Semantic Web in Disaster Management: A Systematic Literature Review

Teduh Dirgahayu¹, Hendrik², Hari Setiaji³
Department of Informatics, Universitas Islam Indonesia, Yogyakarta, Indonesia

E-mail: {¹teduh.dirgahayu, ²hendrik, ³hari.setiaji}@uii.ac.id

Abstract. Disaster management requires extensive and various information. Semantic web offers a large potential to be utilized in the applications for supporting disaster management with its ability to integrate heterogeneous data from diverse sources. This study aims at investigating the extent to which semantic web is used in disaster management systems. The study conducted as a systematic literature review on 13 papers from academic databases that are leading in the area of computer science, i.e. ACM Digital Library, IEEE Explore and Science Direct. The result shows that the applications in the selected papers are mainly provided to institutions responsible for disaster management. Emergency relief is the phase that is supported by most applications. The study indicates that common geospatial ontology is necessary to facilitate the development of semantic web applications for disaster management. In the selected papers, the use of semantic web for data integration is done via an integration layer. This layer includes semantic processing to ensure that all data from multiple sources have proper semantics and to facilitate the application in querying the integrated information.

Keywords: semantic web, disaster management, ontology, data integration, semantic processing, literature review.

1. Introduction
Disaster management consists of several phases, i.e. disaster risk analysis, disaster preparedness, early warning systems, emergency relief, and reconstruction [1]. To be effective, all relevant parties should be actively involved in disaster management. Those parties can be categorized into three groups, namely (i) institutions that are responsible for disaster management, i.e. governmental agencies or companies whose business has the potential for large-scale accidents e.g. airports and oil mining/refinery, (ii) first responders, i.e. medical staffs, search-and-rescue teams, firemen, and volunteers, and (iii) people hit by disasters or living in the disaster-prone areas [2].

Information technology (IT) has been intensively used in every phase of disaster management. For example, a community-based information system [3] is used in the phase of disaster preparedness to identify the availability of logistics and local volunteers. DERMS [4] and Sahana [5] are IT applications to support in the phase of emergency relief. Wireless technology is already commonly used to support the coordination between involved parties in emergency relief [6].

Disaster management requires extensive and various information. For example, during emergency relief, first responders do not only need to know the number of the people hit by disasters and their locations, but also the safe evacuation routes and the possibilities that the disaster would hit again.
Some of which have already made publicly available on the Web. When such information is also available in a machine-readable format, IT applications can be developed to make use of that information for supporting the first responders.

Semantic web is intended to extend the information that is available on the Web by giving the information well-defined meaning that can be understood and processed by applications [7]. It allows different applications to share and reuse data between them [8]. In fact, semantic web is mainly used to facilitate the integration of diverse and heterogeneous data [9].

Semantic web relies on ontology for representing conceptualized knowledge from the information. An ontology is a graph database that is composed of vocabularies and their relationships, e.g. in RDF or OWL. Applications may then query the ontology using query languages, e.g. SPARQL or OQL.

With its ability to integrate heterogeneous data from diverse sources, semantic web offers a large potential to be utilized in the applications for supporting disaster management. In this study, we aim at investigating the extent to which semantic web is used in disaster management systems. Hence, we can identify promising research in this area. Also, we can identify what shall be considered when we develop a semantic web application for disaster management.

The paper is further structured as follows. Section 2 describes the method that we use to conduct a systematic literature review. Section 3 presents and discusses the review results. Finally, Section 4 concludes this paper and identifies some future work.

2. Method
We conduct this study by following the guidelines for systematic literature reviews from Kitchenham and Charters [10]. More specifically, we follow a similar study in the same area [2]. The steps are described in the followings subsections.

2.1. Research Questions
We define the following research questions to be answered in this study.

RQ1. In which phase of disaster management is semantic web used?
RQ2. How semantic web are used in systems for disaster management?

2.2. Search Strategy
We define a search string i.e. (“semantic web” AND “disaster”). Instead of using the keyword “disaster management”, we use keyword “disaster” to include all papers discussing the use of semantic web in any phases of disaster management. The searching is done in abstracts only.

Also, we define an inclusion criterion to select a list of relevant papers. The criterion is “the paper must describe the use of semantic web in disaster management systems”. We conduct the searching on July 19, 2019.

We select academic databases that are leading in the fields of computer science as the data sources of our study. The selected databases are ACM Digital Library (dl.acm.org), IEEE Explore (ieeexplore.ieee.org), and Science Direct (www.sciencedirect.com). We are aware that Google Scholar is a comprehensive index for scholarly papers. However, it has a limitation that makes us exclude it. Using Google Scholars, searching in abstracts is limited to papers published in the last year only. Thus, it does not give us complete demographic information of all available papers. Searching in full text resulted in 10,300 papers that we cannot manage to handle manually.

