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The possibilities of GIS in preventing serious industrial accidents caused by hazardous substances

PhD Thesis

Author's review

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The scope of the thesis

Chemical industry is one of the most dynamically developing sector today. The production, storage, processing and use of hazardous substances carry the risk of the occurrence of serious industrial accidents. If you work with hazardous substances, the risk of an accident is inevitable. Hazardous chemicals released form enclosed spaces or technological processes may cause injuries and even death, may pollute the soil, the atmosphere, the food, drinking water and fodder reserves, may seriously harm the wildlife and the man-made environment. In the case of injuries caused by hazardous materials, taking due measures in due time is an important factor of the minimisation of damage.

Protection against serious industrial accidents is a complex activity, which involves the technical aspects of prevention, the mitigation of the harmful effects of accidents, and measures towards the protection of the population.

The subject matter of the thesis is the **development of the concept of such geographic information system** for hazardous operation, which is the most appropriate for the local conditions, covers the entire country, is based on realistic map and attribute data, has a unified structure, is up-to-date and efficiently supports protection efforts, in view of the **safety reports** of hazardous chemical factories falling in the category of upper tier establishments. The thesis discusses the **geographic information system techniques, procedures and methods**, and analyses the map and attribute data, the problems arising from data analysis and data publication, as well as the methods applicable to specific purposes. It also recommends new methods based on data collected from a sample area.

The topic of the thesis is an integral part of research areas that belong to the scientific discipline of military technology. In view of recent serious industrial accidents I am convinced that my research area contributes and gives orientation to disaster recovery, the Hungarian Defence Forces, the law enforcement, various organs of the state administration, and also the civil sector, including the operators of hazardous facilities. Probably the most important result of the research is that it may provide a basis for developing a national **unified geographical information system for disaster recovery** that covers all hazardous factories of Hungary, and is integrated in the European geometrically defined, map-based geographical information system which is suitable for various kinds of analyses.

Timely research topic

The timeliness of raising this scientific problem is primarily based on Act LXXIV of 1999 on the management and organisation of disaster recovery and protection against serous accidents relating to hazardous substances, and Government Decree 18/2006 (I.26.) on the protection against serious accidents relating to hazardous substances, which provide the legal basis for this activity. The official supervision of hazardous factories has begun in accordance with the applicable laws.

An important part of the regulations is the official approval required for hazardous activities. The procedure is based on the safety report. Its purpose is that the operator should prove that hazardous activities carried out by it do not involve risks greater than permitted, and that the operator has taken all reasonable measures to prevent potential serious accidents, and the relating consequences.

It is inevitable that economic changes cause the change of the scope of risks in terms of both quantity and quality. The efficient management of environmental issues should be a priority for all countries because safe living conditions belong to fundamental human rights.

The delimitation of the research topic

Protection against serious accidents relating to hazardous substances is an extremely complex activity, which involves the technical and organisational aspects of prevention, the mitigation of the harmful effects of accidents, as well as measures to protect the population. These activities include, although not as a major but rather an additional task, the use of geographic information techniques. Due to the limits of the thesis, not all partial areas have been discussed in full depth. The focus of the research is on hazardous factories in Hungary, and in particular **chemical factories falling in the category of upper tier establishments**. The thesis specifically discusses the possibilities of geographical information relating to the compilation of the safety report, the preparation of which is a statutory obligation of chemical factories falling in the category of upper tier establishments.

The major objectives of the research

When preparing this thesis, I have set up the following objectives:

Development of a concept for a practical geographical information system which may be applied by managers of hazardous factories, as well as managers of operative organs directly or indirectly involved in the rectification of damage, in taking efficient measures in the course of prevention and rectification activities.

- Analysis of the requirements concerning the geographical information system to be developed

Determination of the role of geographical information in the prevention of serious accidents relating to hazardous substances. Review of the legislative background of protection against serious industrial accidents caused by hazardous substances from the viewpoint of geographical information content. Taking into account of modern geographical information techniques, methods, procedures that may be used in data collection methods.

