GIS as a Tool in Emergency Management Process

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***Abstract* — This paper shows how GIS could be used to support decision making in emergency risk management. Paper describes GinisEmergency tool, which is based on existing semantic interoperability platform called GeoNis. The proposed prototype is intended to function as an intelligent, computer-based consultant in assisting diagnostic and decision making processes in potentially hazardous situations. Intelligent integration of heterogeneous data sources based on semantics (represented by ontologies) is important part of this research.**

***Index Terms* — emergency management, GIS, interoperability platform, semantic integration.**

I. Introduction

Emergency management has been the hot topic in recent times. Emergency events imply all events that endanger normal functioning of services and companies, endanger lives or resources (living environment) as well as events that are threatening stability of state. All situations resulting from fires, explosions, technological and traffic accidents, terrorist attacks, transport of hazardous materials all comprise hazardous events. Individuals and organizations responsible for emergency management use many tools to preserve economic assets before, during and after a catastrophic event. Correct and timely information is a critical part of any successful emergency management program. A geographic information system (GIS) can provide that sort of information and tools for the analysis of the spatial data and the representation of the results in spatial format.

Driven by trends in storage technology, computational power and network bandwidth, number of geo-data and geo-processing applications is rapidly growing every day. Every moment, these applications, are producing and analyzing large amount of geographic datasets that can contain great number of files and data objects. In such environment, accurate and simple methods for identification and retrieval of, often distributed and heterogeneous, geo-data is very crucial. Integration of information gathered from all these services will provide needed knowledge required in the process of visual representation and analysis of hazardous events. This enables timely notification (using GIS interface) of current status of all relevant parameters.

The purpose of this paper is to illustrate how GIS could be used to support decision making in emergency risk management. This was done by using an existing semantic interoperability platform called GeoNis [1], and embeds it into a distributed, spatially enabled decision support system – GinisEmergency. The proposed prototype is intended to function as an intelligent - computer-based consultant in assisting diagnostic and decision making processes in potentially hazardous situations.

II. Related Work

As already identified in numerous papers related to this domain [2], [3], several phases can be differentiated in the process of emergency management (Fig. 1):

- Planning,
- Mitigation,
- Preparedness,
- Response, and
- Recovery.

Geographic information is involved in all phases of emergency management processes, from prevention to immediate reaction. In each of the mentioned phases GIS can provide additional tools and make the phase more efficient and intuitive.

Fig. 1: Phases identified in a typical emergency management process

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The geospatial aspects may be explicit, such topographic maps, providing background information, or implicit, e.g. demographic data about population distribution in an affected area. In the same way either dedicated tools are used to analyze or incorporate geospatial aspects (e.g. the usage of a GIS by a GI expert) or the information is integrated via interoperable GI components or GI services in a specific emergency management application.

Types of data usually needed in emergency management can be classified as follows [4]:

- Data on the emergency phenomena (for example, landslides, floods, earthquakes), their location, frequency, magnitude and so on.
- Data on the environment in which the disastrous events might take place: topography, geology, geomorphology, soils, hydrology, land use, vegetation and so on.
- Data on assets that might be destroyed if the event takes place: infrastructure, settlements, population, socioeconomic data and so on.

During emergencies, GIS enables emergency managers to quickly access relevant data about an affected area. However, the problem is that the needed spatial and non-spatial data is usually geographically dispersed and stored in heterogeneous databases. The new generation of information systems including GIS should be able to solve semantic heterogeneity [5]. The need to share geographic information is well documented [6], [7]. Making local geographic datasets publicly available and establishing a common interoperability framework over shared data interchange protocols are important parts of this research.

Although distributed geo-libraries offer numerous advantages over stand-alone geographic databases, there are institutional and technical problems of geo-data sharing. These problems have become, over the last several years, the focus of international research and infrastructure efforts and have been discussed at several international conferences and workshops focused on GIS interoperability [8].

One solution for data exchange between different GIS data sources would be a single architecture and set of standards for geospatial data. A broader discussion of geographic information exchange formats can be found in [9]. One of important strategies for interoperability is conversion of different data formats in common data structure. This kind of data structure is usually based on one of existing GIS standards. However, it is all but impossible to conceive that the global GIS community would adopt a single geospatial architecture or data standard worldwide. This means that standardization efforts alone not produce interoperability.

