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The use of geographic information systems in major accident risk assessment and management

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Abstract

The paper discusses the use of modern information technologies, and in particular geographic information systems (GIS), in the management and control of major accident risk. For this purpose, the regulatory framework of the recent "Seveso II" Directive is briefly described. This asks for more transparent procedures and decision-making, and requires consultation of the public in land-use and off-site emergency planning. Correspondingly, new demands are put to support tools being developed. The main features of tools dealing with hazard sources mapping, risk assessment, risk management, and emergency planning are discussed and examples are given. Moreover, it is argued that, if appropriately designed, their use can enhance the dialog between plant operators, authorities and the public to facilitate a consensus on risk issues. Finally, limitations in the use of these tools and prospects for future developments are discussed.

Keywords: Seveso Directive; Major accident hazards; Risk assessment; Emergency planning; Land-use planning; Geographic information systems

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1. Introduction

The analysis and management of risk of major accidents in industrial activities involving dangerous substances is a subject of major concern to the regulatory agencies

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after a number of disasters that occurred in both industrialised and developing countries. After gaining experience with the implementation of the early “Seveso Directive” [1], the “Seveso II Directive” (Directive 96/82/EC) was issued in 1996 [2] as a legislative framework in the European Union for the control of major accident hazards in fixed installations. In addition to reinforcing provisions for prevention, the new Directive focuses on social-organisational aspects of the control policies [3], e.g. land-use planning (LUP) around industrial installations with provisions for information and consultation of the public, which shall also be consulted on the drawing up of emergency plans.

Each member country, by adopting the Directive, establishes a national legislative and regulatory framework for risk management. According to the inventories involved, each establishment falling within the terms of application of the Seveso II Directive has certain obligations, such as to submit to the authorities a Notification or a Safety Report. The Notification contains a description of the establishment and the processes taking place in it (Article 6); and of the adopted Major Accident Prevention Policy (MAPP) and Safety Management System (SMS, Article 7).

The Safety Report aims at demonstrating that:

- major accident hazards have been identified;
- all necessary measures (including MAPP and SMS) have been taken to prevent such accidents and to mitigate their consequences;
- internal emergency plans have been drawn up;
- adequate information is given to enable the authority to define the Land Use Policy and the External Emergency Plan.

In certain Member States (e.g. the Netherlands, the UK), the Safety Report, and especially the information needed for land use planning, includes also risk quantification (QRA).

QRA is a well-consolidated procedure [4,5] applicable to both fixed installations and to the transport of dangerous goods by road, rail, pipeline and waterways. It is used to inform a number of decisions, such as cost effective design changes to reduce the risk, siting and LUP policy [6], emergency plans [7], choices of routes for the transport of dangerous goods, etc. At this purpose, however, QRA needs the integration of many data, e.g. on the process, hazardous substances, accident scenarios and meteorology with cartographic data of the area of interest. This calls for the use of geographic information systems (GIS). The rapid improvement, since early 90s, of the performance characteristics of personal computers, has made generally available powerful desktop GIS, which raised a process of development of GIS-based support tools for risk management for decision making purposes. A major conference on this subject was held in the Netherlands in 1997 [8], where several papers dealing with GIS applications in environmental and risk studies were presented.

Furthermore, the generalised use of the web allows dissemination of risk information and control actions in a way, which has no comparison with the past.

The paper is organised as follows: Section 2 briefly summarises the main aspects of QRA and shows the types of geographically referenced data needed. Section 3 describes the main characteristics of four GIS-based support tools developed for risk analysis and management. The first tool serves at monitoring, mapping and control of the 'Seveso' sites in the European Union at a Community and national level, while the second one focuses at a regional and local level. The third tool supports area risk assessment, management and control, while the fourth tool supports emergency planning for fixed installations. Finally, in Section 4, the main benefits and limitations of such systems are discussed.

2. The accident risk related to installations involving dangerous substances

The QRA procedure can be sub-divided into four main steps, as shown in Fig. 1, i.e.: Hazards Identification, Accident Frequency Estimation, Consequence Assessment, and Risk Calculation and Presentation. The results can be summarised by means of risk indicators, the most important of which are the local, individual and societal risk.[2] The local risk, represents the value of the annual frequency of occurrence of the reference damage (e.g. the death), at any point of the geographical area, for a person permanently present 24 h a day, with no protection and no possibility of being sheltered or evacuated. This is a useful figure to characterise the risk at a given location. The local risk is represented on the site map by means of risk contours; i.e. closed curves connecting points of equal risk. The individual risk has a definition similar to the previous one. It takes into account the probability of the presence of a person, depending on the category he belongs to (resident population, workers, commuters, tourists, etc.), as well as of his possibility to be protected from the effects of the accident. This is a figure useful to characterise the risk at a given site depending on its occupancy. Also, the individual risk is represented by risk contours. Finally, the measures of Societal Risk concern the whole geographical area of interest and require the knowledge of the population distribution. F–N curves and I–N histograms are used to represent the societal risk. An F–N curve describes the cumulative frequency (F) of accidents from all considered sources leading to the reference damage (e.g. death) for a number of people equal to or greater than N. It is a figure useful to characterise the societal dimension of possible accidents. An I–N histogram describes the distribution of the number N of people in the impact area exposed to an individual risk range I; it is a figure useful to characterise the societal exposure to risk.

As shown in Fig. 1, QRA results can be applied in a number of decision-making processes. A complete QRA or an assessment of consequences of selected accident scenarios is included in the safety report that the operator must submit to demonstrate that adequate safety measures have been taken to prevent a major accident and to minimise the consequences to man and the environment. According to the Seveso II

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[2] Several indicators are being used for characterising individual and social risk. In the following, reference is made to the definitions used in a project described later on this paper (see Ref. [20]).

