Ontology for Developing Web Sites for Natural Disaster Management: Methodology and Implementation

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***Abstract*—Recent natural disasters have highlighted the need for disaster preparedness, planning, and management. Hurricane Katrina demonstrated the usefulness of Web sites in dealing with natural disasters. However, little is known about the necessary contents and structures of Web-based information systems for natural disaster management. In this paper, we focus on developing an ontology structure of elements for Web-based disaster management systems. Web elements are identified, following a grounded-theory approach, from an inventory of 6032 Web pages drawn from 100 disaster management Web sites. Selected semistructured data representation approaches are used to organize the resulting ontology structure, which consists of 2094 Web elements. The ontology structure is further coded into a Web-based system, allowing easy online access.**

***Index Terms*—Disaster management, grounded theory, ontology design, qualitative analysis, schema integration, Web design.**

I. Introduction

DURING the 2005 hurricane season, the largest three hurricanes, namely, Katrina, Rita, and Wilma, impacted millions of lives [1]. Katrina devastated nearly 90 000 square miles. Rita struck within a month, damaging and destroying more than 350 000 residences [2]. The use of the Web in disaster recovery efforts demonstrated the usefulness of Web sites in dealing with a disaster. The ubiquity and asynchrony of the Internet make it a natural platform for information exchange and communication for managing mass crises. For example, after Hurricane Katrina, the use of a Web-based immunization information system was very helpful in identifying over 18 000 immunization records of children who were forced to evacuate the New Orleans area, resulting in an estimated cost savings of more than $3.4 million on vaccine and administration expenses [3]. Turoff and Hiltz [4] reported on a survey of health-related emergency response management professionals, indicating that they rely heavily on the Web. In addition, digitalization of information is critical for timely transmission and information sharing in emergency management [5].

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Although there are many disaster-related Web sites, little is known about the necessary contents and structures of such sites. This paper presents a first attempt in developing an ontology structure of elements for such Web sites. We strive to answer the following research questions.

1) *What data representation approaches are suitable for developing an ontology structure of Web elements in Web-based natural disaster management systems (WB-NDMS)?*
2) *What are the necessary Web elements and their ontology structure for WB-NDMS?*
3) *How should one develop such an ontology structure based on available sample data?*
4) *How can such an ontology structure be distributed online for easy navigation?*

An accessible and comprehensive ontology structure developed in this research, called Web-based ontology structure (WB-OS), can potentially assist organizations, managers, and individuals who are involved in disaster management in their WB-NDMS development and evaluation. First, it provides a useful resource to those who are involved in developing WB-NDMS. WB-OS covers all phases of natural disaster management and allows easy navigation of the ontology structure at different levels of detail. It can serve as a foundation in assisting in the development of natural disaster management Web sites, with a focus on contents. It provides support in designing dynamic emergency response management information systems (DERMIS) articulated by Turoff *et al.* [6]. Second, WB-OS can be used as a benchmarking tool to evaluate the completeness and quality of existing disaster management Web sites, leading to further enhancement and improvement of such Web sites. As the first of its kind in such a complex domain as WB-NDMS, WB-OS makes a valuable contribution to WB-NDMS development and evaluation.

Our work can also be extended to develop and implement ontology structures for the management of other types of disasters such as man-made disasters. More generally, this paper shows how the synthesis of ontology design, schema integration, grounded theory, and semistructured data representation approaches can make it possible to identify and code an ontology structure of Web elements for a large and complex domain.

The rest of this paper is organized as follows. We first lay down a relevant background in Section II. Next, we present our methodology in Section III. We then illustrate the application of our methodology using an example in Section IV. In Section V, we report on the resulting WB-OS and its evaluation. Finally, we conclude this paper and discuss future research directions in Section VI.

II. Background

Across the world, disasters happen frequently. There are various types of disasters, including natural disaster, technological disaster, pandemic disaster [7], and mass violence, where each of which has certain level and type of impacts [8]. Although the impacts of disasters have been extensively investigated, there has been inadequate research on the design of disaster management systems. Furthermore, little attention has been paid to Web-based disaster management and its contributions to the well-being of affected individuals and organizations. More generally, existing research on emergency response information systems is still scant [9], [10].

In this paper, we focus on natural disasters and, specifically, on issues related to the design of Web-based information systems for managing various phases of natural disasters. A natural disaster may be a hurricane, tornado, typhoon, flood, fire, or earthquake. Generally, "a natural disaster occurs when an extreme geological, meteorological, or hydrological event exceeds the ability of a community to cope with that event" [11, p. 176].

In the context of organizational crisis, Pearson and Mitroff [12] suggested that there are five phases in disaster management: signal detection, preparation/prevention, containment/damage limitation, recovery, and learning. Signal detection may be a stand-alone phase in organizational disasters. For natural disasters, however, signal detection and preparation typically take place in the same phase. On the other hand, there is a "general preparation" phase, which is not tied to a particular disaster occurrence but is related to information and public education regarding preparation for natural disasters in general. Similarly, Mileti [13] proposed a model of disaster management with four phases: mitigation, preparedness, response, and recovery.

By synthesizing these two studies, we argue that the management of a natural disaster involves five phases: general preparation, preparation for a given disaster, disaster in progress, disaster recovery, and learning. The first phase involves general preparation for various possible natural disasters. The goal of this phase is to prepare and plan for future occurrences of disasters and to educate stakeholders about the course of action in such circumstances. In the second phase, as a forthcoming disaster is predicted, specific plans regarding that particular disaster are put into place. The third phase is when the disaster is in progress. The goal in this phase is to assist those in immediate danger and to reduce and contain the damage. Recovery begins immediately after a disaster, including a wide range of activities such as process restoration and individuals' health recovery. Finally, in the learning phase, lessons learned from the disaster are assimilated as a practice for the refinement of general preparation for the next round.

Web elements are critical in developing Web-based systems to deal with various phases of natural disasters. The Web elements are the features, components, and information used to create Web sites. In the context of e-commerce Web sites, Song and Zahedi [14] identified and categorized essential Web elements using a grounded-theory approach. The categories of the Web elements have been used to develop a theoretical foundation for understanding the connection between Web elements and beliefs [15]. The Web elements for the WB-NDMS are numerous and far more complex than those in e-commerce. Furthermore, there has been little attempt to conceptualize these elements. There is still a considerable gap in our knowledge about the nature, structure, and categories of Web elements for developing WB-NDMS. This paper takes a first step in addressing this gap.

