MODELS OF DYNAMIC DATA FOR EMERGENCY RESPONSE: A COMPARATIVE STUDY

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ABSTRACT:

The first hours after a disaster happens are very chaotic and difficult but perhaps the most important for successfully fighting the consequences, saving human lives and reducing damages in private and public properties. Despite some advances, complete inventory of the information needed during the emergency response remains challenging. In the last years several nationally and internationally funded projects have concentrated on inventory of emergency response processes, structures for storing dynamic information and standards and services for accessing needed data sets. A good inventory would clarify many aspects of the information exchange such as data sets, models, representations; a good structuring would facilitate the fast access to a desired piece of information, as well as the automation of analysis of the information. Consequently the information can be used better in the decision-making process.

This paper presents our work on models for dynamic data for different disasters and incidents in Europe. The Dutch data models are derived from a thorough study on emergency response procedure in the Netherlands. Two more models developed within the project HUMBOLDT reflect several cross border disaster management scenarios in Europe. These models are compared with the Geospatial Data Model of the Department of Homeland Security in USA. The paper draws conclusions about the type of geographical information needed to perform emergency response operations and the possibility to have a generic model to be used world-wide.

1. INTRODUCTION

The data used in emergency response (ER) can be static (existing prior to disaster) or dynamic (collected or simulated during the disaster). The dynamic ER models developed so far can be subdivided into two large groups as data models for storage and exchange of information (e.g. dynamic and predicted) and numerical models for simulation and prediction (e.g. simulation of disaster evolution, impact, human evacuation, rescue action). Although many of the developed models are disaster specific (e.g. flood, earthquake, hurricane), attempts are made to develop multi-purpose and multi-user models to be used in any emergency situation (e.g. Chen et al. 2008, Vlotman et al. 2009). This paper focuses on data models for storage and exchange of information.

There are many challenges in developing such models (Cutter et al. 2003, Diehl et al. 2005, Zlatanova et al. 2006, Scholten et al. 2008). A major bottleneck is that data that is coming from the field operations is stored in an unstructured way, e.g. several files in the system, which makes it problematic for a systemized analysis and exchange between ER actors.

This paper presents four data models for the emergency response information in Europe. The models are developed within the Dutch funded project 'Geographical Data Infrastructure for Disaster Management' (GDI4DM), by the Dutch standardization organization Geonovum (www.geonovum.nl) and within the European project HUMBOLDT (www.esdi-humboldt.eu). While the developments of GDI4DM and Geonovum are focused on the creation of a spatial data infrastructure to assist the decision-making during an emergency response in the Netherlands, HUMBOLDT has the more general goal of developing tools for harmonization of data sets for any application domain and with emphasis on the cross-border situations. These models are compared with the Department of Homeland Security (DHS) Geospatial model developed in USA.

The following sections 2 and 3 present the developed models. Section 4 introduces briefly the DHS Geospatial

Data Model and the last section discusses the differences with the European models.

2. DUTCH DATA MODELS

The Dutch models are the Information model for safety and security (abbreviated in Dutch IMOOV) and the Geographical Data Infrastructure for Disaster Management (GDI4DM) model. The two models are very much related and derived from the Dutch procedures for emergency response.

A disaster incident in the Netherlands is managed through processes. Each process has a well-defined objective, which realization requires certain information and often produces information during its execution. Depending on the type of process, different ER units (which are fire brigade, police, para medics and municipalities) get involved in the incident. Each process consists of a number of tasks, which define roles and responsibilities for ER people. The processes and the tasks were thoroughly investigated and analyzed by interviews, workshops and observing during trainings. Following this approach, information needs were identified and translated to a conceptual data model (Snoeren 2006, Diehl et al. 2006, Snoeren et al 2007, Dilo et al. 2008).

