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Case study

An operational centre for managing major chemical industrial accidents

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Abstract

The most important characteristic of major chemical accidents, from a societal perspective, is their tendency to produce off-site effects. The extent and severity of the accident may significantly affect the population and the environment of the adjacent areas. Following an accident event, effort should be made to limit such effects. Management decisions should be based on rational and quantitative information based on the site specific circumstances and the possible consequences. To produce such information we have developed an operational centre for managing large-scale industrial accidents. Its architecture involves an integrated framework of geographical information system (GIS) and RDBMS technology systems equipped with interactive communication capabilities. The operational centre was developed for Windows 98 platforms, for the region of Thriasion Pedion of West Attica, where the concentration of industrial activity and storage of toxic chemical is immense within areas of high population density. An appropriate case study is given in order to illuminate the use and necessity of the operational centre. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Chemical accidents; Chemical emergency management; Decision support systems; Emergency operational centre

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1. Introduction

A major chemical accident is defined as an unexpected damage-state that may occur in an industrial installation, during the process or storage of large quantities of chemicals, affecting areas both inside and outside the boundaries of the installation. Thus, an accident may harmfully influence the adjacent population, environment and the ecosystem. Common characteristics of such type of accidents are:

- the significant number of expected human health effects (fatalities and/or injuries) caused either by toxic concentration of chemicals, radiation heat or blast waves;
- the increased probability for domino accidents to take place;
- and the usually extended accident duration which imposes the necessity for efficient resources logistics.

These characteristics bring forward the necessity for all responsible services to closely collaborate on accident management and on complicated protection actions. In such cases, appropriate actions to protect the affected population should be based on rational and quantitative information that would lead to correct and efficient decisions. This information must be based on well-established estimates of accident consequences, proper quantitative evaluation of risk assessment and a conceptual framework for decision making under crisis, a situation typified by emergency response.

The concept of quantitative risk assessment is sufficiently straightforward. However, it is difficult to undertake manually because the calculations involved are difficult and time-consuming to perform. In addition, the summation of risk requires a huge effort even for individual risk; for societal risk the effort required for manual calculation would be overwhelming [1]. For these reasons, it is apparent that quantitative risk analysis can be made feasible only by the use of integrated computer facilities.

A number of software packages have been developed aiming at assisting with accident management. The SAFETI package was developed by Technica for the risk assessment of chemical process industries [1]. The first version of the package was completed in 1983. Since then, it has been revised several times, mainly to improve performance and to incorporate better modelling features. In its current form, it is a major piece of software which runs on mainframe or minicomputers.

The WHAZAN consequence analysis package calculates the consequences and hazard zones resulting from incidents involving toxic and flammable chemicals [1]. It was developed by Technica to implement methods described in the Manual of Industrial Hazard Assessment Techniques [2], commissioned by the World Bank. The package consists of a number of programs, linked to a menu-driven system, built around a number of robust mathematical codes for estimating accident consequences. A database of materials is also included.

The ARIPAR project [3,4] aimed at the assessment of the major accident risks connected with storage, process and transportation of dangerous substances in the densely populated area of Ravenna in Italy. Within the context of the project, a complete inventory of fixed installations and transportation activities capable of provoking major fire, explosive and toxic release events is maintained. Probabilities are assigned to events so that iso-risk contours and F-N diagrams can be evaluated both for single sources and for the overall area. The contribution of each single risk component to the overall risk of the region is evaluated and certain high-risk installations are outlined.

Decision making during crises is marked by a rapid increase in the number of decisions made and the volume of information to be processed. As a result, crisis managers cannot easily analyse all the options available. Feeling intense time pressure and operating under the stress of dealing with life-threatening events, critical information is often ignored or not appropriately recognised and assessed. In such cases, computer technology can be a crucial component. In particular, a crisis management support system can be used to help decision makers access large on-line databases, cope with information overload, analyse data reliability and consult distributed knowledge bases using learned reasoning to learn lessons from past crises [5]. Andersen and Rasmussen [6] review the state of the art of decision support system (DSS) and their application in cases of emergency. They focus on management science, social science and system science as different approaches to crisis management. Belardo and Wallace [7] analyse the use of artificial intelligence and expert systems in this area. They describe the construction of appropriate knowledge bases and rule-based decision trees related to decision making under crisis. Rasmussen and Gronberg [8] transformed the knowledge experience gained after studying a total of 25 accident cases, into emergency education. Ikeda et al. [9] explore the use of advanced communications and information processing technologies as the basis for real-time decision support during emergency response. Khan and Abbasi [10] have presented a software tool which combines a knowledge base for accident scenarios generation along with a consequence estimation tool in order to identify "high-risk" points in an industry, to simulate probable accidents and develop disaster management plans. Mak et al. [11] presented an application of workflow technology to co-ordinate and disseminate tasks and related information for crisis management support systems. They discuss the potential benefits of using a workflow approach for a DSS and describe the development of a suitable framework for an existing one.

The development of a distributed environment for the integration of software applications sharing data and operations through a common database repository can evidently support the large-scale organisation, manipulation and retrieval of process engineering data. This effort is chiefly based on careful definitions of data type objects and the construction of focused methods to manipulate these objects. Users benefit from the consistent behaviour and look of the system, minimising the frustration and time spent in learning the mechanical aspects of the programs used, since similar user interfaces are implemented to present individual tasks. By using and developing focused applications for specific object types, users and programmers alike benefit by an increase in application reusability. The guidelines provided by the organisation of the data reassure the programmer that only the specific object types are used. This allows applications to grow and develop together with the objects, or to remain operational even if the object definitions evolve and change. The only restriction the user needs to be aware of in using an application is that it must be given an object of a certain type and that it will return a new object as an instance. Future users benefit because the consistency imposed upon a project allows history maintenance and retrieval mechanisms to be incorporated.

In this work, an operational centre for managing large-scale industrial accidents has been developed. It was designed in order to provide quantitative estimation of the accident consequences and help the users evaluate their options and effectively implement their decisions. Its architecture involves an integrated framework of geographical information system (GIS) and RDBMS technology systems equipped with interactive communication capabilities. The operational centre was developed for the region of Thriasion Pedion of West Attica, where the concentration of industrial activity and storage of toxic chemical is immense within areas of high population density.