III. Research Methodology

Following a grounded-theory approach, we identify the Web elements of the WB-NDMS from existing Web sites related to natural disaster management. To handle the complexity of these elements, we develop an ontology [16] with a hierarchical structure using a proposed incremental schema integration (ISI) method and employ selected semistructured data representation approaches to code the ontology structure. An ontology is "an explicit specification of a conceptualization" [17, p. 199]. The main purpose of ontologies is to facilitate knowledge sharing and promote reuse [17], [18]. In an ontology, we define the terms of a domain and identify the relationships among them, thereby formalizing domain knowledge. In this paper, we group and define the Web elements in the WB-NDMS and identify the relationships among them, hence creating an ontology structure for the Web elements.

A. Grounded-Theory Approach

To identify the Web elements, we carry out constant comparison and categorization of elements, as prescribed by the grounded theory, which is "the discovery of theory from data" [19, p. 1] and which advocates an iterative, qualitative, and inductive process [20]. The grounded theory was originally developed by Glaser and Strauss in 1967 [19]. Later, Strauss and Corbin [21] proposed a more structured process with three types of coding: open, axial, and selective. Starting with a collection of qualitative/textual data, open coding involves an inductive and iterative process of constant comparison and categorization of data, leading to the emergence of unitary abstract concepts. These concepts are further categorized, and their relationships are established at the axial stage of the coding process, again using constant comparison and categorization. The relationships normally have a hierarchical structure. The selective coding stage involves further abstraction and the development of an emergent theory or the conceptualization of a general structure from the data.

Following open coding, we compare and contrast data elements (textual Web-element data from Web sites), leading to conceptual Web elements and their categories. The axial coding process structures the categories in hierarchies of relationships. New data elements are introduced iteratively, the analysis is repeated, and the results are modified. The process continues until all of the available data have been consumed or the

TABLE I
BASIC SUMMARY STATISTICS ABOUT THE COLLECTED WEB SITES

Type	Number of Sites	Average Number of Pages Per Site
State Sites	50	67
City and County Sites	37	35
Other Governmental Sites	8	130
Non-profit Organization Sites	3	97
Commercial Company Sites	2	29

introduction of new data does not change the identified categories anymore. The axial coding allows for a hierarchical general-to-specific structure of the categories. In selective coding, the core structures of the Web elements (categories and their relationships) are finalized/selected when new data elements do not add new concepts or change the categories and when all of the data elements are fit into the structure, resulting in a comprehensive abstraction of data.

To construct the ontology structure for WB-NDMS, we group the Web elements into five categories that correspond to the five phases of natural disaster management: general preparation, preparation for a given disaster, disaster in progress, disaster recovery, and learning. Within these five main categories, subcategories surface through a constant comparison of Web elements found in various natural disaster management Web sites. We embed the grounded-theory approach within the proposed method for developing the ontology structure (as discussed in the following).

In order to arrive at a comprehensive ontology structure, we need a large inventory of Web sites with a wide and varied coverage of natural disaster management elements. We therefore identified a collection of 100 disaster preparedness or disaster management Web sites of various government agencies and organizations. The collection includes official disaster and emergency management sites from 50 states and top search results from the Google search engine. We used a total of 6032 Web pages drawn from these Web sites (between 21 and 231 pages per site; see the basic summary statistics in Table I). The Web pages contain a vast array of Web elements.

B. Selection of Data Representation Approaches

We adopt a semistructured data representation [22], [23], which helps us constantly identify, compare, and categorize new Web elements following the grounded-theory approach. We select eXtensible Markup Language (XML) [24], XML Schema [25], and Document Object Model (DOM) [26] as the specific modeling approaches.

We use XML to represent semistructured data models. A semistructured data model is used to capture the structure of a document instance [27]. *XML* is one of the most popular data models for semistructured data on the Web today [28].

We use XML schema to represent data schemas. A data schema is an abstraction of data models, and it contains constraints, types, and relationships of the data elements. For the semistructured data, the structure is often not fully known in advance and is created after the data become available [29]. XML Schemas are also written in XML (in an XML-based language named XML Schema Definition).

TABLE II
ADVANTAGES AND DISADVANTAGES OF THE POSSIBLE COMBINATIONS OF DATA REPRESENTATION APPROACHES

Combination	Advantages	Disadvantages
XML and XML Schema with DOM	**• W3C recommendations • Are in XML format • Support elements and attributes • Support text and graphical representations**	
XML and DTD with DOM	• W3C recommendations • Support elements and attributes • Support text and graphical representations	• DTD is not in XML format
OEM and S3-Graph	• Support graphical representation • Support elements	• Are not W3C standards • Are not in XML format • Do not support attributes • S3-Graph does not support text representation
OEM and DataGuides	• Support elements • Support graphical representation	• Are not W3C standards • Are not in XML format • Do not support attributes • DataGuides does not support text representation
Lore's XML and DataGuides	• Lore's XML is in XML format • Support elements • Support graphical representation	• Are not W3C standards • Do not support attributes • DataGuides does not support text representation
Lore's XML and XML Schema	• Are in XML format • Support elements • Support text and graphical representations	• Lore's XML is not a W3C standard • Lore's XML does not support attributes

Finally, we use DOM for graphical representation of both data models and data schemas, as XML and XML Schema per se do not have graphical capabilities. DOM visualizes an XML document as a tree with object nodes, which correspond to the elements, attributes, or text contents in the document [26].

Our selection of data representation approaches is based on a review of several alternatives, including, besides those of our choice, Object-Exchange Model [30], Lore's XML Data Model [31], Document Type Definition [24], S3-Graph [32], and DataGuides [33]. Table II lists the major advantages and disadvantages of the possible combinations of various approaches. The selected approaches are all World Wide Web Consortium (W3C; http://www.w3.org/) recommendations and are all in XML format. They support the representation of the data elements, as well as the attributes of the elements. For the ontology structure of the Web elements that we are developing, "attribute" support is needed in storing some additional information about an element. For example, "the date of last update" is a possible attribute associated with some Web elements. Another advantage of the selected combination of approaches is their support of both text and graphical representations.

In addition to the apparent advantages listed in Table II, our choice allows the resulting ontology to be exported into the Resource Description Framework (RDF; http://www.w3.org/RDF) and the OWL 2 Web Ontology Language (http://www.w3.org/TR/owl-overview/), which are W3C recommendations too. OWL 2 is the latest version of OWL, which is an extension and revision of the previous version (http://www.w3.org/2004/OWL/), referred to now as OWL 1. OWL 2 is backward compatible with OWL 1. As such, our choice makes the ontology compatible with various standards. RDF and OWL 2 are among the currently most popular semantic Web technologies, aiming to describe concepts and relationships between concepts on the Web in a machine-understandable format. These languages are designed for computers to automatically process information and to interpret the meaning of the contents on the Web. By using RDF or OWL 2, ontologies can be described in standardized machine-readable statements. Ontologies represented in such languages can facilitate the interoperability of Web sites, helping computers or software agents interpret, understand, integrate, and exchange contents across various Web sites. In the field of natural disaster management, software agents may be developed in the future, with the help of ontologies represented in RDF or OWL 2, to automatically exchange/distribute up-to-date disaster information across disaster management Web sites and to identify needs for recovery in a specific location or by a group of victims.