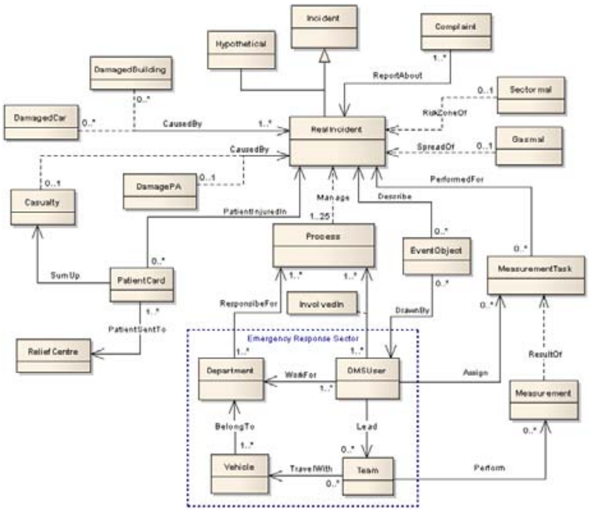

Figure 1. GDI4DM data model for emergency response in NL.

The GDI4DM data model (see Figure 1) captures the situational information (Diehl et al. 2005), e.g. incident and its effect, and the operational information, e.g. the processes activated to handle an incident, responsible departments, persons (system users) involved in each process. The top class is the class *Incident*, which can be *Real* (any kind of disaster) or *Hypotethical* (e.g. large events, which might be problematic such as football games or concerts). Different measurements are performed during an incident that involves dangerous substances. A dedicated process, Measurements and Observations, takes care of the process of performing measurements. A measurement task is designed by an advisor of dangerous substances (AGS), and sent to a team that performs the measurement according to task specifications. The class *Measurement* contains results of the measurements. The measurements have a specific form for recording, which differs from the ISO 19156 Observations and Measurements. These measurements are used to calculate a gas plume (class *Gasmal*), elaborating the rough estimation given by *Sectormal*. The class *EventObject* contains drawings done by system users to locate different events happening in the field, e.g. a gas leak, blocked road. Damages in infrastructure, animals and people are also recorded, as well as detailed medical information for the injured persons in *PatientCard* (classes in the left of Figure 1).

A *RealIncident* is managed by one or more *Processes* (at most 25). Class *Department* contains information about an emergency response unit, which might be responsible for several processes (for the same incident or different incidents). A department participates in the incident with one or more vehicles, e.g. a fire brigade owns trucks and boats. The class *Vehicle* keeps information about vehicles. The class *DMSUser* contains information about the system users and the class *Team* keeps information about teams, e.g. number of its members and position of the team. Detailed description of the model can be found in (Dilo and Zlatanova 2010).

The data model is implemented in Oracle Spatial (Dilo et al. 2008) and tasks performed by different actors in the emergency response are translated to context-aware services, which are to be accessed via well-designed user interfaces (Scholten et al 2008). New data types are created for temporal and spatiotemporal information: dynamic counts to store, e.g. number of injured; moving point for, e.g. the position of a vehicle; moving region for, e.g. gas plume.

The second model, IMOOV, was developed by the Dutch standardization organization, Geonovum. The approach was more general and without considering the ER processes in detail. The IMOOV model contains information about an incident, damaged infrastructure, affected animals and flora, as well as involved people and units, their equipment and vehicles (Geonovum, 2008). Although similar to GDI4DM model, the classes and their relations however slightly differ from GDI4DM. IMOOV does not keep data that is specific for one ER unit, e.g. measurements, gas plume and patient information. The operational information is not as detailed as in GDI4DM, which has classes belonging to ER Sector (dashed box in Figure 1) and their relation with ER processes. In contrast to GDI4DM, IMOOV keeps information about existing data, given as map layers and URL's of their location. The IMOOV model includes also information related to mapping (a set of symbols) and processing of data. A first attempt to integrate the two models was done in (Heide et al. 2009).