- Analysis of geographical information data included in the system

Analysis of the problems involved in the perception, reception, collection, storage, processing and evaluation of data, considering the requirements concerning the content of the safety report prepared by the upper tier establishment. Analysis of the upload related problems of the data base of the geographical information system to be established in relation to protection against serious industrial accidents. Inclusion in the geographical information system of data provided by the monitoring systems used in the protection against serious accidents related to hazardous substances.

- Examination of the structure of the geographical information system to be developed

Identification of the functions of the system and investigation of the relating requirements. Identification of the objectives of the geographical information system to be developed, from the analysis of needs to the introduction of the system. The role of data collection in the establishment of the geographical information system. Integration of the records of industrial facilities endangered by serious accidents relating to hazardous substances, based on technical and IT considerations, in the geographical information system. Analysis of the implementation of a geographical information system consisting of the following subsystems: geographical information, technology, administration and

supplementary issues. Analysis of requirements concerning map features that provide relations to locations. Unified depiction of map and design data with different technical content due to different sources. Possibilities of the integration of remote sensors and remote surveillance photo and film data in the system. Analysis of mixed management of raster and vector based map information. Solution for maintenance issues concerning the map basis and attribute data of the geographical information system to be established. Integration of CAD drawings in the descriptive data base of facilities. Analysis of the selection and evaluation of the geographical information software managing location related information. Determination of issues concerning ownership and responsibilities. Review of the issue of the right of data modification. Preparation of a development plan for the geographical information system for the prevention of serious accidents relating to hazardous substances. Review of linking map characteristics and objects to multimedia documents, reports and other web based applications. Analysis of problems relating to data publication and data provision. Review of modern geographical information applications concerning Internet/intranet data publication, taking account of relating possibilities with regard to protection against serious accidents relating to hazardous substances.

- Modern data collection and display for geographical information sample project

Data collection for a sample geographical information system and for setting up a sample data base. Filling up a sample data base with geometric, special and other attribute data that are suitable for analysis. Possibilities of using the data from the geographical information system in preventing accidents. Review the effect of an event of damage from the viewpoint of fixed locations. Retrieval of geographic and attribute data of selected facilities and objects, with 3D display and navigation in the holographic space. Application of immediate data collection and processing method in relation to the survey of the consequences of an accident.

Research methods

In the course of my research my essential considerations were to comply with the principles of **scientific justification, systematic approach, observations and synthesis-oriented conclusions**.

I intended to achieve my objectives by the analysis of relating literature and other documents, as well as my **own experience, experimental measurements and making conclusions**.

I have studied the **regulations and methodology** concerning the protection against serious accidents relating to hazardous substances, searched for, analysed and critically assessed relating books, notes, studies. I scrutinised the safety report of several hazardous factories from the viewpoint of geographical information. I **reviewed and compared** similar systems, geographical information techniques and methods currently in use in Hungary.

I carried out my **research** in hazardous factories falling in the category of upper tier establishments in Hungary, and used my relating results, as well as the results of my **consultations** with the associates working there, in the course of creating the concept of the geographical information system concerning hazardous operation. My research was based also on my experience gained through my previous scientific activities.

My thesis is basically prepared by using **facts** and **experimental measurements**, however, it also implies individual conclusions, recommendations and approaches.

My research activity was hindered by the fact that the modern geographical information methods, techniques and procedures used in the evaluation of serious industrial accidents caused by hazardous substances, and in particular in the course of the preparation of the safety report, are a thoroughly researched area neither in Hungary nor internationally, and the relating Hungarian and international literature is rather limited. A further hindrance was the limited financial resources with regard to filling up the experimental and geographical information system with geometric data pursuant to the survey method proposed by me. My research work was facilitated by the Hungarian authorities introducing internationally recognised legislation regulating the protection against serious industrial accidents, which made it possible that I obtain proper information on the content of the safety reports.

The summery of the thesis

My thesis discusses the possibilities of geographical information relating to the compilation of the statutory safety reports of upper tier chemical establishments in Hungary. I have developed a systematic concept which is suitable for satisfying the requirements raised by the original objective, in particular it facilitates the preparation of the safety report, and in addition, due to its structure, it is also suitable for setting up a national geographical information system relating to hazardous operation.