C. Proposed ISI Method

Following the axial and selective coding in the grounded theory, we apply a schema integration approach in integrating the semistructured data schemas derived based on different disaster management Web sites. Schema integration is "the activity of integrating the schemas of existing or proposed databases into a global unified schema" [34]. Previous studies (e.g., [34] and [35]) have suggested different but similar processes.

Batini *et al.* [34] proposed a process consisting of four steps: preintegration, comparison of the schemas, conforming the schemas, and merging and restructuring. In the preintegration step, integration processing strategies, including ladder binary, balanced binary, one-shot n-ary, and iterative n-ary, are evaluated and selected. Binary strategies integrate two schemas at a time, whereas n-ary strategies simultaneously integrate multiple schemas at a time. The ladder binary strategy merges a local schema into an existing integrated schema. The balanced binary strategy pairs two schemas at a time and creates intermediate schemas, which need to be paired as well. The one-shot n-ary strategy allows the integration of multiple schemas all in one step, while the iterative n-ary strategy applies the integration in an ongoing manner. At the comparison step, conflicts, such as homonyms and synonyms, are checked and identified. The conforming step refers to the resolution of the identified conflicts across local schemas. Finally, the local schemas are merged and restructured to reach completeness, minimality, and understandability.

Ram and Ramesh [35] proposed another method, which involves four steps: schema translation, schematic interschema relationship generation, integrated schema generation, and schema mapping generation. As the databases that are to be integrated may have different data models, the local schemas are first translated into a common model. Schematic interschema relationship generation refers to the identification of related objects from the translated local schemas. Integrated schema generation involves resolving conflicts across the local schemas and generating an integrated schema. The last step involves generating mappings between local schemas and the integrated schema.

We adopt the ladder binary strategy of schema integration with a bottom-up approach. This is the most suitable approach since the integration should take place starting from many local Web pages (hence bottom-up). Since no global schema exists, it has to emerge by merging local schemas generated based on an inventory of Web pages. To simplify the manual construction of the ontology structure, we use the binary strategy and focus on integrating two schemas at a time. We also use the ladder strategy as it reduces the complexity when pairing up similar Web elements from different Web pages. We apply this ladder binary strategy using the graphical structural integration proposed by Zamboulis [36], which allows us to carry out integration on schemas with graphical representations (DOM in our case).

Since the ontology structure is developed based on comparisons of numerous Web pages, the global schema emerges as comparisons are made iteratively and new Web elements are identified in each iteration. Once a new Web element is identified, it is merged into the current global schema in the ontology structure and is placed under the appropriate section.

While the manual construction of ontology structure is a long process, the intermediate results become usable as soon as enough local schemas are integrated. This process also provides valuable insights into the structure of the ontology as the categories emerge.

Our schema integration method, called ISI, is a synthesis of the methods proposed by Batini *et al.* [34] and Ram and Ramesh [35]. This method is used iteratively in numerous rounds within the overall ontology structure development procedure (discussed in the next section). ISI consists of four phases: preintegration, schema matching, schema merging, and schema restructuring.

Preintegration: This phase synthesizes the ideas of preintegration from Batini *et al.* [34] and schema translation from Ram and Ramesh [35]. All of the Web elements identified from the Web pages are captured as XML elements and are described by XML Schemas, which are visualized as tree structures using DOM. The resulting local schema of round j is a tree (denoted as L_j), whose nodes represent the identified Web elements.

Schema Matching: Naming conflicts and naming matching are checked, marked, and maintained in this phase. The first step of schema matching is to find the corresponding elements from two schemas: the current global schema (G_{j-1} prior to round j) and the local schema (L_j) under investigation. Initially, the global schema G_0 has the root "Natural Disaster Management" and one level with five Web-element categories that correspond to the five phases of natural disaster management. In a subsequent round (j), we match the Web elements in the local schema (L_j) with those in the global schema (G_{j-1}) using a nested breadth-first search. We consider the Web elements in L_j in a breadth-first manner. For each Web element (m) in L_j, we search for a matching Web element in G_{j-1}, also in a breadth-first manner. If the parent or an ancestor of m has already been matched to a Web element n in G_{j-1}, the search for a Web element in G_{j-1} matching m is restricted to the subtree rooted at n. Starting from the root of each schema tree, we mark the matching Web elements.

According to the schema matching literature [37], [38], while several semiautomatic matching techniques have been proposed, human intervention is still necessary. We carry out the enumeration of the Web elements manually in this paper. We adopt to manually perform schema matching and merging due to the novelty of the process and the lack of a natural disaster management dictionary.

Selected names are stored in a dictionary. We avoid synonyms and homonyms and assign a parent prefix to names that are common in more than one branch. For example, "Tips and Guidelines" is a Web-element category that commonly occurs in all phases of natural disaster management. However, its substructure may vary for each phase of natural disaster. In this case, we use "GP_SKP_Tips and Guidelines" to refer to the Web-element category of "Tips and Guidelines" under "Supplies Kit Preparation" in the "General Preparation" phase. In the graphical representation, we skip the prefixes for simplicity as the tree structure can disambiguate the names. For example, the node named "Tips and Guidelines" below the node "Supplies Kit Preparation" below the node "General Preparation" represents the category "GP_SKP_Tips and Guidelines." Finally, all elements with synonyms are mapped, and all substructures under each pair of matched elements should be merged through the steps in the next phase.

Schema Merging: The goal of this phase is to merge a new local schema into the current global schema. In the previous phase, all corresponding Web elements are identified and marked. In this phase, new elements in the local schema will be added one by one into the global schema.

Fig. 1 shows our schema-merging procedure. The procedure integrates a local schema with the global schema in round j ($j = 1, 2, 3, \ldots$). Step 1 makes a copy of the current global schema, which will be updated through schema merging. If the local schema contains new elements only, it is directly inserted as a subtree (a subgraph in a tree that is itself a tree [39, p. 457]) into the global schema (step 2). Otherwise, steps 3–7 manage to add the new elements of the local schema into the global schema under different conditions. Step 3 deals with subtrees that are completely composed of new elements below a match. Step 5 deals with new elements below a match, while some of them have already been merged into the global schema. Step 7 deals with the remaining new elements that are located above the merged elements. Finally, the result of round j is an updated global schema G_j.