Today, semantics is a key factor of successful interoperability between information systems. During the past several years, many different solutions for problems of semantic heterogeneity have been proposed [1], [10], [11]. One way of making the meaning of information more explicit is the use of ontologies [12], also in the geographic field.

III. GinisEmergency – GIS tool for Emergency Management Support

Emergency management poses significant challenges for data collection, data management, discovery, translation, integration, visualization and communication. Emergency management can be managed well through spatial planning and one requires a GIS for such a management. Effective emergency management requires the thorough use and understanding of the semantics of the heterogeneous (geo-) information sources with their many differences: scale/resolution, dimension (2D or 3D), classification and attributes schemes, temporal aspects (up-to-date-ness, history, predictions of the future), spatial reference system used, etc. Typically, emergency management depends on large volumes of accurate, relevant, on-time geo-information that various organizations systematically create and maintain.

GIS as a tool in emergency management can been used in the emergency prevention phase for managing the large volumes of data needed for the hazard and risk assessment. In the emergency preparedness phase it is a tool for planning of evacuation routes, for the design of centers for emergency operations, and for integration of satellite data with other relevant data in the design of disaster warning system. In the emergency relief phase, GIS is extremely useful in combination with GPS (Global Positioning System) in search and rescue operations in areas that have been devastated and where it is difficult to orientate. In emergency rehabilitation phase GIS is used to organize the damage information and the post disaster census information and in the evaluation of sites for reconstruction.

Intelligent integration of heterogeneous data sources based on semantics (represented by ontologies) represents key factor for realization and usage of platform for integral management of hazardous and emergency situations. Semantic integration will allow for highly flexible information services as well as effective information exchange and integration. Connecting geographically distant and functionally and structurally different services for the purpose of establishing common management mechanism, this platform will enable creation of virtual organizations for hazardous events management.

In general, the purpose of our research is development of the meta models, methodologies and tools to crate multimedia platform for integrated hazard maintenance. GinisEmergency (Fig. 2) is based on GeoNis [13], [14] interoperability platform for integration and accessing distributed data required for emergency management.

Objectives we are striving to accomplish include [14]:

- Access to distributed sources through a single integrated system
- Automatically resolving semantic heterogeneities
- Identify relevance of available data sources
- Responsive query time

