Designing formal semantics of geo-information for disaster response

PhD Research Proposal

Amin Mobasheri, MSc.

GISt Report No. 60

GIS TECHNOLOGY

Delft University of Technology

Challenge the future

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Summary

Over the past decades, people have suffered small and large-scale natural and man-made disasters. Recently, the earthquake and tsunami happened in Japan (March, 2011) and the series of floods occurred in Queensland, Australia (beginning from December, 2010) limelighted the issue of disaster management much more than before. Nowadays, almost all countries or unions put their most effort and attention for improving Disaster Management. Disaster response; as one of the important phases in Disaster Management, involves specific sectors and actors with different roles and responsibilities for responding to disasters. Actors have to perform specific pre-defined tasks such as evacuation, firefighting, etc. which all require access and use of up-to-date geo-information. Current systems for search and access of geo-information used in disaster response are restricted to keyword-based search, and do not take into consideration the semantics of geo-information. The result would be that for a given task, users should search the most important terms as keywords and would be faced with many results (e.g. geo-datasets, maps). From those results what would be relevant for his/her tasks? The problem is even worse in time critical situations when users should focus on their tasks and do not have enough time to search and integrate relevant (geo) information in order to create maps suitable for their tasks.

This research proposes to employ Semantic Web technology in order to make computer systems *smarter*, which means they would be able to understand the concepts behind geo- information. Therefore, formal semantics of geo-information would be designed and used to design a web service called *ASSIST* (Access, Semantic Search and Integration Service and Translation). ASSIST employs ontologies and by performing search, translation and integration of geo-information, creates maps relevant for different tasks of users involved in disaster response. Finally, it is planned to test and evaluate ASSIST with creating real scenarios to show the benefits that sematic web technology brings compared to current state-of-the-art solutions.

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1 Introduction

This section provides brief background information regarding the proposed research topic (section 1.1), and tries to highlight the problems involved in current systems used in disaster response, with providing two sample scenarios in section 1.2. In section 1.3 we elaborate the problems that exist with current software's/solutions available for disaster response, and in the next section (1.4) provide our understanding of possible solution for solving the mentioned problems. At the end, in section 1.5, an overview for the next sections of the plan is provided. In order to avoid misunderstanding on some important terms in this document, a glossary of terms is provided (see: ANNEX A).

1.1 Background and motivation

Over the past decades, people have suffered small and large-scale natural and man-made disasters. International disasters have claimed 3 million lives and have adversely affected 800 million over the past 20 years [24]. Recently, the earthquake and tsunami happened in Japan (March, 2011) and the series of floods occurred in Queensland, Australia (beginning from December, 2010) limelighted the issue of disaster management much more than before. Nowadays, almost all countries or unions put their most effort and attention for improving emergency management (e.g. EU-MEDIN [37]).

Emergency Management also known as disaster management is defined as the formation and management of resources and responsibilities for dealing all kind of emergencies. Specifically, it includes four main stages named *mitigation*, *preparedness*, *response*, and *recovery* [57]. In other words, disaster management is the combination of plans, structures, and arrangements between responsible organizations (government, voluntary, and private agencies) in a way to support effective response to all kind of emergency needs. The importance of all four phases of emergency management is well known. For improving the efficiency and functionality of each phase more research and efforts should be carried out. The aim of this research is to improve the quality of emergency management in response phase. For this mean, the rest of the document will continue to focus on the processes, tasks, and properties involved in emergency response phase.

Emergency *response* is defined as "the provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. It can be of an immediate, short-term, or protracted duration" [57]. The same definition of Emergency Response (ER) is understood in this research with slight modification. It is believed that in addition to people, animals and goods could also affect from disasters and therefore should be taken care of in Emergency Response. The response phase starts whenever the disaster has already happened. The organizations involved in emergency management search and plan to manage the disaster. Municipality, Police, Fire Bridge, and Medical Service are the main actors of emergency management in the Netherlands (see: APPENDIX B). Each actor/decision-maker is responsible for a number of tasks which should be handled individually and/or by team-work. For handling such tasks, the decision makers need to be fed by sufficient, relevant and up-to-date datasets. Some of these datasets are static. While apart from decision-makers need for static data, based on the dynamic nature of response phase and the changing environment, they also need to be updated on the last situation of emergency. This is carried out with providing dynamic data to them. These dynamic data carry the last information available about the situation of the disaster and changes in the environment. Most of the required datasets for disaster management have spatial component [28]. In other words decision makers of disaster response often deal with spatial datasets. Examples of static spatial datasets used for disaster response could be topographic dataset, road network dataset, hospital and buildings datasets. While damaged buildings dataset, location of victims, and location of emergency workers are examples of dynamic spatial data which are necessary for operations such as search, relief, rescue, medical service, shelter, and repair. The larger the happened disaster, the higher number and larger volume of spatial datasets would be required for planning and management of it. Disaster response is also time-sensitive with little allowance on delay in decision-making and response operations. Therefore any delay or problem in data search, integration and usage has negative impacts on the quality of decision-making and hence decreases the quality of disaster response.

Obviously, one of the initial main jobs in disaster response is to search for relevant up-to-date data in the shortest time possible. For search and retrieval of relevant data, it is important to know the purpose and application of which that data is going to be used for. Therefore, two sample scenarios are presented in the next section in order to show the requirements for geo-information discovery and integration in disaster response.

1.2 Sample scenarios

For the purpose of this research, two disaster scenarios with differences in their scales and occurrence probability will be defined. The first scenario is a large-scale scenario that does not happen very often, but in case of occurrence it has severe effects and damages making the response to such disaster much more complicated. Many countries including the Netherlands have drawn the same lesson from Katrina, that contingency plans should include preparation for low-probability incidents with high-consequences [[26],[59]]. Therefore, flooding is selected as the first case scenario in this research study. For the Dutch situation, it is considered that flood scenarios need to be defined under more extreme conditions than flood defenses (embankments, dunes, dikes, etc.) can stand [108]. Apart from large-scale disasters, in real life, small-scale disasters such as incidents in roads, water ways, etc. happen more often and have their own effect and damages which might be less than large-scale disasters, but still have to be responded in an appropriate manner. For such cases, in this research study the second case scenario is defined as a cargo ship accident carrying dangerous goods in water ways which creates an explosion and affects both the waterways neighborhood and the urban area nearby (e.g. moving toxic cloud). This section continues with building two case scenarios, and in section 1.3 the problems involved in (geo) information collection and preparation for disaster response are mentioned.

1.2.1 Scenario 1: Flooding by a storm surge on the North Sea

In 2004, the RIVM [79] showed that the threat of flooding is one of the largest risks in the Netherlands where about two thirds of the country is prone to flooding from the sea, lakes, or the rivers Rhine and Meuse [108]. The need for further preparation was addressed by the government [[77],[78]]. Together with what has been learned from the experiences of Hurricane Katrina in New Orleans, it is of significant importance to improve the preparation for and ability of responding to severe floods.

This case scenario adopts the concept of worst credible flood scenarios defined by ten Brinke et al [108], and the need for worst case is addressed by Clark [25]. Worst cases are used to find out what could happen under very extreme conditions. In the past decades, the Netherlands has focused primarily on flood prevention. Nowadays, the country has a flood defense system with the highest safety standards in the world [108]. The flood defense system would highly decrease the chances of flooding, but despite the safety level, absolute safety cannot be guaranteed. In case the flood occurs, the consequences in terms of casualties and damage would be significant. Based on differences in characteristics, the flood-prone area of the Netherlands is divided into six regions [108]:

- The southwest region with a large number of islands
- The central connected coast
- The northern region with the Wadden Sea coast and its islands
- The IJsselmeer lake district
- The upper river courses of Rhine and Meuse
- The lower (tidal) courses of Rhine and Meuse

Based on the total amount of estimated flooded area, 1) the southwest and central coast, and 2) the Wadden Sea coast are predicted as the most extreme flood-prone regions where a total area of 4340 km^2, and 4560 km^2 would be drowned, respectively [108]. In addition, research study shows that weather systems that might happen on the North Sea cannot result in extreme conditions along the entire coast at the same time, and because of this a flood of the entire coastal zone is unlikely to happen [108]. Two main coastal flood scenarios that might happen are: (1) a storm surge in the Straits of Dover which affects southwest region and the central coast, and (2) a storm surge to the north that affects the Wadden Sea coast. For the case scenario of this research, the flooding caused by storm surge on the North Sea which affects southwest region and the central coast is chosen since based on current research study is known as the worst credible flood scenario for the Netherlands. For such a case due to highest population density, a possible amount of 2,269,000 victims, 10,300 casualties, and a damage cost of 121 billion euros is predicted [108].

Historic data shows dozens of storm disasters on the North Sea starting from year 838 until 2007 which those leading to flooding in the Netherlands include (and are not limited to) [123]:

- 1064, February 16, *Saint Juliana flood*, several thousands of deaths
- 1170, November 1, *All Saints' Flood*, unknown number of deaths
- 1219, January 16, *Saint Marcellus flood*, 36,000 deaths
- 1287, December 13, *Saint Lucia flood*, 50,000 - 80,000 deaths
- 1362, January 16, *Grote Mandrenke* (big drowner of men) or *Saint Marcellus flood*, happened in Netherlands, Belgium, Germany and Denmark, 25,000 to 40,000 deaths, according to some sources 100,000 deaths
- 1421, November 19, *second Saint Elisabeth flood*, Netherlands, storm tide in combination with extreme high water in rivers due to heavy rains, 10,000 to 100,000 deaths
- 1477, *first Cosmas- and Damianus flood*, Netherlands and Germany, many thousands of deaths
- 1530, November 5, *St. Felix's Flood*, Netherlands and Belgium, many towns disappear, more than 100,000 deaths
- 1570, November 1, *All Saints flood*, Netherlands and Belgium, more than 20,000 deaths
- 1686, November 12, *Saint Martin flood*, Netherlands, 1586 deaths
- 1717, December 24, *Christmas flood 1717*, Netherlands, Germany and Scandinavia, more than 14,000 deaths
- 1953, January 31/1, *North Sea flood of 1953*, most severe in the Netherlands, 2533 deaths
- 2007, November 8/9, *North Sea flood of 200*, unknown number of deaths

It could be concluded that approximately every 70 years an extreme flooding caused by storm surges from North Sea has happened.

A storm surge is an offshore rise of water associated with a low pressure weather system, typically tropical cyclones and strong extra-tropical cyclones. Storm surges are caused primarily by high winds pushing on the ocean's surface. The wind causes the water to pile up higher than the ordinary sea level [125]. The Netherlands has installed storm surge barriers and dikes (also known as levee): an elongated artificially constructed fill or wall, which regulates water levels. It is usually built along low-lying coastlines in order to prevent the water flooding into land in case of storm surge disasters. These dikes are mainly built of cement, concrete, stone, sand and clay or a mixture of them. Dikes can fail in a number of ways. The most dangerous and frequent case that might happen is dike breach where a part of the dike breaks or is eroded away opening a large amount of water to flood. In other cases, water can overtop the crest of the dike. This will cause flooding on the floodplains, but because it does not damage the dike has fewer consequences for future flooding.

In this section we try to build a real scenario to show the importance of the research problem. Please keep in mind that we are considering only one possible scenario out of hundreds of disaster events and dozens of flooding causes which might occur in real life. Due to certain meteorological condition (low pressure weather system, etc.) in straits of Dover along with strong northerly winds in and to the north of the North Sea, the storm surge level has the potential to become about 70 cm higher than the dikes, causing water overtops and flooding. To make matters worse, floods can weaken dikes and cause them to breach in relatively weak spots, releasing billions of gallons of water into already flooded areas of southwest and central coast of the Netherlands. In a worst case scenario the estimated total flooded area (residential, agriculture, polder, etc.) of southwest and central coast is approximately 4340 km^2[108]. Flash flooding from dike breaches happens so quickly that the only response may be immediate evacuation.

For managing the evacuation task, the decision-makers need to prepare a map of flooded area, integrated with on-the-fly (dynamic) data collected in the field such as wind speed, wind direction, etc.