3. HUMBOLDT DATA MODELS

The second group of data models presented here was developed within the European project HUMBOLDT. The project cannot be classified as an ER project (as other European funded projects, such as ORCHESTRA, WIN or OASIS). HUMBOLDT project has run from 2006 to 2010 and focused on cross-border data harmonization aspects with the intention to provide tools in support of the European INSPIRE (Infrastructure for Spatial Information in Europe) Directive (inspire.jrc.ec.europa.eu) and the European Earth Observation Programme GMES (Global Monitoring for Environment and Security, ec.europa.eu/gmes/). 27 partners from 14 European countries representing public administration, research and industry have contributed to the developments. Suitable software architectures and type of processes were investigated and described; an extensive study on user requirements of a variety of application domains was performed. The analysis served as a basis for the development of 'HUMBOLDT Framework', which includes tools and services to support spatial data and service providers in offering standardized spatial information.

Nine scenarios were defined based on real-world use cases, covering a wide range of application domains: atmosphere, air quality, border security, flood risk management, forest & urban planning, oil spill monitoring, protected areas, sustainable urban atlas and trans-boundary catchments. The scenarios were defined in such a way to cover territories of neighboring countries (Austria, Czech Republic, France, Germany, Greece, Italy, Hungary, Portugal, Spain, Switzerland and the United Kingdom) that experience the problems of heterogeneous data.

Although no scenario was explicitly devoted to ER, several scenarios were dealing with security and emergency issues such as border security, flood and oil spill. The applications models developed were strictly derived from (and in certain respect limited by) user requirements, available data sets, software developments and the current status of the INSPIRE specifications (Fichtinger et al. 2010). Two of the application data models are discussed below.

3.1 ERiskA Scenario

The European Risk Atlas (ERiskA) aimed at developing a cross-border ER scenario for the Lake Constance Region, which includes Swiss, Austrian and German territories. The use cases within the scenario focused on creating a harmonized spatial information infrastructure (SII) for floods. The needed data were specified as roads, railways and hydrographic features (as static data sets) and water level measurements and pre-calculated flood extent features (dynamic data).

The main information required by disaster managers and citizens, can be summarized as follows:

- Harmonized information base including infrastructure like roads, railways and hydrographic features (static data)
- Relevant gauges to assess the current water level.
- Potentially flooded areas and resulting inundation of infrastructure like roads and railways in case of an actual flood event or in a simulation / preparedness exercise. For each gauge, pre-calculated potentially flooded area extents for different water levels are stored.

Based on this information, further analysis is performed, e.g. a corresponding flooded area is overlaid or spatially intersected with the road or railway features.

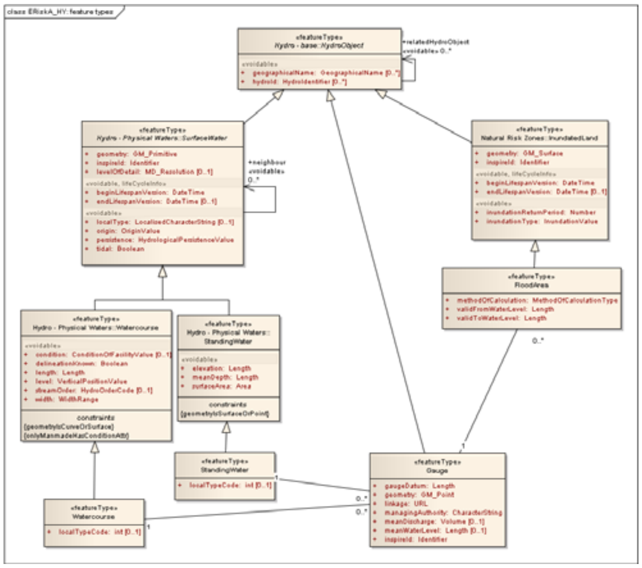

Figure 2. Hydrography of ERiskA data model (static and dynamic data)

Based on the analysis of information needs, the required features with their attributes and relationships were modeled in an application data model (Fichtinger et al. 2010). For the static features, this scenario has re-used several of the INSPIRE Data Specifications by importing the respective packages of the INSPIRE data model: Hydrography, Transport Networks, and Geographical Names.

