantas et al. 2006; Bharosa et al. 2010).

However, information sharing and coordination in disaster response and recovery are not as fluent and efficient as they should be. Various levels of obstacles from individual to community limit the communication of information (Bharosa et al. 2010). Technical constraints make information inaccessible as well (UNCHA 2002). The information sharing model of web portals such as ReliefWeb, the United States Agency for International Development (USAID), Redcross, FEMA, CNN, Sina, Yahoo, etc. is mostly monodirectional. Additionally, information on these portals tend to be general and informative; it focuses on the width instead of the depth of information, which could hardly support operations. Many other platforms and systems are designed to promote information sharing, such as the Virtual On-Site Operations Coordination Centre (VOSOCC) (OCHA Field Coordination Support Section 2014), Inter-Organizational Information-Sharing Systems (IOISS) (Bharosa et al. 2010), and Sahana Free and Open Source Disaster Management System (https://sahanafoundation.org/). Some frameworks and platforms were proposed to establish the linkages, templates, and sharing standards to enable information sharing during emergency response activities (Dantas et al. 2006; Martin and Rice 2012; Sakurai 2016). With the development of communication technology, mobile applications were created to support disaster response for private and public communications even without Internet access or cellular data, like FireChat, FEMA App, First Aid, Earthquake by American Red Cross, Hurricane by American Red Cross, etc.

Another trend is that social media has been and will abidingly be involved in disaster response and recovery. For the huge user base, accessibility and fast response, social media enables online exchange of information through conversation and interaction, thus publics have been turning towards social media sites for timely communication (Yates and Paquette 2011; Besaleva and Weaver 2016). In disaster response, decision-making is based upon information and reports from the public (Dantas, Seville, and Nicholson 2006). Social media like microblogs are believed to be the ideal sources of information, through which information is organized in clusters, such as topics, comments, and tags on posts and images (Garg and Kumar 2016; Yates and Paquette 2011). However, extracting useful information from social media is a challenging task.

Ineffective management of online information will in reverse increase workloads for both public and relief agencies. Several problems emerge due to this. First, people are faced with severe time pressure and a burst of information that can result in cognitive overload (Bharosa, Lee, and Janssen 2010). Second, poor quality of data and information, such as irrelevant, inaccurate, or outdated information may cause improper, even inaccurate, decisions (Bjerge, Clark, Fisker, and Raju 2016). Third, the public uses natural language on social media. Common naming conventions are absent, leading to communication dilemmas and difficult information retrieval (Yates and Paquette 2011). Fourth, categorization, common standards, and frames are underdeveloped to share information (Dantas, Seville, and Nicholson 2006; Yates and Paquette 2011).

There is a gap between the ideal application of information and the existing tools and methods. Raw online information is difficult to use until it is organized. Converting ambiguous terminologies to standard terminologies for annotating information helps to maintain information quality (UNCHA 2002). Decision support requires integration of, and interoperability between, datasets. Time pressure favors standardized information for sudden-onset disasters (Van de Walle and Comes 2015). Taxonomy is a useful tool for standardizing and organizing information (Bardet and Liu 2010).

Taxonomy is a kind of knowledge organization system that models the underlying semantic structure of a domain (Hill et al. 2002). Taxonomies supply terminologies and their relationships. Organizing information by taxonomy can meet users' specific decision-making and action-taking needs (Pellini and Jones 2011). Several taxonomies related to disaster response and relief have been developed and are introduced below. These taxonomies have different contents, structures, and purposes.

The AIRS/211 LA County Taxonomy (AIRS: Alliance of Information and Referral Systems) (211 LA County 2019) sets a standard for defining human services and for indexing and accessing human services. The "disaster services" section of the taxonomy is built from the perspective of a government agency for organizing, managing, and coordinating disaster services. It covers "disaster management organizations," "disaster preparedness," "mitigation," "warnings," "response," "relief," and "recovery services." There are many categories that might be adopted to build our taxonomy, e.g., "disaster management organizations," "disaster preparedness," "disaster mitigation," "disaster warnings," "disaster response service," "disaster relief services," "disaster recovery service," and their sub-categories.

The Humanitarian Decision Makers Taxonomy has a constraint domain within decision makers in sudden-onset disasters. It presents only the stakeholders of disaster response and recovery. It is the basis for mapping the information needs of humanitarian decision makers in sudden onset disasters, which helps to identify the decision makers and then target information towards them (Gralla et al. 2013). To serve our purpose, the categories such as "donors," "international organizations," "public sector," "private sectors," "military," "media," "non-governmental organizations," "individuals," and their sub-categories serve a good framework.