2. Structure of the operational centre

The architecture (implementation structure) of the operation centre involves a GIS with interactive communication to a central database and individual software tools that perform all necessary numerical calculations, cartographical and graphical tasks related to the specific management of a major chemical industrial accident. The GIS (ESRI ArcView GIS) is the background information system of the operational centre, since it includes all the necessary cartographic information and its relation to the database system. The cartographic information derives from the existent general maps updated with suitable photogrammetric methods, at various levels of analysis and accuracy. A typical view of the GIS main document window is given in Fig. 1.

The database system (Microsoft SQL Server) is the heart of the operational centre and it serves a two-fold role. Within its relational infrastructure, detailed information concerning several regional and operational data related to local industrial companies and their associated sites of agencies as well as details of the road network and transportation facilities of the region are a significant part of the information compiled and maintained. In addition, the database system serves as the common repository of all tools to store and exchange data within the framework of each application. In particular, each tool retains its own part of the database and stores data and information produced by the interactive communication with the user. The level and complexity of database transparency to each tool depends on the access privileges of each application for a specific task.

The accident simulation tool (AST) performs the necessary numerical calculations that would quantify the extent of the consequences of an industrial accident. The type and characteristics of the accident scenario studied are interactively specified by the user. The simulator has its own library of mathematical models and a solver to evaluate the exact geographical region where the consequences are most intense for the population so that immediate actions should be carried out.

The DSS is responsible for evaluating and implementing the appropriate course of actions that would reduce the extent of the consequences. In particular, the DSS includes computational algorithms to determine with efficiency the shortest routes between the mustering areas and the destination areas through a given road network. These routes are used by assembled population to abandon the affected region. The GIS performs all graphical tasks related to the operation of these tools. In particular, detailed information on the geographical characteristics of the region at various levels of detail are combined with an efficient graphical way to represent accident consequences and evacuation path within the regional road network.

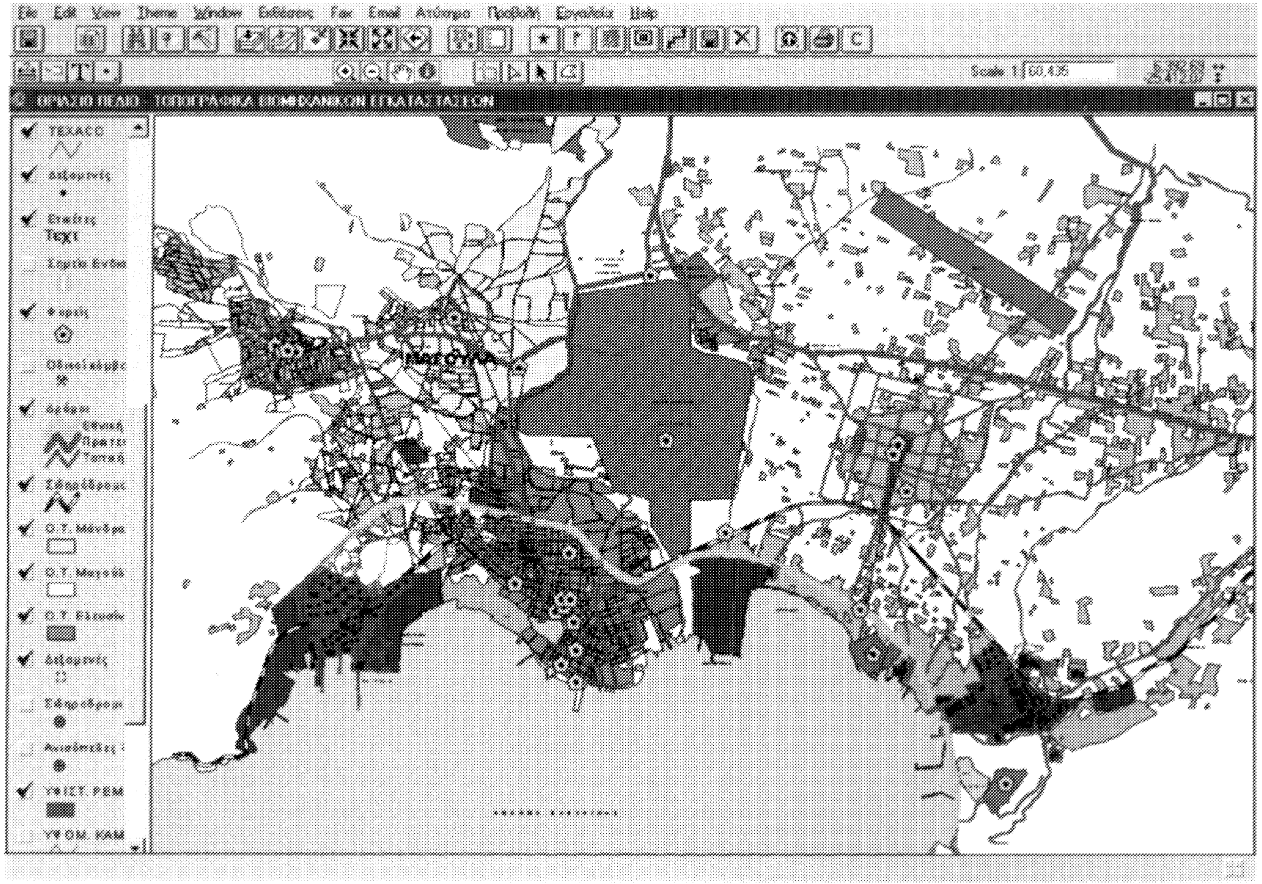


Fig. 1. Typical view of the GIS main document window.

2.1. Distributed environment for software development

Distributed environments for the integration of software applications sharing a common database repository, encourages the development of small applications that perform specialised tasks. This dictates the re-use of software components and the development of consistent use of user interfaces. Such tools use an architecture and application dependent object format to achieve an integrated environment. Object-oriented techniques enables users to tailor the system at their demand and needs. Distributed software systems allow for different people or groups to be assigned to a particular part of the project, and be able to work on it independently of the other project sections. Each team member, however, can access other people's work through the facilities provided by the distributed software system. The architecture of data exchanged for distributed software systems within the operational centre described is given in Fig. 2 [12].

Object-oriented programming is a modern technique for designing and implementing programs by modelling the structures and capabilities of real-world objects. The concept of object-oriented programming is mainly based on a modular fashion for designing and constructing programs, and this style of programming makes it practical to organise large programs, since it significantly eases decomposition of complex problems into functional and easy-to-use modules. The database system is the heart of every distributed software system. It is the place where process data as well as specific information of the individual tool are stored involving results and simulations. There are generally two basic types of database systems according to their architecture and functionality; relational and object-oriented. Relational databases are the most commonly used ones since all commercial software database packages are based on this architecture. Generally, object-oriented concepts can be implemented within relational databases and there are ways to model process and application data so that an object-oriented approach is adopted.