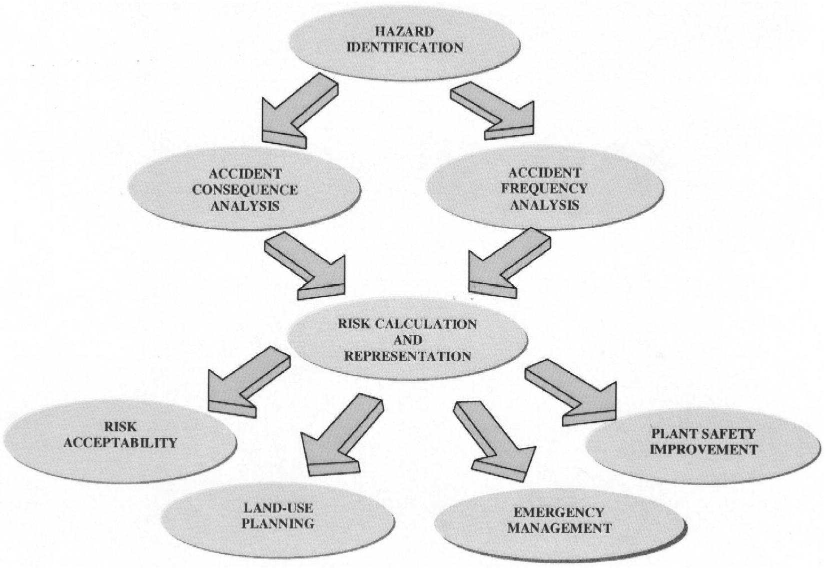


Fig. 1. Simplified diagram of the quantitative risk assessment procedure.

Directive, the safety report and the adequacy of such measures are subject to judgement by the authorities that shall use the information therein in order to:

- establish adequate inspection systems on the operation of the plant;
- plan for external emergencies;
- control that the uses of land be compatible with the risk;
- assess risk of domino effect accidents for neighbouring plants;
- and, ensure that persons liable to be affected by a major accident be kept informed on the accident hazards.

The public, whose active participation in the decision-making process is explicitly recognised, must be consulted on issues of LUP and external emergency plans.

All actors involved in the complex process of consensus about risk issues (see Fig. 2), i.e. the operator, the competent authorities and the public, need a framework for mutual understanding, communication and, possibly, conflict resolution. This implies that data,

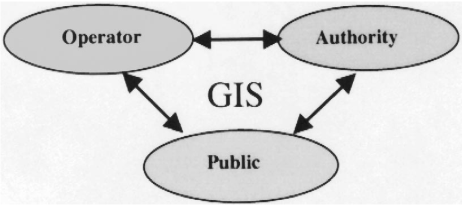


Fig. 2. The main stakeholders according to the Seveso II Directive.

assumptions made and results of each phase of the risk analysis should be presented in an understandable and retrievable form. It should be possible to run the plant risk model with various data and assumptions, to analyse alternative scenarios, to perform sensitivity analysis and to represent results on geographical maps.

In order to meet these requirements, a suitable support tool is needed, containing databases, mathematical models, modules for the treatment of maps and geo-referenced data, and a powerful graphical user interface (GUI). To this purpose, several ad hoc software tools for plant safety and accident consequence analysis with simple mapping facilities have been developed in the past. They facilitate, to some extent, the dialog between the operator and the authority, but they are far from being considered a good environment for consensus building in controversial cases.

Table 1 shows the main models and data used in the different phases of risk analysis and management. From the table, it is easy to realise the type and amount of data geographically referenced. Map scales depend on the application. Generally, for risk studies the basic site map has a scale ranging from 1:25,000 to 1:10,000, whereas for the plant layout the scale range from 1:10,000 to 1:2000.

The large amount of geographically referenced data prompts the use of GIS [9,10]. A GIS is a software tool that allows easy manipulation of spatial data, i.e. data that are characterised by information about position (x, y co-ordinates) and qualitative or quantitative attributes. Data types used in a GIS are vector (set of points, lines and polygons) and raster (grid). A layer is a vector or raster file containing thematic data such as soils, land use, hydrology, population, risk contours and so on. Overlay is the operation that allows the user to represent more layers together to better describe features. Map operators and filters can be applied to layers to get new layers, thus adding new attributes to spatial data.

Risk assessment tools developed in the 80s included the possibility of graphical representation of results on a map (see for example SAFETI [11], RISKCURVES [12]). These systems however employed an ad-hoc Cartesian system of co-ordinates rather than geo-referenced maps. An advanced tool developed at that time in the frame of collaboration between the Joint Research Centre (JRC) and International Institute for Applied Systems Analysis (IIASA) was Ispra Risk Management Support (IRIMS) [13]. IRIMS attempted to integrate a number of databases containing the information relevant to risk management with several simulation models, which could be used to address problems of environmental assessment, risk analysis and system optimisation. The prototype software tool presented an advanced user interface through high-resolution graphics and user-friendly menus. This pioneering work was followed by other support tools developed at IIASA in collaboration with Delft Hydraulics, VROM (Dutch Ministry of Housing, Spatial Planning and the Environment) and RIVM (Dutch National Institute of Public Health and the Environment) until the implementation of XENVIS [14], the risk information system for the Netherlands.

At that time, commercial GIS were expensive systems, working on Unix platforms and mainframe computers, requiring high expertise, and applications — mainly environmental and cartography — required heavy resources. In early 90s, commercial desktop GIS systems, running on personal computers, appeared in the market, thus making the benefits of this new technology available to a much larger number of users, including

Table 1
Main geo-referenced data and results in industrial risk studies
PHA: Preliminary Hazard Analysis; ETA: Event Tree Analysis.
Hazop: Hazard and Operability Analysis; FTA: Fault Tree Analysis.
FMEA: Failure Mode and Effect Analysis; CCD: Cause Consequence Diagram.
MKA: Markovian Analysis; HRA: Human Reliability Analysis.

Phase	Models	Main information and data	Geo-referenced maps and data	Geo-referenced results
Hazard identification	PHA; HAZOP; FMEA; Master logic diagram	Process information; P&I diagram; Substances database; Accidents database; External events	Plant layout; Natural hazard maps; Transport routes	Release – fire–explosions–source mapping.
Accident frequency analysis	ETA; FTA; CCD; MKA; HRA	Hazards; Process information; P&I diagram; Reliability database; Human reliability data	Transport routes, traffic data	
Accident consequence analysis	Fire, explosion, release, fragments	Substances database. Meteorological data. Source terms and storage conditions.	Plant layout. Road, rail, channel, pipeline networks. Digital terrain model.	Damage zones
Risk assessment	Risk calculation	Vulnerability data	Site maps. Satellite imagery. Plant layout.	Local point risk. Local risk contours. Individual risk contours.