Federal Emergency Management Agency (FEMA) proposed a taxonomy for disaster recovery activities from the perspectives of government agencies, humanitarian organizations, and personnel. It divides disaster recovery activities into four phases—disaster preparedness, short-term recovery, intermediate recovery, and long-term recovery (FEMA 2011). The four phases demonstrate the timeliness of disaster management, which is a marked feature that we should take into account to develop the taxonomy.

3.0 Methodology

A constructivist/interpretivist research paradigm, which is "the theoretical framework of most qualitative research" (Tuli 2010, 100), was used in the study. It sees the world as constructed and interpreted by people in their experiences and interactions with each other and the wider social systems (Bogdan and Biklen 1992; Lincoln and Guba 1985; Maxwell 2006; Merriam 1988; Tuli 2010). This paradigm acknowledges and recognizes the researchers' active role in constructing the interpretation of the data gathered (Lauckner, Patterson and Terry 2012).

A taxonomy was constructed by the researchers using online information resources. The taxonomy can be evaluated by experts of earthquake disaster management for internal validity, and/or can be adjusted and applied to organize current online information resources to show some external validity. In the constructivist/interpretivist paradigm, we applied the taxonomy to organize current online information resources in two case studies in an attempt to demonstrate the usefulness of the taxonomy for organizing and sharing information. If the two case studies are meaningful and successful, the taxonomy is interpreted by the researchers as useful to some extent.

A taxonomy has a structure, categories, and terms. This section introduces the method of developing the structure and categories of the taxonomy, specifically, the method of selecting information resources and the terms of the taxonomy, and the procedure of developing the taxonomy.

3.1 Developing the structure and categories of the taxonomy

The structure of a taxonomy can be lists, tree structures, hierarchies, polyhierarchies, matrices, facets and system maps (Pellini and Jones 2011). Simple hierarchical structure (e.g., enumerative classification) with IS-A relation between concepts is the most common structure of taxonomy (Knezić et al. 2015). Sufficient information is needed for multitasking in disaster response and recovery. For example, person finding involves multiple aspects as shown in Figure 1. It is obvious that "personal details" and "missing persons phone lines" are not species of "person finding." "Contact person" and "name" have a connection of "relation to the sought person." Various hierarchies are not demonstrated in the mini-taxonomy and not all terms exhibit a genus-species relation. However, this mini-taxonomy serves its purpose. "A scheme of categories of terms which will do more than imitating the genus-species relation" is more suitable for the taxonomy of disaster response and recovery (Foskett 2009, 1819). A hierarchical structure that expresses more than the genus-species (IS-A) relationship between a category and its sub-categories is applied to the development of the earthquake response and recovery taxonomy.

- disaster response
  - person finding
    - personal details
      - name
      - the last known address
      - the last known time
      - contact person
      - contact number
      - relation to the sought person
    - person finder
    - missing persons' phone lines

Figure 1. An incomplete taxonomy of person finding in disaster response (data source: vocabularies are extracted from Sina Weibo).

The major categories of the taxonomy are developed based on facet analysis. Facets are "homogeneous or semantically cohesive categories," which are used to create term groupings of a subject discipline with a manageable size (Svenonius 2000, 139). Facet analysis can "provide a framework within which all the various types of terms can be accommodated, together with rules for their combination" (Foskett 2009, 1819). The categories in a faceted classification can be combined with each other, thus faceted classification can be flexible and can accommodate new phenomena (Vickery 1966, 46; Hjørland 2013; Kwaśnik 1999). In the enumerative classification, all classes are listed. By contrast, new facets can be added as needed and classes are built by combinations of building blocks in the faceted classification (Hjørland 2013). "By combining terms in compound subjects it introduces new logical relations between them, thus better reflecting the complexity of knowledge" (Vickery 1966, 46; Hjørland 2013). A hierarchical and systematically ordered scheme and the syntactic and semantic relations between categories provided by the facet analysis can represent various complicated attributes of disaster response and recovery and also address the need of describing dynamic information.

