

Response Information Interoperability: A Development of Data Standards in the Fire Incident Context

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Abstract

Emergency management requires efficient information sharing and exchange among agencies for the smooth operations of intra- and inter-organizational emergency management processes. However, the lack of consistent data standards presents a challenge and hampers the information interoperability. In this paper, we develop a XML-based data model that prescribes a comprehensive set of data standards (semantics and internal structures) for emergency management that attempt to mitigate the information interoperability challenges. The data model is developed using Activity Theory and it is validated through interviews with domain experts. The paper applies the standards in a real case of a fire incident scenario. Further, it complies with the national leading initiatives in emergency standards (National Information Exchange Model) which leverage its implications on the information sharing in emergency context.

Keywords: Data Model, Interoperability, Emergency Management, XML

1. Introduction

Interoperability is defined as the ability of two or more entities or systems to exchange information and to use the information that has been exchanged (IEEE 1990). In emergency response, a low degree of interoperability hampers the information sharing among responders (e.g., Fire, Police, and Emergency Medical Service) and consequently the collective situational awareness. Interoperability is of multiple levels; the development of data standard addresses the information level interoperability (COMCARE 2002). To date, there is no existing data standard that provides sufficient support for the management of common incidents (DHS 2005). This paper investigates the data standard development for fire incident response, one of the most frequent and threatening types of incidents. This paper has two contributions. First, the paper develops an information management framework which identifies the focal dimensions of response management information in fire context. It provides guidelines for data standard development and also facilitates the management of real time information sharing. Second, guided by Activity Theory we develop an object oriented XML data model that standardizes emergency response information semantics and structures for fire response.

2. Review of Existing Emergency Standards

There exist a number of data standards addressing interoperability issues in specific emergency domains (Aylward et al. 2006; SICOP 2005). Few of them, however, go beyond single domain and support cross organizational operations. In a typical fire response, for example, the response involves Police, Fire, Emergency Medical Service, Hazard Material, etc. The existing emergency standards are thus insufficient for day-to-day responses. The existing standards are exemplified by National Information Exchange Model (NIEM) which is the national leading initiative in emergency standard and it is endorsed by U.S. DOH and DOJ (DHS et al. 2006). The existing NIEM standards for emergency management however are narrowly defined around alarm, resource request, and message distribution. It is therefore insufficient to support many other aspects that are critical for emergency management, including incident command, response operation, risk assessment, etc. In this paper, we develop a set of data standards that complement the existing NIEM to provide a full range of support for incident management.

3. Response Information Management Framework – Fire Context

Emergency response is characterized by complex information consumed to offset the challenges introduced by incomplete information. A further understanding of the components in response information not only facilitates the response data standardizing but also benefits the information management practices – the strategy design and information system development. In this regard, we contribute to the response community and IT developers with a systemic response information framework (see Table 1). This framework identifies the major dimensions and structure of task critical information for incident management. The framework development is grounded on national and local response procedures and management guidelines (DHS 2004; DOS et al. 2006; OFPC 2000). It further incorporates findings in prior emergency literature (Auf der Heide 1989; Turoff et al. 2004). Finally, we validate the framework through two-round focus group study methodology; a panel of response managers from the related stakeholders is invited for evaluation. We develop the fire response information standard following this framework.

Table 1. Information Management Framework for Fire Response

Major Dimensions	Sub Dimensions	Example Components
Threat Assessment <i>Facts about fire incident occurrence and its consequences. Source of the response decision making and strategy development</i>	Incident Setting <i>Descriptions of the physical attributes of the incident. Valuable for response preparation and initial set up</i>	<i>Incident specifics, weather, incident location, structure, ignition</i>
	Fire Hazard <i>Details of the fire hazard factors and fire behaviors. Bases of fire mitigation procedures for achieving operation safety</i>	<i>Fire behavior, fire hazard factor</i>
	Threat <i>Information on the incident impacts. Required for response strategy development (e.g., prioritizing and resource allocation)</i>	<i>Civilian casualty, fire service casualty, property damage, environment damage, public safety</i>

Incident Command System <i>Records of incident response structure and progresses. Source of response coordination and control</i>	Response Management <i>Descriptions of the command system and entities involved. Valuable for the structuring of adaptive response management</i>	<i>ICS unit, response facility, response organization, responder, resource, association</i>
	Response Operation <i>Details of the response activities design and implementation. Bases of monitoring and evaluating the response progress</i>	<i>Operation plan, response activity, activity, responders, organization, resource, association</i>

4. Fire Incident Response Data Model Development

In this section, we briefly introduce the new information standard, referred to as fire incident response data model. The data model consists of a well-defined data vocabulary and an object-oriented dictionary structure. They provide both semantic and structural consistence, supporting the inter-agency sharing of response information. The data model development process is guided by Activity Theory (Engestrom 1987; Engestrom 1999). Activity theory is a descriptive tool rather than a strongly predictive theory (Nardi 1996). It has been used to provide a lens to study the design of artifacts for individuals and organizations (Bertelsen et al. 2003; Chaudhury et al. 2001). It provides a framework in which the critical issues of context can be taken into account for system design (Bertelsen et al. 2003; Uden et al. 2007). In Table 2, we provide an illustration on the application of Activity Theory in the data model development. The Activity Theory informed design implications drive the data model development as in Table 3.