2.2. Data management and operation

The software infrastructure described above is based on policies of common exploiting data and scenarios from the database. Within the database environment a complete set of regional data is stored. More specifically:

- complete cartographic description of the entire region is provided, including elevation contours and land use;
- demographical information on population classified into several categories. Both spatial and temporal distributions are also stored within the GIS Tool shape files;
- local companies related to sources of potential accident. Spatial information on agencies tanks, warehouses and utilities are stored in appropriate GIS shape files;
- local agencies and authorities as well as vulnerable buildings (schools, hospitals, etc.) in the region. Spatial information is appropriately provided;
- the complete road network is stored in nodes/links format. Special points of transportation interest are also provided in the form of spatial information;
- a comprehensive set of data for more than 150 substances, including thermophysical properties, transport and thermodynamic properties as well as appropriate protection guidelines in the form of MSDS information;

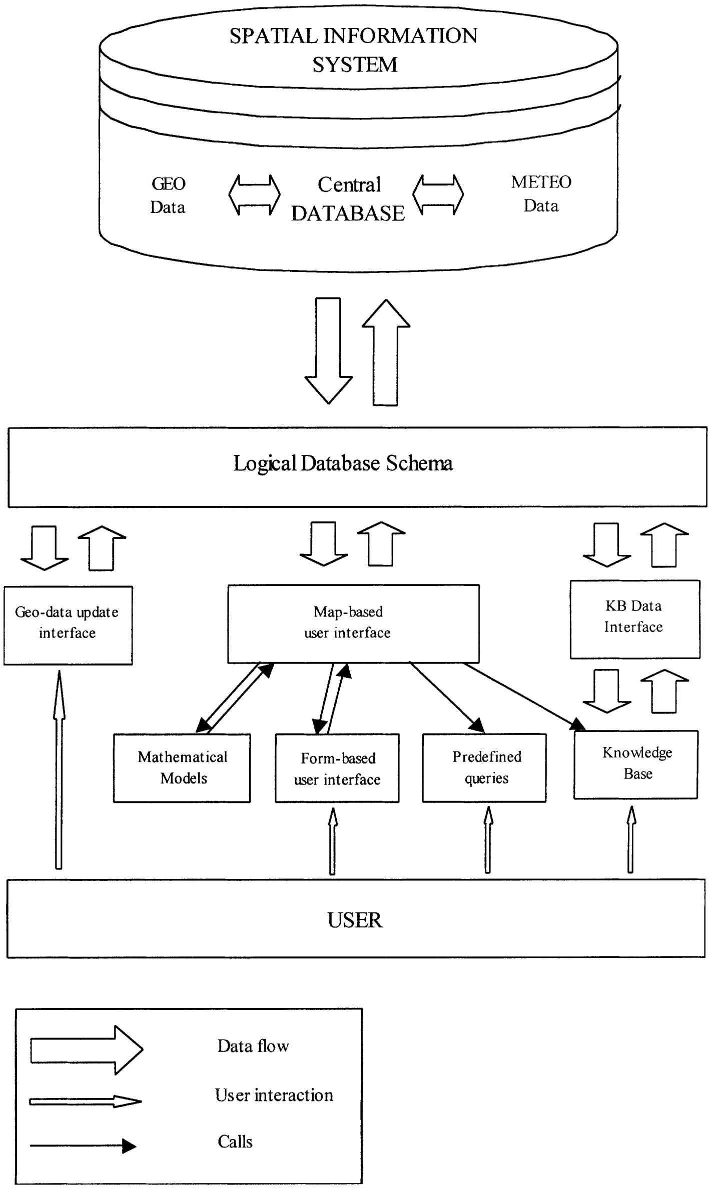


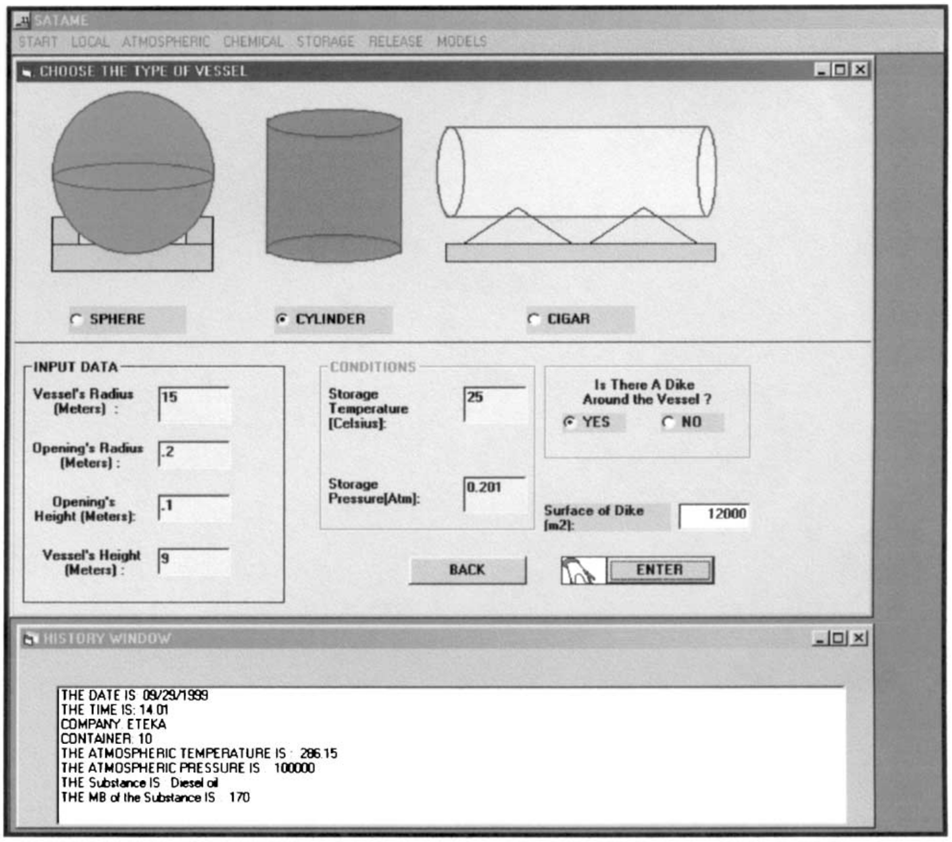
Fig. 2. Architecture of data exchanged for distributed software systems within the operational centre.