Schema Restructuring: Following the axial coding in the grounded theory, starting from the root element, we compare and contrast newly integrated elements with the old elements in the current subontology structure G_j. A guideline for developing an ontology structure recommends ordering the categories from general to specific [18]. We follow this guideline and reorder and restructure the elements based on the generality of their categories. According to the grounded theory, a new category of elements may emerge as Web elements are compared and grouped together.

D. Ontology Structure Development

Ontology development is labor intensive and time consuming. There are several techniques for learning ontological

Inputs:
  The current round, j.
  The global schema prior to the current round, G_{j-1}.
  The local schema of the current round, L_j.
  Schema matching (between L_j and G_{j-1}) result stored in M, which is a sequence of pairs of references. M=(m_1, m_2, …m_n). $m_i.L$ and $m_i.G$ refer to "matching" nodes in L_j and G_{j-1}, respectively. M is sorted in descending order on the depth (number of levels from the root) of the node referred to by $m_i.L$.
Output:
  An updated global schema G_j.
Begin
1. G_j=G_{j-1}.
2. If M is empty,
   Insert L_j as a sub-tree into G_j under the node that is the immediate conceptual parent of the root of L_j.
   Go to the End.
3. For i from 1 to $|M|$,
   For each sub-tree S in L_j that is directly below the node referred to by $m_i.L$ (denoted n) and does not contain any "matching" node,
     Insert the sub tree S into G_j under the node referred to by $m_i.G$.
     Mark the nodes in the sub-tree S as "merged".
   If all nodes directly below n are marked as "merged",
     Mark n as "merged".
4. If the root of L_j is marked as "merged",
   Go to the End.
5. For i from 1 to $|M|$ such that the node referred to by $m_i.L$ (denoted n) is not marked as "merged",
   For each l from 1 to i-1such that the node referred to by $m_l.L$ (denoted m) is two or more levels below n and none of the nodes between n and m is marked as "merged",
     Insert the path between n and m into G_j as a path between the node referred to by $m_i.G$ and the node referred to by $m_l.G$.
     Mark the nodes between n and m as "merged".
   Mark n as "merged".
6. If the root of L_j is marked as "merged",
   Go to the End.
7. Starting from the lowest level and processing upward level by level, for each node n in L_j that is not marked as "merged",
   If the root of L_j is not marked as "merged",
     Insert the path from the root of L_j to n into G_j under the node that is the immediate conceptual parent of the root of L_j.
   Else,
     Insert the path from the root of L_j (excluding the root) to n into G_j under the node corresponding to the root of L_j.
   Mark the nodes in the path from the root of L_j to n as "merged".
End.

Fig. 1. Schema-merging procedure.

knowledge from various forms of data (see [40] for a comprehensive survey), potentially reducing the cost of ontology development and refinement. However, fully automating the ontology development process still remains infeasible, and most learning techniques require some existing top-level ontology or seed concepts [40]. Considering the novelty of our ontology structure development process (this is a first attempt in developing an ontology structure of elements for WB-NDMS) and the lack of an existing natural disaster management dictionary, we choose to adopt a manual procedure and follow a rigorous grounded-theory approach, trading efficiency for higher quality.

Noy and McGuinness [18] suggested a guideline for ontology design with seven steps: 1) determine the domain and scope of the ontology; 2) consider reusing existing ontologies; 3) enumerate important terms in the ontology; 4) define the classes and the class hierarchy; 5) define the properties (slots) of classes; 6) define the facets of the slots; and 7) create instances. The first four steps focus on developing an ontology structure,

Inputs:
The initial ontology structure G_0 consisting of five elements corresponding to the five phases of natural disaster management.
An inventory of webpages drawn from WB-NDMS sites.
Output:
An ontology structure for WB-NDMS induced from the sample webpages.
Begin
1. Randomly select a fresh webpage from the inventory of webpages for processing.
2. Identify pieces of information in the webpage as instances of web element.
3. Develop a local schema (L_j in round j).
 3.1 Model the identified elements *using* XML.
 3.2. Capture the structure of the XML document using XML Schema.
 3.3. Represent the elements and structure in the DOM graphical model, resulting in a local schema.
4. Using the grounded theory, compare and contrast the elements in L_j with those in the current global schema G_{j-1}. Apply the ISI method to create updated global schema G_j.
5. Repeat 1-4 until all webpages in the inventory have been consumed or the global schema does not change anymore.
End.

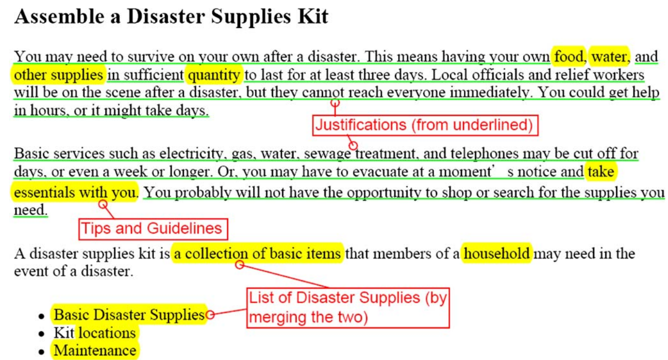
Fig. 2. Ontology structure development procedure.

while the last three elaborate an ontology with properties and instances.

We synthesize the first four steps of Noy and McGuinness' [18] guideline, which are relevant to our need, with our proposed ISI method to develop the ontology structure. We categorize the Web elements into five categories, with each corresponding with one of the phases of natural disaster management. Thus, Web elements are grouped according to the categories to which they belong.

Based on the suggestions in the literature [18], [41], it is encouraged to reuse existing ontologies. However, as there is no reported structure or ontology for Web elements in WB-NDMS, we have to enumerate important terms and to categorize Web elements from scratch. Based on the grounded theory, we identify instances of Web elements, categorize them into Web elements in a hierarchical fashion, and identify the relationships among the Web elements. The instances of Web elements and their relationships are modeled using XML. The elements of XML are compared and categorized to allow the XML schema to emerge. The XML schema is then visualized as a DOM tree. The DOM trees are used as local schemas in the ISI method for developing the global schema for the ontology structure.