			Road, rail, channel, pipeline networks. Land use and population distribution. Vulnerability centres.	$I-N$ histograms.
Risk management	Risk tolerability. LUP	Risk acceptability and LUP criteria	Local point risk. Local risk contours. Individual risk contours. $I-N$ histograms. Site maps. Satellite imagery. Plant layout. Road, rail, channel, pipeline networks.	Risk zoning. Land-use zoning. Preferred transport paths.
Emergency planning and response	Population behaviour. Traffic. Evacuation. Indoor/outdoor. Vulnerability. Minimum paths. Optimum resource allocation.	Substances database. Meteorological data. Accidents damage zones.	Road, rail, channel networks and traffic distribution. Resources location. Site maps. Satellite imagery. Plant layout. Land use and population distribution. Vulnerability centres. Damage zones.	Emergency evolution. Location of rescue services vs. time. Spatial population distribution. Traffic distribution vs. time. Location of evacuation means vs. time.

the risk analyst community. The main benefits of using a GIS platform in major accident risk management can be summarised as follows:

- To facilitate the use of geo-referenced data, thus enabling links between risk results and other inputs of the decision making process (e.g. urban growth, land uses, vulnerable centres);
- To enable easy representation and clear interpretation of results;
- To substantially reduce the time and effort for software development and testing;
- To easily customise the applications, also allowing the users to add new functions according to their needs.

The four support tools described in Section 3 represent concrete examples of GIS technology application in risk management.

3. Examples of GIS-based support tools for risk management

In this section, four support tools dealing with problems of risk mapping, risk analysis, risk management and emergency planning are briefly presented. They have been developed — at different times and within different projects — using a low-cost desktop GIS, namely ArcView for Windows.

3.1. Seveso Plants Information Retrieval System (SPIRS)

An example of the implementation of the European Commission's risk management policy in the context of the Seveso II Directive is the "Seveso Plants Information Retrieval System" (SPIRS). SPIRS is an information system on hazard and risk related characteristics of major hazardous establishments in the EU that fall under the Directive ("Seveso Plants"). The incentive of developing SPIRS originates from the numerous requests from institutions and the general public to the Commission on the number and type of plants falling under the Directive.

SPIRS provides the general public information by giving an insight into the geographical component of risk from Seveso Plants and supports the Competent Authorities of the Member States in their risk management related decision-making processes. This is done by:

- providing geographical maps of all Seveso Plants in the EU together with basic information on their risk potentials (GIS component);
- providing a flexible, largely user-defined tool to rank the risk potentials of such plants (risk assessment component, for the use of the Competent Authorities only).

Maps are for the purpose of information to the public on the risk potentials of Seveso Plants and will be accessible via the Internet.

"SPIRS Data", such as name and location of a Seveso Plant, type and quantities of dangerous substances handled on-site, etc., are defined in Article 6 (Notification) par. 2 and — for upper tier establishments — in Appendix V (Items of information to be communicated to the public as provided for in Article 13 (1)) of the "Seveso II Directive".

The legal basis for the Commission's requests to the Competent Authorities of the Member States to provide "SPIRS Data" is defined in the following Articles of the Directive:

> *Article 20 — Confidentiality: Member States shall ensure, in the interests of transparency, that the competent authorities are required to make information received pursuant to this Directive available to any natural or legal person who so requests. ...*

For upper tier establishments, i.e. Seveso Plants that have to prepare a Safety Report, it is additionally required:

> *Article 13 — Information on safety measures: 4. Member States shall ensure that the safety report is made available to the public. ...*

The risk potential ranking capabilities of SPIRS are additional tools offered to interested Competent Authorities. Its application will be restricted to the use by the Competent Authorities only, and it would not be appropriate to make it available for public use. This is mainly because any risk assessment tool has to be applied with great care. The qualitative or quantitative risk estimate obtained with such tools only makes sense if the data used to describe the operational and safety related characteristics originate from plants whose "technical background" is comparable (e.g. plants involving the same types of equipment/processes in similar operating environments), and have been collected and analysed with respect to common criteria (see also discussion at Section 4). In reality, such a basic homogeneity of the data samples used to describe plant characteristics can only be assured for small numbers of plants for which a similar safety management regime and similar operational practices can be expected. In other words, risk ranking analysis results across "all" different types of plants, across "all" countries, across "all" types of industrial processes involved, etc. would be highly misleading. The model used for this purpose is very flexible, but is not "the tool for universal truth".

The flexibility of the SPIRS system would, however, allows Competent Authorities to introduce their own risk assessment models, such as pre-defined accident scenarios. Therefore, some Competent Authorities have already expressed their interest in this option.

SPIRS is still in a developing phase and the entire spectrum of its functionality has been only recently made available to all Competent Authorities. In its final version, SPIRS will consist of one central database located at the European Commission and accessible via the Internet and local databases for the Competent Authorities of the 15 EU Member States. A "light version" of SPIRS (without GIS and database editing functions) can be downloaded from http://mahbsrv.jrc.it/spirs/Default.html for trial use. The final release of SPIRS is expected by mid 2000.

Accordingly, the status of the map of all Seveso Plants in the EU is still in its early phase:

- Only five Member States have so far reported data on their Seveso Plants;
- From some of these countries, data have been reported from only a certain number of provinces or regions, often depending on the willingness of the local authorities.

The data to be collected in SPIRS are [15]:

- Data to be provided by the Competent Authorities, i.e. qualitative and quantitative information describing each Seveso Plant with regard to its geographical location, plant characteristics and dangerous substances contained therein;
- Other data, i.e. GIS data, describing the surroundings of the plants (e.g. population within certain areas around plants).

As soon as the system is ready, the Commission will — on the legal basis of the new Directive described above — approach the Competent Authorities to notify information on their Seveso Plants and use the SPIRS tool for that purpose.

Over the last years, the number of Seveso Plants and thus of potential risk sources has increased [16,17]. However, due to lack of consistent and sufficiently detailed information on the Seveso Plants available under the “Seveso I Directive”, it is not possible to give a quantitative assessment of any trend. Under “Seveso II” classification conditions, a significant increase of Seveso Plants in the Member States is expected [18]. When the reporting from the Member States will be operative, SPIRS will provide a complete mapping of all Seveso Plants in the EU. Eventually, the system will satisfy a demand originated from the strong interest from institutions and the general public in getting access to such data.