With respect to the analysis of the requirements concerning the geographical information system

In the first chapter of my dissertation I worked out a procedure through which a traditional safety report becomes a set of data suitable for management by cutting edge geographical information techniques. I determined the role of geographical information systems and reviewed the legislative regulations concerning the protection against serious industrial accidents caused by hazardous substances from the viewpoint of geographical information content.

I summarised all up-to-date geographical information techniques, methods and procedures that may be applied through data collection. I endeavoured to give priority to primary data collection methods, and neglected, where it was possible, the expensive subsequent processing of data from previous surveys. The data of the safety report are integrated in the geographical information system partly as geometric and partly as attribute data. I discussed the various types of laser scanners. These devices play an important role later in my thesis, in particular with regard to geometric data collection.

The other major type of data collection serves the purpose of collecting attribute data. As the geographical information system to be developed focuses on hazardous factories falling in the category of upper tier establishments, also **the collection of attribute data is reviewed with due consideration of the elements of the safety report.** The system design I developed includes all data required by the legislators. The data structure of geographical information provides all the advantages implied in managing geographic data links. The solution I developed complies with the obligations in a manner that it provides the data in a very informative, cutting edge digital format.

With respect to the analysis of the geographical information data included in the system

I reviewed the problems arising from the perception, reception, collection, storage, processing and evaluation of data. I developed the structure of the system design on the basis of the law specifying the elements of content of the safety report.

The entire long-tem implementation process was „built" upon data collection, because this seemed to me the only feasible approach. I also analysed the potential problems with regard to filling up the data base of the geographical information system relating to protection against serious industrial accidents. I also determined the set of considerations relating to the selection of the appropriate geographical information system.

With respect to the examination of the structure of the geographical information system to be set up

The second major chapter of the dissertation focuses on the complex issue of giving geographical information support for operational duties that facilitate the prevention of serious industrial accidents caused by hazardous substances. During my visits to the National Disaster Recovery Directorate and certain hazardous factories I developed a plan according to which a long-term project may be implemented. I did my best to consider all opportunities and conditions. I also made a few general comments, which demonstrate the differences between the current multiple development projects and my concept.

In summary, I think that **technical requirements must be given preference to the requirements arising from geographical information in the case of factories**. In the long term both types of data will be needed as technical requirements cannot be simply satisfied within the system.

The major focus of the project must be data collection, and not the acquisition of hardware and software elements, mostly because of financial considerations. As long as there is not enough up-to-date, recent and accurate data available, we certainly don't have to purchase expensive hardware and software resources that get amortised quickly. Instead of software that could be used exclusively for geographical information purposes, I recommend to acquire software products that are suitable for **both geographical information and also technical purposes**. In the case of clients with average needs, , it should be endeavoured to use **free or cheap software products** for publication in the web due to the great number of potential users.

I developed the major phases of setting up a comprehensive technical geographical information system concerning hazardous operation. My main consideration was to create a

concept that is easy to use, easily feasible, and which takes into account the potential conflict of interest between privately owned factories and state organs. According to my concept, the system to be set up consists of a national comprehensive subsystem and a factory-level subsystem, where both include additional modules that are separated in terms of function because it is reasonable to apply different software solutions for the various elements of individual modules.

The development plan has been broken down into **three phases**.

In the **first phase** no genuine development is carried out, this is the period of making decisions. This is the time for identifying the final work schedule, clarifying organisational issues, responsibilities, and determining the quantity and composition of resources to be made available for the implementation of the project. The person who will be in charge of providing the data concerning hazardous factories for the system should be appointed and also the form of data provision should be decided.

In the **second phase** the filling up of the system with data begins. Focus should be given to the digital processing of data that can be easily structured, and also the non-structured data are collected and operated as a kind of document archive. It is the second phase when training takes place with regard to the usage of the system. The various territorial and organisational units should be informed and convinced of the practical advantages of the system, and the paper-based reporting system is transformed.

From the viewpoint of development the **third phase** is the last one. The processing of the entire data set is completed, and level or readiness is achieved which could receive regular updates of safety reports. By the end of the third phase the new system will be set up, and the storage of data is performed primarily in digital form, and the organised set of data is suitable for obtaining such analyses and statistical data which the previous system was unable to provide.