For preparing such a map, several different types of information (spatial/non-spatial) are necessary. Note that the number and type of needed (geo) information is directly related to the role and responsibility of the user who needs the data. Later we will discuss how different people (e.g. on the operation field, decision-makers, etc.) need different information in means of volume, type and scale. But here in the initial scenario we consider the information necessary for a special case. For example the spatial datasets necessary for creating the flooded area map are (and not limited to):

- The location and of the source(s) of the disaster (flood) (dynamic data)
- The speed, and direction of water flow in different buffer zones (dynamic data)
- Information collected via sensors (e.g. water gauges)
- Wind speed and direction in different buffer zones (dynamic data) for simulating and understanding the behavior of flood
- Reference datasets and aerial/satellite imageries (Land cover and land use) (static)
- Road network dataset (dynamic; this dataset should be the updated version, because of the damage which flooding could bring to road networks and also because of traffic jams)
- Number and location of casualties/victims in different zones (dynamic)
- Digital Elevation Model (static)
- Evacuation sites (dynamic)
- Evacuation Plans

The before-mentioned information is necessary for helping disaster response actors to make decision about the evacuation and also rescue affected people. In addition to them several other types of information are needed. For example for evacuation:

- Demographic information and distribution in different zones (static)
- Information regarding nearest operational airport(s) (dynamic)
- Map of possible sites for helicopter landing (dynamic)
- Map of utility networks (dynamic)

Also for task of rescuing injured people map of hospitals and health centers which can provide health care to affected people should be in hand. This dataset should be the updated version, because the hospitals and health centers also have the threat of being flooded away.

1.2.2 Scenario 2: Incident of cargo ships carrying hazardous materials

As a second scenario it is decided to build a scenario which happens more often in real life, and in case of occurrence it could have severe effects and damages but usually for a small location. In the Netherlands, 7700 km2 of the country area (approximately 18%) is water. This country also runs several ports (Port of Rotterdam, Port of Amsterdam, Port of Den Helder, etc.) which amongst all, port of Rotterdam is the largest port in Europe and one of the most busiest ports in the world. In year 2008, a total amount of 36,315 sea ships have arrived in this port [124], and in 2010, cargo throughput in the port of Rotterdam rose to 430 million tonnes [73]. Considering the high traffic of waterways there is always a chance of incident occurrence. Recent incidents in water ways such as Fowairet 2005, Westerschelde (Figure.1), and J-SAR 2006, Den Helder (Figure.2), has brought attention to water management boards about the importance of study on legislation water and the organization of incident management [103]. As a cascading effect of cargo ship accident carrying dangerous goods, an explosion happens which makes responding to disaster much more complex by creating a moving toxic cloud to the urban city nearby.

As an important phase of incident management, proper and quick response to incidents in waterways is crucial. In order to manage this task properly, incident responders on the operation field need to have a map which locates the happened incident along with relevant up-to-date information (static and dynamic). Depending on the type of incident, such a map may include several kind of (spatial) information such as:

- The exact location(s) of the incident(s)
- The speed, direction and depth of water
- Wind speed and direction
- Information about the materials carried by the ship(s)

- Information about people inside the ship(s), number of injuries, casualties, etc.
- Map of vulnerable and risky objects/area
- Reference datasets (land cover, land use)
- Information about locations of other ships around the location(s) of the incident(s) in different buffer zones
- The map of city neighborhood around the location of incident(s) in different buffer zones.

The definition of *vulnerable* and *risky* areas in this sample scenario is based on the degree of danger that disaster can cause to humans life. Therefore, some areas/objects such as other ships/boats and residential buildings are vulnerable since they accommodate people/goods, and some areas such as gas stations are risky areas since they can cause another disaster (e.g. explosion). One can note that the definitions of these terms could be quite different for other application and/or other people. Also, for task of rescuing injured people map of hospitals and health centers which can provide health care to affected people should be in hand.

Figure 1. Incident in water, Fowairet 2005, Westerschelde. [103]

Figure 2. Incident in water, J-SAR 2006, Den Helder. [103]

In addition, it is necessary to extract relevant information with respect to the context of the user. In the first scenario, a decision maker who plans for evacuating people from affected areas might need to have a small-scale map in hand, but if the user is in the field for operation he/she would need a more detailed large-scale map of the area. Hence, the relevancy of information is directly related to the role of the users as well as the tasks he/she should perform. For the case of evacuation, a user who is in operation field would be interested in maps of buildings/zones (that should be evacuated), roads, and evacuation sites. On the other hand, in case of fire (for another disaster), a fireman would need the map layers of streets, trees, risky areas (e.g. gas stations), and hydrants. The same concept is relevant to the second scenario as well.

These two scenarios demonstrate only one step of actions which should be made in disaster response. Please keep in mind that number and volumes of information necessary for performing tasks in disaster response is more than these mentioned in the scenarios. Apart from the scales and occurrence probability of the disasters defined in these two scenarios, responding to the disaster in each scenario requires different sector/actors with different roles, which is also related to the GRIP level that the disaster is going to be managed (see: ANNEX C). Therefore, various geo-information would be required. Some of the geo-information might be overlapping in two scenarios (e.g. reference datasets, etc.) and some might be unique depending on the nature of disaster (e.g. dangerous materials carried by the ships in second scenario). Hence, the two scenarios have their own differences and the reason for defining these two scenarios is to show that the final solution provided in this research is generic and can be applied to different types and scales of disasters.

1.3 Problems of current systems

The main problem is that discovery and integration of information is done by humans. It is necessary to employ machines to help us automate (or semi-automate) the process of discovery and integration of information. The reason is that discovery and integration of information in disaster management is time-critical and at the same time it is impossible (or very difficult) for humans to do such when facing large amount of heterogeneous information and to produce relevant information for different purposes. The other problem is that available geo-information are produced for different purposes and provided in different formats.

Due to developments in Spatial Data Infrastructure (SDI), geo-portals and geo-services are the state of the art solution for dissemination of data. Since almost every task in emergency response activities require up-to-date data, and because most disaster responders should be available in the operational fields in order to perform their tasks use of geo web services would be the best choice for handling the process of search and access to up-to-date (geo) information. Web services are in reach at any-time, in any-place, and have the ability and possibility of being up-to-date. Since in disaster response all kind of geo-information could be useful, in the rest of the text "geo-information" refers to both geo-datasets and geo-information (information retrieved from geo-datasets). Also the remaining text refers to Spatial Information Infrastructure (SII) instead of Spatial Data Infrastructure (SDI).

However, web services have the potential to break down due to network malfunction especially in cases of disaster (or its aftermath). In such cases, the service would not be available to users of disaster response via Internet, and therefore other alternatives should be examined. Although this is an important aspect, but solutions for such problems are not addressed in this research.

Current efforts for geo-information search and integration have been restricted to key-word based matching in SII [98]. That is, the search engines use algorithms of syntax matching for information search. Geo-information are produced and disseminated by different data provider organizations. Each provider might have different understanding for definition of different terms related in spatial datasets. For instance, assume the decision-maker in both scenarios want to search for a map of health centers in a specific region. He/she will type and search the keywords "health centers" or "hospital" in the disaster management service and would be faced with large amount of results that are related to the keyword. Apparently, he/she needs to choose one (or several) that are (combined) to satisfy the need. But by considering the semantics of this information it becomes clear that (Figure 3):

- **Case #1:** The keyword "health center" in different geo-services (or datasets) means the same thing, but with different data format for storage (e.g., one with XML-Complex format and the other with Shapefile). (Same name with the same domain concept but with different data format, figure 3).
- **Case #2:** The keywords "health center" and "hospital" in different geo-services (or datasets) are referring to the same meaning (different names with the same domain concept and with the same data format, figure 3).
- **Case #3:** The keyword "hospital" in different geo-services (or datasets) is referring to different meanings: one refers to a place which provides simple health services while the other refers to a place which provides full health care and surgery services (same name with same data format but with different domain concept, figure 3).

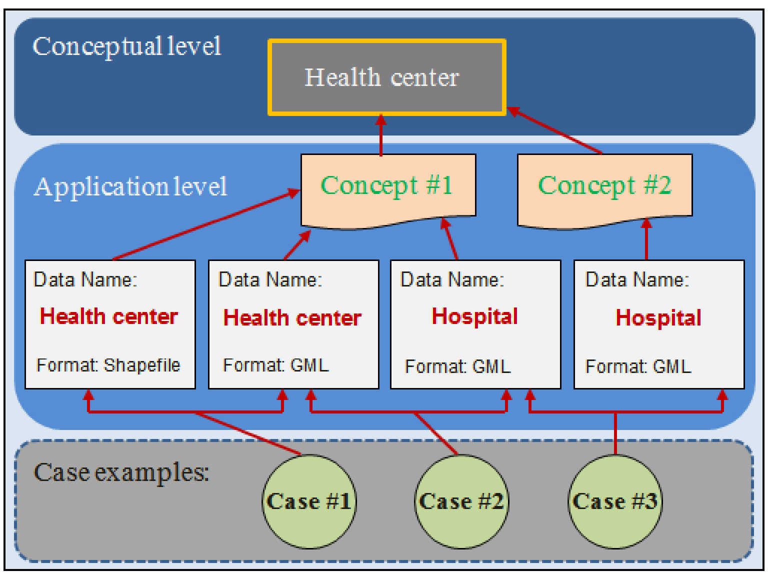

Figure 3: Semantic Interoperability issues for the terms "hospital" and "health centre"

The process of data selection and integration of these two datasets is difficult because the decision-maker does not realize about the definition and concepts behind the terms of "Hospital" and "Health Centre" as well as data formats. Note that this problem would be even more serious when dealing with terms related to geo-informatics domain for decision-makers who are not GIS specialists.

This example demonstrates only one step of actions (understanding the semantics behind information) which should be made in disaster response. Please keep in mind that number and volumes of (geo) information necessary for handling tasks in disaster response is far more than these mentioned in the scenario. Without ontologies (or explicitly formal semantics) of these data, humans need to spend a large amount of time on collecting, examining, and integrating large amount of data sets which leads to waste of time and un-reliable outputs. In cases of severe disasters, the job of preparing up-to-date suitable maps for various tasks of emergency response in a short time is almost impossible.

Due to the dynamic nature of events in disasters, the dynamic (geo) information changes very frequently and because the responders need to have the most recent up-to-date (geo) information it is very cumbersome for humans to collect and interpret the relevant information frequently (e.g. every 15 minutes), and integrate them for creating maps without making mistakes. Therefore, using machines for handling such tasks is expected to be much more promising and efficient since machines are perform operations faster and are unlikely to make mistakes like humans.

In order to give the machines the ability of performing the task of map creation for various tasks of disaster response, it is necessary to make them understand the concepts of geo-information just like geo-specialist humans do. In addition, they should also understand the different tasks, processes, actors, sectors, roles, and all concepts and organizational relationships involved in disaster response activities. For this purpose, Semantic Web technology seems the best candidate since it relies on a conceptual framework and provides various well-known standards/languages for assuring interoperability between geo-information and geo-services (see: ANNEX B) . Different tools exist for addressing semantic interoperability issues related to geo-services and spatial datasets. Nowadays, ontology is one of the main tools for this issue [41].

To conclude, there is a need of using machines for handling the search, access, translation and integration of geo-information in time critical situations. Based on the ability of Semantic Web in defining formal ontologies and improving interoperability, it is suggested to enable and apply semantic web technology for spatial data search and integration. By this, more efficiency and reliability for disaster response will be achieved.

1.4 Solution for improvement of current systems

Nowadays, the problem of computable semantic interoperability for integration of geo-information in open and distributed environments still exists [92]. Interoperability is the ability of different systems as well as organizations to work together. Interoperability is defined as “the ability of information and communication technology systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge” [135]. There exists European programs focusing on Interoperability solutions for eGovernment services and public administrations such as IDABC of European Commission [135] and ISA (Interoperability Solutions for European Public Administrations) programme [136]. The first programme provides guidelines to achieve interoperability with respect to various aspects such as technical, semantic, and organizational interoperability [135]. Later, On 31 December 2009, the new ISA programme replaced the activities of the 2004 IDABC programme and delivered a European Interoperability Framework (EIF) draft version 2.0 [136]. The EIF 2.0 adds a legal level and a political context to the interoperability levels, as originally defined by IDABC [135]. The main solution for semantic interoperability of integration of spatial datasets is to make the formal semantics of geo-information available [86]. By this, different users involved in disaster management (e.g. decision-makers) can exchange and integrate their spatial data, by means of semi-automated procedures, which is a really important job to handle in time-critical jobs. For solving semantic interoperability and allowing semi-automated geo-information search, integration and translation, the semantics of data should be defined explicitly and represented in a formal way. This is the reason why formal semantics is a chosen approach for this research problem. The research tries to address such problems and find the best solution for them and show the ability of formal semantics in search, access, translation and integration of geo-information. There have been some research and projects done in this subject area (see: ANNEX B), but crucial gaps still exists which should be solved (see: chapter 2).

Almost every task in emergency response activities require up-to-date data, and because most disaster responders should be available in the operational fields in order to perform their tasks use of geo web services would be the best choice for handling the process of search and access to up-to-date (geo) information. Web services are in reach at any-time, in any-place, and have the ability and possibility of being up-to-date.