Fig. 2 shows our overall procedure for ontology structure development. Step 1 selects a new Web page for processing. One may process Web pages either by randomly selecting pages from the inventory of Web sites or by systematically focusing on Web pages from one site and by completing the site analysis prior to moving to another site. We apply a random sequence, as the grounded-theory approach mandates. Step 2 corresponds with the enumeration of terms and the definition of classes in ontology development. Step 2 also accomplishes the categorization phase of the grounded-theory approach. Step 3 corresponds with the development of class hierarchy in ontology development. Step 4 accomplishes the comparison and further categorization phase of the grounded-theory approach. Finally, step 5 accomplishes the "constant" aspect of the grounded-theory approach, which requires continuation of processing and building from additional data and evidence.


Assemble a Disaster Supplies Kit

You may need to survive on your own after a disaster. This means having your own food, water, and other supplies in sufficient quantity to last for at least three days. Local officials and relief workers will be on the scene after a disaster, but they cannot reach everyone immediately. You could get help in hours, or it might take days.

Basic services such as electricity, gas, water, sewage treatment, and telephones may be cut off for days, or even a week or longer. Or, you may have to evacuate at a moment' s notice and take essentials with you. You probably will not have the opportunity to shop or search for the supplies you need.

A disaster supplies kit is a collection of basic items that members of a household may need in the event of a disaster.

- Basic Disaster Supplies
- Kit locations
- Maintenance

Fig. 3. Portion of a Web page from FEMA (source:http://www.FEMA.gov/plan/prepare/supplykit.shtm).

IV. Illustrative Example

To illustrate our procedure (Fig. 2), we present a simplified example of the process of constructing the Web element "Supplies Kits Preparation" in the ontology structure. We discuss two rounds of the procedure with this example.

In the first round, at step 1, a Web page from the Federal Emergency Management Agency (FEMA), which is shown in Fig. 3, is chosen for processing. At step 2, we identify and categorize the Web elements in the page. The identification of the Web elements is a subjective process that captures the key concepts and terms [18]. The Web elements may be directly identified from the Web page or may be created through the categorization process of the grounded theory. For example, "Other Supplies," "Food," and "Water," can be captured from the first paragraph of the FEMA Web page (with highlights in Fig. 3) and can be categorized as "List of Disaster Supplies" using the grounded theory. Similarly, a few other elements can be identified and categorized.

At step 3, to construct a hierarchical structure, we branch out the Web elements from general to specific. The categories are thus represented by XML elements in a hierarchy [Fig. 4(a)]. Finally, the corresponding XML schema [Fig. 4(b)] is represented by a DOM tree (Fig. 5).

At step 4, the DOM tree is added to the current ontology structure using the ISI method. Assume that, at the beginning of the process, the FEMA's Web page shown in Fig. 3 is used to generate the first global schema (G_1). Following ISI, since no matched element can be found between L_1 and G_0 in the schema matching phase, step 2 of the schema-merging procedure (Fig. 1) is carried out for the merging of L_1 and G_0. FEMA's local schema (L_1), corresponding to the DOM tree in Fig. 5, is attached under the element "General Preparation" in the current global schema (G_0), resulting in the updated global schema G_1 at the end of round 1 (shown in Fig. 6).

In round 2, another Web page from the American Red Cross (Fig. 7) is selected for processing. This page contains some Web elements that match those in the current global schema G_1, as well as some new Web elements. The DOM representation of the local schema L_2 at the end of step 3 (Fig. 2) is shown in Fig. 8.

At step 4, the local schema L_2 is compared with and is merged into the current global schema G_1 using the ISI method.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Supplies_Kit_Preparation name="Supplies Kit Preparation">
    <Storage_and_Maintenance name="Storage and Maintenance">
        <Location name="Location"/>
        <Quantity name="Quantity"/>
    </Storage_and_Maintenance>
    <For_Users name="For Users">
        <Household name="Household"/>
    </For_Users>
    <List_of_supplies name="List of supplies">
        <Water name="Water"/>
        <Food name="Food"/>
        <Other_Supplies name="Other Supplies"/>
    </List_of_supplies>
    <Justifications name="Justifications"/>
    <Tips_and_Guidelines name="Tips and Guidelines"/>
</Supplies_Kit_Preparation>
```

(a)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
    <xs:element name="Supplies_Kit_Preparation">
        <xs:complexType>
            <xs:all>
                <xs:element name="Storage_and_Maintenance">
                    <xs:complexType>
                        <xs:all>
                            <xs:element name="Location">
                                <xs:complexType/>
                            </xs:element>
                            <xs:element name="Quantity">
                                <xs:complexType/>
                            </xs:element>
                        </xs:all>
                    </xs:complexType>
                </xs:element>
                <xs:element name="For_Users">
                    <xs:complexType>
                        <xs:all>
                            <xs:element name="Household">
                                <xs:complexType/>
                            </xs:element>
                        </xs:all>
                    </xs:complexType>
                </xs:element>
                <xs:element name="List_of_supplies">
                    <xs:complexType>
                        <xs:all>
                            <xs:element name="Water">
                                <xs:complexType/>
                            </xs:element>
                            <xs:element name="Food">
                                <xs:complexType/>
                            </xs:element>
                            <xs:element name="Other_Supplies">
                                <xs:complexType/>
                            </xs:element>
                        </xs:all>
                    </xs:complexType>
                </xs:element>
                <xs:element name="Justifications">
                    <xs:complexType/>
                </xs:element>
                <xs:element name="Tips_and_Guidelines"/>
            </xs:all>
        </xs:complexType>
    </xs:element>
</xs:schema>
```

(b)

Fig. 4. XML and XML Schema representations of the Web elements identified in the FEMA page. (a) XML representation. (b) XML Schema representation.

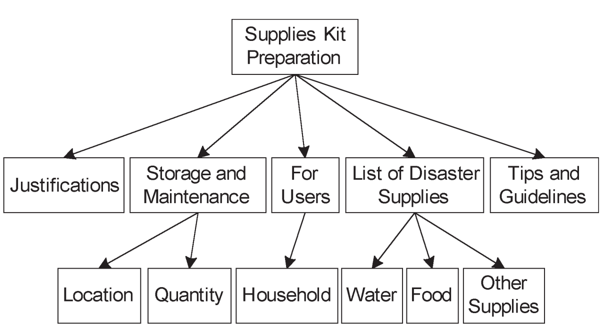


Fig. 5. DOM representation of the local schema L_1 for the FEMA page.