- the complete list of fire distinguishing units and protection facilities and their spatial distribution within the area of interest.

The operational centre combines open architecture and user-friendly interactive operation. Its operation is based on menu-driven controls and dialogues, while results are formally obtained through appropriate diagrams and graphs. In all cases, the user can specify the accident scenario for a specific type of equipment that can be a possible accident site, provide the appropriate information needed to quantify meteorological and regional details and proceed with the evaluation of the consequences and the determination of the extent of the affected part of the adjacent area. Thus, the user is supported in taking actions to protect the population residing in this area. Under severe and pressing circumstances the system can provide the optimum way for the population to evacuate the affected region.

3. Modelling and simulation of major chemical industrial accidents

The AST performs the necessary numerical calculations, needed to quantify the extend of the consequences of an industrial accident. Developed for Windows 98 environment, AST provides a user-friendly interface for the simulation of chemical industrial accidents (Fig. 3).



○ SPHERE ● CYLINDER ○ CIGAR

INPUT DATA

Vessel's Radius (Meters) : 15

Opening's Radius (Meters) : .2

Opening's Height (Meters): .1

Vessel's Height (Meters) : 9

CONDITIONS

Storage Temperature [Celsius]: 25

Storage Pressure[Atm]: 0.201

Is There A Dike Around the Vessel ? ● YES ○ NO

Surface of Dike [m2]: 12000

```
THE DATE IS 09/29/1999
THE TIME IS: 14.01
COMPANY ETEKA
CONTAINER 10
THE ATMOSPHERIC TEMPERATURE IS : 286.15
THE ATMOSPHERIC PRESSURE IS   100000
THE Substance IS  Diesel oil
THE MB of the Substance IS   170
```

Fig. 3. AST interface.

The simulator has a build-in library of mathematical models and a build-in solver to evaluate the exact geographical region where the consequences are most intense for the population so that immediate actions should be taken.

The user interactively specifies (Fig. 4) the type and characteristics of the accident scenario studied. When a new scenario is implemented the user selects the place (company and container) and the time of the accident. The AST retrieves from the database the meteorological parameters of the nearest meteorological station for the time that the accident takes place. These values are used in the various build-in models (pool fire, unconfined vapour cloud explosion (UVCE), fireball, dispersion). The ASTs advantage is that it also retrieves all the information that is stored in the database concerning the accident site, thus providing a more analytical and representative solution. This information is stored in the database after agreement with local authorities and the industries and includes: the type of the container, the shape and the dimensions of the container, the substance stored and also all its thermophysical, chemical, transport and thermodynamic properties. Consequently, the program provides the user with almost everything that is needed to run the accident simulation model. All these parameters can change so that a “future scenario”, for example, with a different chemical substance, can be implemented.

All the models included in the AST are semi-empirical and are subjective to constraints. The accuracy of the results depends on the assumptions made by the model and the accuracy of the input data. The constraints applied to the models used and their limitations are described in the relevant literature [13,14]. On the other hand, the accuracy of the input data depends on their availability during the accident and the ability of the user to describe correctly the ongoing situation. Although this is not always feasible, the user is called to decide which would be a “worst case scenario” and apply the relevant data (e.g. considering that a tank is full) using the in-built database.

The AST makes the assumption that the physical phenomena encountered are steady state. AST must be run again to re-evaluate the ongoing situation, each time a significant change has occurred during the accident. Finally, the user must be well-trained and familiarised with chemical accident management, thus be able to understand and evaluate the results and their relative significance to the reality.

3.1. Release model description

The examined releases can be grouped into three categories.

3.1.1. Outflows out of a vessel

A distinction is made between gases, liquids and substances which are gaseous under atmospheric pressure and atmospheric temperature, but can be liquefied through compression or cooling.

- In the case of a gas outflow, it is assumed that prior to the failure, the vessel was filled with a liquid above which saturated vapour was present and that the hole through which the outflow takes place is located above the liquid level. The possibility of a two-phase flow is also taken into consideration in the calculations.