The searching results in several papers as listed in Table 1. It initially results in 45 papers. In these papers, we apply the inclusion criterion in their abstracts and then in their full texts. We finally get 13 selected papers to review, i.e. [11]-[23]. This number of papers might be considered too few for a systematic literature review, but it can be understood as the topic is quite narrow.
Table 1. Search results.

| Database            | Initial results | Relevant (abstract) | Relevant (full text) |
|---------------------|-----------------|--------------------|---------------------|
| ACM Digital Library | 18              | 4                  | 3                   |
| IEEE Explore        | 12              | 12                 | 8                   |
| Science Direct      | 15              | 7                  | 2                   |
| Total               | 45              | 23                 | 13                  |

2.3. Data Extraction

The demographic analysis of the selected papers is described as follows. Four papers (30.8%) are published in journals and nine papers (69.2%) are in conference proceedings. About 61.5% (8 papers) are published in IEEE-indexed journals and conference proceedings. They were published between 2015 and 2019. Figure 1 depicts the distribution of the papers based on their publication years. On average, 2.6 papers are published per year. The figure does not indicate any trend in the publication numbers. It should be noted that the number of papers published in 2019 may increase until the end of this year.

![Figure 1. Number of papers vs. publication year.](image)

Based on the affiliations of the selected papers’ authors, the papers were recognized from fourteen countries. Note that a paper may have several authors from different countries. Table 2 depicts the distribution of the countries of the authors. The table also indicates the risk index of the corresponding countries. A risk index is a combination of four components, i.e. exposure, susceptibility, coping, and adaption. The index is categorized into very high (10.49 – 36.45), high (7.36 – 10.48), medium (5.63 – 7.35), low (3.53 – 5.62), and very low (0.09 – 3.52) [1]. Although there are 68 developed and developing countries whose risk indices are high and very high, only authors from the Netherlands (risk index = 8.41) contributed to the selected papers. Other countries, such as Japan (risk index = 13.47, very high) and Indonesia (risk index = 10.49, very high) did not contribute to the selected papers. Interestingly, most countries (9 of 14; 64%) have low or very-low risk indices.
Table 2. Countries of the authors of the selected papers.

| Country     | Number of papers | Number of authors | Risk index | Risk index category |
|-------------|------------------|-------------------|------------|---------------------|
| Canada      | 1                | 1                 | 3.31       | Very low            |
| China       | 1                | 6                 | 6.81       | Medium              |
| France      | 1                | 2                 | 2.73       | Very low            |
| Greece      | 1                | 3                 | 7.11       | Medium              |
| Germany     | 2                | 2                 | 3.09       | Very low            |
| India       | 2                | 5                 | 7.00       | Medium              |
| Italy       | 1                | 5                 | 4.63       | Low                 |
| Netherlands | 2                | 4                 | 8.41       | High                |
| Slovenia    | 1                | 1                 | 3.62       | Low                 |
| Taiwan      | 2                | 8                 | N/A        | N/A                 |
| Tunisia     | 1                | 2                 | 5.62       | Low                 |
| Turkey      | 1                | 1                 | 5.42       | Low                 |
| UK          | 2                | 4                 | 3.60       | Low                 |
| US          | 1                | 4                 | 3.90       | Low                 |

3. Results and Discussion
The answers to our research questions are described in the following subsections.

3.1. Phases of disaster management (RQ1)
Applications in the selected papers use semantic web for data integration. Table 3 lists in which phases and by whom the applications are used. Most applications (6 papers) are for supporting emergency relief. Other phases are supported by applications in 2 or 3 papers only. Most applications (7 papers) are available to be used by institutions. Few applications (2 papers) are targeted for people as their users. It should be noted that an application may support several phases and be targeted for many types of users. The application in [14] is used to monitor a disaster management process from risk analysis (diagnosis), preparedness, emergency relief (response) to reconstruction (recovery).

Table 3. Phases and relevant parties.

| Phases            | Institution | Responder | People | #papers |
|-------------------|-------------|-----------|--------|---------|
| Risk analysis     | [14][16]    |           |        | 2       |
| Preparedness      | [14][17]    | [23]      |        | 3       |
| Early warning     | [13][18]    |           | [13]   | 2       |
| Emergency relief  | [14]        | [11][15][19][21] | [12] | 6       |
| Reconstruction    | [14][20][22] |           |        | 3       |
| #papers           | 7           | 5         | 2      |         |
Different applications in the selected papers address different types of disasters. Disaster can be (i) natural disasters, e.g. tsunami, typhoons, and earthquakes, or (ii) man-made disasters, e.g. humanitarian crisis, forest fire due to carelessness, and oil spill at sea from drilling. The applications can address specific disasters, e.g. disaster at the sea [13], earthquake [17][22][23], tsunami [18], flood [20] or generic disaster, i.e. the paper does not mention the type of disaster being addressed. It should be noted that an application may address several types of disasters.