Table 2. Application of Activity Theory in Data Model Development

Activity Theory Construct and Perspective	Example Design Implications
Subject: A subject in Activity Theory is an agent that undertakes activity. In our case the subjects are individual responders who provide or consume information.	The subjects involved in mitigating incidents that involve fire need to be identified. Their individual experience and viewpoints will help us comprehend the response information requirement and its management.
Object: An object is an artifact shared by a community of subjects that work together to reach a desired outcome. The object in our case is the data model being developed to improve collaboration and coordination (outcome) to effectively deal with fire incidents by developing common operating picture.	The data model should be comprehensive and that the exchange of critical information is easy in terms of data model usability. This prompts the use of XML in describing the data model because of its extensibility and structured nature, platform and software independence.

<p>Community: Community includes subjects that share an object. The first and second responders are subjects who form community in our case. The first and second responder community includes several sub-communities such as fire and rescue, law and order, and emergency medical personnel, FEMA, hazmat teams, etc. Sub-communities also form based on the agency to which they belong. Each sub-community brings in a different perspective that derives from their routine daily tasks, functions during critical incident, group culture, etc.</p>	<p>Interoperability needs of the different communities needs to be elicited. In addition requirements should also consider between-group communications needs. This prompts that requirements should be elucidated from the different communities at the county level as well as different local levels and different responder groups.</p>
<p>Tools / Instruments, Rules and Division of Labor: The relationships between subject, object and community are mediated by tools, rules and division of labor. Tools of communication include current paper and legacy systems that are used for communication to develop common operating pictures, exchange task critical information, etc. NIEM provides general vocabulary to be used for such messaging. Rules and division of labor serve to mediate between the responders and responder groups.</p>	<p>The requirement elicitation process should analyze the existing forms used for communication during critical incidents. In addition it is important to consider existing standards such as that provided by NIEM. Further the data model should provide the elements necessary to function under the Incident Command System (ICS) prescribed by Department of Homeland Security. ICS structure imposes protocols for interaction, governance structure and division of labor.</p>
<p>Activity Activities transform objects via a process that typically has steps or phases. Chains of actions guided by a subject's conscious goals carry out an activity over a period of time resulting in objective results.</p>	<p>All the activities that responders engage in should be analyzed. Responders typically engage in activities such as providing information about the scene, requesting resources and exchanging information to develop common operating pictures (reflective communication).</p>
<p>Environment Environment is a construct that includes all external issues that have an impact on the conduct of the activity. This includes threats, hazards, environmental conditions such as direction of wind, operating conditions, etc. We adapt activity theory to include this construct for our purposes.</p>	<p>Requirements need to consider the different environmental elements that need to be captured and the properties of those elements. The data model should contain element labels to specify threat conditions, intensity, scene location, etc.</p>

Table 3. Data Model Development Process Overview

Development Process	Design Events
<p>Document Collecting: Collecting relevant documents, information sharing requirements, management guidelines</p>	<p>- Over 40 key documents are collected from the local response community. These documents include fire incident response technical data forms; fire incident response dispatch forms; field notes and chronological logs; fire incident messaging systems (e.g., National Fire Incident Reporting System - NFIRS), and fire response plans.</p>

<p>Data Analysis: Synthesize and reconcile the core information and internal relationships</p>	<ul style="list-style-type: none"> - Following the Incident Command System as the basis, the rest of the documents are analyzed to develop a general information management framework which captures the key elements and structures for data model - This process is facilitated by interviews with domain experts in incident management
<p>Data Model Specification: Define typing of identified components</p>	<ul style="list-style-type: none"> - NIEM is utilized as the foundation of the new data model for data elements reuse and extension. NIEM contains emergency management components and is endorsed by U.S. DOJ and DOH. The NIEM compliance allows the new data model to maximize its utility - Object-oriented structure is used for the data model to allow inheritance based design for reuse and extension - XML based data model specification and implementation are used. XML is a machine readable and platform independent specification language.
<p>Request for Comment (RFC): Solicit data model review opinions from domain experts</p>	<ul style="list-style-type: none"> - Four subject matter experts in fire management - Detailed tutorial is given in RFC to explain to responders how the data is structured through object-oriented approach for inheritance and extension - Two rounds of comments collecting
<p>Feedback and Model Update: Improve the data model with expert review</p>	<ul style="list-style-type: none"> - Data model revision is facilitated by the panel of seven evaluators. Consensus building is achieved through a Delphi like approach. - 30 comments are collected and 20 major changes are made to the data model
<p>Data Model Finalization: Documentation</p>	<ul style="list-style-type: none"> - Data model specification in XML Schemas and EXCEL spreadsheet - Data model contains 47 data types, 168 data elements, and 69 coding sets