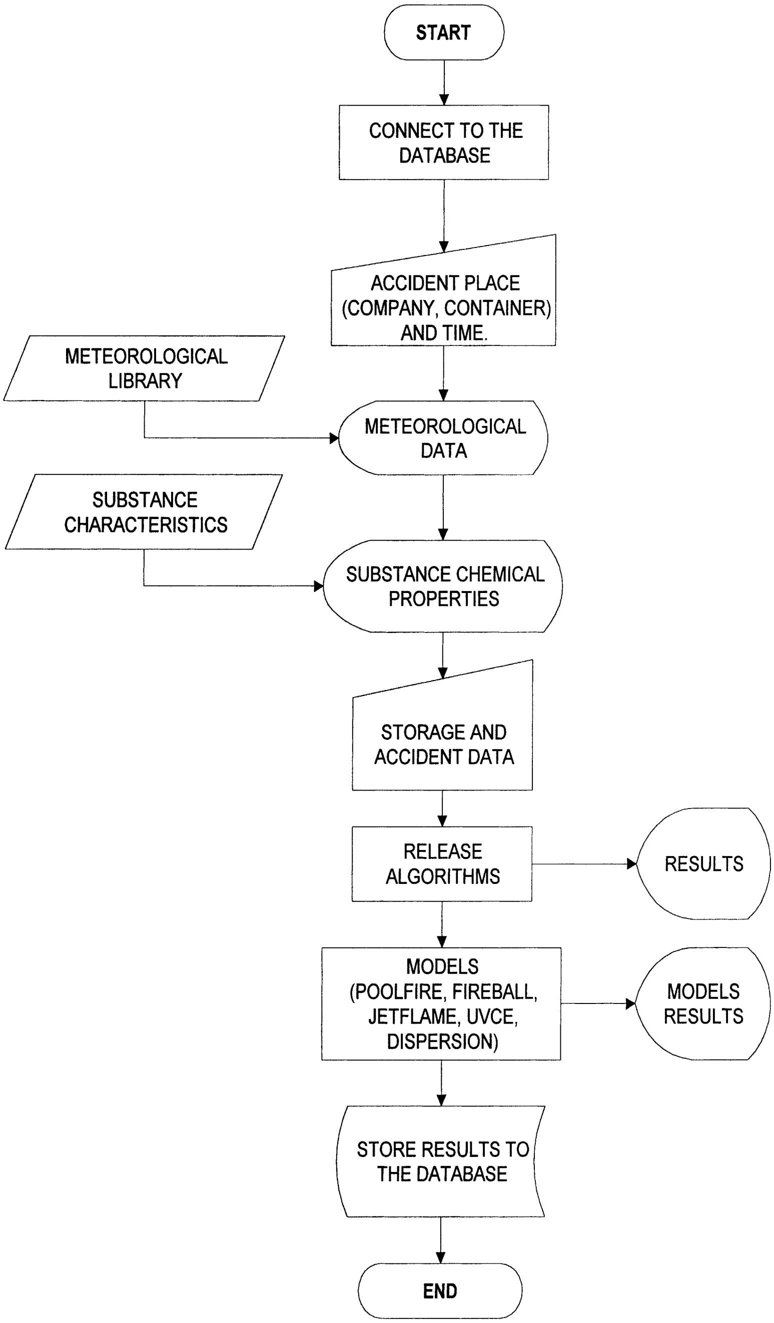


Fig. 4. AST process flow diagram.

- In the case of a liquid outflow, it is assumed that prior to the failure, the vessel was filled with liquid and that the hole through which the outflow takes place is located below the liquid level.
- In the case of an outflow of a gas compressed to a liquid state, it is assumed that prior to the failure, the inner pressure of the vessel is equal to the saturation pressure of the condensed gas at ambient temperature. In case of an outflow of a gas cooled to a liquid state it is assumed that prior to the failure the inner temperature of the vessel is equal (or less than) the boiling point of the condensed gas at ambient pressure. The possibility of a gas or of a liquid or of a two-phase outflow is taken into consideration in the calculations.

3.1.2. Outflows out of a pipe

A distinction is made between gases, liquids and substances which are gaseous under atmospheric pressure and atmospheric temperature, but can be liquefied through compression or cooling. Depending on the substance that is present inside the pipe and the magnitude of the outflow hole the gas or the liquid or the two-phase outflow can be calculated.

3.1.3. Evaporation of liquids or liquefied gases released on land

For the calculation of the evaporation of liquids or liquefied gases released on land, a distinction is made between a permeable and a non-permeable sub-soil. The liquid or the liquefied gas evaporates while it spreads until it reaches a minimum thickness. If there is some kind of a barrier around the release point then the liquid or the liquefied gas forms a confined liquid pool through which it evaporates.

3.2. Categorisation of the industrial accidents and models used

The possible accidents can be grouped into two major categories.

3.2.1. Accidents where flammable and/or explosive substances are involved

The phenomena examined for these accidents, depending on the substances involved and the storage conditions, include: (1) pool fire; (2) fireball; (3) jet flame; (4) flash fire; and (5) UVCE.

The models used for the analysis of each type of accident are the following:

- for the pool fire the “surface-source model” is used. The flame is considered as a radiator with a cylindrical shape and an average radiation emittance;
- for the fireball the “point-source model” is used. In this case the flame is considered as a point in which part of the energy released in a fire is being sent-off in the form of radiation;
- for the jet flame the “surface-source model” is used;

  the consequences in such type of accidents are due to the thermal heat flux and the thermal dose, which are calculated as a function of the distance to the radiating surface/point following the TNO methodology [13];
- for the flash fire the DEGADIS [14] model is used for the calculation of the dispersion of the vapour cloud up to the distance where the concentration of the substance reaches the lower flammability limit;

- finally for the unconfined vapour cloud explosion the shock wave model is used. The overpressure due to the explosion is calculated as a function of the distance to the point where the emission of the explosive substance takes place.

3.2.2. Accidents where toxic substances are released

For accidents that involve toxic substances the DEGADIS model is used for the calculation of the dispersion of the toxic cloud up to the distance where the concentration of the substance reaches specific limits posed by the relevant authorities.

4. Development and implementation of the decision support system

The DSS constitutes an essential part of the operational centre. It provides the user with the necessary capabilities to assess the situation of an accident and make the appropriate decisions to respond to the accident effectively and efficiently. The following sections describe shortly the methodological framework for the development of the DSS, as well as its functional specifications and design [15].

4.1. Methodological framework for the development of the DSS

The development of a DSS was based on the following steps: (1) identification of user needs; (2) development of functional specifications; (3) determination of the business architecture; (4) system implementation; and (5) evaluation/validation.

In order to extract the user requirements, a questionnaire was developed based on an extensive state-of-the art and state-of-practice review and on the expertise gained from the development of other emergency response systems [12,16,17]. The aim of the questionnaire was to collect information covering the following issues:

1. information regarding the profile and the role of the responding organisation in emergency response operations;
2. questions addressing the emergency response functions of the responding organisations, the availability of the emergency response resources and the information exchanged between the responding organisation and other organisations participating in the emergency response operations;
3. methods, policies and systems adopted by the responding organisations for emergency response operations;
4. measures of effectiveness used evaluating the performance of emergency response operations;
5. degree of adoption of advanced informatics and telecommunications techniques for emergency response operations;
6. identification of problems bottlenecks and deficiencies in the current organisation of emergency response operations.

The results of the user requirements analysis for the DSS system which were used at the subsequent phases of the DSS development can be summarised as follows:

1. the performance of the emergency response system depends to a great extent on the availability and timeless processing of both static and dynamic data;
2. all decisions are taken under time pressure and stress, that limit the time available for data entry;
3. the assessment of the accident evolution and expected impact, and the consequences that result from the application of different response actions and measure are of great importance for the decision makers;
4. information/data is exchanged between spatially distributed agencies;
5. the DSS should support the following decisions: (a) assessment of accident consequences and accident evolution; (b) development of the appropriate emergency plan; (c) identification and notification of required response actors; (d) determination of the appropriate response actions and the required resources; (e) dispatching and monitoring of the responses; (f) selection and implementation of evacuation plans.

4.2. Functional specifications

The functional requirements are completed with the following set of operational requirements:

- the DSS should be able to handle both static and real-time data (i.e. data that evolve overtime);
- the DSS model base should contain mathematical models and empirical rules that should be able to provide estimation of the impact and the consequences of the accident, and to optimise the use of the available resources;
- the model base should contain empirical rules for associating the appropriate response actions to the accident characteristics;
- the model base should be able to operate under limited data availability, and should take into consideration that the quality and the quantity of data evolves overtime;
- the model base should contain mathematical models and algorithms for implementing evacuation plans;
- the database should be able to retrieve information from external sources or from databases spatially distributed, for example extract experience from the specific type of accident from other agencies located abroad;
- the human machine interface (HMI) of the DSS should be user-friendly, should operate under a graphical environment, and should not require a large amount of input data;
- the GUI of the system should be GIS-based for representing the spatial data of the system;
- the system should take advantage of the innovative telematics, networking, and communications technologies.