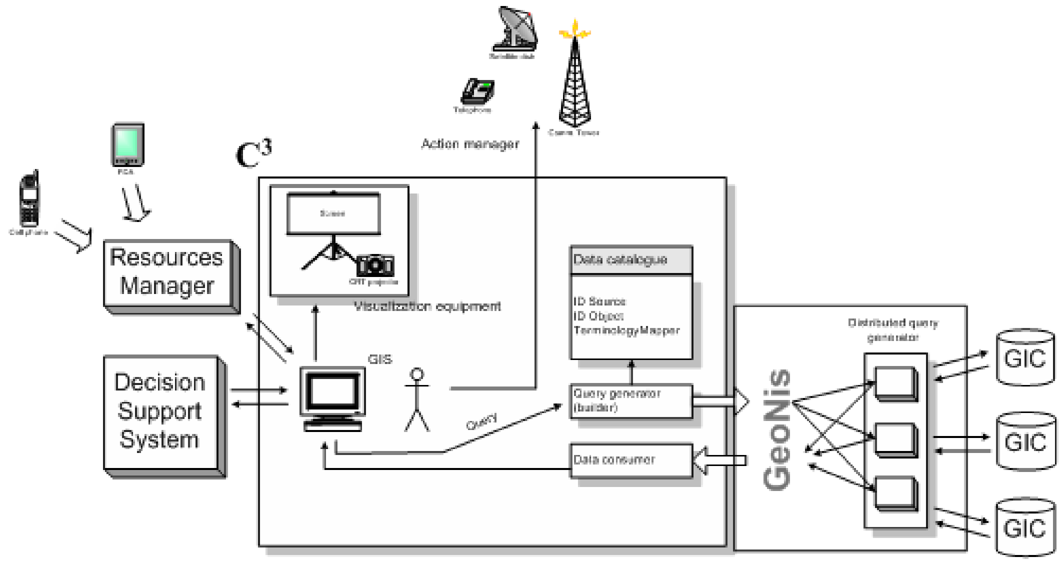

Fig. 2: Proposed architecture for GinisEmergency

All cited requirements are fulfilled through GeoNis interoperability platform. GeoNis is a framework for interoperability of GIS applications that have to provide infrastructure for data interchange in the local community environment. Data sources are local services and offices that own geo-data in some format.

GeoNis platform is inserted between C3 (Command and Control Center) unit and specific, distributed GIC data stores (Fig. 2). Its role will be explained later more thoroughly. Several of its components are also integrated in C3 unit offering query translation services in order to enable interfacing with GeoNis. These components include Query generator (builder), Data catalogue and Data consumer.

In the envisioned C3 facility typical user of the system is emergency manager. User interface presented to the emergency manager is a GIS application running on the workstation (Fig. 3). This application is interfaced with other components: Resources Manager, Decision Support System and GeoNis interface towards data sources. GIS user interface incorporates various visualization devices ranging from simple monitors, video projectors and touch screens up to virtual reality sets and rooms. Standard command techniques are used implementing radio, fixed and mobile telephone lines.

Resource Manager component is keeping track of resources available in the field. All information from the environment concerning risk factors and information about developing emergencies is routed to the system through this connection. Mobile nature of the personnel in charge of this is dictating usage of mobile and hand-held devices for information acquisition and reporting. This part of the system heavily relies on wireless and mobile networks and also on various mobile positioning techniques (GPS as well as GSM, UMTS and WLAN locating methods).

Decision Support System is supposed to act as knowledge repository. This is the target database where knowledge acquired from recovery phases of previous emergency situations is stored. It also includes predefined response plans constructed in preparedness phases. Its role is to present emergency manager with a choice of response plans applicable to currently developing emergency. Response and recovery personnel are already trained for these predefined procedures and ready to act immediately. Finally, DSS is basing recommended decision on data gathered from other GICs like location, distance, timing, dangerous hotspots etc. and assigning duties to various units, rearranging routing for vehicles etc.

I. GeoNis Interoperability Platform

As previously mentioned, GeoNis is a sort of buffering interface between C3 unit and various GICs. Typical user of Ginis Emergency is not and does not want to be aware of terminology and database specifics of various GICs. GeoNis is a generalized framework for GIS interoperability. It provides infrastructure for data interchange in the local community environment [15]. The basic architecture of GeoNis framework is shown on Fig. 4 [16].