Therefore, in this research, for means of access, search and integration of information sources a service would be designed. We name this service ASSIST (Access, Semantic Search and Integration Service and Translation). ASSIST employs the semantic web technology (ontologies) and arranges multiple web services within a service composition. Such a composition will be produced by a service composer whereas different datasets necessary for disaster response planning is presented as the output of the service. The process of information and service discovery is essential within this scenario. Before all required services can be composed, they have to be found. In today's information technology infrastructure, service registries like UDDI (Universal Description, Discovery and Integration) or OGC (Open Geospatial Consortium) Catalog Service can be used to discover appropriate services (see: ANNEX B). A service composer can search these yellow pages of the web by syntactic keywords.

1.5 Structure overview

The rest of the document is structured as follow: chapter two introduces the PhD research identification including research hypothesis, problem, objectives, questions, and innovations. The chapter ends with notification of topics outside the scope of PhD research. In chapter 3, the research phasing to be followed, as well as the time table for the coming years is proposed. The chapter continues with information regarding the communication plan for supervision, and it lasts with proposing a list of education courses required and deliverables of the research study.

In addition, Annex B provides an overview of related works and research studies in Semantic Web technology and Disaster Response are presented. First, in computer science and knowledge engineering domain, the semantic web technology, and its building blocks are reviewed and discussed. This section also provides necessary information regarding the tools and applications involved in the field of semantic web. In ANNEX C, overview of disaster response domain by means of relation to the research topic is provided.

2 PhD Research

The chapter starts with identifying the research topic. After presenting the hypothesis, details of the PhD research properties, such as research objectives, questions and targeted innovations are elaborated. Finally, the topics that are out of the research scope are mentioned.

2.1 Research identification

As it can be inferred from the research problem (see section 1.3), the research mainly deals with **semantic interoperability of geo-information and geo-services in means of search, access, integration, and translation of geo-information**. This research will focus on using ontologies for expressing formal semantics of geo-information, and applying them for the domain of disaster management in order to obtain the benefits.

Due to developments in Spatial Data Infrastructure (SDI), geo-portals and geo-services are the state of the art solution for dissemination of data. Since almost every task in emergency response activities require up-to-date data, and because most disaster responders should be available in the operational fields in order to perform their tasks, use of intelligent geo web services would be the best choice for handling the process of search and access to up-to-date geo-information. Web services are in reach at any-time, in any-place, and have the ability and possibility of being up-to-date.

Therefore, in this research, for means of access, search and integration of information sources a service would be designed. We name this service ASSIST (Access, Semantic Search and Integration Service and Translation). ASSIST employs the semantic web technology (ontologies) and arranges multiple web services within a service composition. Such a composition will be produced by a service composer whereas the different datasets necessary for disaster response planning are presented as the output of the service. The process of information and service discovery is essential within this scenario. Before all required services can be composed, they have to be found. In today's information technology infrastructure, service registries like UDDI (Universal Description, Discovery and Integration) or OGC (Open Geospatial Consortium) Catalog Service can be used to discover appropriate services (see: ANNEX B).

One of the final goals is to create on-the-fly maps (integration of information) directly related to the tasks and processes the disaster responders have to perform. Thus, ontologies would be used to make machines understand users' needs based on the tasks (e.g. type of geo-information, levels of detail, scale, etc.). Also, ontologies are employed to search for relevant geo-information and integrate them in an appropriate manner based on the concepts behind the tasks, in order to create the appropriate maps for disaster responders. In addition, ASSIST allows the users (e.g. decision makers) of disaster response to search for additional information in order to create customized maps for planning purposes. In this case, the ontologies are used to match the concepts of the searched item (e.g. a specific term) in SDI and find and use the most relevant available information.

Compared to traditional methods (syntax-based search), ASSIST can facilitate the process of search, access, integration, and translation of spatial datasets used for disaster response by employing ontologies.

2.2 Research objective and questions

The main objective of this research is to design formal semantics (e.g. ontologies) and apply them in order to make geo-information and geo-services interoperable for means of search, access, translation and integration of geo-information used in disaster response.

The main question of this research is "How Semantic Web technology (e.g. ontology) adds value compared to existing solutions for disaster response?". The following are sub-questions related to the main question:

- Who are the different actors involved in disaster response? What are their roles and responsibilities? And which data/information (type, level) do they need mostly?
- What are the different specification and characteristics of the current geo-information and geo-services used in disaster response? What standards are they based on? What standards are used for design, storage and access of geo-information?
- What tools are suitable for defining formal semantics of geo-information? Which tool(s) can be the best candidate?
- What is a suitable methodology for designing ontologies? (local, application, and data ontologies).
- How to match different ontologies? How to apply semantic indices and perform spatial and temporal reasoning on ontologies? How to extract meanings from objects attributes and relationships?
- How to integrate formal semantics in decision-making? How to query and process the ontologies? How are ontologies and corresponding data used together to provide solutions?
- How should we start building the formal semantics in a web-service? Which framework is suitable for implementation purpose? What are the difficulties and problems for making this web service operational as a semantic SDI node?
- Compared to existing "classic" approaches, to what extent can the web service satisfy decision-makers needs for access, search and integration of geo-information? How does it improve the current systems used by disaster managers?

- What are the strengths and weaknesses in the designed formal semantics and the web service prototype? What can be the alternative solution for improving the weakness properties?
- How to manage to improve designed formal semantics and web service in order to cover the weaknesses?

2.3 Innovations aimed at

Since current systems used by decision-makers for geo-data search and discovery use syntax-based queries, employing ontologies as formal semantics of geo-information and processing context-based queries is the main innovation of this research. Following the issue, ontologies bring the possibility to translate and integrate geo-information in a context-aware procedure. The result would be that a web service (e.g. ASSIST) can handle sophisticated tasks (e.g. matching, reasoning, etc.) much more efficiently in means of time and cost, compared to a human user. These results also add to the innovation of the research study, since not much work has been done so far in this area. The other innovation of this research is the ability of ASSIST to create on-the-fly maps, necessary for the tasks and processes to be performed by different users considering users' role, levels of details, and scale of the map.

2.4 Topics beyond the PhD research

Due to the complexity of the proposed research problem, some areas of research are excluded from this research. For example one of the important factors involved in this research is the fact of working with different formats of information (datasets). Research study on different languages to encode data schema's into models are beyond this research. However, in this research the information modeled and implicitly/explicitly defined in data schema's (GML, XML schemas, and UML schemas) are considered as an important source of semantic knowledge. Due to semantic interoperability of geo-services, we specifically focus on GML geo-datasets, since they are the standard of geo-data storage used by the web services in the World Wide Web. Since the current version of GML encoding standard supports storage of 3D data, we consider both 2D and 3D data in our study. It is assumed that existing necessary geo-datasets are available and stored (whether in a federated or distributed data storage).

Geo-information integration can be referred by both attribute and geometric integration. It is admitted that both integration perspectives are important in disaster response, but based on the proposed research problem and research objectives only attribute integration of geo-information is considered and geometric integration is out of the scope. By this it is meant that ASSIST might use objects with different geometry from different data sources in order to create the map. What ASSIST would not do is the issue of addressing to problems related to positional accuracy. Thus, as the result of geo-information integration, in a possible case two or more objects might collapse in the final output map or not perfectly fit in one map. The issue of proper geometric integration is out of the scope of this research.

Finally, since ASSIST is a web service and needs network connections (e.g. Internet, LAN, etc.) in order to be used by end-users, it is prone to network malfunctions that might be caused by the possible disaster (or its aftermath). Although this is an important issue, but solutions for such problem would not be addressed in this research.

3 Project Setup

This chapter includes information about the different phases of the research (section 3.1), tools and datasets used (3.2) and the time schedule (section 3.3). In addition, section 3.4 covers the communication plan with supervisors and the involved organizations/companies. The education courses to be followed during the research study are mentioned in section 3.5. Finally, the chapter ends with providing information regarding the deliverables of the research as well as a list of journals and conferences related to the research topic (section 3.6).

3.1 Research phasing

This research is a technological and design-oriented research and is broken down into five phases (in totally four years). Each phase has its own research type/activity, goal, and duration of work. Hereby we elaborate the plan of works that have to be done in each phase. The tasks of first phase; as the first year of study, are explained more specifically, while the plans for the four other phases are provided more general. Figure 5, illustrates the overview of phases and the proposed time table of the work plan during the whole period of study.

3.1.1 Phase I: User requirement identification, and ontology design

- **Step 1:** The first year of the PhD study is concerned about gathering information about the requirements that users of disaster response have. This task is directly related with defining the domain and scope of the case study, reviewing the current systems for disaster response (e.g. Eagle), finding reference information (e.g. documentation of Eagle software), gathering information through collaboration with other students working in the disaster management domain, and finalizing and evaluating the results of user requirement identification.
- **Step 2:** The next task is to use the information collected in the previous step in order to design/reuse formal ontologies which could be divided into different categories based on the users roles and/or different application levels. Experiencing use of tools/software's/languages for ontology design is also another task for the first phase. Note that the degree of formality of the designed ontologies depend on their usage and the final decision of ontology type selection (see: ANNEX A) would be made later in Phase III, and IV.
- **Step 3:** The vocabularies and thesaurus would furthermore be used in order to design the ontologies (domain, application, and data ontologies). The task of ontology design itself includes different steps such as knowledge engineering methodology selection, ontology design, and ontology refinement.

A literature review sub-step for each previous-mentioned step is necessary, and the results are written as drafts that would be used for preparing research articles and for finalizing the PhD thesis.

3.1.2 Phase II: Semantic indexing and searching of geo-data ontologies

There are several steps that should be performed in order to prepare a service to perform semantic integration (see: ANNEX B, section B.6). These steps include: *semantic matching and translation*, *semantic indexing and classification*, and *semantic search and reasoning*. It is believed that semantic indexing and searching is the core task of this phase, hence this phase borrows its title from this specific task. In the first step, ontologies are to be used in order to perform semantic mapping (Figure 4). Second step is to create and apply semantic indices on populated ontologies in order prepare them for semantic search and reasoning in step 3 and 4. In order to remind, in this step ontologies are going to be used to create and apply semantic indexing mechanism of data repositories (indexing the triple sets), facilitating the process of semantic search (see: ANNEX A). To sum up, users can enter different "terms" to search for information and the ontology would be used to find relevant information by using the concept of the searched term.

3.1.3 Phase III: Semantic integration of geo-data ontologies

This phase mainly deals with using the ontologies, and the results gained from previous phase in order to perform context-aware integration of geo-datasets. The result of this phase contributes to the famous aim of providing *the right information in the right time*. This is done by translating the selected data (or objects) to a common standard schema facilitating the task of information integration and using it in order to create the output map.

3.1.4 Phase IV: Build and evaluation of ASSIST prototype web service

In the fourth phase, the web service prototype is going to be implemented based on the designed formal semantics (step 1). The aim is to run the web service as a semantic SDI-node on the World Wide Web for search, integration, and translation of geo-information in server/client mode. Also, in step 2 and 3 of this phase the test and validation of the automated web-service is to be performed. For this issue, several different kind of real spatial datasets would be available in the network, and by use of web-service, the user would try to search for specific datasets which are needed. A real scenario would be performed and different users would try to use ASSIST and compare the maps produced (data found) by the one prepared in existing solutions (e.g. Eagle). The strengths and weaknesses of the prototype compared to existing solutions are found and new approaches for improvement of formal semantics would be developed. Figure 4 depicts the system architecture of ASSIST and its main parts. It also shows different tasks (e.g. mapping and translation, indexing, etc.) in the *semantic execution* *environment* black box where ontologies are employed for performing the necessary tasks (see: ANNEX B section B.6).

Note that prototype evaluation is an important step in the prototyping process and one for which there is little knowledge. Users of a prototype require proper instructions prior to its use. It is important that the prototype becomes a learning medium for both the developer and the costumer and the later should have confidence that the time-consuming activities involved are actually converging to a stable set of requirements. Normally the evaluation process takes a number of cycles until this happens and requires timely feedback for productive learning.

3.1.5 Phase V: Explore and refinement of possible problems of ASSIST

In this phase, in the first step the aim is to find and apply solutions for possible problems encountered in phase IV. In the second step, we would redesign formal semantics in order to improve the weaknesses it has. This is done based on the test with real users (scenarios) that would be gained through design and implementation of formal semantics, as well as the results of previous phase. Finally, the results of how efficient the designed ontologies and the web service are (compared to existing software/services used by disaster managers) would be figured out and discussed.