4.3. System design

The proposed DSS consists of the following structural elements:

1. model base, that contains all mathematical models, algorithms, rules and knowledge that can be utilised for minimising accident duration and consequences;

2. database, that contains all data needed for the system operation;
3. a GIS-based graphical user interface.

4.3.1. *Model base*

The model base contains the following types of mathematical models, rules, and algorithms.

1. Models for estimating the impact and the evolution of the accident. This set of models is used for assessing the following problem:
    - 1.1. given the type of hazardous materials, the weather and environmental conditions, the characteristics of the facility (if the accident occurs in the vicinity of a stationary facility), the characteristics of the area around the accident site (i.e. population density, environmental sensitive areas, distance from adjacent facilities, traffic conditions, etc.) determine the impact area, the severity of the accident, and predict the evolution of the accident.
2. Mathematical models for determining optimum evacuation plans by solving the following problem:
    - 2.1. given the population distribution of the evacuation area, a set of candidate destinations for transporting the inhabitants of the evacuated areas, the topology and the capacity of the roadway network, and the available vehicles, identify the set of destinations where the population centres should be transported, determine the routes that should be used and the relevant traffic volume that should be assigned to each route, and specify the optimum signal setting and traffic management actions, in a way that minimises the evacuation time.

4.3.2. *Database*

The database contains all data needed for the operation of the DSS which can be classified into two distinct categories: (a) static and historical data that do not change during the accident evolution, e.g. transportation network, industry plans and facilities layout, etc.; and (b) dynamic data that may change overtime, e.g. accident characteristics, environmental conditions, RU location, etc. [17].

4.3.3. *Human machine interface (HMI)*

The development of the HMI is based on the user requirements and their subsequent transformation into functional specifications, and other special needs revealed during the development phase. The HMI is GIS-based (to handle all spatial data and perform the relevant operations), operates on a PC and performs the following operations: (a) interacts with the user; (b) serves as a front end for entering real-time information into the system; (c) provides features for extracting and displaying all information stored in the database; (d) illustrates the application site including the mathematical network representation, and all facilities that may be important for the system operation, e.g. hospitals, industrial plants, etc.; (e) performs all required associations with real-time and/or historical information with the mathematical graph; (f) displays the contours that illustrate the impacted area; (g) displays the RU that has to be dispatched for servicing a specific incident (i.e. the output of the dispatching function) along with the optimum route (the output of the routing function);

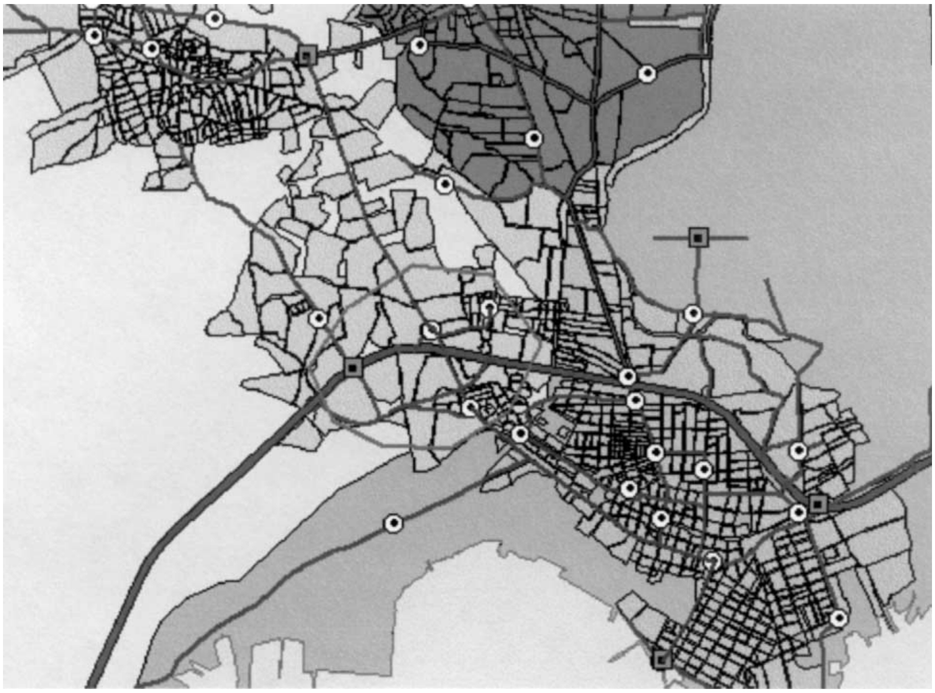


Fig. 5. Sample output of the DSS: evacuation plan.

(h) displays the list of response (i.e. the output of the suppression function); (i) presents the evacuation plans.

Fig. 5 presents a sample output of the system that illustrates the implementation of an evacuation plan (the blue polygon shows the area to be evacuated, the black and white bullets show the population centres, the green squares corresponds to the destination points, and the purple line correspond to the routes that should be used for the transportation of the evacuated population).

5. Case study

In this section we illustrate the use of the operational centre by considering a chemical accident scenario within a major oil refinery located at Thriassion Pedion of West Attica. This particular accident scenario was included in a recent drill organised by the Prefecture of Attica (where the Thriassion Pedion of West Attica is located). The oil refinery, the prefecture, the fire brigade and the traffic police participated. During the drill, the opportunity was given to test the operation of the software and the communications and to deduce valuable lessons. The possible consequences of the accident and the actions that could be taken to mitigate them are discussed. The scenario examined, includes the following sequence:

- a tanker truck is loading propane from the LPG storage facility located within the premises of an oil refinery. The volume of propane in the container of the truck is 35 m^3 or about 17,600 kg;
- accident initiation due to accidental two-phase release of propane from a partial fracture of a 3 in. (0.0756 m) pipe. The outflow rate of propane is estimated to be 4.4 kg/s;
- release of propane leads to the formation of an explosive vapour cloud in the surrounding area. The release is controlled (stopped) by installation employees within 2–5 min.

The atmospheric conditions during the time of the accident are considered to be: atmospheric stability class D; wind velocity 5 m/s; atmospheric temperature 20°C; and relative humidity 70%.