5. Fire Incident Response Data Model Description

The data model contains rich set of data types and elements. Due to the page limit, we present an overall illustration (See Figure 1) and a brief description in this section. A detailed model description is provided in Appendix A. Also, we provide the detailed data model specification and XML schema in Appendices C and D. As an illustration, we present two small data types created (See Figure 2). Note that we utilize object oriented dictionary structure and reuse portion of elementary data components from NIEM.

Take incident location data for example. Information on *incident address*, *geographic coordinates*, and *terrain* is critical for response entry preparation, while information on *surrounding area*, *district*, *population density* is important for strategic planning of the response process (proactive or reactive). We therefore develop a data type termed *IncidentLocationType*. As NIEM data type *em:LocationType* defines in part similar data elements, we design *IncidentLocationType* through an inheritance from *em:LocationType*. In this way, only new data elements (such as *terrain*, *population density*, and *district*) missing from *em:LocationType* are

defined in the new data type *IncidentLocationType*. The other data elements such as *incident address*, *geographic coordinate*, and *surrounding area* are not redefined in *IncidentLocationType* since they have similar counterparts in NIEM *em:LocationType*. Information on the *weather* is also critical for the fire response management. Attributes of weather (such as *temperature* and *precipitation*) may facilitate or inhibit firefighting. Accurate weather information allows the responders to take precautionary actions (e.g., neighborhood evacuation) as well as create an adaptive or preventive response strategy. In the absence of similar NIEM standard, we develop the *WeatherType*, with 9 elements. NIEM defines the *u:SuperType* as the root data type; it does not include any elements but serves as the parent of all basic data types, which do not inherit from any others. We follow this typing convention and denote the *WeatherType* in a way that it inherits from *u:SuperType*.

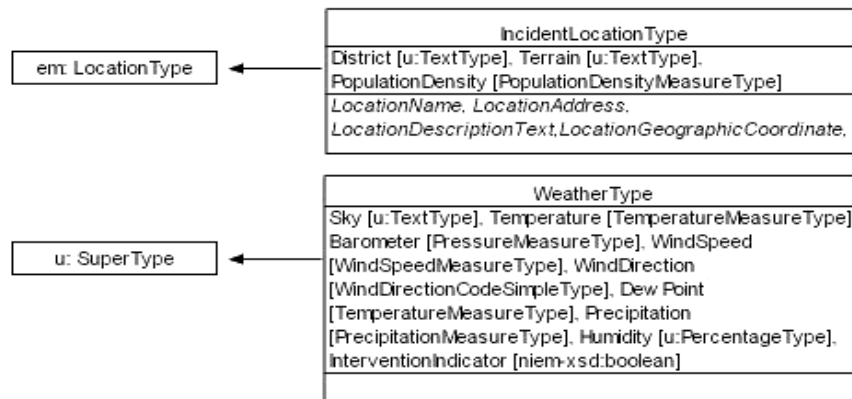


Figure 2. Example Illustration of Incident Setting Data Vocabulary

6. Data Model Application and Implementation

To demonstrate the usability of this data model in addressing interoperability challenges, we have applied it in standardizing one real document shared in fire response. The application illustrates the role of this newly proposed data model in response information standardization and it also presents the general approaches is doing so (See Figure 3). To facilitate the three-step process, we have also designed and implemented two GUI-based software (Association Wizard) which semi-automate the standardization process. These implementations may greatly help the response practitioners to improve standardization efficiency. The response document examined is not part of the materials collected for the data model development. This document is exchanged between local fire companies and other supporting agencies for collaborative fire incident management purpose. Using the new data model, we successfully standardize the document. We provide a detailed description on data model application in Appendix B.