3.2. Management of Safety Reports and mapping of hazardous sites at regional level: the GIRL support tool

Another tool for mapping of hazardous installations focusing at regional and local level has been developed under contract from IReR (the Research Institute of the Lombardy Region). The purpose of Georeferenziamento degli Indici di Rischio delle industrie Lombarde (GIRL [19]) is to support the regional authority in managing the large amount of information coming from the evaluation of Safety Reports/Notifications, and their periodical revisions, of hazardous installations located in the Lombardy Region. Moreover, the tool allows the authorities to keep track of plant modifications (including closed-down industries and sites that, at a given time, fall outside the scope of the Seveso II Directive but for which there is still concern about safety). GIRL also tracks the evolving status of evaluation of the Safety Reports, audits and inspections.

The main objectives of GIRL are:

1. To assist the regional competent authority in assigning priorities for the analysis of safety reports of hazardous industries;
2. To manage the results of the analysis of safety reports and their periodical revisions;

3. To produce statistics on the distribution of hazardous installations according to various geographical-type and risk-type parameters;
4. To calculate and display, on geo-referenced maps, accident effects.

GIRL is composed of a safety report database, containing the results of the analysis of safety reports, a simplified model for accident consequences, the data analysis module, the cartography of the region, and the ArcView user interface.

It is noteworthy that the system has been developed in a very short time, also thanks to the availability of all the necessary cartographic data. The Scale of data thematic vector maps used (plant distribution; road, rail, channel networks; administrative boundaries; land-use; residential areas) was 1:250,000. Around plants raster maps at 1:10,000 have been used to better describe the establishment and its surroundings. An example of a screen shot of GIRL is given in Fig. 3. The tool can easily evolve towards other applications, e.g. emergency planning and land use plans.

3.3. Area risk analysis and control: the ARIPAR-GIS support tool

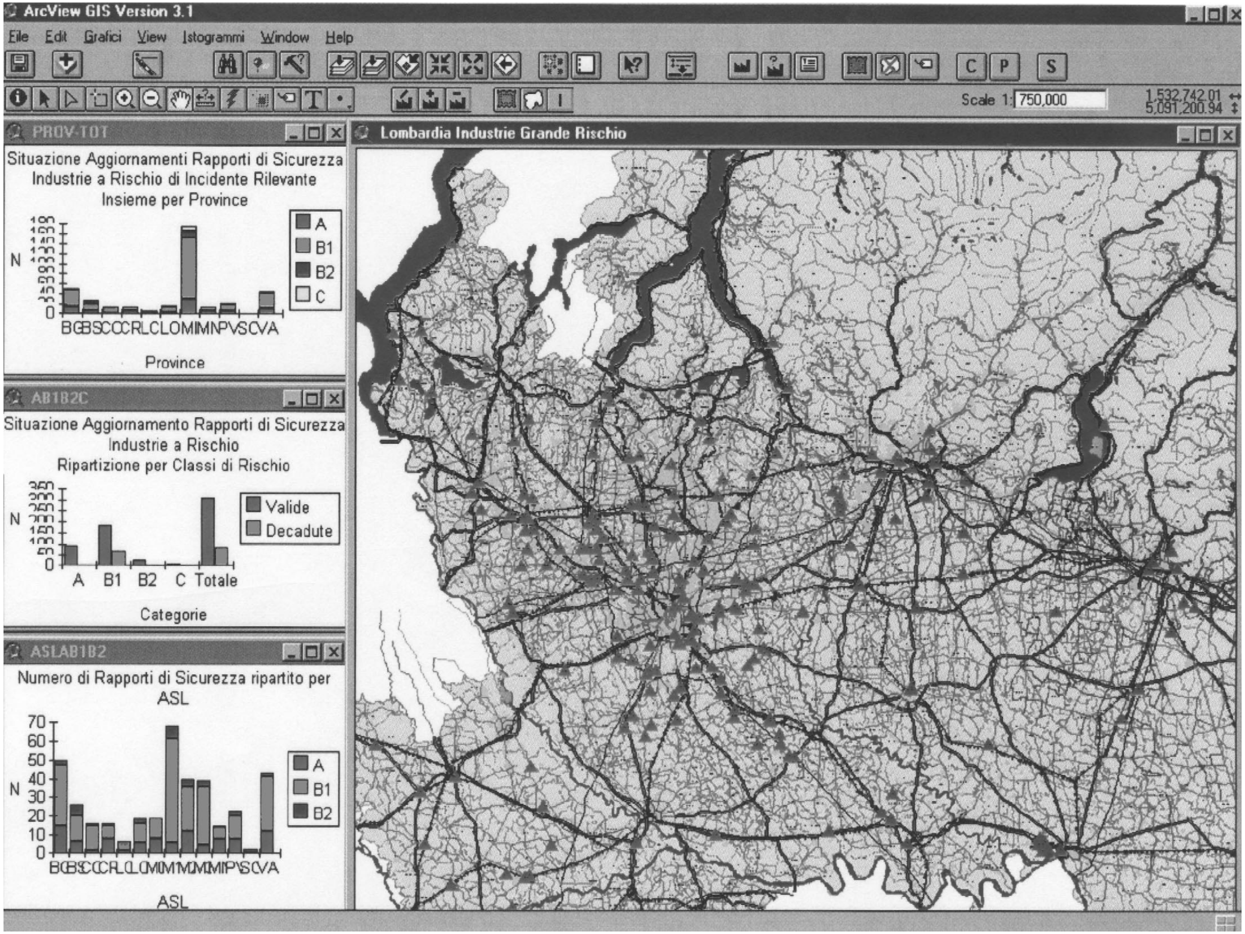
Potentially dangerous industrial plants may be located one close to another in a relatively small geographical area. These plants use hazardous substances, which are transported by road, rail, ship, and by pipelines. The determination of the risk to the population and the environment from industrial activities concentrated in a particular area is referred to as *Area Risk*.

The area risk analysis is a complex task that involves the estimation of the potential damage due to a large number of accidents that may occur during the storage, process and transportation of dangerous substances. It starts with the identification of accident hazards connected to each plant and transport activity in the area. For each potential accident, damage zones are determined. From these results, the risk is calculated on the bases of vulnerability data and the spatial population distribution.

The large amount of data collected and elaborated during an area risk study, represents an important source of information for a better understanding of the industrial activities and for the effective implementation of the risk control policy.

The ARIPAR-GIS support tool is a joint effort between the Civil Protection Service of the Regione Emilia Romagna, the Department of Chemical Engineering of the University of Bologna, and the JRC. This software is based on the methodology developed in late 80s/early 90s during the ARIPAR project, aiming at assessing the major accident risks connected with storage, process and transportation of dangerous substances in the densely populated area of Ravenna on the Adriatic Sea [20].