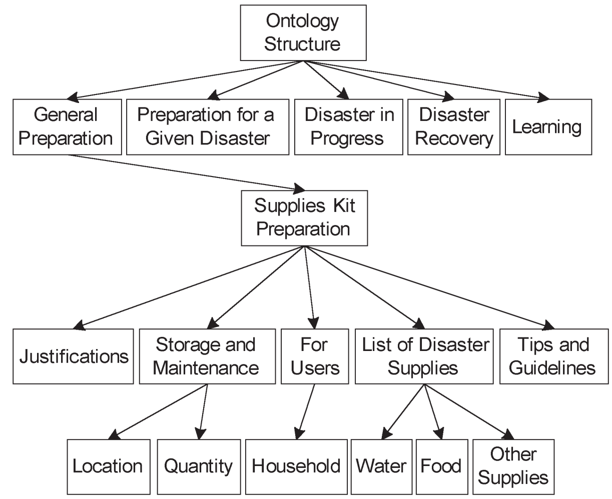


Fig. 6. Global schema G_1 at the end of round 1.

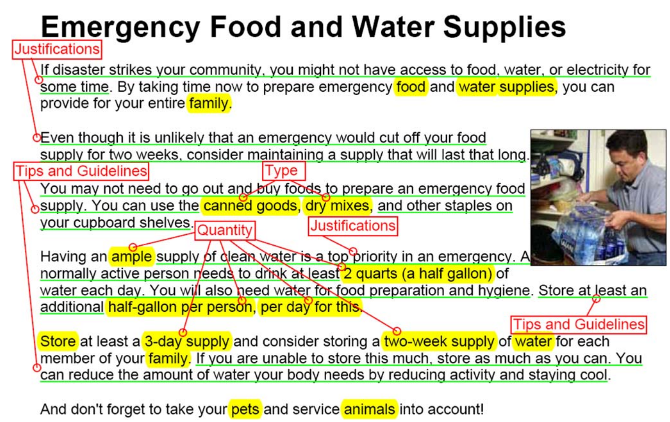


Fig. 7. Portion of a Web page from the American Red Cross (source: http://www.redcross.org/preparedness/cdc_english/foodwater-1.asp).

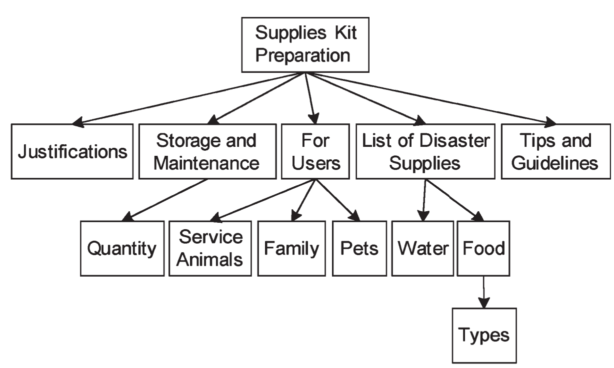


Fig. 8. DOM representations of the local schema L_2 for the American Red Cross page.

Fig. 9 shows the result of the schema matching between the local schema L_2 and the current global schema G_1. A matching is found on the root element of L_2. Similarly, another eight pairs of matching elements are found. Step 3 of the schema-merging procedure (Fig. 1) is applicable in this case. Finally, an updated global schema G_2 is generated (shown in Fig. 10).

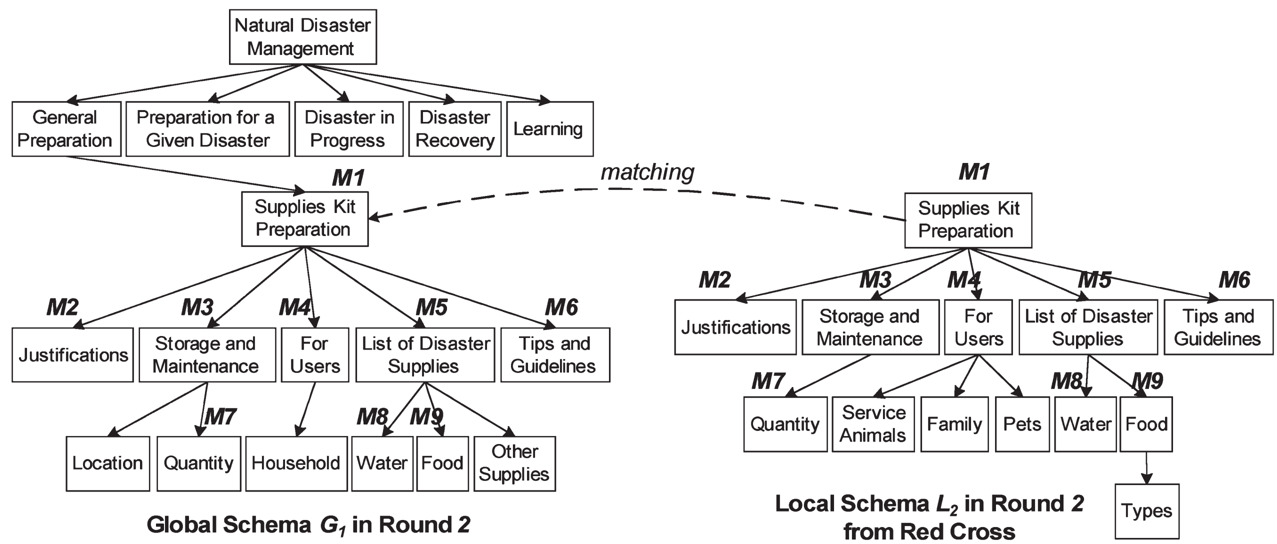


Fig. 9. Example of the schema matching in ISI.

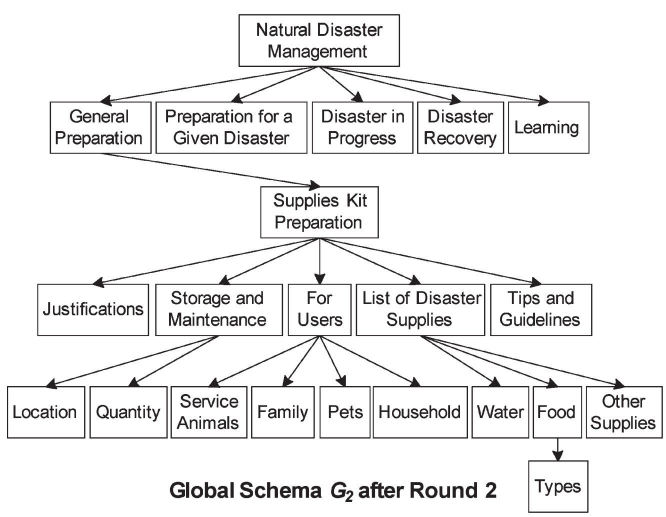


Fig. 10. Example of the global schema after schema merging.