3.2 Tools and Datasets used

The main ontology languages that are going to be used are Resource Description Framework (RDF) and its Schema (RDFS), Notation3 and Web Ontology Language (OWL) for means of ontology design, and Sematic Web Rule Language (SWRL) for defining rules and constraints, and SPARQL as the query language. In addition, Protégé is selected as the suitable software infrastructure for creation, manipulation and visualization of ontologies (via plugins such as OwlViz, IsaViz, etc.). OntoJava is chosen as the programming framework candidate for this research and Oracle 11g (semantic technology extension) as the best solution for storing both ontologies (knowledge and concept level) and data (instance level). For more information regarding these tools and languages and the reason they are selected please see ANNEX B. Finally, this research would use necessary geo-datasets for creating real scenarios based on our proposed scenarios for test and validation of the system, specifically focusing on geo-datasets in GML format.

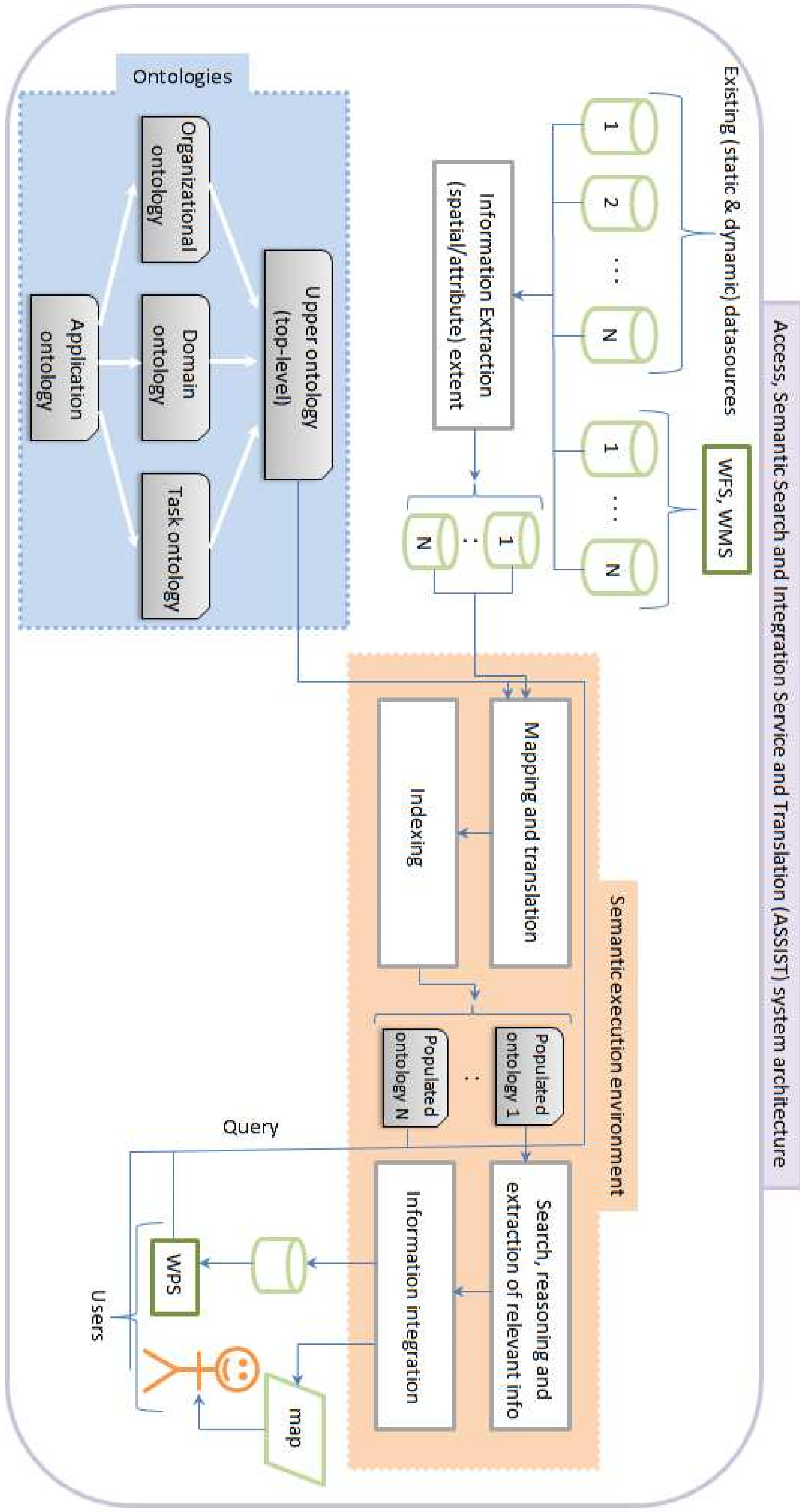

Figure 4. System Architecture of ASSIST

3.3 Plan of the project

This section tries to give a rough idea about the research activities carried out through the whole PhD research work (four years). The tasks mentioned in Figure 5 are exactly related to those mentioned in research phasing (section 3.1). It is important to mention that several minor tests would be performed to evaluate the performance and applicability of designed parts of system in phase II and III. Note that Dissertation writing (DW) takes place in every phase of research (based on chapters, which are earlier publications).

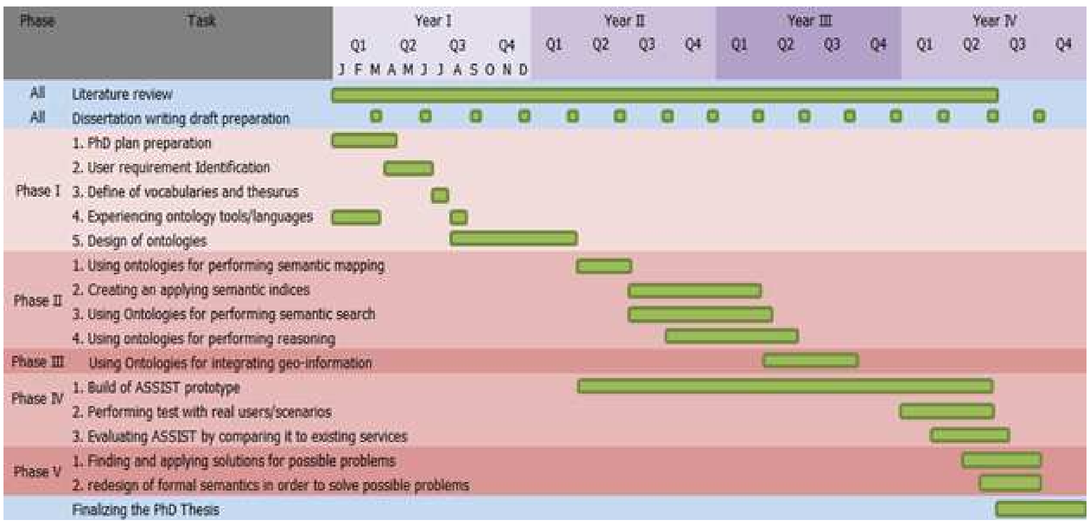

Figure 5. Timetable to illustrate the research schedule.

3.4 Communication plan

To communicate with my supervisors; Prof. Dr. Ir. Peter van Oosterom and Dr. Sisi Zlatanova, I intend to have 1~2 hours face-to-face meeting on Friday every two weeks, and the remaining supervision time will be used to read and comment on the documents that will be submitted (to supervisors) via email. However, the date and time of the face-to-face meeting can be changed depending on the timetable and availability of the supervisors. It should be mentioned that meeting with second supervisor (Dr. Sisi Zlatanova) might happen less often (e.g. once a month). Visit to partner universities, organizations and companies should also be planned in order to share ideas and improve the quality of both theoretical and technical research output, because it is believed that discussion with other colleagues in the related subject could greatly improve the quality of research and its application in real world. The involved organizations/companies include (and are not limited to):

- Rijkswaterstaat (website: http://www.rws.nl/)
  Rijkswaterstaat is part of The Ministry of Infrastructure and the Environment in the Netherlands. This organization is one of the main sectors/actors responsible for waterways, highways and train

infrastructure. In case of disasters (mentioned in scenario 1 and 2), RWS would be actively involved and responsible for responding to the disaster. The relation with this sector would be to exchange information and ideas about the current problems related to this research. Meetings with people in this organization would help in answering the research questions 1, 2, and 3, as well as getting further advice about the defined scenarios. Later, RWS can benefit from the results of this research in several ways. Most important one is that we would share our experience and gained knowledge and advise them for further possible research directions in this field of research, and they would have a smarter system compared to their classic solution.

- Geodan (website: http://www.geodan.nl/)
  Geodan is a private company specialized in Geo-IT solutions for both the private and public sectors. Geodan provides solutions for all problems related to geo-information and offers consultancy and project management, application development, and LBS products for different purposes. The main reason we collaborate with Geodan is because of its software called Eagle, which is the state-of-the-art net-centric application for disaster response in the Netherlands, and also one of the best in the world. Their contribution would be providing information about the problems involved in management of geo-information from technological point-of-view. In return, we can provide scientific advice to Geodan regarding employing semantics of geo-information for improving Eagle.

- StrateGis (website: http://www.strategis.nl/)
  StrateGis is an innovative start-up company. Their core business is speeding up urban development processes and making the results financial feasible and sustainable. As a TNO building and construction research spin-off company StrateGis has strong ties with international scientific research. The main reason we collaborate with StrateGIS is to share information and knowledge of semantic web technology and its usage in urban applications specifically disaster response.

- E-Semble (website: http://www.e-semble.com/)
  E-Semble is a private company which develops simulation software "*Serious Gaming*" for the education, training and assessment of incident response and safety professionals, such as police, fire and medical services.
  E-Semble's mission is to increase the knowledge and expertise of these professionals resulting in a decrease of the number of victims during disasters. The main reason we collaborate with E-Semble is to use their experience and relations with sectors involved in disaster response in case of understanding the disaster response system in the Netherlands. In return, in future, we would be happy to give them scientific and technical

advice regarding how they can improve their simulation software's by using semantic technology.

3.5 Planned education

An education agenda for PhD research is also made, which includes (but not limited to):

- Geo-informatics related courses offered by TU Delft, such as:
    - Geo-Database Management Systems (course code: GM1080)
    - Geo-information Infrastructure Technology (course code: GE4612)
    - Geo-informatics for disaster management (course code: GM1110)

- Computer science related courses offered by TU Delft, such as:
    - Web Data Management
    - Semantic Web Technology

- Generic and research skills courses offered by TU Delft, such as:
    - English for academic purposes (EAP3) (course code: WM1101TU)
    - Writing scientific English papers
    - Presentation skills
    - Writing PhD thesis

- Workshops and/or online courses offered by universities around the world related to the research topic, such as:
    - interdisciplinary summer school on ontological analysis (link: http://iaoa.org/isc2012/index.php)
    - Workshop conferences (see: section 3.6.1)

3.6 Deliverables (publications)

Besides this plan, which is the first published document of this PhD research, several deliverable publications are planned to be presented as the output of the research. The publications would be presented in conferences and peer-reviewed journals.

3.6.1 Conference publications

In order to document, present, and discuss the results of each phase of PhD research with other colleagues in related research field and to learn from others, there is a publication goal of submitting 1 or 2 papers per year to related conferences. Related conferences include (and are not limited to):

- **Gi4DM:** Geo-information for Disaster Management conference has existed since 2005 and is put together by various groups within the International Society for Photogrammetry and Remote Sensing (ISPRS). Gi4DM has gotten the attention of major researchers and organizations like the United Nations Office of Outer Space Affairs, the IGU and the Group on Earth Observations to use the latest state-of-the-art space-based geomatics technologies to understand the dynamic earth processes and geo-hazards (website: http://www.gi4dm.net/).
- **SeCoGIS:** The International workshop on Semantic and Conceptual Issues in GIS is the leading workshop in semantic web technology in Geographical Information Systems which is held annually. (website: http://cs.ulb.ac.be/conferences/secogis2012/)
- **ISCRAM:** An international community on Information Systems for Crisis Response And Management (website: http://www.iscram.org/).
- **AGILE:** AGILE is the Association of Geographic Information Laboratories for Europe. The association organizes AGILE conferences on GI-Science every year, where GI-professionals and educators meet and exchange ideas and experiences (website: http://www.agile-online.org/).
- **GISCIENCE:** An annually international conference on Geographic Information Science. The conference has a tradition of focusing on **basic research findings** across all sectors of the field. (website: http://www.giscience.org/)
- **SDH:** The International Symposium on Spatial Data Handling (SDH) is the biennial international research forum for Geospatial Information Science (GIScience), co-organized by the Commission on Geographic Information Science and the Commission on Modeling Geographical Systems of the International Geographical Union (IGU). The conference is held annually.
- **ISPRS:** International Society for Photogrammetry and Remote Sensing is "an international NGO devoted to the development of the international cooperation for the advancement of knowledge research, development and education in the Photogrammetry, Remote Sensing, Spatial Information Sciences and Crisis Management to contribute to the well-being of humanity and sustainability environment" (website: http://www.isprs.org/).
- **UDMS:** Urban Data Management Society organizes international symposia at various locations in Europe in order to promote the development of information systems in local government" (website: http://www.udms.net/).
- **FOIS:** The international conference on Formal Ontology in Information Systems is an outstanding annual conference in semantic technology and ontologies for different disciplines and applications (website: http://www.formalontology.org/).
- **ISWC:** The International Semantic Web Conference is the leading conference for research on Semantic Web topics. It is held annually and is

the successor of the Semantic Web Working Symposium (website: http://iswc.semanticweb.org/).