The simplified architecture of ARIPAR-GIS is represented in Fig. 4. The system is composed of databases and models controlled through the ArcView 3.1-interface [21]. DB-2 databases have been developed in MS-Access and contain data on plants and transport activities, accident scenarios, accident frequencies, hazardous substances, meteorological data, coefficients of interpolating functions, population distribution and population concentrated in particularly vulnerable centres. The DB-1 database represents



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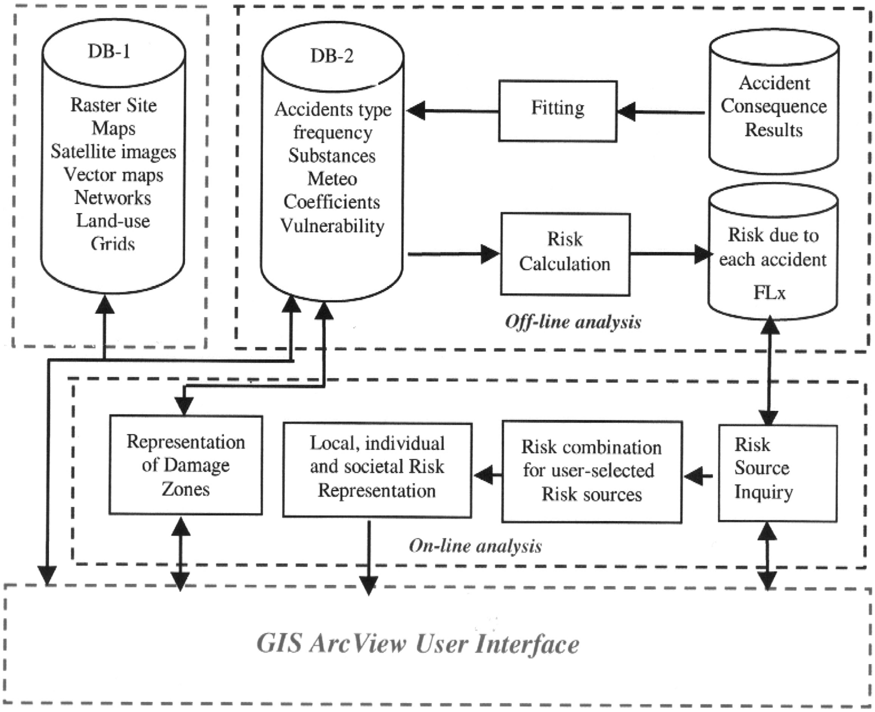

Fig. 4. Simplified architecture of ARIPAR-GIS.

that part of ArcView dealing with geo-referenced raster and vector maps, necessary for completely describing the impact area and for the representation of geo-referenced data.

The area risk analysis starts with the definition of the source area, i.e. the area including all risk sources, and of the impact area, i.e. the area in which the risk has to be determined. The dimension of the impact area is established considering many factors, e.g. the extension of the source area, the maximum distance at which effects of the accidents may impact, the transport activities, the land-use. The representation of the impact area requires geo-referenced raster maps at scale 1:25,000 or greater, depending on the desired detail.

Vector thematic maps are used to describe road, rail, waterways, and pipeline networks, vulnerability centres (e.g. hospitals, churches, schools, supermarkets), the inhabited areas and the location of possible accidents.

The risk calculation needs the definition of a grid covering the whole impact area. The user can define the grid cell dimensions; the smaller is such a dimension, the better

Fig. 3. Screen shot from GIRL showing some thematic maps of part the Lombardy Region, as well as some statistical results on the distribution of hazardous plants.

is the precision in risk results, but the higher is the computer time for risk calculation. Thus, the dimension of the grid should vary according to the land-use, e.g. source area and residential areas should be covered with denser sub-grids than non-populated areas. Merging sub-grids of different cell dimensions generates the grid needed for risk calculation.

The results of accident consequences, performed by means of an external package, are stored in DB-2 in the form of interpolating functions, whose coefficients are determined applying the best fitting programme FIT, developed during the ARIPAR project. This type of representation of accident consequences is very helpful to save computer time in the risk calculation phase.

The risk calculation module determines the risk — in the centre of each cell of the grid — due to each accident scenario considered. Results are stored into a set of files (FLx).

At the end of the off-line analysis, which represents the risk analyst's task, the system contains all data needed to proceed with the on-line analysis for the study of risk-control measures, the typical task of the public authority. With ARIPAR-GIS, the decision-maker uses very simple commands to inquire the system and to get the results in graphical form, either on maps or as curves/histograms. The main module to use is Risk-Source-Inquiry, aiming at selecting the set of risk sources for which the user wishes to determine all risk figures, namely:

- Local point risk (with relevant risk contributors);
- Local risk-contours;
- Individual risk-contours;
- Societal risk as F–N curves and I–N histograms;
- Ranking importance of risk sources for a given N (number of people exposed);
- Importance of risk typology vs. N;
- Local and individual risk variation in time.

Risk contours may be represented as risk curves or risk surfaces.

It is possible to obtain all the above listed figures for a single substance or for a class of substances, for one or more risk sources, for each risk typology, and so on. Based on the results, the user can easily identify the major causes of risk in the area. For instance, clicking with the mouse in any point of the area (e.g. where a hospital is located), the system displays the point risk value and a histogram showing the main risk contributors sorted by decreasing importance.

ARIPAR-GIS offers the user the possibility to calculate risk differences, considering that the risk in the area is changing over time as a consequence of different actions, e.g. closure of plants, installation of new ones, variations in type and quantity of hazardous substances, variation in the population distribution.

Fig. 5 shows an example of a screen shot from ARIPAR-GIS.