With regard to up-to-date data collection and display method for geographical information sample project

In the third chapter of my dissertation I discussed the **use of a geographical information related sample data base** built up in a modern and forward looking manner. First I reviewed a part of a hazardous factory by a more traditional, map-based approach. Obviously, the **entire work procedure was based on digital data**, and processing by computer. The base map of the factory part was prepared in digital format, and it was

supplemented by various other surveys. The most important ones are the layout map of the utility lines of the factory part (with data base connections) and the layout drawing of machines and equipment within buildings. The geometric survey of the piping system within the factory part was made by cutting edge terrestrial laser scanners. On the basis of the raw point cloud vector-based geometric data were obtained in 3D by CAD software, which reflect the actual sizes and are suitable for performing various analyses.

I pointed out the paradox that although the generally used geographical information and technical systems are capable of managing highly developed 3D data, we always have to deal with the limits of 2D display surfaces. In order to solve this problem, I suggest the use of **holovision display**. One of the biggest advantages of holovision is that, unlike other types of displays, it facilitates 3D display.

Beyond the issues of display, I suggested a 3D geographical information application where navigation in the data base and also the searches are carried out in 3D. This can be achieved by holovision display that are supplemented by appropriate movement sensors. I discussed how the joint application of these techniques may assist in reviewing an entire protection procedure, and how we can display in 3D not only the national level but also the environment of the factory and even the inside of the buildings and the very details of the faulty part.

I developed a sample data base by which the main characteristics of setting up the geographical information data base of a hazardous factory falling in the category of upper tier establishment may be modelled.

I raised the risk analysis to a new level by placing the analysis of emergency scenarios in a 3D display environment. I pointed out that positioning in 3D environment and the introduction of a holovision-based location and movement sensors could be entirely independent of the previous keyboard and mouse based data recording. The use of 3D movement sensors provide for exceptionally spectacular usage of descriptive data relating to graphic elements, and other documents managed separately.

In the closing part I gave an example which also constitutes an innovation. I supplemented the positioning of detectors used for tracing hazardous substances on aircrafts by making the data flowing in upon an accident part of the geographical information concept I developed. In this manner the data received on-line are available for geographical information analyses, and thematic maps may be prepared on this basis.

By uniting the on-line LIDAR observations with holovision display technology, you get a real-time analysis and prevention system for accidents in hazardous factories, which performs both data collection and data publication in 3D, and facilitates the complex protection efforts by the immediate 3D processing of detected data, and the optimal distribution of available resources.

The geographical information system developed by my concept is based on technologies that will be spreading in the near future. A specific application may be the preparation of the safety reports of hazardous factories falling in the category of upper tier establishments by the use of cutting edge 3D technologies, as discussed above.

Conclusions

With regard to the analysis of the requirements relating to the geographical information system, I drew the following conclusions:

- We cannot even talk about the role of geographical information with regard to the prevention of serious industrial accidents caused by hazardous substances as long as we do not have such geographical information system concerning hazardous operations which is unified, works with a consistent set of data, operates at least with regard to upper tier establishments, available also for the authorities, covers the territory of the entire country, and is based on genuine data, and whose data content could compete with the quantity of data currently stored on paper.

- The cutting edge GIS technology is currently not yet widespread in protection against serious industrial accidents in the case of chemical factories falling in the category of upper tier establishments although in the case of an emergency they could provide significantly easier access to data and a more complex data analysis.

- The legal regulations currently in force do not specifically require the use of GIS, and data provision is performed on paper base, which has several disadvantages.

With regard to the analysis of the data included in the geographical information system, I drew the following conclusions:

- The key of the feasibility and success of the geographical information system is the widespread access to the data.

- Instead of acquiring hardware and software products, the project must **focus on data collection**, particularly for financial considerations.

- Instead of software products suitable only for GIS purposes, priority is given to use **software products that are suitable for both GIS and technical purposes.**

With regard to the assessment of the development of the geographical information system, the following conclusions may be drawn:

- It is possible to set up a geographical information system geographical information system that facilitates that the managers of hazardous factories, and the operative managers of organisations directly or indirectly involved in the rectification of damage, take efficient measures in the course of prevention and rectification activities.