Note that the planned conferences are not limited to the above list, some other conferences related with geo-information, disaster management and semantic web might also be attended considering the relevance and time with respect to the PhD research.

3.6.2 Journal publications

In addition to conferences, there is a publication goal of 2-4 papers in peer-reviewed journals which might be (and are not limited to)**:**

- Computers, Environment and Urban Systems (website: http://www.elsevier.com/wps/find/journaldescription.cws_home/304/description#description)
- Computers and Geoscience (website: http://www.elsevier.com/wps/find/journaldescription.cws_home/398/description#description)
- Web Semantics: science, services and agents on the world wide web (website: http://www.elsevier.com/wps/find/journaldescription.cws_home/671322/description#description)
- Disaster Management and Response (website: http://www.sciencedirect.com/science/journal/15402487/5)
- Asian Journal of Environment and Disaster Management (website: http://rpsonline.com.sg/rpsweb/)
- GeoInformatica (website: http://www.springer.com/earth+sciences+and+geography/geographical+information+systems/journal/10707)
- Geo-spatial Information Science (website: http://www.springer.com/earth+sciences+and+geography/geographical+information+systems/journal/11806)
- Journal of Geographical Systems (website: http://www.springer.com/economics/regional+science/journal/10109)
- International Journal of Geographical Information Science (website: http://www.tandfonline.com/toc/tgis20/current)
- Journal of Information Technology (website: http://www.palgrave-journals.com/jit/index.html)
- International Journal of Information Technology and Decision Making (IJITDM) (website: http://www.worldscinet.com/ijitdm/)
- European Journal of Operational Research (EJOR) (website: http://www.journals.elsevier.com/european-journal-of-operational-research/)
- Transactions in GIS (website: http://www.blackwellpublishing.com/journal.asp?ref=1361-1682)

- International Journal of Spatial Data Infrastructures Research (IJSDIR) (website: http://ijsdir.jrc.ec.europa.eu/)

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ANNEX A: Glossary of terms

In order to avoid (probable) misunderstandings while reading the document, this section provides a list of important terms (in alphabetical order) and their definition and interpretation in this research. The terms of the glossary includes:

Decision-maker

Generally, decision-maker is anybody who is responsible for making decisions and plans for a specific task in a specific group/organization. In this research, decision-makers in organizations involved in disaster response are the people who plan for search and rescue and give orders to regional operational team members. Note that users in operational fields are not called decision-makers even if their work requires some level of decision-making.

Geo-information

In this research, geo-information refers to both spatial and/or non-spatial datasets and the information interpreted from them. However, for mentioning this term in the document, we usually put the term "geo" in brackets and write (geo) information.

GRIP levels

In the Netherlands, a disaster, depending on its spatial scale and nature is responded in 5 different levels called GRIP levels. Different actors with different roles and responsibilities will get involved in each GRIP level.

Level of details

In this research, level of details corresponds to both the scale of the map necessary for performing the tasks of disaster responders as well as the amount of information/attribute provided for a given object (not all information of an object is relevant for the end-user's task)

Ontology

"A logical theory which gives an explicit, partial account of a conceptualization" [51].

Semantic Web

"A web of data that can be processed directly and indirectly by machines" [12].

Spatial Information Infrastructure (SII)

In this research, since the term "information" also refers to "data", Spatial Information Infrastructure also refers to Spatial Data Infrastructure (SDI).

ANNEX B: The Semantic Web

One of the main study areas related to this research is semantic web technology in Computer Science and Knowledge Engineering. Therefore, this section provides a review of this technology, as well as the state-of-the-art in using relevant tools/software applications.

Tim Berners-Lee, the inventor of the World Wide Web (WWW), defines semantic web as “a web of data that can be processed directly and indirectly by machines” [12]. The purpose of the semantic web is improving the current web technology by enabling the users to find, share and combine information more easily. In the current web technology, humans are capable of using the web to perform various tasks such as finding the cheapest price of a second-hand book and ordering it online. However, since web pages are designed to be read by people (not machines), machines cannot accomplish such tasks without human direction. Therefore, the main aim of the semantic web technology is to provide structure to the meaningful content of web pages which leads to creation of an environment that web services can carry out sophisticated tasks for users [12].

Figure 6 illustrates the semantic web stack, which is a hierarchy of languages and technologies, where each layers exploits and uses capabilities of the layers below. It shows the organization of standardized technologies designed in order to create the semantic web.

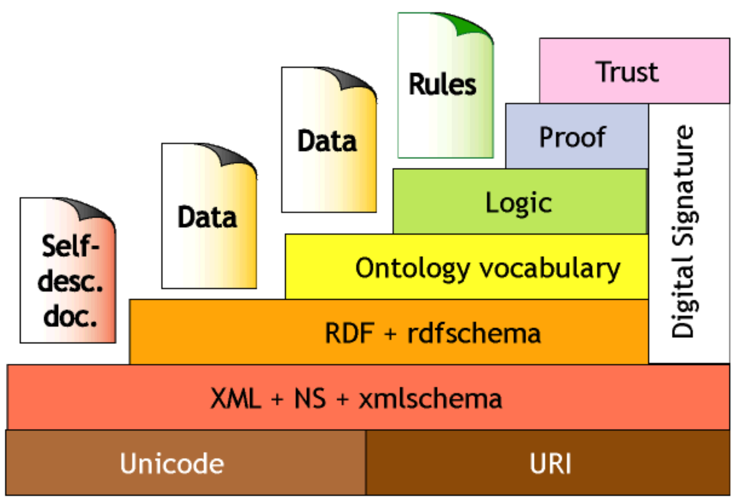

Figure 6. The semantic web stack. Adopted from [9]

Starting from the bottom layer, the Unicode[127] and URI[126] provide well-known hypertext web technology which can be used as the basis for semantic web. Unicode is for representing and manipulating texts in different languages expressed in most of the world’s writing systems. Basically, in the context of World Wide Web (WWW), Universal Resource Identifier (URI) is a string of characters which identifies a resource. In Semantic Web technology, the same standard is used to provides means for uniquely identifying semantic web resources. In the second layer of the stack, Extensible Markup Language (XML)[121] is used along with its Schema and Namespaces (NS)[128] in order to encode documents composed of structured data in the web, in a format that is both human-readable and machine-readable. The Namespaces could be seen as a set of identifiers providing a way to use markups from various sources. The rest of the layers on top, are related to the semantic web domain and will be presented in the next sections. As depicted in Figure 4, the vision foresees the employment of ontologies and formal descriptions for providing the necessary machine readable descriptions of contents and services.

B.1. What is an Ontology?

The term "ontology" comes from the greek words *οντος* ("being") and *λογος* ("theory", "science") [91]. In the domain of philosophy, ontology deals with actual existence of things, as well as with categorization and organization of them. In computer science domain, ontology is a formal model of a specific domain. Due to the fact that there can be more than one formal model of a specific domain, computer science deals with many ontologies, while in philosophy ontology is used as a singular word. One of the most cited definitions of ontology in computer science belongs to [48] which defines it as "an explicit specification of a conceptualization". Referring to the definition, it is stated that the specification is *explicit* meaning that it does not contain any hidden assumptions. Other researchers have extended this definition in several forms. One of which states that an ontology is "a logical theory which gives an explicit, partial account of a conceptualization" [51]. The later definition completes the former one by noting that ontologies are *formal* (have a logical theory), and *partial* (cannot fully capture a domain in every detail).

B.2. Types of Ontologies

There exist several types of ontologies, each of which developed for different purpose and applications. Various classification approaches for comparison of those ontologies. One of the most general (and also oldest) classifications is proposed by [56] who differentiate ontologies based on their amount of structure and their subject. Considering the amount of structure that ontologies have, three types are distinguished namely: *terminological ontologies*, *information ontologies*, and *knowledge modeling ontologies.* An ontology specifying a list of terms and their meanings in natural text is called *terminological ontology,* while *information ontology* specifies the structure of data, and *knowledge modeling ontology* refers to the conceptualization of knowledge (concepts reflecting knowledge). A more detailed classification of ontologies is provided by [67], illustrated in Figure 7.

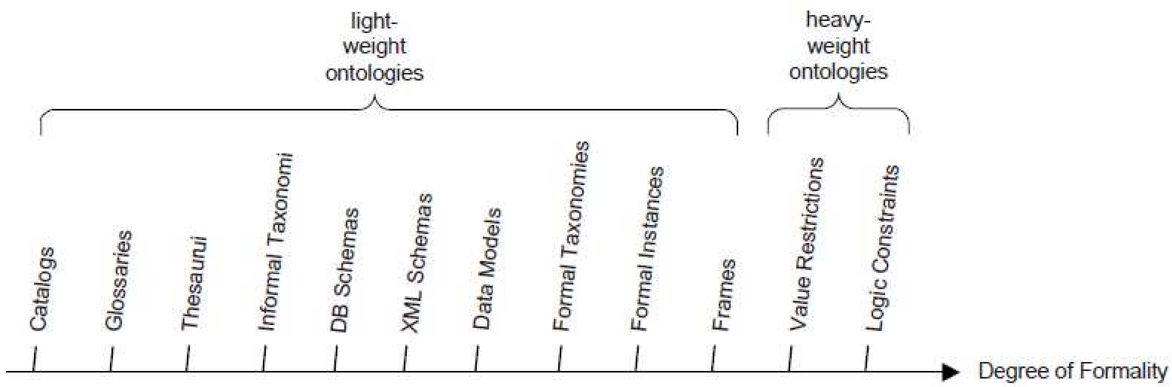

Figure 7: Ontology types based on their degree of formality. Adopted and modified from [[67],[91]].

Based on the degree of formality, different types of ontologies are reviewed and grouped into two different categories: *light-weight ontologies*, and *heavy-weight ontologies.* Obviously the term "weight" strongly refers to the degree of formality. Ontology types which are "weakly" formal include [91]:

- Catalogs: Collection of terms without any further descriptions
- Glossaries: catalogs enriched with description for the terms
- Thesauri: glossaries enriched with additional relations between terms
- Informal taxonomies: glossaries where terms are arranged in a hierarchy
- DB Schemas, XML Schemas, Data Models: schema models carrying large amounts of concepts and relationships in a standard language/notation (e.g. UML class diagrams as one of the most common and accepted approach to modeling)
- Formal taxonomies: glossaries where terms are arranged in a formal hierarchy (have stricter sense by defining constraints)
- Formal instances: formal taxonomies enriched (populated) with instances (also referred to as *populated ontologies*).
- Frames: ontologies used to define relationships between concepts

On the other hand, "strongly" formal ontology types include [91]:

- Value restrictions: frames imposed with additional domain and range constraints
- Logic constraints: frames imposed with constraints that go beyond domain and range definitions

One might note that database schemas, XML schemas and data models also carry a lot of semantics and therefore should somehow be classified as formal ontology. Therefore [91] classifies them as light-weight ontologies somewhere between informal and formal taxonomies, as they contain formal definitions to some extent (e.g. type definitions, etc.), but at the same time lack rules in a formal language which can make them formal ontology (Figure 6).

It is also worthy to mention that there exist different categorization of ontology types, where the types are divided into *informal* and *formal* ontologies.

From the list of ontology types mentioned above, the first four types are *informal*, and *formal* ontology types starts from formal taxonomies and continues to logic constraints. In addition, the first four ontology types listed above are also often referred to as *controlled vocabularies* [94], due to the reason that they merely define terms and avoid the relations between them.

In addition, [50] proposed a classification of knowledge modeling ontologies (no data instances, only concepts reflecting knowledge) based on their level of abstraction and their usage (figure 8).