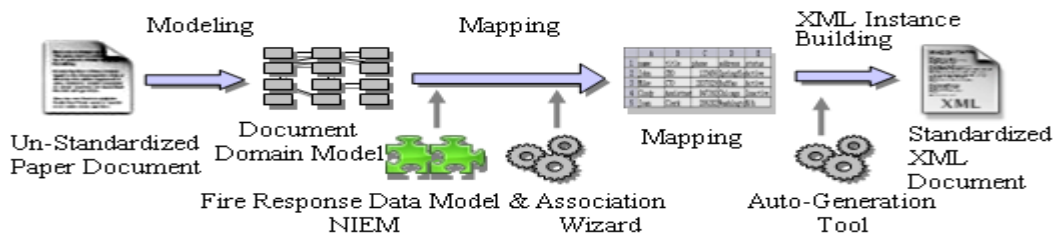


Figure 3. Overview of Application Process

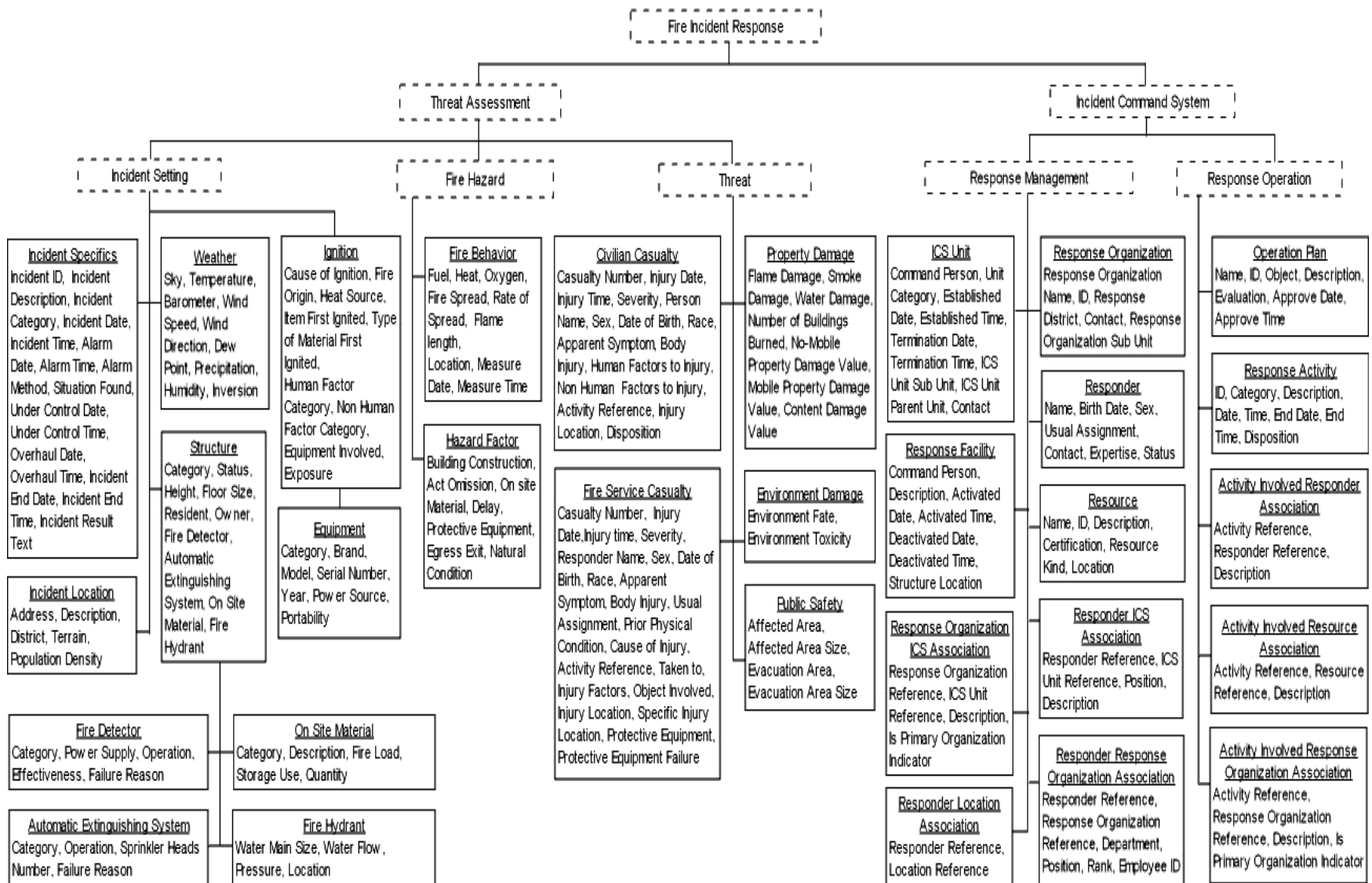


Figure 1. Fire Response Standard Data Model Overview

7. Conclusion and Future Research

The lack of response information standard threatens the collaborative emergency response. Information interoperability is fundamental to the information sharing and exchange in incident management. In this paper, we propose an object-oriented XML data model for fire response. The research is among the first attempts in the response community to attack the interoperability issues. Compliant with NIEM, the data model provides consistent semantics and structures to standardize the response information. Future research may extend the existing data model to provide information standardization support for generic types of incidents.

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Appendices

Online appendices A, B, C, and D are available at:

<http://www.som.buffalo.edu/isinterface/ray/appendix/web2007-appendix.htm>