An obvious field of use of the results of area risk analysis is LUP. LUP issue arises from decisions related to siting of new establishments, modifications to existing ones,

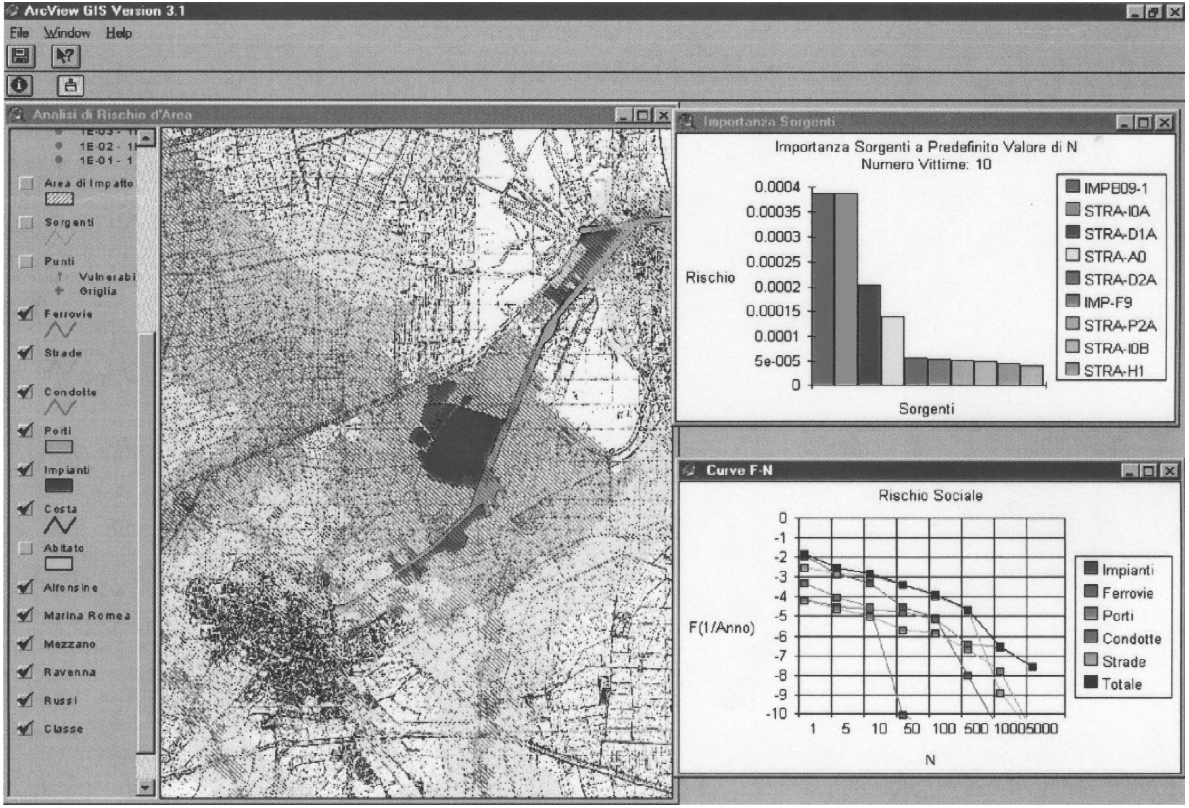

Fig. 5. Screen shot from ARIPAR-GIS showing individual risk areas on a geo-referenced map. Points in each colored area correspond to a given risk level (purple represents higher risk values). Also shown are the histogram of relative importance of risk typologies and the Societal $F-N$ risk curves.

and urban developments in the vicinity of existing establishments. Indeed, the various Member States (see for example Refs. [3,6]) confront this new requirement posed by Article 12 of the Directive, in a different way. In general, three categories of approaches can be distinguished:

- Use of “generic” safety distances, depending on the type of activity;
- The “consequence-based” approach, suggesting the establishment of safety zones according to the level of consequences of a number of “reference” accident scenarios;
- The “risk-based” approach, suggesting the establishment of safety zones according to the level of risk deriving from a Quantitative Risk Assessment.

The representation of the safety zones on a map depicting the uses of land (e.g. residential, commercial, industrial area), the main transport routes, the main networks, etc., provides the decision maker(s) with the necessary input to deal with the problem. The conflicts between the interests of the various stakeholders can also be highlighted on such a map. Moreover, the criteria used in the various approaches can readily be introduced in the map, giving a better support to the decisions. In more detail, if “generic” safety distances are in use, these distances — depending on the relevant activities — can appear on a map of the site. If the “consequence-based” approach has been adopted, the relevant safety zones, corresponding to pre-selected endpoints of the physical magnitude describing the consequences, can appear on the map. In a “risk-based” approach, both the risk contours and the F–N curves provide the adequate input for LUP decisions. An example of a GIS tool facilitating LUP decisions based on the probabilistic approach is the HSEMAP [22], developed on Mapinfo for use in UK. Finally, multi-objective considerations, as discussed in Ref. [23,24] or in Ref. [25] in the same issue, can be addressed through a GIS-based tool.

3.4. Emergency planning for fixed installations: the HARIA-2 project

HARIA-2 is a project aiming at developing a methodology and a prototype support tool for the definition of external emergency plans for hazardous chemical/petrochemical industries as well as for training decision makers.

The project started in 1997 and it is now in its final stage. Participants, besides the JRC, are: the University of Pisa (Department of Nuclear and Mechanical Construction — coordinator of the project — and Department of Social Sciences), the University of Trieste (Department of Human Sciences), the International Institute of Sociology in Gorizia (ISIG), and the Centro Studi Esperienze, a specialised technical service of the Italian Fire Brigade

This project presents various innovative aspects, namely:

– The consideration of the probable behaviour of the population depending on the type and frequency of the information received, both preventive an during the emergency;

– The simulation of the emergency taking into consideration the road traffic evolution and the movement of rescue services according to the action taken, e.g. closure of roads, evacuation of a vulnerable centre or of a residential area;
– Assessing the effects of different decisions and compare results for a better understanding of emergency problems.

HARIA-GIS is the prototype version of the support tool developed in ArcView [26]; the simplified architecture is shown in Fig. 6.

The system will allow the user to:

– improve his/her knowledge on the characteristics of the industrial activities taking place in the area of interest and the potential for damage in case of accident;
– identify the necessary resources to face emergency situations;
– evaluate the intervention time of rescue services depending on the status of the road network and the traffic density;
– compare evacuation against staying indoor;
– compare different intervention strategies;
– examine the effects of the most probable population behaviour and identify the arising problems.

The procedure implemented for emergency planning can be subdivided into three main phases: Initialisation; Simulation; and Documentation.

On selecting the reference accident, the time it is supposed to occur, and the drawing on the screen of the dangerous area, a number of operations are automatically carried out by HARIA-GIS for the detailed description of the initial situation. The system displays a number of windows containing information, e.g. type of accident and time of occurrence, substance(s) involved, establishment involved, surfaces of the damage areas, number of people at risk in each area, vulnerability centres with pick up points for evacuation, road traffic distribution. The user can ask for more information, e.g. find out which type of resources are needed and where they are located, the time needed for their arrival on the accident scene, the best path from origin to destination, the protective equipment needed.