Facet analysis is conducted based on Raganathan's PMEST ("personality," "matter," "energy," "space," and "time") facets. P ("personality") is identified as stakeholders (see Appendix 2 for the category of stakeholders in the taxonomy). M ("matter") is the disaster itself, such as earthquake, flood, and tsunami. S ("space") represents the location, such as epicenter, refugee center, hospital, etc. T ("time") represents time, such as the time a disaster happened, the timeframe of disaster management, and the last known time of a missing person. E ("energy") is disaster preparedness, response, and recovery according to a timeframe of disaster management, which is addressed below.

Disaster management, also called emergency management, is a dynamic process. It has three phases including preparing, responding, and recovering (UNISDR 2017). Disaster preparedness enables timely, effective, and appropriate responses. Response has to do with immediate needs, short-term needs, and basic needs. Recovery includes restoring and improving of livelihoods, health and other development of disaster-affected societies. Each phase focuses on different missions, thus disparate information is needed for decision support. Disaster management needs to be operated in a timely manner. From the beginning, effective disaster preparedness is measured by coordinated and timely manner of avoiding gaps, duplication of effort, and parallel structures (United Nations 2008). Timely warning, timely liaison, timely role conversion of organizations, timely decisions, timely action, timely information, and timely post-disaster review are required in an effective disaster response and recovery (Carter

2008). The timeframe is a critical attribute of disaster management. Especially information for response and recovery is for time-sensitive demands and should be disseminated for emergency needs in a timely manner (United Nations 2018). In the AIRS/211 LA County Taxonomy, the "timeframe" elements are featured in the lowest level categories, e.g., "disaster preparedness," "emergency preparedness and response planning," "pre-disaster donations collection/storage," post "disaster emergency medical care," "post disaster child care." However, the taxonomy does not organize the categories in accordance with "timeframe." In the National Disaster Recovery Framework (FEMA 2011), the "timeframe" elements including preparedness, short-term, intermediate, and long-term, are at the top level. As elements of timeframe, preparedness, response, and recovery are embedded in the taxonomy.

The timeframe is a feature of many disasters, not only earthquakes. A modular design is adopted for multi-field applications. Modularization means the elements of a system are split up and assigned to modules according to a formal architecture or plan (Clark and Baldwin 2002). The original design of the taxonomy focused on the earthquake domain. The first step to modular design is to remove the "earthquake" term from the top categories, particularly from the top three level categories so that it can be applied to other disasters. The second step is to design the structure of the taxonomy for maximum independence of categories. Particular elements of a modular design may be changed in unforeseen ways as long as the design rules are obeyed, which makes module tolerant of uncertainty.

When developing the specific categories and terms, a combination of top-down and bottom-up approach is used. It is the best practice in taxonomy construction as discussed in knowledge organization literature (Wang, Chaudhry and Khoo 2010; Ramos and Rasmus 2003; Cisco and Jackson 2005; Holgate 2004; Wu and Yang 2015). A bottom-up approach builds up important categories from the concepts or vocabularies that are extracted from online information sources. Automated technologies such as information extraction and clustering can automate bottom-up analysis (Ramos and Rasmus 2003) but offers little control over the semantic meaning and organization of higher-level categories (Cisco and Jackson 2005). A top-down approach starts at the general, conceptual levels and establishes an overall framework for the taxonomy based on the objectives of the taxonomy (Ramos and Rasmus 2003). Therefore, it offers control over the top- and higher-level categories of the taxonomy (Cisco and Jackson 2005). A combination of the top-down and bottom-up approach develops the higher-level categories in the taxonomy first, creates lower-level categories according to the grouping of terms, classifies specific terms into lower-level categories along the way, and refines the lower-level categories according to the constraints of the higher-level categories (Wu and Yang 2015). The higher-level categories can be adjusted and refined according to the need of controlling the lower-level categories.

The primary taxonomy should be broad and shallow since multiple and at times disposable taxonomies can then be used for specific purposes (Pellini and Jones 2011). The top and second level categories are adjusted when the subordinate level categories are created. Third-to-bottom level categories are developed from tags and terms that are extracted from online information using a bottom-up approach.