Table 4. Types of disasters addressed.

|                     | Natural          | Man-made |
|---------------------|------------------|----------|
| Specific disaster   | [17][18][20][22][23] | [13]     |
| Generic disaster    | [11][12][14][15][16] [19][21] | [12]     |
| #papers             | 12               | 2        |

3.2. Use of semantic web (RQ2)

Disasters happen at certain locations. Geospatial information is then very importance in disaster management. Most applications (ten selected papers) [13][14][16]-[23] make use of ontology that related to geospatial information. Applications in other selected papers [11][12][15] might use spatial-related ontology, but the papers do not clearly indicate that. There is no consensus however which geospatial-related ontology shall be used as different applications serve for their purposes. For example, the application in [22] develops a geographic ontology to perform classification and damage assessment in OWL. The ontology consists of three sub-ontologies, i.e. surface area, disaster, and damage. The surface includes geographical concepts including land cover and land use classification. Time is included as disasters happen at a certain time.

Figure 2. Ontology includes spatial information.

Four selected papers indicate that the latest technology has been used in disaster management, i.e. robotics [11][21], Internet of Things (IoT) [18], and unmanned aerial vehicle (UAV) [19]. This technology relies on sensors to be able to capture the disaster situations. Data observed by the sensors are transmitted to a semantic processing component with predefined ontologies to be interpreted or reasoned into information. For example, Figure 3 depicts an excerpt of W3C Semantic Sensor Network Ontology (SSNO) [24] that defines the relationships between sensors and their observed data that is used in [18][21]. These papers further extend SSNO with other ontologies to satisfy the application requirements.

Semantic web data integration ability should be exploited more in disaster management. Only four selected papers explicitly mention the use of multiple (internal or external) data source in their applications, i.e. Google public alerts [12]; distributed and heterogeneous databases [13][17]; and satellite imagery, weather, and atmospheric condition [16]. When data from diverse sources are integrated, they would enrich the resulted information. The integration, however, should be made transparent to the application. In all those papers, a common approach to providing such transparency is to establish an integration layer with semantic processing between data sources and the application.
as illustrated in Figure 4. External data sources may include sensors. The semantic processing is necessary for two reasons, i.e. (i) to ensure that all data from different sources have proper semantics and (ii) to facilitate the application in querying the integrated information. For the latter reason, semantic processing can also be found in other selected papers [15][18][20].

Figure 3. Excerpt from SSNO [18].

Figure 4. Integration layer with semantic processing.

4. Conclusion and suggestion
The study conducted in this paper has reviewed 13 papers discussing the use of semantic web in disaster management. The papers are selected from ACM Digital Library, IEEE Explore and Science Direct. While the idea of semantic web has arisen since 2001, papers discussing the implementation of semantic web in disaster management were published since 2015 only.

Based on the result of our demographic analysis, we suggest that researchers from developed and developing countries with high and very-high risk indices contribute more to this area. Especially, we may expect more publications in using semantic web for disaster management that are specific to their countries.

The applications in the selected papers are mainly provided to institutions responsible for disaster management. Emergency relief is the dominant phase that is supported by most applications. Future research shall be conducted to address other phases and different parties.

Geospatial ontology is very important in disaster management as disasters happen at certain locations. Each application in the selected papers develops its geospatial ontology. Some work on geospatial ontology has been done, e.g. [25][26]. Future research on a general-purpose geospatial ontology will facilitate the development of a semantic web application for disaster management. This idea has been demonstrated in the case of a semantic sensor network ontology (SSNO).
Disaster management requires extensive and various information. Semantic web allows the integration of heterogeneous data from multiple (internal and external) data sources to enrich information for relevant users. Semantic processing is required during data integration to ensure that all data have proper semantics. We expect more applications on semantic web in disaster management so that we can learn how to use it effectively and efficiently.