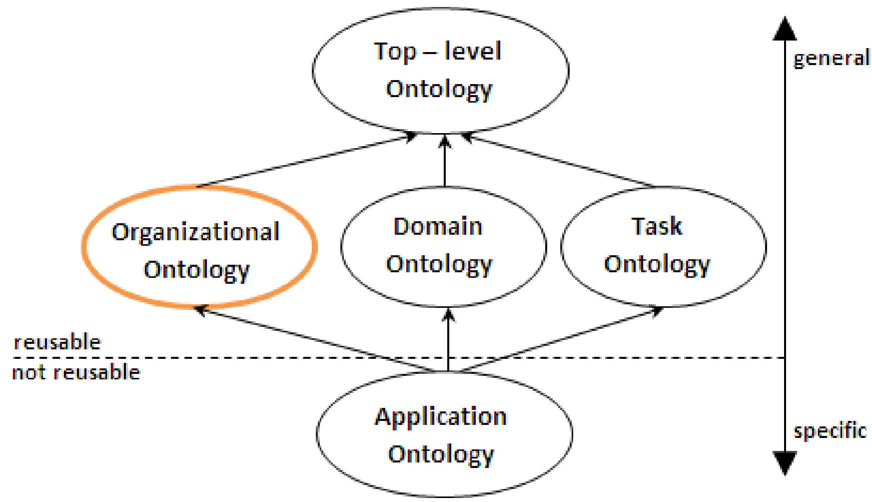

Figure 8: Classification of ontologies based on their level of abstraction. Adopted and modified from [50]

Top-level ontologies capture general concepts useful across several domains. The main role of this ontology type is to bring interoperability between several domain ontologies, for means of comparing, aligning and merging [85]. They are also referred to as *upper ontologies* and are most often based on human perception of the world [64]. One of the famous upper ontologies used in various applications is SUMMO [104]. The Suggested Upper Merged Ontology (SUMO) provides definitions for general-purpose terms, and is the foundation for more specific domain ontologies [85]. Second type of ontologies in Guarino's classification (Figure 8) are *domain ontologies*, which define concepts of one specific domain of interest. An example of domain ontology for this research is geometry ontology; an ontology capturing all concepts and relations involved in geometric/spatial domain. *Task ontologies* define the activities of a task/process without being specified for a certain domain [91]. Task ontologies can include concepts and relations of various measurement approaches, and measurement units common in all domains. Finally, *application ontologies* could be thought as ontologies with the potential to define specific activities (by making use of *domain* and *task* ontologies). This is done by stating which entities from the domain ontology play which role in an activity defined in the task ontology [91]. By adopting the concept of ontology type classification based on their level of abstraction and usage, in this research, the application ontology would be an ontology for Disaster Response carrying collection of definitions and relations/rules for relevant processes/tasks involved in Disaster Response. Apart from these types, in this research two other types of ontologies are going to be designed and used. First, an organizational ontology (as a knowledge modelling type) would be designed which carries organizational structures and information of roles/responsibilities within an organization. These information are to be used by Disaster Response application ontology. As depicted in Figure 7, organizational ontologies are generic and re-usable in different application ontologies. On the other hand, in a technical level of abstraction, later in the process of information integration, an ontology would be created on-the-fly by carrying various terms different ontology types (mentioned above), and populated with all the necessary instances for a specific task/process. Since it carries data instances we call this type of ontology *populated ontology*. Populated ontologies are specific in means of their usage, but depending on the different tasks in an application usage scale, it could be both re-usable and not reusable. Note that since populated ontologies carry data instances, they are not type of knowledge modelling ontologies and hence not depicted in Figure8.

B.3. Methodologies for developing ontologies

In the context of ontological engineering, several approaches have been proposed for developing ontologies. The first ontological engineering methodologies were introduced by [49] where they identified six steps for creating ontologies. Firstly, a scenario is defined in order to describe use cases from the domain of interest. From that scenario, informal competency questions are derived, which can be thought of as queries in natural language (not formal) that by using the ontology, a system should be able to answer. In the third step, the concepts used in the questions are formulated in first order theory and a terminology is created. In an iterative process, the informal competency questions are translated into formal competency questions by using an appropriate query language, and the axioms needed to answer the queries are inserted into the ontology. Finally, completeness theorems are defined, which identify the conditions under which the axioms in the ontology lead to correct conclusions beyond the initial competency questions.

In another methodology for ontology design and development, four main steps are introduced [110]: first the purpose and scope of the ontology are defined. Next, the actual building of ontology starts by capturing the ontology (e.g. identification of concepts and relations). In the third step, named as ontology coding, the identified concepts and relations are translated into formal statements, integrating other ontologies, whenever some of the concepts and relations identified are known to exist in other ontologies. Final step takes care of evaluation of the ontology and documentation of both the ontology and the modeling decisions made.

METHONTOLOGY [42] is frequently cited as more detailed ontology engineering methodology concentrating on the capturing and coding phases. The methodology comprises eleven tasks, which follow each other sequentially. The ontology engineer can step back in the process-flow if revision is necessary (e.g. whenever new terms are introduced). The approach starts with building a glossary of terms, which in the next step is converted into taxonomy by inserting the relation definitions. The process follows by identifying ad hoc binary relations between the identified concepts and the results are used to build a concept dictionary. Based on that dictionary, additional relations, class and instance attributes, and constants are defined. Finally, for building a *heavy-weight* ontology, the following tasks comprise the definition of formal axioms and rules, and optionally, of instances. Based on the well-defined stages of this methodology, as well as its popularity in different applications for ontology design and engineering, METHONTOLOGY is selected to be applied for designing ontologies in this research.

B.4. Ontology languages

In order to implement the vision of the *semantic web*, a set of standardized languages for ontologies have been proposed by the World Wide Web Consortium (W3C). By considering the semantic web stack reference architecture (Figure 6), a number of languages for semantic web implementation are advised. Resource Description Framework (RDF) [116] is the base language of the semantic web layer stack. RDF is a framework for representing information in the web. The underlying structure of any expression in RDF is a set of triples called an RDF graph, where each triple consists of a subject, a predicate, and an object. In other words, each triple represents a statement of a relationship between the things denoted by the nodes (subjects and objects) that it links.

RDF comes in different syntactic flavors. The most principal syntax is an XML syntax for RDF called RDF-XML. In order to encode the RDF graph in XML, the nodes and predicates have to be represented in XML terms (e.g. element names, attribute names, attribute values, etc.). RDF-XML makes use of *Qualified Names* (a name containing namespace prefix associated with a namespace URI) to represent RDF URI references. Notation 3 (N3) is a language which is a compact and readable alternative to RDF-XML syntax, but also extended to allow greater expressiveness [11]. The aims of the language are: 1) to optimize expression of data and logic in the same language 2) to allow RDF to be expressed 3) to allow rules to be integrated smoothly with RDF 4) to be as readable, natural and symmetrical as possible, just to mention a few [11].

While RDF is used for expressing statements about individuals (in *subject predicate object* form), ontologies are used to define the categories of those individuals, and their relations. Ontologies contain statements about hierarchies, relations between category members, or additional constrains (see section 1.2). In the semantic web stack, languages used for defining ontologies are RDF Schema [115], and the Web Ontology Language (OWL) [112]. RDF Schema, known also as RDFS, is a set of classes and properties using the RDF extensible language. The main job of RDFS is to provide basic elements for the description of ontologies (in other terms RDF vocabularies). On the other hand, OWL is designed for use by services/agents that need to process the content of information. OWL facilitates greater machine interpretability of Web content than that supported by RDFS, by providing additional vocabulary along with formal semantics [112].

OWL comes in three different flavors each having different expressive power and complexity: OWL Lite, OWL DL, and OWL Full. The recently proposed OWL 2 language provides further extensions, such as more fine-grained definitions of data types, more precise statements about relations, and property chains which provide a means for defining basic rules [91]. OWL 2 has different subsets with different complexity which are called *profiles* [120].

As mentioned in section A.2, rules are used to express additional axioms. Different rule languages have been proposed as the rule interchange formats in the semantic web stack (Figure 4). The Semantic Web Rule Language (SWRL) [117], and Rule Markup Language (RuleML) [15] are the dominant languages which allow for more flexible definitions than property chains in OWL 2. In addition, the mentioned rule languages have the power of defining constraints.

Finally, in order to query the information contained in the semantic web, defined in RDF, ontologies, and rules, various languages have been proposed [[6], [52]]. The most widely accepted standard for query language, as proposed in the semantic web stack (Figure 6), is SPARQL [119], a SQL-like query language for RDF-based documents.

In this research, the main ontology languages that are going to be used are RDF, RDFS, Notation3 and OWL for means of ontology design, SWRL for defining rules and constraints, and SPARQL as the query language since they are all the standard semantic web languages proposed by World Wide Web Consortium (W3C).

B.5. Software infrastructures for working with ontologies

In order to build intelligent systems/services with ontologies, several infrastructures are necessary. Ontology editors are used to facilitate the process of ontology creation. When dealing with large ontologies, the ontology codes are hardly ever understandable for humans to read and interpret. Some software exists that visualize the ontologies in order to facilitate this process. Also, in order to use the designed ontologies in development of semantic services, programming frameworks and storage solutions are necessary.

B.5.1. Ontology editors

Standard text editors are the simplest editors for ontology design and development. They can be used for XML-based formatted such as RDF-XML. The results of a survey conducted by [22] showed that more than 10% of researchers and practitioners (out of 600 participants) in the field of semantic web technology use text editors for their work, making them score as the fourth popular tool in a list of 14 different tools. Besides these simple editors, more sophisticated tools exist, which Protégé [46] is the most popular tool being used by more than two thirds of the users.

Protégé is a plugin based tool which allows for authoring OWL ontologies, and implementing rules by supporting SWRL. There are also further plugins for querying and reasoning purposes which makes Protégé the most powerful and popular ontology editor up to now. In a work conducted by [94], Protégé was used as a framework for building ontology-based applications with means for editing ontologies. [91] lists other popular ontology editors such as SWOOP [61], OntoStudio [87], the commercial successor of OntoEdit [105], and its open source counterpart NeOn Toolkit [53], WebODE [4], and Altova Semantic Works [2]. A detailed comparison of state-of-the-art ontology editors is presented in [[44], and [76]]. Based on the fact that Protégé is currently the strongest and most flexible software for designing and editing ontologies, it will be used in this research.

B.5.2. Ontology visualization

As discussed before, when dealing with large ontologies, in order to view the whole structure in ontology validation and refinement phase, and also for means of showing the ontology to the end user ontology visualization tools become handy. There exist many tools providing graphical views of RDF and ontology data. The most common ontology editor; Protégé, comes with plugins such as IsaViz, OwlViz, and Jambalaya, all providing different visual representations. RDFGravity [47], and W3C's RDF validation service [118] are two other best known tools for this mean.

In Addition, in order to browse the web of linked data several browsers have been developed. For instance, Tabulator [10] was one of the first tools for providing such service. Its basic view presents a tree-like structure of the starting concept, with each relation unfolding a new level containing the related concepts. Surveys and comparisons of ontology visualization methods and tools are given by [[62], and [66]].

B.5.3. Programming frameworks

In order to use the designed ontologies in development of semantic services, programming frameworks or Application Programming Interfaces (APIs) are needed. The main functionality of such frameworks is to load, process, query and manipulate ontologies. [91] provides an overview of state-of-the-art frameworks including RDFReactor [113], OWL2Java [60], agogo [90], and OntoJava [33].

RDFReactor receives an RDF Schema as an input, and represents each class in the schema by a Java class, hence creating a set of Java objects. By using the generated Java API access to RDF data is fully controlled. OWL2Java uses a similar approach, but takes the more expressive OWL Full as input to the code generator, incidentally trading the loss of computational completeness for expressiveness, as computational completeness is not an essential property for working with the generated Java classes [91].

Jena [23] is another well-known ontology programming framework. Jena works on general *graphs* instead of directly working on OWL constructs [7]. This allows for the processing of ontologies in RDF(S), and all dialects of OWL. Jena is suitable for implementing highly scalable applications working with large-scale ontologies [94], containing a simple set of built-in reasoner and support for external reasoners. Detailed comparisons of programming frameworks are given by [[14], and [94]].

Different from presented approaches, agogo does not use existing ontologies as input. It relies on its own input language, which uses SPARQL statements for defining operations on the classes to generate. This approach results in maintainable models due to defining reusable design patterns provided by the input language [91]. Finally, OntoJava allows for more expressive models by receiving both RDF Schema and RuleML as input to the code generator. In addition to restrictions formulated in RDFS, rules defined in RuleML may be used as constraint rules for defining further consistency checks. Therefore, this framework is selected as a well candidate for this research study.

B.5.4. Storage solutions

When faced with several large ontologies, the problem of efficiency and performance regarding ontology storage becomes a real challenge. In a simple case, ontologies can be stored as files (e.g. OWL files). However, in real-time applications, parsing an ontology file leads to longer response time when answering a query. Also, loading the whole ontology in the main memory decreases the efficiency of service (and sometimes makes it impossible) when working with large ontologies. Therefore, more sophisticated storage solutions, often referred to as *triple stores* are developed. Such solutions support querying the ontologies by using standardized query languages (e.g. SPARQL), transaction management, as well as bulk loading of large amounts of data [129].