The dynamic information such as data from gauges, flooded areas and water level was modeled with respect to the available information. The location and characteristics of gauges in the Lake Constance Region is available from websites of flood risk management agencies. Provisional flooded areas were calculated from the digital terrain models. Here different resolutions and different vertical reference systems of the digital terrain models had to be taken into consideration. The flooded areas are thus available at certain intervals of water levels for each gauge.

The water level measurements are available for watercourses and standing waters from the websites of the four different flood risk management agencies in the Lake Constance area. After the measurements are obtained, the websites are updated (at different intervals in the different regions). Here various differences in the measurements were experiences. For example, the water levels are measured against different reference heights in the different regions, e.g. referring to see level or gauge level.

Part of the model concerning the Hydrography including the needed measurements is shown in Figure 2. Detailed report on the data model and the UML classes can be found on the HUMBOLDT web pages.

3.2 Border Security

Border security scenario was developed because of several important issues concerning the border security of the European Union (EU) such as:

- Growing awareness of the need for cross-border cooperation on the EU external borders.
- Difficulties in effective border control especially in rural areas with low density of infrastructure and population and coastal borders of EU.
- Support the work of FRONTEX (www.frontex.europa.eu) in coordinating the national institutions responsible for border security.

After discussions with end users in Hungary and the Slovak Republic, the goal of the scenario was defined as detection of incidents along the border of all kinds: illegal entry, smuggle, security endangering activities, pollution (via water and air). The 'intruders' were identified broadly as humans, animals, natural phenomena (e.g. pollution, oil spill on river) or devices of all kind. The border equipment and the way of working in the two countries were extensively studied. The part of the data model dealing with dynamic information is given in Figure 3.

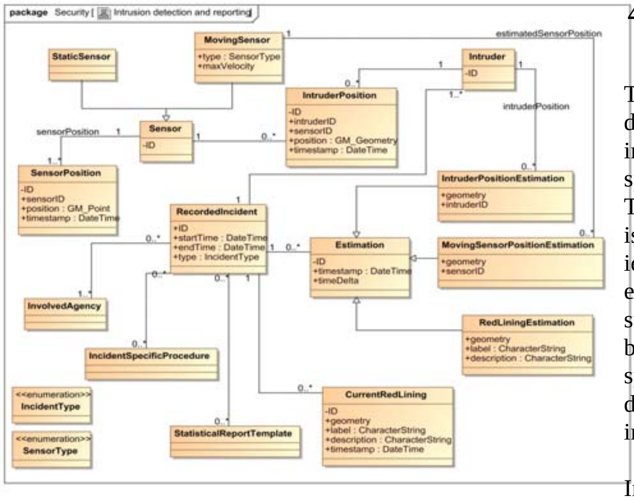

Figure 3. Border Security data model

The model contains information about the incident, the involved actors, the intruders, the information from the sensors and predictions of positions of sensors and intruders. Similar to the Dutch cases the information is organised with respect to a specific incident (class *RecordedIncident*). Depending on the country and the type of the incident, different procedures can be initiated (class *IncidentSpecificProcedure*) by the responsible institutions (described in class *InvolvedAgency*). Classes *CurrentRedLining* maintain all drawings (such as tracks of people or cars or other types of intruders) that are made by the border security institutions. Several classes contain information about the sensors in use. All the sensors are classified in *SensorType*. It was experienced that the sensors can be static and dynamic (i.e. mounted on moving platforms, as cars, helicopters, etc.). *SensorPosition* keeps track of all the locations of the sensors. A special class *Estimation* and its specializations maintain information about all possible predictions. Such estimations are of critical importance for the border institutions as the exact position of intruders is not known in many cases.

The needed static spatial data such as topographic maps, images, orthophotos, terrain models, city models and other available data are modeled separately and will be available to the border security authorities via services as discussed in the HUMBOLDT Framework. Similar to the ERiskA scenario, appropriate classes from the INSPIRE themes such as Transportation, Geographical Names, Land Cover, Administrative Boundaries and Hydrography are used.