References
[1] UNU-EHS 2017 World Risk Report. Analysis and prospect 2017
[2] Dirghahayu T, Hendrik and Setiaji S 2019 Context-aware applications for disaster management: A systematic literature review Proc. 2019 IEEE Int. Conf. Cybernetics and Computational Intelligence (CyberneticsCom 2019)
[3] Troy DA, Carson A, Vanderbeek J and Hutton A 2008 Enhancing community-based disaster preparedness with information technology Disasters vol 32 no 1 pp 149-65
[4] Turoff M, Chunmer M, van de Walle B and Yao X 2004 The design of a dynamic emergency response management information system (DERMIS) 2004 J. Information Technology Theory and Application (JITTA) vol 5 no 4 p 3
[5] Curron P, de Silva C and van de Walle B 2007 Open source software for disaster management Communications of the ACM vol 50 no 3 pp 61-5
[6] Reddick C 2011 Information technology and emergency management: preparedness and planning in US states Disasters vol 35 no 1 pp 45-61
[7] Berners-Lee T, Hendler J and Lassila O 2001 The semantic web Scientific American vol 284 no 5 pp 28-37
[8] W3C 2011 W3C Semantic web activity
[9] Shadbolt N, Berners-Lee T and Hall W 2006 The semantic web revisited IEEE Intelligent Systems vol 21 no 3 pp 96-101
[10] Kitchenham B and Charters S 2007 Guidelines for performing systematic literature reviews in software engineering EBSE Technical Report EBSE-2007-01
[11] Bagosi T, Hindriks K V and Neerincx M A 2016 Ontological reasoning for human-robot teaming in search and rescue missions The Eleventh ACM/IEEE Int. Conf. on Human Robot Interaction pp 595-6
[12] Pandey Y and Bansal S 2017 Safety check: a semantic web application for emergency management Proc. Int. Workshop on Semantic Big Data p 7
[13] Santipantakis G, Kotis K I and Vouros G A 2015 Ontology-based data integration for event recognition in the maritime domain Proc. 5th Int. Conf. on Web Intelligence, Mining and Semantics p 6
[14] Chen N, Liu Y, Wang C, Xiong C, Chen Z and Xiao C 2018 SWRO-DDPM: A sensor web resource ontology for the dynamic disaster process monitoring Proc. 26th Int. Conf. on Geoinformatics pp 1-4
[15] Mobasheri A and Bakillah M 2015 Towards a unified infrastructure for automated management and integration of heterogeneous Geo-datasets in disaster response 2015 IEEE Int. Geoscience and Remote Sensing Symposium (IGARSS) pp 4570-3
[16] Masmoudi M, Tatak H, Lamine S B A B, Karray M H, Zghal H B, Archimed B and Guegan C G 2018 PREDICAT: a semantic service-oriented platform for data interoperability and linking in earth observation and disaster prediction Proc. IEEE 11th Conf. on Service-Oriented Computing and Applications (SOCA) pp 194-201
[17] Liu C H, Bau J F and Lee C R 2015 Integrating various data sources of geospatial information systems with semantics Proc. 2nd Int. Conf. on Information Science and Control Engineering pp 274-8
[18] Poslad S, Middleton S E, Chaves F, Tao R, Necmioglu O and Bügel U 2015 A semantic IoT early warning system for natural environment crisis management IEEE Transactions on
Emerging Topics in Computing vol 3 no 2 pp 246-57

[19] Cavaliere D, Saggese A, Senatore S, Vento M and Loia V 2018 Empowering UAV scene perception by semantic spatio-temporal features Proc. 2018 IEEE Int. Conf. on Environmental Engineering (EE) pp 1-6

[20] Kurte K R, Durbha S S, King R L, Younan N H and Vatsavai R 2016 Semantics-enabled framework for spatial image information mining of linked earth observation data Proc. IEEE J. of Selected Topics in Applied Earth Observations and Remote Sensing vol 10 no 1 pp 29-44

[21] Dey S, Bhattacharyya A and Mukherjee A 2017 Semantic data exchange between collaborative robots in fog environment: Can CoAP be a choice? Proc. 2017 Global Internet of Things Summit (GIoTS) pp 1-6

[22] Bouyerbou H, Bechkoum K and Lepage R 2019 Geographic ontology for major disasters: Methodology and implementation Int. J. of disaster risk reduction no 34 pp 232-42

[23] Chou C C, Jeng A P, Chu C P, Chang C H and Wang R G 2018 Generation and visualization of earthquake drill scripts for first responders using ontology and serious game platforms Advanced Engineering Informatics no 38 pp 538-54

[24] W3C 2017 Semantic Sensor Network Ontology

[25] Klien E and Probst F 2005 Requirements for geospatial ontology engineering Proc. 8th Conf. on geographic information science (AGILE 2005) pp 251-60

[26] Arpinar I B, Sheth A, Ramakrishnan C, Usery E L, Azami M and Kwan M-P 2006 Geospatial ontology development and semantic analytics Transactions in GIS vol 10 no 4 pp 551-75