

# Emergency Response Ontology Informatics: Using Ontologies to Improve Emergency and Hazard Management

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## Abstract

*The Large-scale natural and man-made hazards and disasters sometimes triggered and/or encouraged by regional conflicts, climate change, or migration are growing in intensity and frequency. These disasters, affecting thousands of homes and lives, have consequences for national security and defense. Adequate preparation, response and recovery are required to manage the effects of such large-scale disasters. With many organisations involved in their handling, of- ten times crossing regional and national borders, information exchange is crucial in order to help save lives and properties. Very often, this information exchange is cumbersome and difficult due to differing vocabularies, semantics and representations at the human language, systems and data levels. This paper describes HERO, the Hazard and Emergency Response Ontology, a vocabulary used to describe hazards, either emerging, existing or ones that might have happened. Having a common vocabulary to describe hazards will give emergency management officials a common language (or a common set of terms) to describe an event, a disaster, or a hazard, making the information exchange between differing political and social boundaries easier, more efficient and more effective. We describe how we have made use of HERO to help us to model migration hazard data. We end with lessons learnt and conclusions.*

## 1. Introduction

The current trends shaping global politics include globalization: globalization of goods, capital and labor. They also include energy depletion and global climate change. Global climate change together with energy depletion are bringing about many changes, such as drought, in many countries. Many of these societies may already have history of internal tensions and probably are of weak governance, making these societies vulnerable to hazards, such as drought, wars, etc. A hazard, e.g. drought, makes that

society more risk-prone to endogenous and exogenous impacts, such as the occurrence of civil wars. All these coupled with globalization of capital and labor, with the ease of communication and location sensing (e.g., via GPS, etc.) and the ease of transportation along the world's ocean routes are making it easier for affected and dislocated groups within a population to migrate to safer havens.

Added to this every year, emergencies, hazards and disasters put millions of lives at risk, destroying properties worth billions of dollars. And when they happen, first responders of public safety agencies (such as law enforcement, emergency medical services, and fire services) are normally called upon to assist in relief efforts and in saving lives and properties. They are also often tasked with the requirements of providing and maintaining communications before, during and after a disaster.

The operations of these public safety agencies are generally legislated at state, national and international levels (e.g. Frontex<sup>1</sup>), and they encompass widely different arms of the emergency services (such as Fire, Health, Police, Army, and Navy). To be effective, these different services need to plan some of the relief operations together and sometimes carry them out in tandem. For these to succeed, their various staff, systems and data need to be able to interoperate and communicate seamlessly. This is not always easy, as the nature of emergencies is unpredictable (sometimes an emergency can build slowly or often suddenly without warning), where the location and degree are not always known in advance. Co-ordination and collaboration of people, data and systems are needed during emergency and disaster situations in order to enhance the productivity of the emergency workers and the smooth and rapid saving of property and life. Data are also needed to inform decision making at all levels and to help form a common operational picture of the developing hazard. This requires fusion of these different data sources, but their co-ordination and interoperation are often difficult due to incompatibilities in system and data infrastructures as well as difficulty in filtering and validating the typical flood of information generated during disaster events.

## 2. Inter-operation of Situation Aware Applications

To improve the inter-operation of situation-aware applications for disaster and hazard management, proper mechanisms for process and data fusion are required.

### 2.1. Challenges of Effective Process and Data Fusion

These mechanisms must address the following:

- the data should be able to support improved decision support, through helping emergency workers to understand and assess prospective actions and alternative courses of action, thereby closing the loop from decisions and actions to results in the field
- the data should be able to support better situational awareness and a common operating picture
- the data should be able to support the development of applications on them that will enhance their comprehension, visualization and trust
- the data should be able to support robust, interoperable and priority-sensitive features, and
- it must address the lack of semantics in modelling emergency situations.

### 2.2. Relevant Data for Hazard Management Operations

- The kinds of relevant data brought onto a hazard management operation field can include:
- Human observations from direct response exercises. These are observations from people on the ground, such as from local emergency centres and pre-positioned trained observers, etc.
- Geographical information system (GIS) oriented data. GIS information, such as maps, flow of refugees, state of properties in the area, etc.
- flow both to the field of operation and from it.
- Logistical information. Information of location and status of properties and lives (e.g. refugees) provide an important part of the common operational picture. These kinds of data include databases of where resources are, what resources are needed by whom, where, and when, and their probable limitations, and schedules of who has been dispatched to which affected locations.

- Sensor data. These are information of status of the infrastructure being used in the relief operations.
- Social data. Information from social media about the event and its evolving nature.