- The geographical information system developed by my is capable not only to provide for national data provision but also to provide for the intra-factory control system.

With regard to the setting up of the GIS sample project, the following conclusions may be drawn:

- In the case of modern geographical information systems, also the incoming data must be in modern form. When surveying hazardous factories **3D information must be emphasized,** and such devices should be used that are capable of producing a high definition 3D point cloud. Also **laser scanning surveys** should be viewed as a priority when capturing data either by terrestrial or airborne methods..

- In the case of hazardous factories falling in the category of upper tier establishments it is essential to have accurate 3D data on the factory and on its entire internal structure. In order to maintain the operability of the otherwise complex system, it is necessary to provide for advanced and realistic display and easily manageable 3D navigation capabilities. All elements of an advanced geographical information system must be in compliance with the advantages of 3D display.

- Display is the less advanced element of current geographical information systems. The future is holovision display, where **the user of the data base manages the system through movement sensors, by 3D data links, by calling the relevant data, datasheets and inquiries**.

- All such data must be uploaded that are needed for making decisions quickly, and the system must be capable of displaying the stored data and analyses in a clear, simple and easily

understandable manner, also in case of emergencies.

- Future systems must be capable of receiving and immediately processing data from on-line sensors fixed on aircrafts. The processing, display and impact analysis of data must be carried out in real 3D projected environment.

New scientific achievements

1. After the thorough review and analysis of the legal regulations and scientific documents concerning the serious industrial accidents caused by hazardous substances, from the viewpoint of geographical information content, **I developed the concept of applying integrated geographical information systems concerning hazardous operation.**

I was the first to develop a system consisting of a national subsystem and a factory level subsystem, that has a modular structure, which operates with regard to upper tier chemical establishments. This GIS system has a **three-phase development scheme**, it may be used also by the authorities, appropriate for local conditions, covers the entire country, is based on real data, has a unified structure, efficiently facilitates protection.

I have provided detailed solution for adding to the national level unified GIS network a relating but separate intra-factory GIS control system.

2. **I have provided a system** including modern GIS techniques, procedures and methods that may be used when planning protection measures against serious accidents caused by the industrial use of hazardous substances for data collection procedures.

I have developed a procedure by which the traditional safety report may be transformed into a modern data cloud manageable by GIS methods.

I have developed primary data collection procedures carried out by various types of laser scanners with regard to the development of the geographical information system of hazardous factories falling in the category of upper tier establishments.

3. By building up a geographical information system at a sample area and a sample data base, **I was the first to develop** a scheme for the 3D analysis of accidents, and **I raised to a new level** the relating risk analysis.

I simplified the use of descriptive data relating to graphical elements and documents managed separately by applying 3D positioning and holovision system based 3D position and movement sensors.

4. By uniting the on-line LIDAR observations with holovision display technology, **I developed a real-time analysis system** for accidents in hazardous factories. Beyond the issues of display, I created a 3D GIS application where navigation in the data base and most of the searches are carried out in 3D environment.

5. **I was the first to develop** a method that provides for transforming the current safety report into a complex 3D GIS application, where interactions within the data base may be carried out by movements and selection, and it is easy to compile the elements of the safety report.

Recommendations of the thesis

1. The conclusions and results set out here may be beneficial for both the authorities and the chemical factories falling in the category of upper tier establishments:

   - for the production and storage of the statutory safety reports and relating documents in a nationally unified, modern, digital form, pursuant to a structure that is suitable for setting up geographical information systems;

   - for the preparation of a work schedule and project plan that identify the phases of the development of such system;

   - for the preliminary assessment of the consequences of decisions made in relation to the prevention of serious accidents, based on the knowledge of the geometric data relating to the decisions;

   - the development of, and data uploading to, operational systems working in cooperation with the national system, and partly using the data of the national system.

2. This dissertation may be used in the framework of the educational system of professional disaster recovery and the Miklós Zrínyi National Defence University, as well as in the educational activities of technical universities and colleges dealing with GIS.

3. The conclusions of the dissertation may provide a basis for developing unified regulations and a set of requirements relating to the geographical information concerning hazardous factories.

4. The contents of the dissertation may provide a basis for further research in this area. The research may be extended to all hazardous factories of the country.