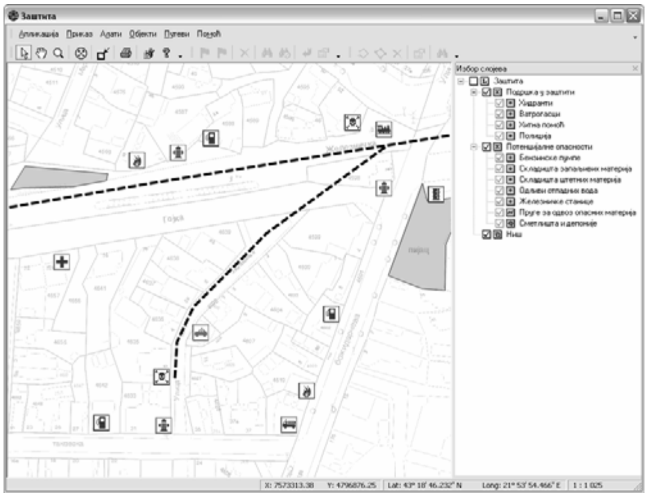

Fig. 3. GinisEmergency GIS application

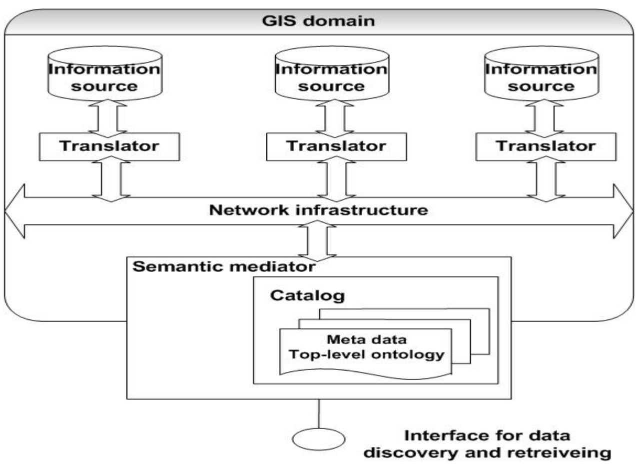

Fig. 4. GeoNis framework for semantic interoperability

Generic architecture of GeoNis recognizes several different components that have important role in geo-information discovering and retrieving process:

- Information source – in each node of GeoNis framework there exists GIS application and corresponding (spatial and non-spatial) data sources. Data in these local data sources are accessible according to user privileges.
- Translator - component that translates information flow between information source and GeoNis system.
- Semantic mediator - requests for specific data set are forward through.
- Catalog - maintains metadata and all shared/common geographic data as addition to domain oriented GIS applications.

When user (human or GIS application) issues a request, system have to decide which source (or sources) is able to deliver the requested information. The simplest way to do that is to query each information source that is registered. If the request succeeds, the results are delivered to the requester. In the sense of intelligent information discovery and retrieval such behavior is not aspired. We want the system to be aware which sources are worth of querying and which are not. This goal can be reached by providing an abstract description of the content of an information sources using ontologies.

The basic components providing interoperability in GeoNis are Semantic Mediators. Semantic interoperability in GeoNis, resolved by Semantic Mediator, is the ability to share geospatial information at the application level, without knowing or, understanding terminology of other systems. Semantic Mediator component acts as an access point for a number of independent geo-information sources and allows integration of their information while bridging over the semantic differences among them. Semantic Mediator enables users to access multiple information systems as though they were a single system with a uniform way to retrieve information and perform computations. It accepts high-level requests from users and automatically translates them into a series of lower-level requests for different GICs.

The total number of geo-data providers for emergency management in local community environment is indeterminable and unlimited. This implies the need for a flexible approach that can deal with the existing and the future geo-data providers in interoperable systems. A standard model for spatial data is the first step to approach the solution for schematic and syntactic heterogeneity. The Open Geospatial Consortium (OGC) specification aims to solve the problem of heterogeneity at the spatial data modeling level. Because of that, GeoNis uses OGC standard as a common data model, to represent geo-data at mediator level. Data models of local information sources are translated into a common model using wrappers.

According to GeoNis architecture, each GIC (i.e. local service or office) contains GIS application and corresponding (spatial) database. For each data source there is a translator (or wrapper) which logically converts basic data objects to common information model. Ginis OLE DB data provider is an example of translator implementation [13]. This approach (unified methods for data access) allows simple chaining of translators. Also, we can easily add new information sources without influencing other GIC environments. In order to do this, we have to provide semantic mapping only for the GIC environment with a new information source. The next layer (Semantic Mediator) performs mediator functions which include transformation of data and mapping between data models.

II. Conclusion

The significance of the research is in creating unique emergency management methodology and developing the software (based on the mentioned methodology) which can be applied in emergency management. Multidisciplinary approach is based on the new information technologies (GIS, Web services, ontology, semantic integration), expert's knowledge about structure and processes in the hazard management system, hazard emerging and possible effects on living environment, as also combine the knowledge of expert's working in different

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domains. This will improve the process of emergency management. The proposed models and services will be specialized for application in involved organizations and public services. So, the solution efficiency provided by proposed system will be especially valuable for local community and local authorities.

The advantages of successful information integration in emergency management GIS applications are obvious for many reasons:

- Quality improvement of data due to the availability of large and complete datasets.
- Improvement of existing analysis and application of the new analysis.
- Cost reduction resulting from the multiple use of existing information sources.
- Avoidance of redundant data and conflicts that can arise from redundancy.