The current well-known database oriented storage systems are *Oracle 11g* [88] (Semantic Technology extension), *Sesame* [19], *Virtuoso* [112], *OWLIM* [89], and *AllegroGraph* [43]. *Oracle 11g* has a RDF store compliant with semantic standards such as RDF, RDFS, and OWL. It also supports open source technologies such as Jena, and Protégé. It uses SPAQRL or SQL for querying RDF data, and brings several tools for scalability and performance (e.g. native inference engine, semantic indexing and querying technology, etc.). *Sesame* is a fast and scalable RDF database which serves as one of the building blocks of the semantic web. It includes features such as highly scalable RDF storage, fast upload of RDF triples, and high query performance with support for SPARQL. In *Sesame*, each ontology query is translated to one or more database queries, where an optimization algorithm tries to produce only few database queries that can be processed efficiently.

Virtuoso is a commercial database system developed by OpenLink Software. It has the ability to store relational data and RDF triples uniformly. It provides SPARQL statements nested into SQL queries, and the conversion of relational data into RDF data [36]. *OWLIM* is a family of semantic repositories (RDF database management systems), carrying native RDF engines implemented in Java which supports for the semantics of RDFS, and OWL 2. It is recognized as one of the best solutions for scalability, loading and query evaluation performance [63]. Like OWLIM, *AllegroGraph* is an RDF storage solution which provides several reasoning capabilities. Besides standard OWL reasoning, it has the ability to deal with spatial and temporal reasoning as well as with Prolog rules. There exists several research efforts that compare different storage solutions [[13], [69], and [71]]. To sum up, *Oracle 11g*, and *AllegroGraph* seem to be powerful solutions for storing ontologies. In this research, since *Oracle 11g* supports open source technologies such as OntoJava, and Protégé (which are nominated for ontology design procedure) it is selected as a relevant storage solution. However, the ability of *AllegroGraph* to deal with spatial and temporal reasoning might make it a more appropriate candidate for replacing *Oracle 11g* in the future of this research. It is believed that there are benefits in means of software and application consistency if the formal semantics (knowledge) and data instances are stored and managed in a single environment.

B.6. Use and benefits of ontologies

Among several usage of ontologies in knowledge-based systems, four are of interest in this research. This section describes each usage with its definition, and some related works in the area.

B.6.1. Semantic matching and translation

As discussed before, ontologies carry meanings of different terms (in a dataset) so that computers can also understand and process data automatically. Thus, they have the potential in order to be used to assist the matching and translation of a term (i.e. a concept) from one vocabulary (i.e. ontology in a specific domain) into a term in another vocabulary. This issue becomes more and more important when dealing with multiple ontologies (each of which is designed for different application by different organization) that have to be used in parallel in an integrated environment (e.g. disaster response case).

In order to automate the task of semantic matching and translation (also known as *semantic mapping)*, complex mapping rules are necessary to be defined and used by ontology matching tools. Typically, ontology mapping tools use a combination of element-based (e.g. name similarity) and structural (e.g. sub and super categories) techniques, as well as external knowledge such as thesauri [40] and/or employing logic rules. Recent comparisons of ontology matching tools are discussed by [1], [38], and [39]], which suggest several powerful tools such as ASMOV [58], RiMOM [70], and AgreementMaker [27].

Semantic matching and translation is the first step in facilitating the tasks of semantic reasoning, which furthermore results in performing semantic search, and integration of information.

B.6.2. Semantic reasoning

Semantic reasoning is defined as the process of deriving new implicit facts from those explicitly encoded in the ontology [21]. For example, from the facts “Aristotle is a man” and “All men are mortal”, a reasoner can derive that “Aristotle is mortal” [95]. Reasoning on ontologies can be used for at least two main purposes, *querying repositories,* and *validation of ontologies.*

With using a query language such as SPARQL (see section B.4), queries such as “find all costumers that are interested in the semantic web” can be addressed. Using formalized such as “if a customer has bought a book about ontology”, “he is interested in ontology” and “ontologies are a sub-topic of the semantic web”, a reasoner can provide an adequate answer set.

The other important usage of semantic reasoning is to *validate* an ontology after designing procedure. [21] show that conceptual inconsistencies in an ontology can be automatically evaluated by using reasoning. For instance, definition of two disjoint categories with a non-empty intersection is a conceptual inconsistency of an ontology being encountered by semantic reasoning.

There are two different types of reasoners named *tableau-based,* and *logic programming based*. Tableau-based reasoners, being the most common, evaluates axioms in the ontology, and derives new axioms until no more axioms can be found, or until a contradiction is reached [80]. In the list of this type of reasoners, Pellet [100], Fact++ [109], and Racer [54] are the most well-known. While KAON2[83], and OntoBroker[29] are logic programming based reasoners, which translate ontologies into a program (in a logic programming language such as datalog), and use a corresponding interpreter to resolve the queries. Overviews of state-of-the-art reasoning systems are given by [[122], [68], [74], and [30]].

B.6.3. Semantic search

As a structuring device for information repositories, ontologies can be used to facilitate the process of semantic search for both services and datasets in SII, and reasoning can draw conclusions from facts that are contained in different databases. Also, by employing ontologies information repositories can be organized and classified at a higher level of abstraction. One of the main issues in searching techniques is the ability to index the information at the best possible way. Ontologies can be used to create and apply semantic indexing mechanism of repositories (indexing the RDF triplets), facilitating the process of semantic search for collection of *the right information in the right time*.

Several researches have been carried out that use ontologies as a tool for semantic search. [107] show that a semantically integrated information access system could deploy mappings between different ontologies, in order to retrieve answers from multiple repositories.

In order to create better services for ontology-based search more formal ontologies are required. OWL-S is an OWL ontology for describing web services [107]. It supplies web service providers with a core set of markup language constructs for describing the properties and capabilities of their web services. OWL-S brings the advantage of web service discovery by intelligent agents in SII.

B.6.4. Data integration

The issue of data integration could be viewed from two slightly different perspectives: *database integration*, and *dataset (information) integration.* The common aim for using ontologies in both perspectives is to resolve the problems on semantic heterogeneity of databases/datasets. While in database integration, ontologies are used for the process of semantic matching and translation of schemas (See section B.6.1) in order to construct a shared ontology and furthermore use the ontology to integrate database schemas. Therefore, in this approach the original database schema's are changed. In the second perspective; integration in dataset level, the aim is to integrate (parts of) data from different data sources into a new single collection, without changing the original sources.

A basic approach in database integration (also known as *schema integration*) uses ontologies to map tables (in database) to classes (in ontology), and column to object or data relation [8]. Mapping database models and ontologies with a 1:1 mapping technique is not always desirable, thus more sophisticated approaches are necessary. In a recent research [91], rules are defined for dynamic mapping from class models to ontologies, and vice versa. The authors take into account instance data of the object instead of mapping on a class level. Some language constructs are used in order to query object graphs formed by the data objects. By utilizing such queries, annotations for objects are realized dynamically by creating a representation in RDF.

For dataset integration, by means of gathering data from various databases in order to obtain a single synchronized collection, several researches have been carried out. Some early researches used some variants of Description Logics (DL) as ontology representation languages. The most often cited language is *Classic* [16] which is used by different systems such as *Observer* [75]. In another research, *Prolog* logic programming language is used as a formal expression of ontologies for means of dataset integration [111]. More recent approach called *Semantic Desktop* encapsulates data in different applications on one machine (e.g. email contacts, calendar entries, etc.), and makes it available via a central query interface. By acquiring an RDF data from integrating different applications datasets, a unified view of a user's personal data could be queried [96]. Overviews of various approaches for ontology-based information integration are presented by [91].

ANNEX C: Disaster Response in the Netherlands

As discussed earlier in section 1.1 of the main text, the focus of this research relies on the processes, tasks, and properties involved in the disaster response phase. Disaster response procedures vary in each country and are primarily based on the predefined rules and regulations. Several research studies [[17], [31], [84], and [102]] present procedures of emergency response in the Netherlands.

C.1. Types of disasters

In the Netherlands, 19 disaster types are categorized into seven groups [31]:

- Incidents in relation to traffic and transport
  - Aircraft accidents
  - Accidents on water
  - Accidents on land
- Incidents with dangerous materials
  - Accidents with fire/explosive materials
  - Accidents with poisonous materials
  - Nuclear accidents
- Incidents in relation to public health
  - Danger for the health of citizens
  - Outbreak (people and animals)
- Incidents in relation to infrastructure
  - Accidents in tunnels
  - fire in large buildings
  - Collapse of large buildings
- Incidents in relation to population
  - Panic
  - Distraction of public order
- Natural disasters
  - Flood
  - Natural fires (forest fires)
  - Extreme weather conditions
- Man-made disasters
  - Failure in utilities
  - Disaster from a distance
  - Terrorism

Note that the three disaster types in natural disasters category are the main threat to this country [31].

C.2. Levels of organization in Emergency Response

In the Netherlands, based on the spatial extent of a disaster, the organization of a disaster response is divided into four levels [31]:

- Local level: Small scale incidents under the authority of single municipality.
- Regional level: Medium scale incidents regionally organized by single municipality.
- Provincial level: Large scale incidents under the authority of several municipalities.
- National level: large scale incidents which have country-wide threat

Most emergency incidents with small-scale nature are responded at local level. In a *local level* disaster, the mayor of the municipality the incident is taking place has the overall responsibility, while the primary operational responsibility for the on-site coordination of local disaster response is on the local fire chief. If the scale of the disaster grows to a *regional level*, a Regional Coordination Team (led by the Mayor of municipality) would be formed to assist the Regional Operational Team (ROT) at the site, and a policy team is also formed to support the Mayor [132].

As a disaster incident surpasses administrative borders (e.g. municipal, provincial or national borders), more structures would be involved in order to response the disaster. For instance, if a disaster transcends provincial borders (e.g. in our first sample scenario, see section 1.2.1), the Ministry of Internal Affairs may take the administrative lead, and work with coordination teams on the site in order to manage the disaster [132].

In the Netherlands, five GRIP levels are defined in order to describe the severity of an incident. As an incident grows spatially, the response to it would be managed in a higher GRIP level. This would require involvement of a wider range of organizations (sectors), more actors and wider range of information [32].

C.3. Sectors/Actors involved in ER

An incident in the Netherlands is managed by performing mostly 25 processes (Figure 10); each process handled by one or more task(s). Different sectors are responsible for processes, such as:

- Fire brigade
- Police
- Medical services (GHOR)
- Municipalities/Veilikeidsregoios (safety regions)

The four above-mentioned units are the main sectors for responding to almost all disasters. In special cases (mostly large-scale disasters) other actors (e.g. Ministry of Internal Affairs, policy team, etc.) may get involved. Several other organizations may also take part in the processes of disaster response if the first responders need support. For example, in case of flood Rijkswaterstaat (www.rws.nl), the Dutch National Reserve (www.natres.nl), KNBRD, Search And Rescue (SAR), KNRM (www.knrm.nl), ProRail, and utility companies may be involved.

C.4. Roles and Responsibilities

The roles and responsibilities of different sectors/actors in Emergency Response in The Netherlands are based on the processes which should be performed. Response and short-term recovery are categorized into four clusters. Each cluster has several processes and a responsible actor. Table 1 shows the information regarding different clusters, its processes and responsible actors.

Cluster number/name	**Responsible actor(s)**	**Processes**
1. Containment and control of the disaster and its effects	Fire Brigade	1. Fighting fire and emission of dangerous substances 2. Rescuing and technical assistance 3. Decontaminating people and animals 4. Decontaminating vehicles and infrastructure 5. Observations and measurements 6. Alerting the population 7. Making accessible and clearing up
2. Medical assistance	GHOR	8. Medical aid chain 9. Preventative public health and medical/environmental measures 10. Psycho-social aid and care
3. Public order and traffic management	Police and Ministry of Justice	11. Clearance and evacuation 12. Fencing of disaster area 13. Traffic control 14. Maintaining the legal order 15. Identification of fatal casualties 16. Giving directions 17. Criminal investigation
4. Taking care of the population	Municipality	18. Advice and information 19. Relief and care 20. Funeral arrangements 21. Registration of victims 22. Providing primary needs 23. Damage registration 24. Environment protection 25. Follow-up care

Table1. List of emergency response processes and the responsible sectors [31]

In order to fulfill the defined tasks, every actor has to perform specific actions, and therefore needs relevant geo-information in order to succeed. Based on the position of the emergency responders, whether they work in office or in the site, the level of details and information relevant to each actor might be different. Levels of detail refer to both the scale of the map which is relevant to the task of users as well as the amount of information/attributes for a special object. In order to relate geo-information to actors' roles, tasks and processes, a conceptualization of the domain knowledge is mandatory. For this purpose some approaches have been used in research studies including Description Logic (DL), object-oriented modeling, and ontology [[5], [3], [55], [92], [131], [133], and [134]]. [130] compares the UML and OWL for modeling emergency response processes and points out the advantages and disadvantages of each approach.