When developing lower-level categories and collecting terms, folksonomy thinking is integrated into the bottom-up approach. Folksonomy is a powerful and innovative tool that complement taxonomies and help reduce the taxonomy's rigidity (Pellini and Jones 2011). Therefore, user-provided tags and terms from social media are absorbed into the taxonomy. For example, road and traffic situations gain intensive attention after an earthquake occurs. "Airport," "air traffic control," "broken roads," "blocked roads," and "road traffic control" were mentioned by media coverage repeatedly during the earthquakes, such as CNN for Haiti earthquake, Tencent, Sina, and Sohu for Ya'an earthquake (2013), USAID for Ecuador earthquake (2016), and Google Crisis Response for several disasters. "Road blockage," "traffic accident," "traffic blockage," etc. were hot topics that attracted followers' comments after Ya'an earthquake on microblogs such as Sina Weibo and Tencent Weibo. These terms can be seen as tags and integrated into the taxonomy.

3.2 Selecting information resources and the terms of the taxonomy

The terminology of a subject domain is obtained by explicating natural language words and phrases (Svenonius 2000). Online information, such as social tagging, can actually help in identifying new terms and categories and in adapting and changing existing taxonomies (Pellini and Jones 2011). Terms restricted to the scope of earthquake response and recovery were extracted from three main types of online information sources: web pages, social networks, and research reports. Websites are the main online venue to transfer disaster information, which may contain a large number of terms of special topics. Social networking reflects what the masses keep watching on during an event and provides opportunities for new ways of creating and managing taxonomies (Pellini and Jones 2011). Research reports, normally of specific topics related to disaster management, are important information sources that supplement web pages and social networks. We used web search engines such as Google and Baidu and microblogs' internal search to retrieve the three types of information sources. We used query terms covering Haiti earthquake (2010), Japan Earthquake (2011), Ya'an earthquake (2013), Nepal earthquake (2015), Ecuador earthquake (2016), emergency response, relief response, disaster response, and disaster recovery, etc. The major information resources under these three sources are provided in Appendix 1.

The scope of the terms needs to be defined when selecting the terms. Classification is purposeful, and every classification brings together resources that go together to differentiate among them (Hemerly et al. 2013). Defining the scope of a domain "helps to ensure that terms to be added or removed from a vocabulary are made on a consistent basis" (Svenonius 2000, 134). Earthquake response and recovery involve a broad range of actions. Terms that match these actions are all selected, such as disaster situation, losses, services, needs, operations, facilities, modality, emotion, programs, and orientation/philosophy (AIRS 2019).

3.3 Procedure

The guidelines from Pellini and Jones (2011) and Wu and Yang (2015) were referenced during the development of the taxonomy. The general procedure is as follows:

Step 1: Select the online information resources and extract terms.

More than 3,500 terms were manually extracted from a total of fifty-three websites and social media sites, and twenty-five digitally published guidelines, field handbooks, and working papers were adopted for extracting terms and categories. When selecting the terms, titles, section headings, and tags of the sites and digital publications, which reflected the topics directly, were extracted preferentially. Then, generally, the nouns in the content that supported the topics were extracted.

Step 2: Normalize all the terms by translating, converting plural forms to singular, removing duplicate terms, and standardizing terms with multiple expressions into one.

A total of 1,574 terms were kept. The mapping of multiple expressions to one standard term is kept for future study.

Step 3: Cluster the terms into homogeneous categories based on subject. Bottom-level and higher-level clusters are generated.

Six clusters were created for the 1,574 normalized terms.

Step 4: Build the basic taxonomy from existing taxonomies related to disaster response and recovery.

The top two levels were initially built using the two-level FEMA categories from the National Disaster Recovery Framework, which satisfies the need of various response and recovery services under severe time pressure during an earthquake disaster.

Step 5: Load and accommodate the bottom-level clusters into the basic taxonomy. Build middle-level categories by combining the top-down and bottom-up approaches.

Step 6: Revise and adjust the categories by adding, splitting, transposing, and merging to reach mutual exclusivity between sibling categories.

The seven-level earthquake disaster response and recovery taxonomy was built. The number of categories at each level is shown in Table 1. Appendix 2 presents a snippet of the top two-level categories of the taxonomy, and Appendix 3 presents a snippet of the bottom levels of the taxonomy.

Level	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level
Number of categories	5	50	218	539	563	163	36

Table 1. Numbers of categories at each level of the taxonomy.