All these sources have their unique ways of structuring their data which may be incompatible with some, or the rest, of the information being gathered, while their effective integration is important to provide a common operating picture of a disaster. Ontologies have been demonstrated to successfully address issues of integrating multifarious data sources to form a unifying data foundation.

### 2.3 Ontologies, Semantic Web, and Representation Formats

In its original meaning in philosophy, ontology is a branch of metaphysics that studies and denotes the philosophical investigation of existence. It is concerned with the fundamental question of "what kinds of things are there?", and this leads to studying general categories for all things. Information systems can benefit from the idea of ontological categorisation. When applied to a limited domain of interest in the scope of a concrete application scenario, an ontology can be restricted to cover a special subset of the world. Examples of ontological categories in the domain of disaster and emergency management and handling are incident, event, disaster, hazard, etc. In this sense, ontology provides a semantic vocabulary to define the meaning of things. While "ontology" studies what exists in a domain of interest, "an ontology" is a computational artefact that encodes knowledge about "this" domain in a machine-processable format in order to make it available to information systems. Making this machine-processable encoded knowledge available to different information systems enhances the connection of different domains, of these information systems, through a commonality of expression, i.e. via an ontology. Different ontologies can be combined, extended and used together: e.g. a description of a book using Dublin Core metadata can be augmented with specifics about the book author using the FOAF vocabulary.

Ontologies are widely used in the Semantic Web, with the Semantic Web consisting of web resources and their respective metadata. These metadata are usually associated with ontologies, describing what these metadata are and how they are related to one another. The Semantic Web report has provided some ontologies for the definition and exchange of data. These ontologies include SKOS (Simple Knowledge Organization System) 2, RDFS (the RDF Vocabulary Description Language, also known as RDF Schema)3, and OWL (the Web Ontology Language)4. SKOS is

an ontology for expressing conceptual hierarchies, often referred to as taxonomies, while RDFS and OWL provide ontologies for describing conceptual models in terms of classes and their properties. A basic representation format for the Semantic Web is the Resource Description Framework, or RDF5. The basic building block in RDF is an object-attribute-value triple, commonly written as A (O, V), i.e. an object O has an attribute A with value V. We can also view this relationship as a labelled edge between two nodes, O and V: [O] - A - [V]. This notation is useful as RDF allows objects and values to be interchanged. RDF consists of a set of "triples", where things are linked to other things and text strings by a directed arc. We call the originating thing the subject, the arc is called the predicate, and the destination is called the object.

### 3. Past Work

It has been noted that past research work have developed ontologies to represent emergencies and disasters. Babitski et. al., [2] devised an ontology stack that described the basic concepts of damages, resources and their connections. They used the stack as part of a prototype for information integration in a service-oriented application. Apisakmontri et. al., [1] described a methodology for constructing an ontology for humanitarian aid information systems interoperability and showed how this ontology can be mapped to a relational database (RDB). Zhang et. al., [3] developed a meteorological disaster ontology (MDO) to describe a meteorological disaster, combining this with the application of Semantic Web Rule Language (SWRL) to identify the implicit relations among the domain knowledge explicitly defined in the MDO. Although the focus of the publications involved disaster representation, none of them treated the representation, handling and management of hazards, while these are the purview of this present work.

## 4. Hazard and Emergency Response Ontology (HERO)

We will be using the terms, defined below, in the rest of the paper:

**Incident or Event:** Incident (or event) is the specific occurrence of a disaster. A single disaster incident may lead to additional incidents. For instance, an earthquake may lead to a tsunami and the tsunami may lead further to flooding.

**Disasters:** Disasters are non-routine events in societies, regions, or communities that involve conjunctions of physical conditions with social definitions of human harm and social disruption. An

example is the 'Left-to-Die Boat' incident<sup>6</sup> where two fishing boats overloaded with migrants from Libya capsized in the Mediterranean Sea on their way to Lampedusa (Italy), where more than 1200 migrants died.

**Hazards:** Hazards are a source of potential or actual harm. Hazards may be natural, technological, or wilful in origin. Examples of natural hazards include floods, hurricanes, earthquakes, tsunamis, tornadoes, and so on. Technological hazards include industrial accidents and other human made sources of potential harm. An example of a hazard is the case of the bacterial contamination of the public water supply in May 2000 of the small town of Walkerton, Canada where 4,800 people became ill, and seven died [5]. A terrorist attack such as that of the July 2005 London (UK), bombing<sup>7</sup> is an example of a wilful hazard.