The two HUMBOLDT data models are derived from specific scenario requirements and are intended to serve specific emergency response authorities. Although they cannot be seen as complete data models for any kind of disaster, the data contained in the models are complementary to C&C system in case of flood (ERiskA) and in case of criminal activities (Border Security).

4. COMPARISON WITH DHS GEOSPATIAL DATA MODEL

The four models presented in the previous section are developed within the European member states, which are independent countries but need to cooperate and share spatial data and other information in case of emergencies. The INSPIRE directive deals with resolving heterogeneity issues in existing spatial data. The working teams have identified 20 different issues relevant for interoperability of existing spatial data. There are data model related aspects such as application schemas, spatial and temporal aspects, but also data instances aspects like spatial reference systems, data quality and consistency. However, the dynamic data models remain scenario-, country- or even institution- specific.

In contrast, the Department of Homeland Security (DHS) developed a model, which aims at solving interoperability issues in both static and dynamic data. A short description of the model follows.

4.1 Department of Homeland Security Geospatial Model

The DHS Geospatial Management Office (GMO) was created to support operations within DHS and between organizations involved in homeland security and emergency response. It incorporates existing Federal and industry standards and practices like the Fire/Hazmat data model, the Homeland Security Infrastructure Protection (HSIP) model, FEMA Multi-hazard Model and the National Incident Management System (NIMS) model (FGDC 2009).

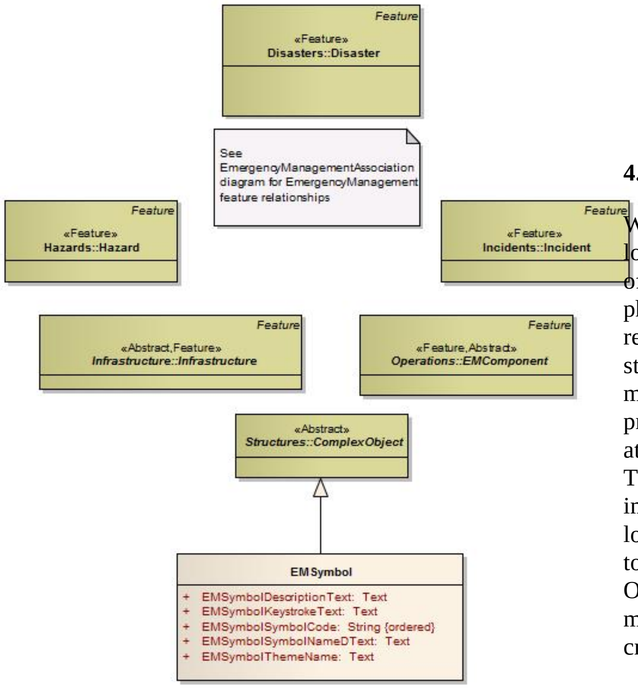

Figure 4. DHS Application Schema ‘Emergency management’

- Security Sectors: contains information about the different sectors relevant to homeland security like energy, telecommunications, healthcare, water supply as well as the different emergency service types.

Security Operations: contains features related to emergency response, such as types of disasters, hazards, emergency response operations (given in the Emergency Management Application Schema, see

- Figure 4) and border incidents (given in the Application Schema International Trade, see Figure 5).

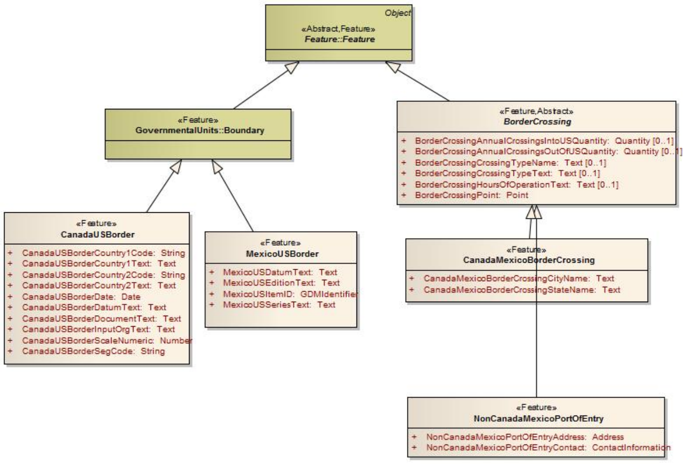

Figure 5. DHS Application Schema ‘International Trade’ (part)