4.0 Difficult problems and compromised solutions

A couple of structural problems emerged in the process of the taxonomy development. We have partial solutions but probably not the best ones. The timeframe is an important foundation of the taxonomy. The top-level categories reflect this feature by using time-related terms: response, short-term recovery, intermediate-term recovery, and long-term recovery. However, not all the terms are time-restricted. Many services are processes extended from the response phase to the recovery phase, such as shelter, evacuation center, medical care, food and water supply, and people finding. Within the recovery phase, some services run through the whole process. To solve this problem, we degraded short-term recovery, intermediate-term recovery, and long-term recovery to second-level categories and added the more comprehensive term "recovery" as their top-level category. We then added "general" as the sibling category to the degraded ones. This partially solved the structural problem but increased the repetition of lower-level categories. For example, the third-level category "housing" exists in all three phases of recovery, and it could not be classified into "general" category, because "housing" in each phase has a special connotation. In long-term recovery, "housing" mainly means permanent housing solution, and in intermediate recovery it means temporary housing, while in short-term recovery it means sheltering more than housing. The current taxonomy achieves categorical homogeneity but also contains term redundancy.

An alternative possible solution to avoiding redundancy is to put those non-time-restricted categories (such as shelter, evacuation center, medical care, food, and water supply) at the same hierarchical level as response and recovery. Putting temporal categories together with non-temporal categories can be found in the Library of Congress *Classification* (LC*C*) when classifying world history (Library of Congress 2018). Under Sub-class D(204)-(475) of LC*C*, modern history has the following temporal categories: 1453-1648, 1601-1715, 1715-1789, and 1789-. Under "1789-," there are both temporal categories (i.e., "period of the French Revolution," "19th century," "20th century," "World War I," "period between World Wars," "World War II," "post-war history") and non-temporal categories (i.e., "developing countries," "eastern hemisphere," "Europe-general"). This approach sacrifices categorical homogeneity to keep structural non-redundancy. Another possible solution is to create a category of "cross-phase issues" to contain those non-time-restricted categories. This category is at the same hierarchical level as response and recovery, but contains hodgepodge terms. This approach avoids redundancy of categories and terms but sacrifices the homogeneity of categories and terms. Which of these three approaches makes more sense to the users will have to be tested by a usability study in the future.

Another problem is that as a first level category, "stakeholder" is not dispersed into each phase of the timeframe. For example, "search and rescue team" is not a sub-category of "search and rescue," "governmental agency" is not a sub-category of "government management," and "doctor" is not a sub-category of "medical services." Having a separate category of "stakeholders" can reduce unnecessary repetition and produce a map of stakeholders. However, the semantic relations between actions and stakeholders are cut off. This problem needs a better solution by adding possible cross-references between the stakeholders and actions.

5.0 Applying the taxonomy to organize and share online information: two case studies

This section presents two case studies of using the taxonomy to organize and share the earthquake response and recovery information: World Vision web portal and Sina Weibo (microblog site). The purpose of the two case studies is to demonstrate that the taxonomy is useful and has some external validity.

5.1 Information organization

5.1.1 World Vision web portal

World Vision Inc. is a registered nonprofit organization. One of its pages (now.worldvision.org, accessed 30 June 2016) presents information related to emergencies and disasters to which it had responded or was responding. It has eight menu items in the menu bar, which are "Nepal," "ebola," "South Sudan," "Syria," "photos," "videos," "disaster response," and "prayer." These menu items are not classified based on a systematic and normalized taxonomy, but mainly by hot topics such as places, disasters, formats of information, and actions, which is a representative characteristic of web portals for eye-catching. Instantiation of the taxonomy application to the website is presented in the following.

The instance is the web page titled "Aid Organizations Face Challenges in Rush to Help Nepal Earthquake Survivors Desperately in Need." Food, water, temporary shelter, the death toll, tarps, blankets, first aid kits, sleeping mats, blankets, water, temporary shelter, protection for children, international relief organizations, and flight are mentioned in the web page. If single-label classification is preferred (Qi and Davison 2009), the web page can be classified into the categories "response"-"emergency relief commodity" according to the title to cover a relatively comprehensive topic. If multi-label classification is preferred (Qi and Davison 2009), all the keywords plus the keywords Nepal earthquake, survivor, and aid organizations abstracted from the title could be classified into the corresponding categories. We can index the web page through tagging it by the categories used when classifying, or we can reduce the granularity to get fewer tags. For example, categories "tarps," "blankets," and "sleeping mats" share the same third-level category, "household item," which means "household item" can be used in lieu of the three ones.