The HERO ontology has been developed to specify and represent hazards in emergency situations and through these specifications, to easily and efficiently inter-link hazard data in data sources. We intend HERO to be an easy to use ontology, and thereby designed it to be light weight with few classes and properties. HERO's base class is the hero: Hazard class, and it contains one major sub-class: The hero:NaturalHazard class; these hazards are mostly human-induced. They may, in conjunction with other events or on their own, initiate other forms of hazards, such as technological and biological hazards (described below). The hero:NaturalHazard class has the following sub-types:

- **Health Hazards:** These are generally caused by a combination of adverse health-induced microbes in the environment. They can be further divided into: (a) Disease Outbreaks, caused by minor, that may lead to major, outbreaks of diseases, such as AIDS/HIV, Chickenpox, and other Infestations; (b) Terrorist attacks, or chemical attacks that may be due to terrorism.
- **Public or Private Infrastructure Hazards:** These are hazards caused by breakdown of or attack on the public or private infrastructure. Examples include highway /motorway accidents, aircraft accidents (such as air crash). This also includes technological hazards, such as hazards to electronic and communications systems (such as the Internet, social media, etc.). The sections below describe the classes of HERO, and its properties that can be used to describe hazards.

### 4.1 HERO's Classes

The classes here can be used to characterise different types of hazards.

- Class hero:Hazard. This is the base class of all the hazard types in the ontology.
  - Class hero:NonHazard. This refers to a happening or event that, at this time, cannot be categorised into a hazard type.
  - Class hero:NaturalHazard. A subtype of Hazard that are human induced.
  - Class hero:HealthHazard. This is a sub-type of hero:NaturalHazard and is generally caused by a combination of microbial factors in the environment.
  - Class hero:TerroristAttackHazard. This is a sub-type of hero:HealthHazard generally caused by a terrorist attack. This hazard, among other things, may lead to health risks within the environment where it occurs.
  - Class hero:DiseaseOutbreakHazard. A sub-type of hero:HealthHazard generally caused by a minor, and sometimes major, disease outbreak such as chicken-pox, AIDS/HIV, etc.
  - Class hero:TerroristChemicalAttackHazard. A sub-type of hero:TerroristAttackHazard caused by an attack that may be terrorist and/or wilful in nature, and it is induced through chemical materials.
  - Class hero:TerroristInfrastructureAttackHazard. A sub-type of hero:TerroristAttackHazard caused by an attack that may be terrorist and/or wilful in nature, and it is against public or private infrastructure.
  - Class hero:TerroristElectronicInfrastructureAttackHazard. A sub-type of hero:TerroristInfrastructureAttackHazard caused by an attack that may be terrorist and/or wilful in nature, and it is against electronic or communications infrastructure.
  - Class hero:TerroristTransportationInfrastructureAttackHazard. A sub-type of hero:TerroristInfrastructureAttackHazard caused by an attack that may be terrorist and/or wilful in nature, and it is against transportation infrastructure.
  - Class hero:InfrastructureHazard. A subtype of hero:NaturalHazard and mostly caused by a breakdown in the technical infrastructure of society. This may be caused by vehicle accidents on the freeway, or an airplane crashing or a breakdown of the electronic infrastructure such as social media. The infrastructure could be public in nature, i.e. built and/run by the government or it could be built and/run by the private enterprise (such as a private blockchain).
  - Class hero:ElectronicInfrastructureHazard. This is a sub-type of hero:InfrastructureHazard, and is due to a breakdown of the electronic infrastructure hazard of a society.
  - Class hero:TransportationInfrastructureHazard. A sub-type of hero:InfrastructureHazard, caused by a breakdown to the transportation infrastructure, such as airports, highways, waterways, etc.
  - Class hero:HydrologicInfrastructureHazard. A type of hazard that is caused by water or water resources, e.g. coastal erosion that may have been caused by rainfalls.
  - Class hero:EnvironmentalHazard. Caused by a combination of human and non-human factors, affecting the environment.
  - Class hero:EnvironmentalDegradationHazard. A sub-type of hero:EnvironmentalHazard. Caused by a sudden or gradual degradation of an area due to environmental factors.
  - Class hero:ChemicalSpillHazard. A sub-type of hero:EnvironmentalHazard. Generally caused by a chemical spill that is not terrorist related. This may be a wilful or nonwilful causation.
- Class hero:Location is a class of the HERO ontology that can be used to specify hazard's location(s). Figure 1 shows the classes of the HERO ontology and their relationships.

#### 4.2 HERO Properties

Here, we describe the properties that can be used to further define HERO's classes.

- hero:hazardPriority. (domain hero:Hazard; range skos:Concept) This property takes a hero:Hazard type and a\_x a priority to that Hazard. This priority is a skos:Concept, whose domain reflects the organization's view of the world and its range is the value type (e.g. ordinal, interval, or ratio) ascribed to it by the organisation.
- hero:hazardLocation. (domain hero:Hazard; range hero:Location) This property specifies the location where the hero:Hazard starts.
- hero:startedAtDate. (domain hero:Hazard; range xsd:dateTime) This property specifies when the hero:Hazard is thought to have started.