In the simulation phase, the user initially defines the time of emergency, the simulation duration and the simulation step. Then the system synchronises the models needed and allows the user at the end of each simulation step to take some decision in order, for example, to facilitate the intervention of the rescue services, to reduce the number of people at risk, or to find other resources. In order to identify problems that may arise during a real emergency, the user has the need to verify the effects of different alternative decisions. In HARIA-GIS decisions and the corresponding results are associated, respectively, to the branches and the nodes of a Decision Tree. The simulation also includes a traffic model and an evacuation model. The latter allows the user to test different ways of allocating transport resources to the pick up points. One of the results of the simulation phase is the variation of the number of people at risk vs. time.

For the documentation of the emergency, the user can select the data to be stored in a Word document and define their sequence. Fig. 7 shows an example of screen shot of HARIA-GIS.

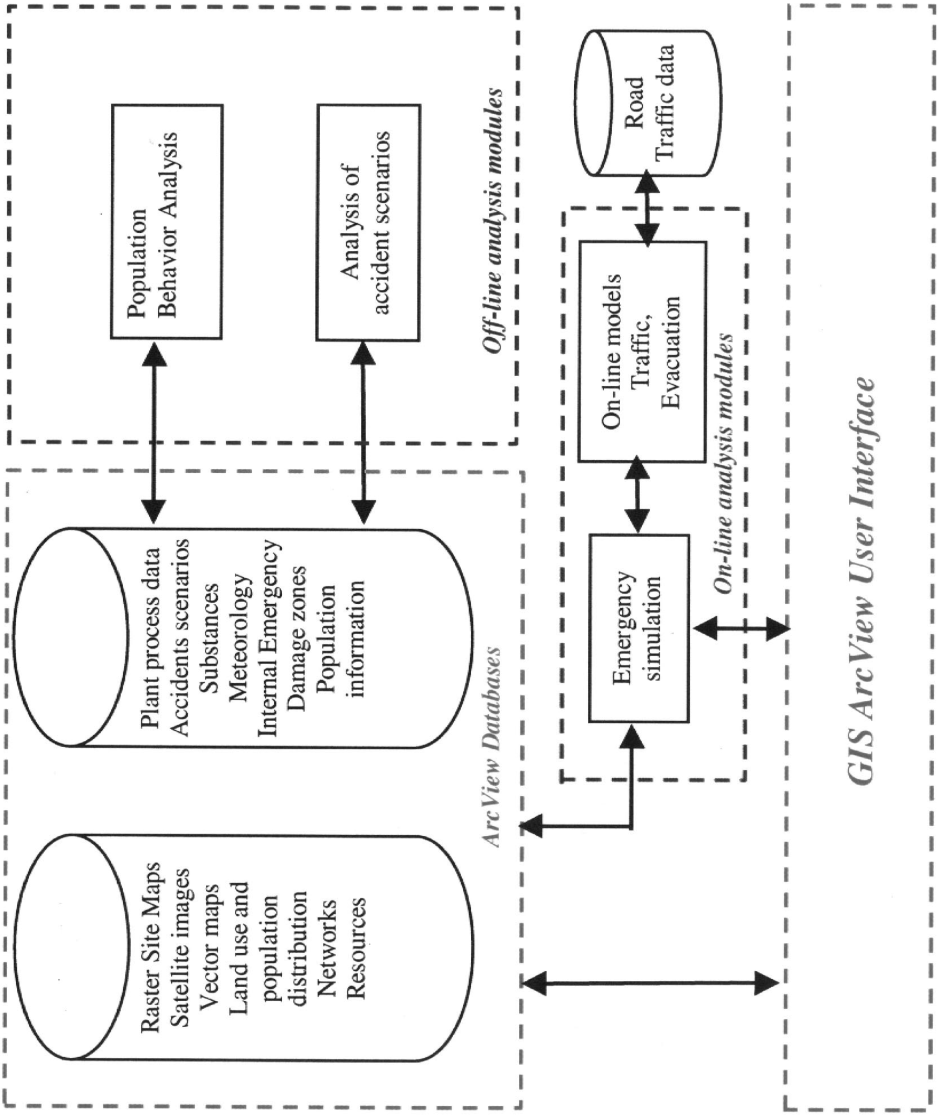

Fig. 6. Simplified architecture of HARIA-GIS.