When classifying the eighty-four web pages of the website into the taxonomy, 211 topics were classified into the top-level categories, whereas fifty-seven topics were uncategorized. The classification of the web pages means that, conversely, we can use the corresponding categories of the taxonomy to tag the web pages. Generally, most of the web pages are displayed in chronological order. Valuable attributes of the web pages can be displayed by tags selected from the taxonomy. It is expected that some categories in the taxonomy may need to be revised and some new categories may be added. The following findings can be made based on this case study.

First, using timeframe to organize online disaster response and recovery information is reasonable. The World Vision website has a category of "disaster response," and all the contents under this category can be classified into "response," which is a top-level category of taxonomy.

Second, modularity creates options of application (Clark and Baldwin 2002). The modular design increases the flexibility and feasibility of the taxonomy, since the website, as most of other sites, is not restricted to earthquake. A flexible tool is critical to organize information from this kind of websites. For instance, "dead body burial" can be used to manage "dead body burial of Ebola." All the information under the "prayer" menu item can be classified into the "prayer" category.

Third, the taxonomy has adaptability and extensibility to deal with specific disasters and situations. For example: "children" is an independent category appearing in "Nepal," "ebola," "South Sudan," "Syria" and other emergency responses on the World Vision website. For Nepal's high altitude and shortage of electricity, categories such as "effect of high altitude," "winter cold," and "electricity outage" are suitable for these special situations.

5.1.2 Sina Weibo

Sina Weibo is the most popular microblog in China. The "topics" and the "official accounts" related to disasters are the two primary venues to access disaster information on its site. We have collected sixty-three topics and forty official accounts with more than 3,000 posts. The topics mainly focus on eight fields: earthquake information, relief and response, education, prayer and love, donation, person finding, memorial, recovery, and reconstruction. Some of these topics have classification labels and tags to describe the contents of posts. Some problems appear. First, not all the topics have classification labels and tags. Second, similar topics have discrepant classifications. For instance, the topic "person finding in Ya'an" has the category of "others" and region of "national," whereas the topic "family finding in Ya'an earthquake" has category of "social" and region of "Hebei Province of China."

The posts following one topic are classified automatically into the category of the topic. For instance, there are several posts under the topic "traffic information of Ya'an earthquake." We can classify all of the posts into the second-level category "traffic and travel information." If greater granularity is needed, we can break them down by the third-level, fourth-level, etc. For the posts not following related topics, the categories in the earthquake response and recovery taxonomy can be used as facets. The facets can be combined for a post-coordinate index. For example, a post with content "two soldiers have reached Chengdu by air medical evacuation" can be indexed by categories of "Sichuan Ya'an earthquake" + "soldiers" + "injured person" + "medical air evacuation."

A total of thirty-four categories were added and sixteen were revised after applying the taxonomy to categorize the online disaster-related information on the World Vision web portal and Sina Weibo. Table 2 shows the number of added and revised categories at each level of the taxonomy. Less than 10% of the categories from the second to fifth levels were added or revised, showing a relative stability of the taxonomy although there is no systematic study so far showing how much revision is considered stable. The added and revised categories have increased the adaptability of the taxonomy.

5.2 Information sharing

A framework of knowledge sharing (Carlile 2004, Yate and Paquette 2011) describes three progressively complex boundaries, syntactic, semantic and pragmatic, and three progressively complex processes, transfer, translation, and transformation. This framework illustrates how to manage and share knowledge by crossing these boundaries sequentially. The taxonomy contributes to the first two boundaries of the model. The syntactic boundary corresponds to transferring knowledge. The primary focus is the storage and retrieval of knowledge, for which a common lexicon is necessary. The semantic boundary corresponds to translating knowledge. The common meaning is a way to address the semantic differences such as ambiguous meaning and interpretive differences.

This framework is used to demonstrate how the taxonomy supports information sharing and exchange in the first two boundaries. As a knowledge organization tool, a taxonomy provides standardized terms systematically. These terms establish the common cognition of a certain domain, which are used to organize and retrieve knowledge. The earthquake response and recovery taxonomy contains standardized vocabularies helping users to build up cognition basis for online information exchange. In addition, taxonomy helps to put knowledge into practice by making sense of the knowledge and a common way of working (Pellini and Jones 2011). The structure of the taxonomy, the facets, and the modules in the structure semantically reflect the activities of disaster response and recovery. Table 3 shows exemplifications from the two case studies.