TABLE III
DISTRIBUTION OF THE ELEMENTS IN LEVELS AND STAGES

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Sum
Level 1	1 (root element)					1
Level 2	1	1	1	1	1	5
Level 3	8	3	14	4	8	37
Level 4	43	16	51	22	24	156
Level 5	151	81	87	56	17	392
Level 6	309	166	50	83	7	615
Level 7	232	171	33	82		518
Level 8	130	37	26	21		214
Level 9	87	15	15	5		122
Level 10	30					30
Level 11	4					4
Sum	999	491	279	274	62	2094

V. RESULTING WB-OS AND EVALUATION

Table III lists the summary statistics of the elements in the ontology structure resulting from our development based on the inventory of 6032 Web pages drawn from 100 disaster management Web sites. The ontology structure consists of 2094 Web elements and 11 levels. The first four levels of the ontology structure are included in theAppendix. The complete ontology structure is available from the authors upon request.

The ontology structure is flexible and extendable. It is expected to continuously evolve as new Web elements emerge, and it has the potential to become a collective knowledge base of Web elements for natural disaster management.

Since our resulting ontology structure is large and complex, we need a tool to store and visualize it. Therefore, we develop our WB-OS tool for the storage and visualization of the ontology structure. We use XML DOM to visualize the ontology structure as a tree. As XML DOM is a platform and language-independent standard, a DOM tree visualization tool can be implemented in any programming language and can be operated on any platform. We use the Xerces Java implementation (http://xerces.apache.org/xerces2-j/) of DOM in implementing the WB-OS.

The WB-OS allows the user to explore the Web elements in the ontology structure by traversing the DOM tree. For example, a general understanding of disaster management can be achieved by browsing upper levels of the tree, while a deeper knowledge can be obtained by traversing more deeply through multiple levels of the tree.

Fig. 11 shows a screenshot of the WB-OS, illustrating a small portion of the "General Preparation" phase. Each node in the DOM tree can be collapsed or expanded by clicking the symbol in front of the node, allowing a convenient exploration.

The WB-OS supports the design principles for DERMIS [6]. For example, the first principle stipulates that there should be a hierarchically structured system directory that contains all the data and information in the system. The WB-OS provides the structure for such a directory. Another example is the principle of content as address. Again, the WB-OS makes it possible to traverse through the links that provide information on each node of the hierarchy. Without access to a comprehensive

Fig. 11. Screenshot of the WB-OS.

TABLE IV
EVALUATION OF THE ONTOLOGY ELEMENTS IN THE TOP FOUR LEVELS

Site No.		1	2	3	4	5	6	7	8
Number of Elements	Level 1	1	1	1	1	1	1	1	1
	Level 2	5	5	5	5	3	2	4	3
	Level 3	16	15	15	19	9	4	10	13
	Level 4	38	44	36	34	20	10	14	22
	Total	60	65	57	59	33	17	29	39
Site Coverage (%)	Level 1	100	100	100	100	100	100	100	100
	Level 2	100	100	100	100	60	40	80	60
	Level 3	43.2	40.5	40.5	51.4	24.3	10.8	27	35.1
	Level 4	24.4	28.2	23.1	21.8	12.8	10	14	22
	Overall	30.2	32.7	28.6	29.6	16.6	8.5	14.6	19.6
Ontology Coverage (%)		100	100	100	100	100	100	100	97.4
Type of Site		State	State	State	State	City	City	City	City
Region		NE	MW	S	W	NE	MW	S	W

ontology of the domain such as the WB-OS, the implementation of the design principles in DERMIS would not be feasible.

Next, we evaluate the created ontology structure using eight governmental disaster management or emergency management Web sites. We randomly choose the Web sites based on geographic regions, defined by the U.S. Census Bureau, in the U.S. We pick two Web sites in each of the four regions, namely, Northeast (NE), Midwest (MW), South (S), and West (W). In each region, one of the Web sites is at the state level, and the other is at the city level. The four state Web sites have been used in ontology development, while the four city Web sites were not. We use the 199 elements in the top four levels of the ontology structure for evaluation (i.e., the reference ontology, available in theAppendix) and report the results in Table IV.

The site coverage of a selected test Web site is defined as the percentage of the Web elements in the reference ontology that can be found in the test Web site. In general, the state Web sites have higher coverage than the city Web sites. Specifically, the state Web sites have a complete coverage of the five stages of disaster management (level 2 of the reference ontology), while at least one and up to three stages are not covered by the city Web sites. For every Web site, either state or city, the coverage reduces to below 50% and 25% when going down to level 3 and 4 of the reference ontology, respectively, indicating potential weaknesses of the Web sites. None of the city Web sites provides contents for all of the five stages of disaster management. While the state Web sites do cover all five stages, they do not provide comprehensive materials in detail (at lower levels of the reference ontology).

The ontology coverage with regard to a test Web site is defined as the percentage of the Web elements found in a test Web site that are covered by our ontology. Our ontology has a complete coverage of seven of the eight test Web sites. Only one new element, which is "disaster preparedness of international cooperative agreement," found in Site 8, is not covered by the reference ontology. This element provides a new perspective of disaster management at a global level, indicating the need for future development of global disaster management systems. The newly found element also points to the need for our developed ontology to continually evolve as new concepts or knowledge are being constantly generated.

VI. CONCLUSION AND FUTURE RESEARCH

Understanding the necessary Web elements and their ontology structure has critical implications in the development of an effective WB-NDMS. Toward that end, we have attempted to address four relevant research questions. The first research question was on the choice of appropriate approaches for managing the large and complex structure of Web elements needed for creating WB-NDMS. Our review and evaluation of existing semistructured data modeling and schema representation approaches led to the choice of the combination of XML, XML Schema, and DOM. The second research question was related to the identification of Web elements and ontology structure for WB-NDMS. By combining the grounded-theory approach and the selected data representation approaches, we have proposed a procedure for this purpose. The third research question was on the method for constructing the ontology structure based on a collection of sample Web pages. By synthesizing a bottom-up ontology design approach with a ladder binary schema integration approach, we have proposed the ISI method and have developed a comprehensive ontology structure covering all phases of natural disaster management based on a large inventory of Web sites. The last research question was on the online distribution of the ontology structure for easy navigation. Again, relying on the selected data representation approaches, we created a Web-based tool (WB-OS) that allows the user to easily explore the contents of the ontology structure.

Our developed ontology structure provides a valuable guideline in creating new WB-NDMS Web sites as well as in benchmarking the sufficiency and comprehensiveness of existing Web sites. Our methodology is general, and it can be applied in modeling other complex semistructured domains about which little knowledge is available and in creating guidelines and tools that would assist developers and evaluators of Web sites in such domains.