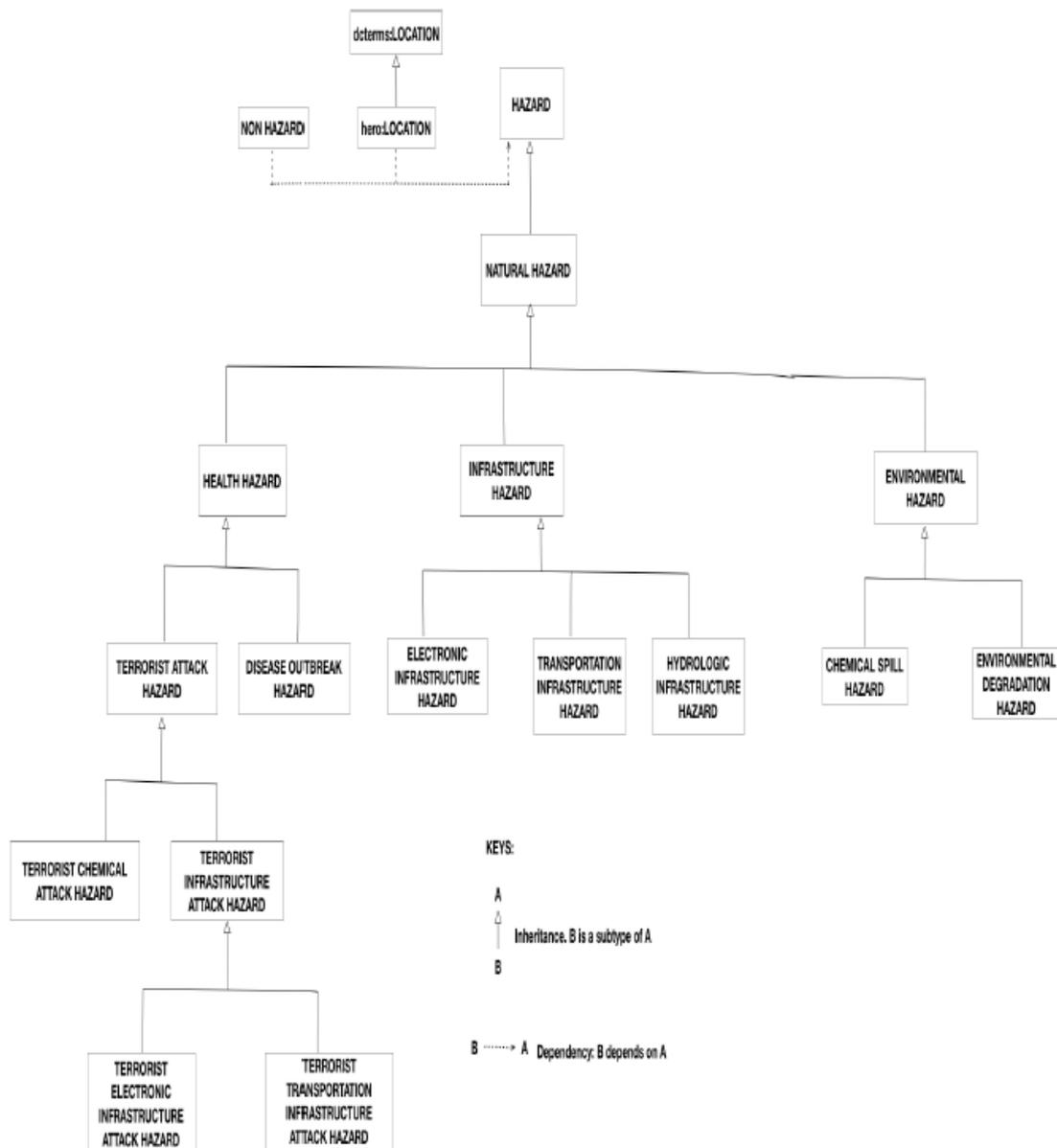


Figure 1: Class diagram for the HERO ontology

- **hero:startedBeforeDate.** (domain hero:Hazard ; range time:Interval) This property specifies the pre-incident date of this hero:Hazard. It returns a time:Interval, rather than a time:Point (as a hero:Hazard's exact start date may not be accurately known). This property allows a degree of approximation.
- **hero:reportedAtDate.** (domain hero:Hazard; range xsd:dateTime) This property specifies when the hero:Hazard is was reported. This may be different from hero:startedAtDate.
- **hero:startedAfterDate.** (domain hero:Hazard ; range time:Interval) This property specifies the date after which the hero:Hazard is thought to have started.
- **hero:causedBy.** (domain hero:Hazard ; range skos:Concept) This specifies possible causation of this hero:Hazard. This can be one reason or a list of reasons.
- **hero:recordedBy.** (domain hero:Hazard ; range prov:Agent) This specifies who records the details

of this hero:Hazard. This could be a human or a computational agent.