After a short period, the vapour cloud meets an energy source and ignites giving rise to an UVCE. The consequences of the explosion (overpressure) are dependent (among other factors) on the quantity of propane released. The explosion is expected to cause:

- injuries to the employees of the installation;
- the truck to be engulfed in fire;
- rupture of a nearby 4 in. (0.10 m) pipe connected to a spherical tank containing 1000 m^3 of propane;
- release of propane from the ruptured pipe and formation of a jet fire.

The management/mitigation of the described accident sequence is achieved taking into account the existing legislative and organisational framework. According to this, the regional emergency operational centre (EOC) acts as the competent authority, it is activated and takes the following actions.

1. Alarm: the alarm sent by the industry to the EOC is diffused to the proper responding authorities. In this case, to the fire brigade, the medical emergency service and the traffic police. Later, depending on accident size, more authorities could be alarmed (e.g. the Ministry of Environment).
2. Accident verification and accident parameters analysis. These activities include the activation of the GIS platform, the identification of the installation, its layout and a preliminary assessment of the accident magnitude and its probable escalation.
3. Dispatching and en route support of the responders' vehicles. Using the GIS utilities and its database, the EOC is able to choose the responders who are closer to the site of the accident (fire brigade stations and hospitals) as well as responding team vehicles which are already patrolling the area and routing them so as to minimise the time needed to reach the site of the accident.
4. On-site response and mitigation of the accident. The EOC provides the responders with valuable information regarding the substances involved and the accident's expected consequences. In particular:
    4.1. transmits MSDS information to the responders regarding the properties of the substances, health problems that they may cause, and fire-fighting information including the proper methods and means to be used;

  4.2. it gives information on the type, layout and the inventory of the industry while they are still en route to the site of the accident;
  4.3. activates accident scenarios already stored in the database (required by the legislative framework) or/and builds new ones to estimate the possible consequences of the accident, its probable duration and the probability of domino effects.
5. Risk communication to the public and protection of the surrounding population. The EOC is responsible to communicate with the radio and TV stations either directly or by fax and e-mail. Communication includes appropriate instructions to both inform the public about the situation and give safety advice in order to protect the public and reduce the expected anxiety of the population.
6. Post-accident off-site remediation.

In the EOC, mathematical models are used to estimate the thermal flux from the jet fire at the base of the spherical tank (15 kW/m^2 at 38 m and 4 kW/m^2 at 44 m). Since the tank is engulfed in flames, the probability of a BLEVE is considered. The fire-fighters are instructed to cool the spherical tank of propane as well as five more cylindrical tanks containing LPG and placed in the vicinity of the jet fire. The responders are also instructed to protect the water pump room in order to ensure the unobstructed flow of water. Appropriate software is used to simulate a probable BLEVE of the spherical tank and predict its possible on- and off-site consequences. Specifically, the distances where the thermal dose of the BLEVE is expected to have as consequence 1% deaths, 1% burns of second degree and 1% burns of first degree are estimated to be 590, 620, and 840 m, respectively. The results are shown in Fig. 6.

Based on the estimated, probable, consequences and on the information retrieved by the available databases and GIS in the operational centre, the prefecture decided to evacuate an area within a radius of 600 m around the place of accident. The proposed evacuation concerns the population of a residential area located within the range of 600 m and the employees of two nearby industrial installations. Based on the extent of the geographical area and the number of people that have to be evacuated, the operational centre provides the user with a consistent evacuation plan which includes:

1. determination of the safe areas outside the consequences range, where the population will be gathered;
2. determination of the evacuation routes from predefined mustering points to each safe area;
3. distribution of the available vehicles (buses, etc.) to each evacuation route;
4. dispatching of the available vehicles from their operational bases to the mustering points.

The mustering area, the evacuation routes and the destination areas are shown in Fig. 7. The inputs and outputs of the evacuation algorithm are given in Table 1. According to the calculations, 1147 people have to be evacuated from the affected area. These people are called by the authorities to proceed to a mustering area. Busses collect the evacuees from the mustering area and drive them to safe destination areas through the calculated evacuation routes. The capacity of each destination area is known and the algorithm allocates the evacuees starting from the nearest destination area in order to reduce the evacuation time. In this study case the starting points of the buses as well as their routes to the mustering area have not been taken into account since the relevant information was not available by