6.0 Summary of findings and implications

An earthquake response and recovery taxonomy has been built for the purpose of managing earthquake-related online information resources. The categories of the taxonomy can be used to organize online information for browsing.

Level	1st level	2nd level	3rd level	4th level	5th level	6th level	7th level
Number of categories in the original taxonomy	5	50	218	539	563	167	36
Added categories	0	3	19	7	5	0	0
Revised categories (including structure update)	0	2	9	5	0	0	0

Table 2. Numbers of added and revised categories at each level.

Boundary	Syntactic boundary	Semantic boundary
Process	Transfer information: information processing	Translate information: creating shared meanings
Solutions of the taxonomy	Standardized terms to facilitate information retrieval and browsing	A facet classification for semantically cohesive categories
Instances	Food insecurity represents "food crisis," "hunger crisis," "hungry," "need food" and other related terms and topics on the World Vision Website.	A webpage with the topic "Updated Ecuador earthquake: World Vision responds" is classified into "shelter supply," while a webpage with the topic "Nepal earthquake: Shelter" is classified into "shelter need."
	"Person finding" is used to express topics such as "find friends," "finding relatives," "missing person" and "find a child" on Sina Weibo.	Posts and topics like "Ya'an Lushan 7 magnitude earthquake," "4.20 Lushan earthquake," "Ya'an earthquake," "Moving forward to Baoxing," "Sichuan 4.20 Earthquake relief and response" actually refer to one quake. Baoxing is one of the towns of the epicenter Lushan, which is one of the counties of Ya'an, a city of Sichuan Province in China and this quake happened on April 20, 2013. Lushan is classified into "epicenter," Baoxing into "seismic region," Sichuan into "impact landscape" and Ya'an, as a landmark, into "location."

Table 3. Information sharing supported by the taxonomy.

The facet-based taxonomy can be used to index and tag information. The two case studies show that the taxonomy is useful and has some external validity. Based on the two case studies, when applied to organize online information resources, the taxonomy experienced slight categorical adjustments and so presents a relative stability, adaptability and extensibility; therefore, it has some internal validity. If the taxonomy is acknowledged by the earthquake management community, it can be used to organize and share earthquake-related online information of future earthquakes; therefore, it has an implication for earthquake online information management.

The earthquake response and recovery taxonomy models the knowledge structure of the earthquake management domain. It can be used by earthquake response and recovery personnel to understand the various aspects of earthquake management. It can also be used by stakeholders as a common language for communication and exchange of knowledge. Therefore, it presents a social relevance and has an implication for knowledge management.

The earthquake response and recovery taxonomy was developed from a broader perspective of disaster management based on the timeframe of disaster management and the idea of modular design. The top three level categories can be applied to the management of other types of disasters other than earthquake. Using timeframe to organize online disaster-related information is reasonable based on the two case studies. The modular design allows the taxonomy to be easily revised to be a taxonomy for other types of disasters; therefore, it has an implication for disaster management.

7.0 Conclusions and future work

Online information explosion and time-sensitive demand of victims after an earthquake make disaster response challenging. Obstacles and constraints limit information exchange that supports decision making. Organized information with standard terms and relationship structures can facilitate information sharing during disaster response and recovery. An earthquake response and recovery taxonomy is built using online information resources from various sources for the purpose of managing online information, especially for web portals and social media sites. The taxonomy is developed using a combination of the top-down and bottom-up approaches. The key features are four-fold: a combination of the enumerative and faceted classification, the timeframe-based categories in different phases of disaster management to address the time sensitivity, the folksonomy thinking in category creation contributing to the flexibility of the taxonomy, and the modular architecture for adaptability and extensibility. For these features, this approach can be easily extended to building taxonomies for other types of natural disasters, such as flood, tornado, wildfire, etc. With standardized terminology, the taxonomy can be used by earthquake management community and the public as a common language for exchanging and sharing information. It presents a social relevance and has implications for knowledge management, disaster management, and online information management.

Two case studies were presented to demonstrate its usefulness in managing online earthquake response and recovery information posted on the World Vision website and the Sina Weibo social network site. They demonstrated that the taxonomy is useful and has some external validity. Based on the two case studies, the taxonomy experienced slight categorical adjustments when applied to organize the information resources on the two sites. The taxonomy presents relative stability, adaptability, and extensibility, and so has some internal validity.