In a recent study [130], five main concepts involved in the emergency response domain in the Netherlands were identified and their relations and inheritance hierarchy were modeled in Unified Modeling Language (UML) using class diagrams (Figure 9). Object-oriented modeling approach is used in order to formally describe the tasks in disaster response.

Following the same concepts, [132] extended the top-level model by modeling 25 processes included in emergency plan of the Netherlands, with respect to the sectors who are responsible for each process (Figure 9). Their efforts resulted in the specification of actors, the communication between those actors and the required information (static and dynamic) of each process [101]. Furthermore, the dynamic information required for processes was organized in dynamic data model [32] to be used for an emergency response system [97].

As discussed, several types of disasters exist. In the Netherlands, depending on the nature, type and scale of the happened disaster, it would be responded in different GRIP levels which would involve different sectors and actors with various roles and responsibilities. These actors would work together and perform specific tasks in order to respond to the disaster. One of the most crucial supporting tools which help them in performing their tasks are maps. The necessary maps vary in number (volume) and types of geo-information they provide which directly depend on the user's tasks and roles (e.g. decision-maker, Regional Operation Team (ROT) member, etc.). This issue makes the task of map creation (relevant for each person) very complex, especially when a time limitation is added to the procedure. This is why a context-aware service for search, access, integration and translation of geo-information is of primary need.

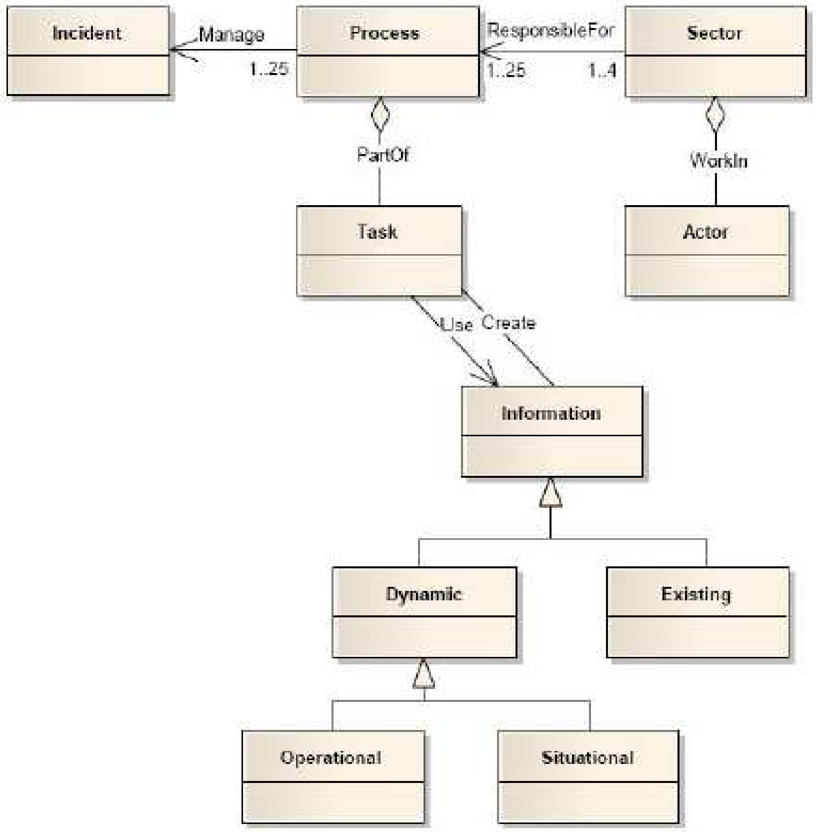

Figure 9: Top-level classes representing the relationships between main concepts in the emergency process in the Netherlands. Adopted from [130].

Studies for context-aware geo-information extraction, geo-information integration, and geo-information reasoning for disaster response case have not been carried out. There have been efforts to convert the available UML class diagrams to Web Ontology Language (OWL) files [130] and using ontologies for querying information from databases [134] which could be pointed as an initial step towards translating semantic of (geo) information from UML diagrams to the semantic web standard language and applying them for extracting context-aware information from databases.

There exist several scientific papers using semantic technology for a specific application domain. One of the famous current running projects is ENVISON [34]. This project provides an environmental service infrastructure using ontologies in order to support non ICT-skilled users in the process of semantic discovery and adaptive chaining and composition of environmental services [34]. All case studies of ENVISION deal with time-sensitive environmental scenarios such as landslide risk assessment, oil spill pollution, etc. In such scenarios it is of great importance to access real time sensor observation measurements in order to detect relevant changes and respond efficiently.

In a recent research study for this project [72], semantic event processing on geo-sensor data has been used in order to efficiently process input data for environmental models. In case of detection of a certain event, provided sensor data are analyzed and ontology event concepts are instantiated. Semantic reasoners process the populated ontologies (with collected facts) in database as well as execute rules to create new knowledge. For this purpose, a semantic mediation mechanism for the sensor web is designed in order to enable automated integration of sensors and services across the network [20]. The *mediator*, computes possible matches by using sensor characteristics (which are well-defined), and service requirements regarding sensors [20]. In addition, [82] present a system for generating and validating rules on environmental data based on EnStreaM [35]. EnStreaM is a scalable system used in ENVISION project for data stream mining tasks. Considering the common characteristics, the results and literatures from ENVISION project could give fine ideas for exploring the possibilities as well as implementing the necessary infrastructure for this research. Note that this research mainly focuses on Disaster Response.

In addition, within the scope of MONITOR (Hazard Monitoring for Risk Assessment and Risk Evaluation) [81], special work has been carried out to collect and define a common base vocabulary in the thematic fields of MONITOR, formalize them as an ontology, and use it as a knowledge base providing access via web interfaces giving query capabilities [65]. Given the fact that this research focuses on flooding, the vocabulary and ontology (namely Risk Ontology) designed could be investigated and used (with modifications) for this research study (especially for the first case scenario: flooding).

The Semantic Web for Earth and Environmental Terminology (SWEET) project [106] is an investigation to improve discovery and use of Earth science data, by formally defining the semantics of web resources. This semantics understanding is enabled by designing formal representations (e.g. ontologies) of concepts and their relationships in a way that supports domain knowledge [93]. In this respect, a collection of ontologies were designed that include orthogonal concepts (e.g. space, time, physical quantities, etc.) and integrative science knowledge concepts (phenomena, events, etc.). SWEET does not create applications of knowledge, but rather creates a knowledge base that can be used in many applications [93]. Therefore, SWEET terminology is a good ontology to be used in our research study since it covers the concepts and relationships involved in the Earth science data. We understand that there are other ontologies available for Earth sciences, but they are limited to specific subsets of the earth system. An example of such ontology is GEON [99] which is limited to solid earth.

In a recent research [137], Nitesh Bharosa studies the information assurance and system quality in public safety networks in means of netcentric information orchestration. The study draws the theoretical and empirical foundations and presents a framework for information orchestration capabilities. Furthermore, a prototype named DIOS is designed and evaluated for different use cases.

Linked Data is another important work relevant to this study. Some major works include Geonames.org as well as the Linked Geo Data project, which provides a RDF serialization of Points Of Interest from Open Street Map [139]. Also, governments and governmental agencies have recently started to develop geo-ontologies and publish their data as Linked Spatiotemporal Data [140]. Examples include the US Geological Survey [141] and the UK Ordnance Survey

[142]. Furthermore, myriad other Linked Data sources contain location-based references. For example, a specific dataset from the digital humanities can link information about exhibits to places and their historic names [143]. Based on these links and connections, scholars can explore these places and learn about events which took place there. Furthermore, this historic events dataset may link to information about physical objects and actors that were involved in these events [144]. Hence, Linked Spatiotemporal Data is also of interest and would be used in this research to apply the state-of-the-art technology in disaster response application.

Finally, In another relevant research study [138], the Simple Event Model (SEM) is created to model events in these application domains, without making assumptions about the domain-specific vocabularies used. SEM is designed with a minimum of semantic commitment to guarantee maximal interoperability. [138] discusses the general requirements of an event model for web data and give examples from two use cases: historic events and events in the maritime safety and security domain. Also, the advantages and disadvantages of several existing event models are discussed in the context of the historic example. It is understood that such research study is in line with our study, thus their approach and model could be also tried in disaster response application where SEM could act as a simple upper level ontology by the ASSIST prototype (See: Figure. 4).

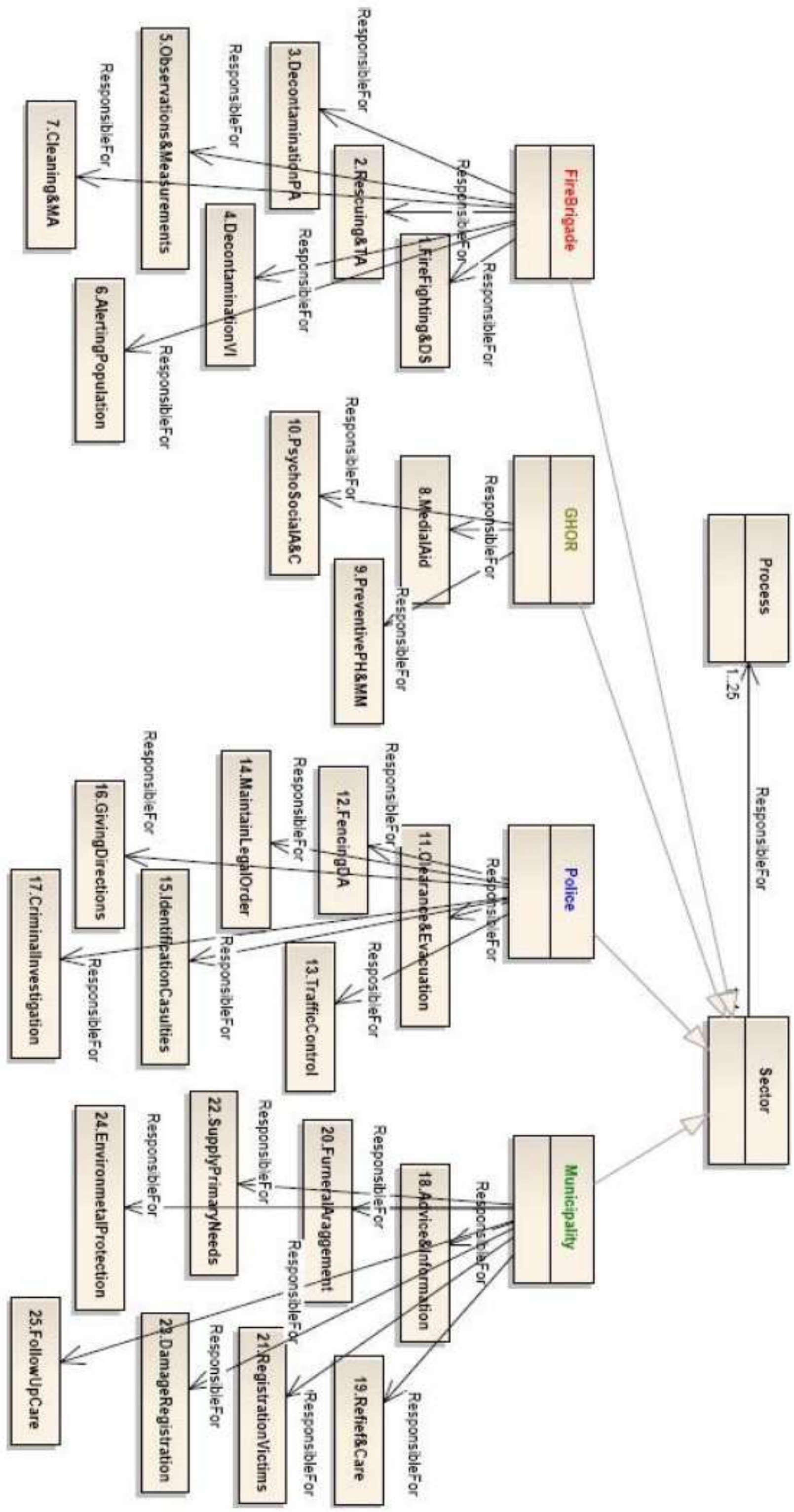

Figure 10: Processes and major emergency response sectors in the Netherlands.

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