- hero:description. (domain hero:Hazard ; range xsd:string) This property is used to describe the hazard.
- hero:affectedAssets. (domain hero:Hazard; range prov:Agent) This property is used to specify what type of entities (human or non-human) are affected by the hazard. Figure 2 is a graphical illustration of the properties of the HERO ontology.

## 5. Raw Data to Actionable Knowledge

This section will explain the importance of stating information need in order to drive data discovery and harvesting.

### 5.1 Stating Information Need

For raw data to be turned to actionable knowledge, the information need requires to be either implicitly or explicitly stated. Once that is done, the next step is the discovery of the data(sets) that will be useful in fulfilling that information need. Data discovery will need to be followed by methods of harvesting the data that have been identified.

### 5.2 Data Discovery and Harvesting

Data discovery is the process of searching for the datasets needed to satisfy an information need. At the present moment, the process of data discovery is a manual process of engaging the usage of a search engine, scouring web sites, reading news items, etc. Once the required datasets have been discovered, then these need to be harvested. Data harvesting is the process of ingesting a particular dataset into one's data space. The datasets being harvested will be of different formats and structures, and different harvesting methods need to be employed on a case-by-case basis. The harvesting ranges from manual download to utilising REST APIs. It could also involve different degrees of web and document (pdf) scraping.

## 6. Modelling a Developing Hazard - Migration

This section describes how HERO was applied to model data regarding migration between borders.

### 6.1 Modelling Migration Data

The EU surrounding compared with countries, the EU has always been a magnet for migrants. Since the 1990s, the EU has consolidated freedom of movement for its citizens and increased restrictions on the entry of non-EU migrants. Therefore, many migrants come into the EU via the sea. In the central Mediterranean region, Libya is one of the main transit routes for migrants, and the instability that ensued after the Gaddafi regime was toppled has made the Libyan state weaker, increasing the frequency by which migrants get to the EU by sea. Most of the vehicles used for these journeys are not sea-worthy which have led to many hundreds dying. For example, Fortress Europe reported that from 1988 to March 2012, 13,417 had died making these crossings [4].

Many of these vehicles come under distress at sea during these journeys, and some of their occupants resort to phoning the nearest Maritime Rescue Co-ordination Centre (MRCC), and in some cases they may get sighted by other sea vehicles, such as a national state's Navy patrol vehicles, large fishing vessels, etc, and the staff on these vehicles can call MRCC to report the sighting of a sea vehicle distress at sea. MRCC then broadcasts distress messages to other vehicles in the area that may be able to rescue the passengers of the distressed vehicle. These broadcast distress messages are called hydrolant messages. Hydrolant messages are navigational broadcast warnings promulgated by the Worldwide Navigational Warnings Service (WWNWS) to provide rapid dissemination of information critical to navigation and the safety of life at sea. Navigational Warnings are issued regularly and contain information about persons in distress, or objects and events that pose an immediate hazard to navigation [6]. These messages, used by search and rescue (SAR) teams as guides to locate and rescue the vehicle under distress, are mostly free-form texts to state the where and the what of the incident. These search and rescue efforts are mainly multi-party and multinational, having disparate systems. These free form texts are good for humans, but the systems involved in the process find them difficult to understand and parse. These hydrolant messages (an example hydrolant message is shown in Table 1) can be classified as being derived from human observations and logistical information, as enumerated in section 2.2.