Our work may be further extended in several aspects. First, our developed ontology structure can be used to quantify the adequacy of existing natural disaster management Web sites of various government (federal and state) agencies and to recommend measures that could be taken to deal with any inadequacy in structure and/or contents. Second, our ontology structure can be expanded and further validated through the exposure to the views and opinions of domain experts and professionals. Third, in addition to official government and nongovernmental Web sites, other relevant data sources, such as online forums [42] and actual documents generated by various agents in dealing with emergency cases [43], may be analyzed to further enrich the ontology structure. Fourth, while we have focused on natural disaster management targeted at individuals, our study can be extended to other areas, such as business disaster management [44]. Fifth, while our WB-OS is a useful tool for human users, it is worthwhile to develop systems using machine-readable languages, such as RDF and OWL 2, which are more amenable to information exchange and machine reasoning. Such implementations may assist in the automatic collection, exchange, and broadcast of up-to-date information about an emerging disaster among pertinent Web sites and in a consequently timely rescue of victims. Sixth, while we have adopted a labor-intensive manual process in developing the initial ontology structure to assure high quality, ontology learning techniques may be explored in the future to dynamically discover new ontological knowledge beyond the current ontology structure, facilitating the evolution of the ontology structure.

Appendix

Top Four Levels of the Ontology Structure of Web Elements for Natural Disaster Management

Natural Disaster Management
- I. Preparation
  - 1. Disaster information and history
    - Damage history
    - Disaster information
    - Presidential disaster declaration
  - 2. Individual and family preparation
    - Protection plans
    - Evacuation plans
    - Building, shelter, & personal security plans
    - Individual supplies kit preparation
    - Individual emergency exercises
    - Individual emergency training
    - Facts about individual and family disaster preparation
    - Emergency preparedness checklist
    - Goals of individual and family preparation
    - Creation of personal support network
  - 3. Business preparation
    - Emergency contact list creation
    - Emergency plans in workplace
    - Business emergency plans exercises
    - Business emergency supplies preparation
  - 4. Public and community preparation
    - Public emergency exercises
    - Community plans
    - Community preparation
    - Planning assistance
    - State mitigation planning
    - State comprehensive emergency management plan
    - Statewide mutual aid compact
    - Public evacuation plan
    - State preparedness report
  - 5. Signals and warnings
    - Warning method
    - System availability in local place
    - Warning systems
    - Warning advisory
    - Current weather condition
    - Homeland security threat level
    - School closing information
    - Up-to-date information and news
  - 6. Emergency contacts
    - State emergency contacts
    - County and city emergency contacts
  - 7. Training
    - Training for preparation
    - Training for specific disaster
    - Training for emergency response
    - Training for recovery
    - Calendar of training activities
    - Certificate of training
    - Officials needed to be trained
  - 8. Goals and facts about the preparation
- II. Preparation for a coming/predicted disaster
  - 1. Information for the coming disaster
    - Up-to-date information for the disaster
    - Emergency contact list
    - Disaster advisory
  - 2. Information specific about a disaster
    - Tornado preparation
    - Hurricane preparation
    - Tsunami preparation
    - Flood preparation
    - Volcano preparation
    - Winter storm preparation
    - Thunderstorm and lightning preparation
    - Wildfire preparation
    - Extreme heat and heat wave preparation
    - Drought preparation
    - Hail preparation
    - Landslide preparation
    - Earthquake preparation
  - 3. Goals and facts of preparation for coming disaster
- III. Disaster in progress
  - 1. Personal safety
    - Shelter-in-place

Evacuation
Self-health caring
2. Updated information about the disaster in progress
Broadcasting methods of information update
Weather information and forecasts
Transportation
3. Contact list for assistance
Nonprofit organization emergency numbers
Governmental emergency numbers
Hot lines
Contacts for individual assistance
Contacts for community assistance
4. Guidelines for helping others
Tips and guidelines for helping others
Helping others with disability and special needs
5. Supplies collections
Supplies management
Available supplies from different sources
Donations
Volunteers
6. Community assistance
Virtual community set-up for information exchange
Online communications
List of community needs
7. Individual victim assistance
Employment information
Relief wish list
Coping with mental issues
Financial assistance
Healthcare assistance
Supplies (shelters, food, clothes) provision
External help information
Missing people information
Transportation
8. Proper actions for disaster in progress
Proper actions in specific situations in specific disaster
Proper actions for the specific disaster
9. Pet and animal safety
Tips and guidelines for animal caring
Missing pet information
Shelters information for pets
Pet and animal transportation
Sanitation for animals
10. Emergency response and communications
Communication resources
Communication systems
Communications capabilities
11. State government responses
Alerts and notifications
Activation of the state emergency operations center
Coordination of emergency support functions
Priorities for allocating resources
State emergency response team
Governmental communications
12. Federal government responses
Operational support
Life support
Power generation assets
Medical responses
Assistance for urban search and rescue
Coordination with state, local, and tribal governments and the private sector
13. Mobile emergency response
14. Response mission

IV. Disaster recovery
1. Recovery mission
Cleaning up
Rebuilding
2. Immediate recovery
Up-to-date information about immediate recovery
Personal safety assurance
Transportation from temporary shelter
Animal care
Family member lookup
Supplies collections and delivery (including food)
Proper self actions after disasters
Helping others
3. Short-term recovery
Informational needs during recovery
Recovery for victims (including finance & medical)
Recovery for environment
Recovery for property
Recovery for communities
Assistance for recovery
Mobile emergency
Social support
4. Long-term recovery
Duration of long-term recovery
Informational needs for long-term recovery
Monitoring victims' health
Monitoring communities' recovery

V. Learning
1. Best practices and case studies
Best practices available
Case studies and examples
2. Damage report and news
News archives
Damage reports
Impact and damage assessment
3. Lessons learned
Areas for improvement
What went right
What went wrong
Recommendation for the future
4. Plans for future changes
Must have plans
Best have plans
5. Recognition of heroes
Stories about the heroes

Photos of the heroes
Credits to the heroes
Types of heroes

6. Efforts/contributions made by institutions
Events involved
Donations made
Efforts made

7. Disaster loss-reduction programs
Hazard mitigation grant program
Predisaster mitigation competitive grant program
National flood insurance program
Flood mitigation assistance program
Severe repetitive loss program
Residential construction mitigation program

8. Goals and facts about Learning

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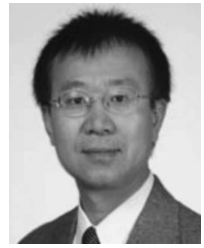

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