The study has found a new problem when building taxonomies for time-sensitive disaster response. Timeframe brings a challenge to the structure of the taxonomy. Duplicating these services under each timeframe brings redundancy of categories, and so is not an optimal solution. Classifying these services to a category of "services throughout all phases of the disaster" may hinder the understanding of the phases of disaster response and recovery.

The future work contains further studies to reach a balance between timeframe and the category redundancy. A systematic evaluation of the taxonomy is to be done to fully assess its internal validity and to find areas to be improved. More case studies are to be performed in order to demonstrate its external validity and to improve the taxonomy's structure, categories, and terms. In the meantime, a method is to be developed to automatically apply the taxonomy to earthquake-related sites to manage the online information of ongoing earthquake response events. During this process, the folksonomies for mapping multiple terms to a standardized term can be useful in organizing web pages and online posts into the categories in the taxonomy for browsing or indexing the web pages and posts for searching.

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Appendix 1.
Major information resources that are used to build the taxonomy

1. Websites and portals

– Online-published coverage from news agencies, such as CNN.com.
– Coverage from web portals, such as Sina.com.
– Websites of humanitarian organizations, such as Oxfam.org.
– Websites of government agencies, such as FEMA.gov.
– Websites of education and research institutes, such as NIED.go.jp.

2. Social network sites

– Social networks and blogs, such as Sina Weibo.
– Bookmarking sites, such as Blogmarks.net.
– Content communities, such as Quora and Zhihu.

3. Research reports

– Handbooks, such as Disaster Response in Asia and The Pacific: A Guide to International Tools and Services (OCHA-ROAP, 2017).
– Field Handbooks, such as the United Nations Disaster Assessment and Coordination (2018) by the Office for the Coordination of Humanitarian Affairs of the United Nations.
– White papers, such as Geographic Information Systems Providing the Platform for Comprehensive Emergency Management (Environmental Systems Research Institute, 2008).
– Working papers, such as the National Emergency Communications Plan (U.S. Department of Homeland Security: https://www.dhs.gov/publication/2014-national-emergency-communications-plan).
– Research papers, such as A Taxonomy of Threats for Complex Risk Management (Coburn et al., 2014).

Appendix 2.
A snippet of the top two levels of the taxonomy

1 disaster
1.1 disaster damage
1.2 location
1.3 post-disaster effect
1.4 secondary disaster
1.5 time
1.6 type

2 preparedness
2.1 community capacity and resilience-building
2.2 disaster preparedness conduction
2.3 legal preparedness
2.4 mitigation implementation
2.5 partnership building
2.6 pre-disaster recovery planning

3 response
3.1 general
3.2 authority action
3.3 communication
3.4 dead body
3.5 disease
3.6 displacement and shelter
3.7 donation

3.8 emergency relief commodity
3.9 emergency response level
3.10 infrastructure
3.11 food
3.12 help seeking
3.13 logistics
3.14 paramedic and medical care
3.15 person searching
3.16 search and rescue
3.17 stress
3.18 traffic and travel information
3.19 warning and notification
3.20 water, sanitation and hygiene

4 recovery
4.1 short-term recovery
4.2 intermediate recovery
4.3 long-term recovery

5 stakeholders
5.1 animal health agency
5.2 celebrity
5.3 civil society
5.4 donor
5.5 earthquake-affected population
5.6 education and research
5.7 expert
5.8 financial institution
5.9 general public
5.10 individual and volunteer organization
5.11 international organization
5.12 journalist
5.13 mother, infant and child
5.14 national authority
5.15 non-governmental organization
5.16 private sector
5.17 relief and rescue worker

Appendix 3.
A snippet of the bottom levels of the taxonomy

3.7 emergency relief commodity
3.7.1 relief item
3.7.2 communication item
3.7.3 power supply item
3.7.4 household item
    3.7.4.1 waterproof supply
        raingear
        canopy
        tarp
    3.7.4.2 cold-weather essential
        blanket
        clothing
            underwear
            headscarf
            other
        glove
        sleeping bag
        hand warmer
    3.7.4.3 individual emergency bag
        general
        band-aid
    3.7.4.4 hygiene product
        hygiene kit
        oral and dental hygiene
            toothbrush
            toothpaste
        trash bag
        cleaning supply
            bathing soap
            laundry soap
            napkin
            bathing tissue
        hygiene material
            sanitary material for menstruation
            washable nappy or diaper
3.7.5 medical item
3.7.6 commodity management
3.7.7 commodity need