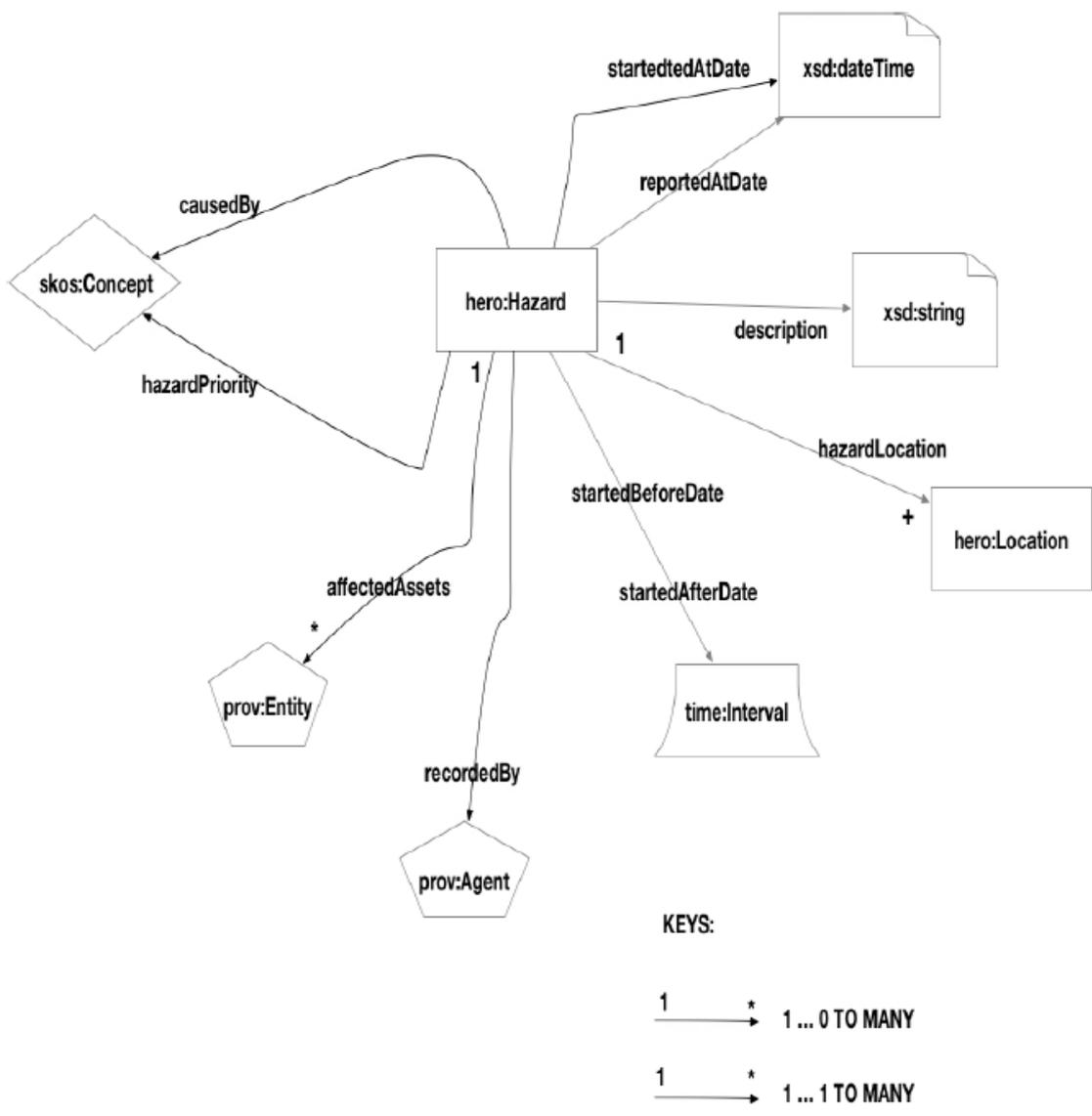


Figure 2: Properties of the HERO ontology

Table 1: DNC 08, DNC 09 Hydrolant Example

EASTERN MEDITERRANEAN SEA.  
 LIBYA.  
 DNC 08, DNC 09.  
 VESSEL, 130 PERSONS ON BOARD, REQUESTING  
 ASSISTANCE IN 33-19N 012-39E AT 160330Z JUN.  
 VESSELS IN VICINITY REQUESTED TO KEEP  
 A SHARP LOOKOUT, ASSIST IF POSSIBLE.  
 REPORTS TO MRCC ROME, INMARSAT-C:  
 424744220,  
 PHONE: 3906 5908 4527, 3906 5908 4409,  
 FAX: 390 6592 2737, 3906 5908 4793,  
 E-MAIL: ITMRCC@MIT.GOV.IT.  
 (160330Z JUN 2016)

### 6.2 HERO Ontology Applied to Modelling Navigational Hazard Messages

In this section, we will describe how we have used the HERO ontology to model hydrolant messages. We have used the Resource Description Framework (RDF) as the normal form for representing these messages. RDF offers many advantages, such as provision of an extensible schema, self-describing data, de-referenceable URIs, and, as RDF links are typed, safe merging (linking) of different datasets. We chose the RDF/Turtle representation of RDF triples for its compactness and clarity. We used Stanford's Parts-of-Speech (POS) tagger [8] to parse the texts in Table 1 to recognise the entities and their types. The POS tagger was able to recognise the following entities:

- "EASTERN MEDITERRANEAN SEA" as a location
- "LIBYA" as a location and a country
- The number value "130", and the entity type "PERSONS"
- Other location types, "33-19N" and "012-39E" as geographical entities
- "160330Z JUN 2016" as a UTC datetime format. (This date is read as 16 JUN 2016 at 03:30 UTC. The latter is not part of the POS tagger, but part of the hydrolant message type as provided by [6]).