REFERENCES

[1] Stoimenov L., Djordjević-Kajan S., "An architecture for interoperable GIS use in a local community environment", *Computers & Geosicence*, Elsevier, 31(2005), pp.211-220.

[2] ESRI White Paper, (1999, July). GIS for emergency management. Available: http://www.esri.com/library/whitepapers/pdfs/emermgmt.pdf.

[3] Zlatanova S., Holweg D., "3D geo-information in emergency response", in: *Proceedings of the Fourt International Symposium on Mobile Mapping Technology* (MMT'2004), 2004, March 29-31, Kunming, China 6p.

[4] Balaji D, Sankar. R, Karthi. S, (2002, February 06-08)"GIS approach for disaster management through awareness - an overview", *Map India 2002 Proceedings*, New Delhi, India, Available: http://www.gisdevelopment.net/proceedings/mapindia/2002/index.htm

[5] Fonseca F., "Ontology-driven geographic information systems", PhD thesis, University of Maine, 2001.

[6] Vckovsky A., *International Journal of Geographic Information Science - Special Issue: Interoperability in GIS*, 1998, 12(4).

[7] Stoimenov L., Djordjevic-Kajan S., & Stojanovic D., "Integration of GIS data sources over the internet using mediator and wrapper technology", In: *Proc. MELECON 2000, 10th Mediterranean Electrotechnical Conference*, Cyprus, 2000, Proc. Vol.1, pp. 334-336.

[8] AGILE Association of GIS Laboratories in Europe (2004), Tutorial & Workshop Interoperability for Geoinformation, *7th AGILE conference on Geographic Information Science*, Available: http://agile2004.iacm.forth.gr/

[9] GDE Geographic data exchange standards (2002), Available: http://www.iecapc.jp/06/diffusenew/standards/gis.html

[10] Bernard L., Einspanier U., Haubrock S., Hübner S., Kuhn W., Lessing R., LutzM., & Visser U., "Ontologies for intelligent search and semantic translation in spatial data infrastructures", *Photogram-metrie - Fernerkundung - Geoinformation*, 2003, pp. 451-462

[11] Klien E., Einspanier U., Lutz M., Hübner S., "An architecture for ontology-based discovery and retrieval of geographic information", Proceedings printed as book, Eds. F.Toppen, P.Prastacos, *7th AGILE Conference on Geographic Information Science*, AGILE 2004, Heraklion, Crete, Greece, April 29 – May 1, 2004., ISBN 960-524-176-5, 2004, Crete University Press pp.179-188.

[12] Spaccapietra S., Cullot N., Parent C., & Vangenot C., "On spatial ontologies", *In Proceedings of the VI Brazilian Symposium on Geoinformatica* (GEOINFO 2004), Campos do Jordao, Brazil.

[13] Stoimenov L., Stanimirović A., Đorđević-Kajan S., "Realization of component-based GIS application framework", Proceedings printed as book, Eds. F.Toppen, P.Prastacos, *7th AGILE Conference on Geographic Information Science*, AGILE 2004, Heraklion, Crete, Greece, April 29 – May 1, 2004., ISBN 960-524-176-5, 2004, Crete University Press pp.113-120.

[14] Stoimenov L., Predić B., Mihajlović V., Stanković M., "GIS interoperability platform for emergency management in local community environment", Proceedings printed as book, Eds. Fred Toppen, Marco Painho, *8th AGILE Conference on GIScience*, Estoril, Portugal, 26-28.5.2005., pp. 635-640.

[15] Stoimenov L., Đorđević-Kajan S., "Framework for Semantic GIS Interoperability", *FACTA Universitatis, Series Mathematics and Informatics*, 17(2002), pp.107-125.

[16] Stoimenov L., Đorđević-Kajan S., "Realization of GIS semantic interoperability in local community environment", Proceedings printed as book, Eds. M.Gould, R.Laurini, S.Coulderon, ISBN 2-88074-541-1, 2003, Presses Polytecniques et Universitares Romandes, *6th AGILE conference on Geographic Information Science*, "The Science behind the Infrastructure", AGILE 2003, Lion, France, April 20-23.2003. pp.73-80.