4.2 Comparison

While comparing the different developments we have looked at several issues related to technical characteristics of the model: scope, semantics (definitions), attributes, physical models, geometry dimension, topology, representation of time, moving objects and use of standards,. With the first criterion we aim to assess the models with respect to their goal (as specified in the projects and scenario descriptions). Semantics and attributes refer to the availability of well-defined features. The criterion physical model assesses the physical implementation (as database model or files). We also looked at the support of any topological structure or topological constraints within the schema (i.e. topology). One of the most interesting elements in a dynamic model is management of time and moving objects (MO). The last criterion is devoted to use of standards.

Table 1. Comparison with respect to the model: - not supported, 0 basic, + supported, ++extended

	GDI4DM	IMOOV	ERiskA	Border	DHS
Scope	+	++	+	+	++
Semantics	+	++	+	0	++
Attributes	++	++	++	0	+
Physical	+	-	+	-	?
Dimension	2D	2D	2D, 2,5D	2D, 2,5D	2D
Topology	-	-	-	-	-
Time	++	+	-	+	+
MO	+	+	-	+	-
Standards	+	+	++	+	++

IMOOV and DHS have the most extended scope (with respect to their goal) covering a large number of features. IMOOV and DHS models provide also the most extensive definitions of the features. However some of the classes in DHS are less elaborated and lack attributes compared to IMOOV. All presented models have a logical model, but currently only two of them are implemented and tested (GDI4DM in a DBMS system and ERiskA as a GML file). There is no evidence for physical implementations of the DHS geospatial model. Quite interesting is the fact that all models focus on 2D geometry (represented by 2D points, lines and polygons) and only some locations are given as 3D coordinates (tracking of vehicles or intruders). All the geometries are compliant with the OGC specifications. None of the models discusses topological issues. Time is kept as a time stamp (begin and end time). Only the physical data model of GDI4DM offers more elaborated data types for managing moving objects, whereas IMOOV and Border include features of type moving objects without specifying a real implementation. All models refer to standards but the most extensive use is observed in ERiskA (e.g. UML2.1 and INSPIRE profile) and DHS (e.g. HAZMAT, NIMS).

The second group of criteria aims at comparing the models with respect to their intended purpose, i.e. to serve the actors within ER. Such criteria are very challenging to establish and apply objectively for the models. In this paper we follow a pragmatic approach. We have defined seven criteria with respect to the emergency management (EM) principles as specified by (Blanchard et al. 2007). We have assessed whether the information in the model would allow emergency managers to perform their work in a comprehensive, progressive, risk-driven, integrated, collaborative, coordinated, flexible and professional way. We have 'translated' the principles into EM characteristics of the models. A model is:

- Comprehensive if it considers all hazards, all phases, all impacts, and all stakeholders relevant to disasters.
- Progressive if anticipation can be made for future disasters to build disaster-resistant and disaster-resilient communities.
- Risk-driven if sound risk management componernets (hazard identification, risk analysis, and impact analysis) can be identified from the model.
- Integrated if it provides information for all levels of government and all elements of a community.
- Collaborative if it creates and sustains broad and sincere relationships among individuals and organizations to encourage trust and facilitate communication.
- Coordinated if it allows for synchronizing the activities of all relevant stakeholders to achieve a common purpose.
- Flexible if creative and innovative approaches are used in solving disaster challenges.