Other recognised entities include 'MRCC Rome', the Inmarsat, phone and fax numbers, as well as the email address.

The HERO ontology helped guide us to generate the RDF data for the hydrolant message of Table 1.

Table 2: DNC 08, DNC 09 Hydrolant description in RDF

```

:dnc08-dnc09 a hero:NaturalHazard,
hero:HealthHazard,
hero:NavigationHazard;
hero:hazardLocation
:dnc08-dnc09Location;
hero:priority :dnc08-dnc09Priority;
hero:reportedAt
"2016-06-16T03:30:00"^^xsd:dateTime;
hero:recordedBy :dnc08-dnc09Recorder;
hero:affectedAssets
:dnc08-dnc09AffectedEntity;
hero:description
"VESSELS IN VICINITY REQUESTED
TO KEEP SHARP LOOKOUT,
ASSIST IF POSSIBLE.
REPORTS TO MRCC ROME,
INMARSAT-C: 424744220,
PHONE: 3906 5908 4527, 3906 5908 4409,
FAX: 390 6592 2737, 3906 5908 4793,
E-MAIL: ITMRCC@MIT.GOV.IT."
:dnc08-dnc09Location a hero:Location;
dbpedia:place dnc08-dnc09Place;
juso:country dbpedia:Libya;
foaf:based near geo:lat="33-22N",
foaf:based near geo:long="013-23E".
:dnc08-dnc09Place a dbpedia:Place;
rdfs:label "EASTERN MEDITERRANEAN SEA".
:dnc08-dnc0Priority a skos:Concept;
skos:notation "9"^^xsd:integer.
:dnc08-dnc09AffectedEntity a prov:Entity;
prov:hadPrimarySource foaf:Person;
prov:value "120"^^xsd:integer.
:dnc08-dnc09Recorder a prov:Agent;
foaf:name "MRCC Rome";
foaf:mbox "ITMRCC@MIT.GOV.IT";
foaf:phone tel:390659084527,
tel:390659084409, tel:870-424744220,
fax:39065922737, fax:390659084793.
    
```

Table 3: Two location sighting DNC 09 Hydrolant Example

```

EASTERN MEDITERRANEAN SEA.
SOUTHERN IONIAN SEA.
DNC 09.
70 METER VESSEL, ORANGE HULL, 860 PERSONS
ON BOARD, REQUESTING ASSISTANCE IN 36-37N
017-09E. VESSELS IN VICINITY REQUESTED
TO KEEP A SHARP LOOKOUT, ASSIST IF POSSIBLE.
REPORTS TO MRCC ROME, INMARSAT-C:
424744220,
PHONE: 3906 5908 4527,
3906 5908 4409, FAX: 390 6592 2737,
3906 5908 4793,
E-MAIL: ITMRCC@MIT.GOV.IT.
(201422Z DEC 2014)
    
```

Table 4: Two location sighting DNC 09 Hydrolant description in RDF

```

:dnc09 a hero:NaturalHazard,
hero:HealthHazard,
hero:NavigationHazard;
hero:hazardLocation :dnc09Location;
hero:priority :dnc09Priority;
hero:reportedAt
"2014-12-20T14:22:00"^^xsd:dateTime;
hero:recordedBy :dnc09Recorder;
hero:affectedAssets :dnc09AffectedEntity;
hero:description
"70 METER VESSEL, ORANGE HULL, 860
PERSONS
ON BOARD, REQUESTING ASSISTANCE IN 36-37N
017-09E. VESSELS IN VICINITY REQUESTED
TO KEEP A SHARP LOOKOUT, ASSIST IF
POSSIBLE.
REPORTS TO MRCC ROME,
INMARSAT-C: 424744220,
PHONE: 3906 5908 4527, 3906 5908 4409,
FAX: 390 6592 2737, 3906 5908 4793,
E-MAIL: ITMRCC@MIT.GOV.IT."
:dnc09Location a hero:Location;
foaf:based near geo:lat="36-37N",
foaf:based near geo:long="017-09E";
dbpedia:place dnc09-1-Place;
dbpedia:place dnc09-2-Place.
:dnc09-1-Place a dbpedia:Place;
rdfs:label "EASTERN MEDITERRANEAN SEA".
foaf:based near geo:lat="34-33N",
foaf:based near geo:long="18-02E".
:dnc09-2-Place a dbpedia:Place;
rdfs:label "SOUTHERN IONIAN SEA".
foaf:based near geo:lat="36-33N",
foaf:based near geo:long="21-07E".
:dnc08-dnc0Priority a skos:Concept;
skos:notation "8"^^xsd:integer.
:dnc09AffectedEntity a prov:Entity;
prov:hadPrimarySource foaf:Person;
prov:value "860"^^xsd:integer.
:dnc08-dnc09Recorder a prov:Agent;
foaf:name "MRCC Rome";
foaf:mbox "ITMRCC@MIT.GOV.IT";
foaf:phone tel:390659084527,
tel:390659084409, tel:870-424744220,
fax:39065922737, fax:390659084793.
    
```