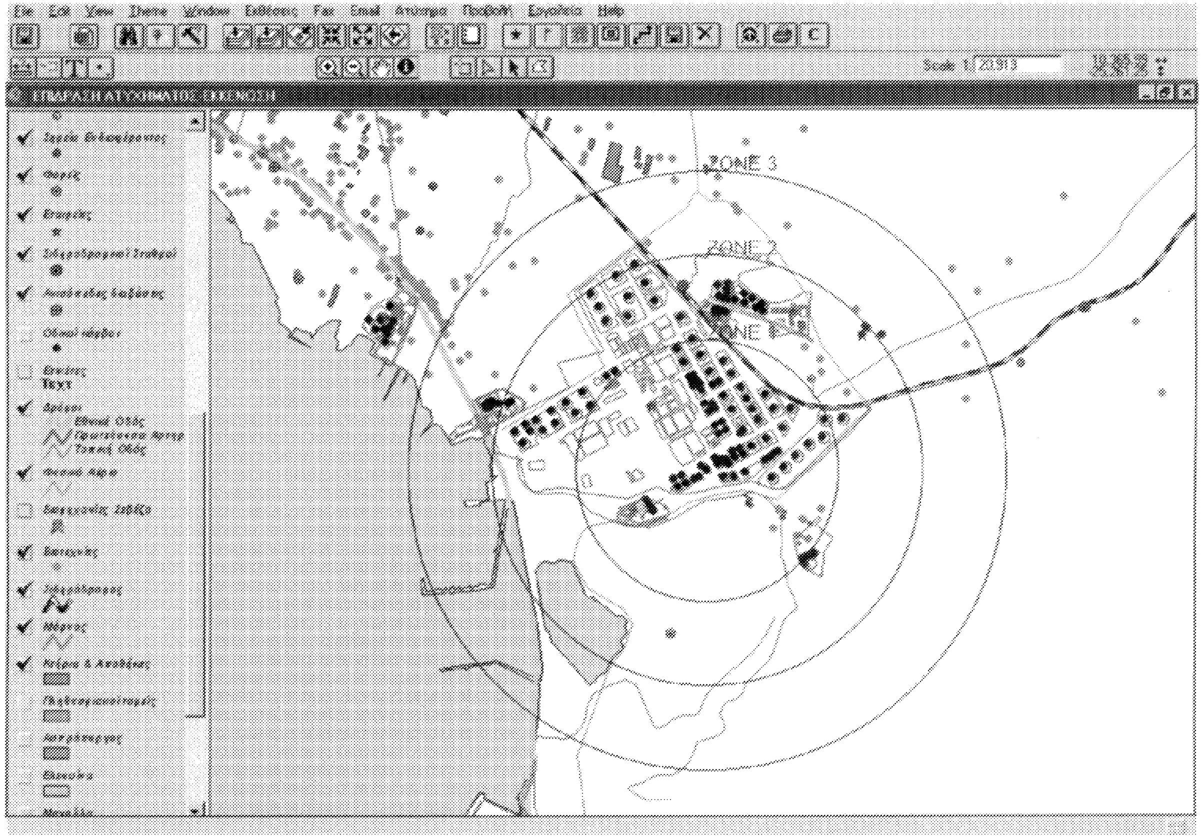


Fig. 6. BLEVE consequence estimation.

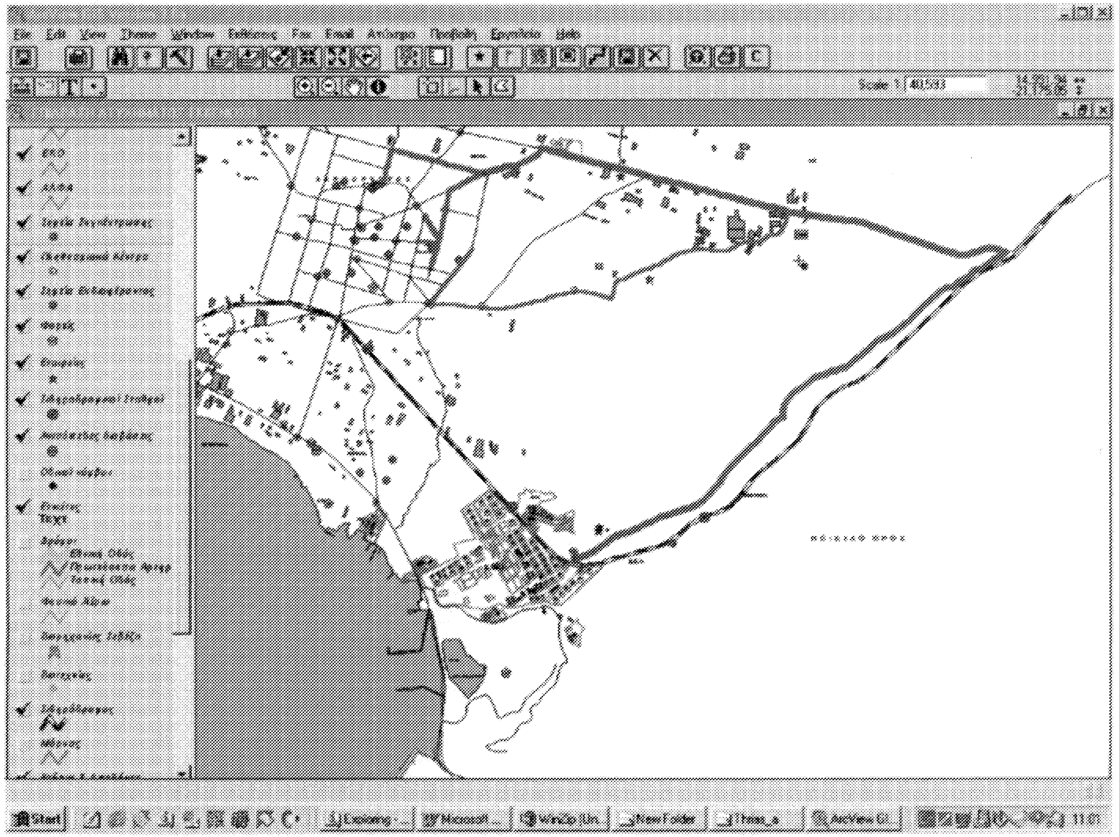


Fig. 7. Evacuation routes for BLEVE.

Table 1
Evacuation algorithm output for the case study presented[a]

No.	Description	Distance (km)	Capacity	Evacuees (buses assigned)	Time (min)
1	School building	11.5	259	259 (5)	10
2	Recreation facilities	11.7	500	500 (10)	10
3	School building	11.8	484	388 (8)	10

[a] Evacuated population: 1147; mustering areas: 1; destination areas: 3.

the authorities. The mean velocity of the buses is considered to be 70 km/h. This decision was made taking into account the road network capacity and its probable overload during a major accident.

Although the drill did not include an actual evacuation of the surrounding population, it gave the decision managers the opportunity to test their capabilities in organising such a difficult task during a chemical emergency.

6. Conclusions

This paper describes the design and development of the software used in the first Greek chemical EOC. The operational centre is operated by the prefecture of West Attica in Thriassion Pedion plain, where the concentration of industrial activity and storage of toxic chemical is immense within areas of high population density. The operational centre was developed in distributed software fashion technology for Windows 98 for PCs. Its architecture is based on an integrated framework of GIS and RDBMS technology systems equipped with interactive communication capabilities between peripheral software tools. The development of the operational centre was a difficult task that brought together the competent authorities with the emergency responders, major Greek industries and Greek universities. Since this is the first chemical EOC in Greece, people who worked in the project had to overcome a lot of difficulties due to the existing legislative framework as well as to incorporate new technologies and practices in their deliverable product. The drill described above is the biggest that has been conducted in Greece. The results of the drill are being evaluated so as to improve the performance of the operational centre according to the observations of the users. Particularly, the GIS information and the AST were the most useful parts of the software. During the drill the responders asked the operational centre for MSDS information and the expected consequences of the accident. Evaluation of the consequences may not be accurate in certain cases but this fact does not reduce usefulness of the tool. The evacuation algorithm included in the software is considered useful by the decision makers. Although evacuation is not the first protection action to choose during an accident, it helps to better organise the available resources and improve logistics support. More exercises are expected to be conducted in the future in order both to test and improve the operational centre as well as to train all those who will be called to participate during a real emergency.

It is noted that the software platform which was developed during the project is going to be used in two more industrial areas of the country where another two regional operational centres are going to operate in the near future.

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