Table 2. Comparison with respect to the EM characteristics: - insufficient, 0 basic, + good, ++advanced

	GDI4DM	IMOOV	DHS
Comprehensive	0	+	++
Progressive	++	+	+
Risk-driven	0	0	++
Integrated	+	+	+
Collaborative	-	-	0
Coordinated	+	+	0
Flexible	+	-	-

As mentioned previously, ERiskA and Border are not developed as disaster management models and therefore they are omitted from the second table. IMOOV, DHS and GDI4DM (to a lesser degree) intend to maintain the information for all kind of disasters and therefore they are most comprehensive. It should be noted that the disaster types considered are country specific. In this respect DHS covers slightly more disasters types compared to the Netherlands. IMOOV and GDI4DM however contain information that is collected only by the direct emergency responders (fire brigade, police, municipality and paramedics). For example, measurements from water level gauges are not included in the models. GDI4DM is the one intended for storage in DBMS (and not only for sharing of data), which should facilitate various post-disaster analysis and simulations and therefore we classify it as most progressive.

The most extended information about risk and hazards (also from historical data) is provided in the DHS model (although some of the risk-related classes have a limited number of attributes). The other models contain risk estimates only during disasters (e.g. threatened areas). The fourth criterion reflects the information from and to the citizens. GDI4DM, IMOOV and DHS are clearly models created for specialists, but information to the citizens can be derived from the records. GDI4DM is the only model that can record some information from citizens (i.e. class *Complaints*).

The collaborative criterion practically refers to the openness of the information between different institutions and the citizens. All the models are created to facilitate the collaboration between institutions, but non-professional organisations (and citizens) are not entitled to have access to the information in these models. Though, some parts of the information of DHS model are public. The sixth criterion reflects the possibility for coordination and here the Dutch models can be ranked highly as they contain elaborated information about the emergency levels and the manner of working during emergencies. GDI4DM has various advanced elements in modelling dynamic objects, which are not that well developed in DHS and IMOOV.

5. DISCUSSION

In this paper we present and analyse five dynamic models developed to support emergency operations. The models are developed for different purposes, e.g. to serve one type of disaster (ERiskA, Border), one country (GDI4DM, IMOOV) or specific authorities (DHS, ERiskA). The models are also derived using different methodology. While DHS and IMOOV follow top-down approach, GDI4DM, ERiskA and Border are typical bottom-up designed models. Despite the differences the models are quite compatible: all of them have acceptable to very good semantic (attributes), 2D geometry, do not support topology and make use of standards (in few cases very extensive). Quick look at some of the classes and attributes reveals many similar features/attributes as well. The second group of criteria clearly shows that the DHS model scores best but this is mostly because it covers large amounts of information that are needed for disaster management. In several aspects, the relatively 'smaller' models are more advanced and adapted to the needs of the users. Very large and complex models are challenging for implementation and use. This poses the very interesting question:

Is it possible to create one global dynamic model for emergency response?

Apparently such a model is necessary because disasters do not stop at administrative borders. Cross-border cooperation and collaboration is crucial in many situations. On the other hand emergency response is very much nationally and even locally organized, since the responsibility often lies with state or local (district) authorities. A large proportion of day-to-day operations also take place within the municipality or district the local authority is responsible for. Only large disasters require national and international cooperation. Another complicating factor is the disaster type which requires different data and management. Each country is prone to a specific set of hazards and risks and organizes its management procedures according to the recognized vulnerability.

Despite all the challenges, we believe the work on a generic model should start as soon as possible. A lot of experience on defining core models is already collected by INSPITE teams, OGC working groups and other international and national standardization bodies. Many existing standards can be reused in this model.

The generic model should be clustered with respect to features of international interest and national (local) interest (disaster types, actors, operational aspects). It should have generic features which are of interest for many countries and should allow for extension with respect to country-specific features. For example, the procedural part (actors, organizations, procedures, etc.) is highly depended on the country (or even a district) and very often not of interest for neighboring countries. Indeed some top-level classes should be available also in the generic model to be able to establish relations between generic and country specific features. The work on such a global model will be an iterative process, where the main challenge is to distinguish between core / generic and country-specific.

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