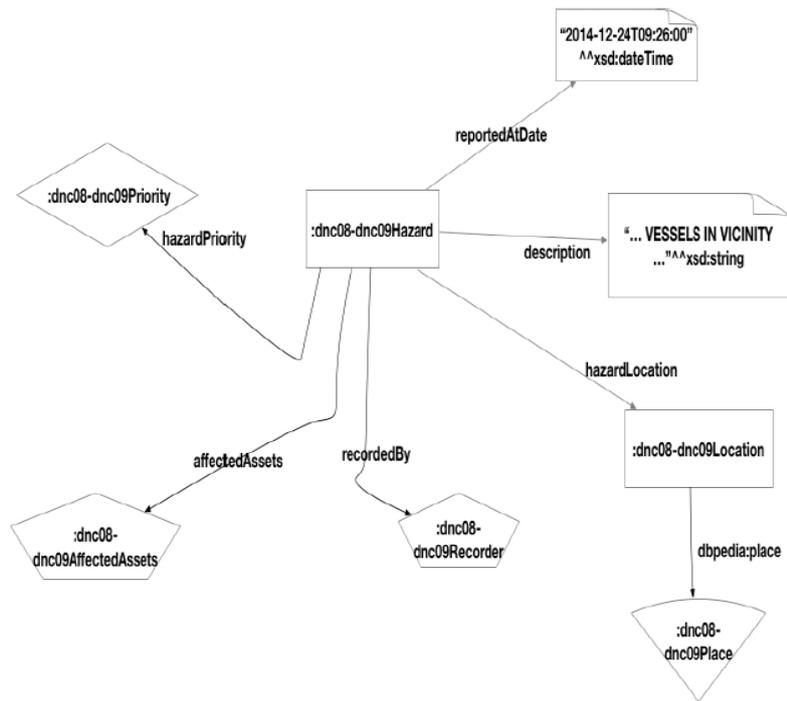


Figure 3: Resources for fulfilling the: dnc08-dnc:09 hydrolant message



Figure 4: Resources for fulfilling the Two location sighting DNC 09 Hydrolant message

The generated RDF data is shown in Table 2. Figure 3 shows, graphically, the classes and properties (i.e. the resources) involved in the RDF data of Table 2. Another example hydrolant message is shown in Table 3. Using POS tagger helped to discern the entities in this message, enabling us to generate its RDF data (see Table 4), and Figure 4 shows a graphical illustration of resources involved.

## 7. Lessons Learnt

In section 2.1, we enumerated some of the challenges that need to be addressed for effective process and data fusion. Some of these challenges include:

- Enhancing the comprehension, visualisation and trust of the data
- The data, itself, should support interoperable and priority-sensitive features
- Lack of semantics in the data must be addressed

HERO ontology, and the generated RDF data from this ontology, has helped to solve some of these challenges:

1. Priority is regarded as a first-class type and, thereby, effectively modelled as a `skos:Concept`. By using a `skos:Concept`, it allows the priority property of a Hazard class to be inter-operable. A different organisation making use of the generated RDF data in Tables 2 and 4 can extend the priority, as modelled, to reflect their organisation's view of the incident's or hazard's priority
2. Having modelled these data as RDF, it provided a common vocabulary, or semantics, that can be used to improve situational awareness
3. By providing a common data semantics, applications can then be built to make use of these semantics that will enhance the dataset's trust, visualisation and comprehension.

## 8. Conclusion and Future Work

This paper has described an ontology, HERO, used to represent hazards and emergencies. The aftereffects of emergencies are normally handled by multiple agencies with disparate systems. Having a common vocabulary to describe an emerging or existing emergency will allow these systems to easily interoperate, leading to more effective operations of

first responders. HERO can be used to perform these roles.

In future work, we will investigate how data semantics and ontologies can be used to support the development of autonomous systems, by characterising autonomous systems' changing operational environments and using the languages of the Semantic Web to model and represent these environments.

## 9. References

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