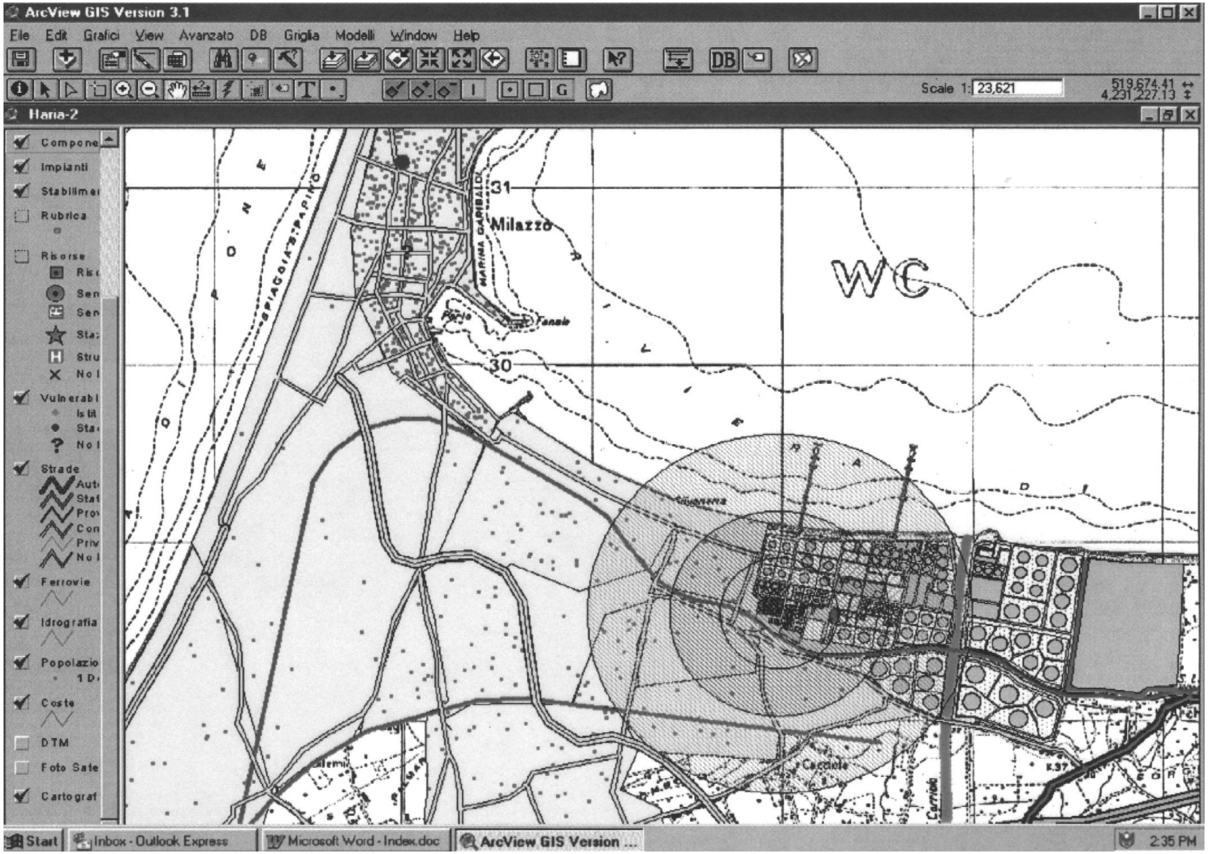

Fig. 7. Screen shot from HARIA-2 showing the damage zones of an explosion, superimposed on the plant layout, the road network, and the population distribution.

4. Discussion

As described in the paper, risk management is information intensive. Large volumes of technical information have to be gathered, processed, analysed and eventually communicated to a broad range of users under quite different conditions, ranging from planning and regulatory activities to emergency managers. Further, the control process involves a multitude of actors and stake holders, including operators of industrial establishments, regulatory authorities, various interest groups and the general public, which all need easy access to appropriate risk-related information.

The integration of data bases, GIS and decision support tools leads to powerful operational systems and their implementation in distributed architectures that support remote access through Internet opens new and promising directions of development.

Some of the basic requirements of a risk management support tools were pointed out in the previous sections and were illustrated through examples. For the decision making process, an adequate risk management tool should facilitate meaningful and focused discussions between the interested parties, and for that reason it needs to be transparent, providing easy retrieval of the assumptions made and clear representation of results. Transparency is a key issue in such tools, greatly contributing to the credibility of results. All models used and all assumptions made should be traceable. Additional advantages should be the ability to take input and present data from the plant model — including the basis for the calculation of frequencies (e.g. databases, or fault trees) — and to perform sensitivity analysis, running the models with modified input/assumptions. Moreover, it should be possible to represent not only the final results but also to show intermediate ones in a clear and transparent way.

The value of the above features in the decision making process is evident. However, it is not of lower importance the selection of the appropriate environment for the development of the tools. The time and resources required for the development, the cost of maintenance and the possibilities to customise/upgrade the tool are aspects to be considered. In this context, GIS systems — either commercial or proprietary — have many advantages and they represent an adequate environment for the development of risk management tools. Commercial GIS are less flexible than proprietary ones, but they offer at least two advantages: an improving environment, i.e. new releases granted by the developing company, and the possibility for the user to add new functions. Whatever type of GIS is adopted, the great benefit of using this technology relates to the low cost of development and maintenance of the application tool.

GIS tools need up-to-dated digital maps of the area of interest, including the plant(s) layout. Sources of cartographic data at community level, e.g. GISCO [27], CORINE [28], and at country level, e.g. Military Geographic Institutes, are generally available for all countries. The situation may be totally different at regional level: some regions offer digital maps that completely cover their territory, whereas in others it becomes difficult to find useful information.

When such data are not available, or are not up to dated, the cost and time for their acquisition may be significant. In these cases, Satellite Remote Sensing may represent an interesting source of data [29]. Satellite images and GIS functionality allow the risk analyst to rapidly generate several vector thematic maps concerning, e.g. land-use and land-cover, especially for inhabited areas, road/rail networks, coastlines, ports. Another important input, the spatial distribution of population, can be estimated from the layer of inhabited areas, the characteristic of houses [29,30] integrated with, if available, information from local authorities. The accuracy of these data will improve as the resolution of satellite images increases. The recent launch of new generation satellites will make available images of high-resolution, from which high scale maps (e.g. 1:5000) can be generated.

It is worth mentioning that in area risk management the periodic re-assessment requires the updating of the data of the area of interest. From two satellite images of the area, taken at different times, a change detection analysis, i.e. the identification of changes in land use, building and infrastructure, can easily be performed, giving the decision maker useful information on the urban growth. Finally, another interesting application of remote sensing images is the generation of the Digital Terrain Model (DTM), which can be used, e.g., to give a 3D representation of the area or to run wind field models for passive gas dispersion calculations.

An important issue to be taken into account when speaking about risk management tools is the proper use of the tools and the limitations in their application. It has been demonstrated [31] and it is widely known in the risk analysis community that the quality of risk results is related to the quality of the models used, the data used and the assumptions made. When communicating these results to the general public, there is always the possibility of giving the wrong message that the level of risk has been "measured" and quantified and is known with certainty. Use of an advanced and user-friendly tool may then enhance this wrong impression as being supported by "objective tools" like computer models. For that reason and independently of the tool used, the models employed and their range of applicability, the assumptions made and the uncertainties related with risk assessment should be clearly stated. The quality of data is of equal importance: sometimes out-of-date or obsolete data are being used in risk studies for various reasons (unavailability of more updated data, high cost of acquisition, etc.), thus giving wrong input to the decision making process. Systems allowing the continuous updating of data through evolving databases would be valuable tools especially concerning the management of change.

5. Conclusions

In this paper, the usefulness of desktop GIS systems for risk studies has been shown through the description of four tools for solving risk related problems, i.e. mapping of Seveso sites across Europe, management of safety reports, area risk analysis and control, and drawing up of emergency plans. GIS-based risk support tools may improve the transparency of results, which is one of the necessary conditions for enhancing the dialog among interested parties and consensus building on risk issues. The credibility of results is achieved through a clear and transparent presentation of the assumptions, models and data used, as well as the possibility to perform sensitivity analysis according to the demands originated from the parties. Concerning the need for geo-referenced data in risk management, it can be concluded that remote sensing satellite images represent a valuable source of information that is becoming more easily available and deserves to be further exploited.

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