SPATIAL INFORMATION MANAGEMENT FOR RISK ASSESSMENT OF MAJOR INDUSTRIAL ACCIDENTS

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ABSTRACT

An operational center equipped with a powerful Spatial Information System (SIS) for managing large-scale industrial accidents is an important tool that provides quantitative estimation of the accident consequences and proposes, under the certain circumstances, a reliable course of actions to be undertaken automatically.

The heart of the operational center is a central Data Base connected to a cartographic representation tool and other assistant individual software tools that perform all necessary numerical calculations, cartographic and graphical tasks related to a specific management of the major industrial accident. The cartographic information is derived from the extant general maps, of a proper scale, updated with suitable photogrammetric methods, at various levels of analysis and accuracy. The database system has a two-fold role. Within its relational infrastructure, detailed information concerning several regional characteristics of the industrial and municipal activity are stored. In addition, the database system serves as the common repository of all tools to store and exchange data within the framework of each application.

An accident simulator performs the necessary numerical calculations that would quantify the extent and the consequences of an industrial accident. The type and characteristics of the accident scenario under examination is interactively specified by the user. A Decision Support System (DSS) is responsible for proposing the appropriate course of actions that would enable the less possible harm on population, depending on the severity of the accident. The SIS performs all graphical tasks related to the operation of these tools. A certain example was developed for the region named the Thriasion Pedion of Attika, where the concentration of industrial activity and storage of toxic chemicals is immense within areas with high population density.

1. INTRODUCTION

Large scale industrial accidents in chemical process industries are defined as the ones whose size and strength might exert severe influence over the nearby population. Take for instance the case of the most usual and sometimes trivial industrial accident, the one concerning liquified gas petroleum. Over the last 30 years more than 20 large scale incidents have been reported including failure in storage tanks, failure during the uploading and downloading of transportation lorries, traffic accidents during the transportation of liquid load or combination of the above mentioned cases. One of the greatest large scale industrial accidents involving liquified petroleum gas has taken place in Feyzin, France (1966), and several others in Brazil (1972), Mexico City (1984), Tayland (1990) and Portugal (1991).

All large-scale industrial accidents involve common characteristics that can be summarized as below:

- Big number of casualties (dead or wounded) mostly due to superficial or deep burns (that therefore demand special treatment in medical burn treatment units)
- High level of probability for initiating industrial domino chemical accidents affecting hazardous storage units or nearby industries
- Large period of accident duration, in many cases would last for days
- Severe consequences beyond the industrial space (damage in materials or even casualties), large road networks are within the zones of consequences

- In several cases the evacuation of population out of a large residential area beyond the industry boundaries is dictated (due to domino accident hazards).

In this case, appropriate actions to protect the affected population should be based on rational and quantitative information that would lead to “correct” and efficient decisions. An operational center for managing large-scale industrial accidents is an important tool that provides quantitative estimation of the accident consequences and proposes, under the circumstances, a reliable course of actions to be undertaken automatically. The architecture of the operation center involves an Information System (IS) in interactive communication with a central database and individual software tools that perform all necessary numerical calculations, cartographic and graphical tasks related to a specific management of a major chemical industrial accident (component tools).

An application of this system, with simulation studies for large-scale accidents, was done for the region named Thriassion Pedion in Attica of Greece. The Thriassion Pedion lies 20 km away on the west of Athens, having an immense concentration of all kind of industrial activity in some cases even in contact with large urban areas. On the contrary to what happens to all the other industrial areas of Greece, an ever increasing number of labor accidents appears there, making the Thriassion Pedion an area of high risk for major industrial accidents and therefore the most proper place for checking the efficiency of the IS for manipulating the crisis.

2. INFORMATION SYSTEM FOR THE MANIPULATION OF INDUSTRIAL ACCIDENTS

2.1 General characteristics of the IS

As mentioned above, not only have the large-scale industrial accidents direct influence to the surrounding areas of the particular industry, but there is a high possibility of spreading the disaster to even broader areas, as well. As the consequences refer to human victims and to material destruction of both the industry and the surrounding extant infrastructure (transportation network, utilities, other constructions), the information related to their confronting refer to the total of the physical, social and financial activities in the area. Critical parameters that must be registered are:

- the topography of the area
- the hydraulic network
- the habitation and the industrial areas
- the transportation networks
- public services and facilities, etc.

These information combine geometric/cartographic data and quality/descriptive data. Consequently the capabilities and the structure of a Spatial Information System (SIS) is considered to be necessary. Such a system can provide the ability of collecting, overlapping, manipulating and visualising a large volume of data, which can be derived from the analysis of the information that describe the possibility of the happening of an industrial accident, of its spreading and the consequences of that. It can also provide the tool for the coordination of all the involved agencies/services that must take the necessary measures for the defense against a disaster of such a size, and also the exact place, timing and way of realisation of these measures.

By using the SIS as a user-system interface a Decision Support System (DSS) can be established. The DSS is a powerful advanced tool for control and decision making. So, the system will combine, in real time, the available spatial characteristics with all the other critical information, that can change the conditions of keeping or spreading an industrial accident, and will contribute to the decision of taking the most proper measures for the direct confronting of such situations.

2.2 Planning and developing the SIS

The Information Management System consists of a central Data Base, connected, with a two directions flow ability, to a software for representation of cartographic information and also to other assistant tools for the entering and manipulation of special information. Figure 1. shows the schematic structure and the operational flow of the SIS.

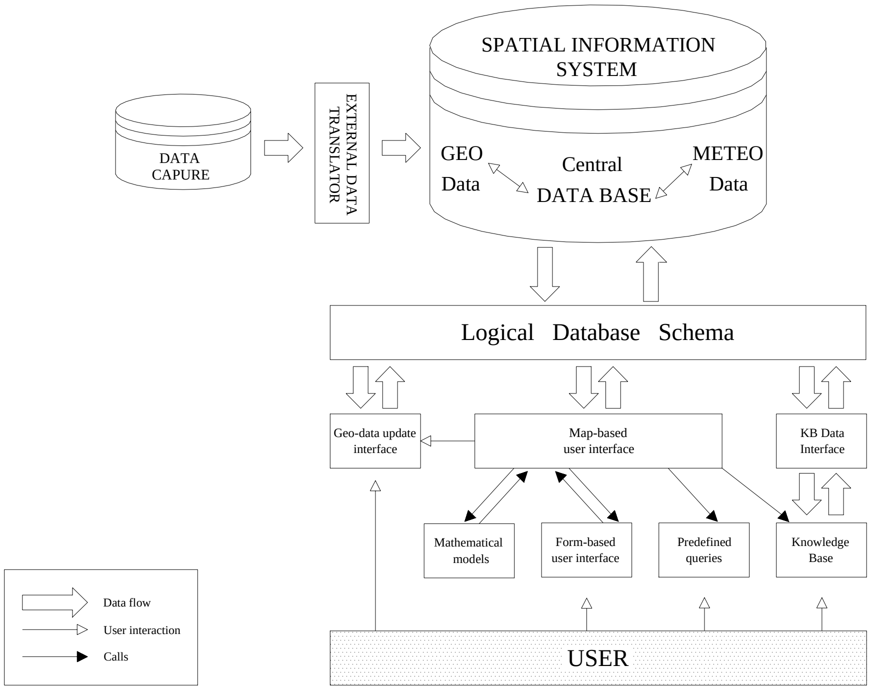


Figure 1. Schematic operational flow of the IS

The central Data Base consistutes the core of the system and it has a two-fold role. Within its relational infrastructure detailed information concerning several regional and operational data related to the local industrial companies and their associated sites of agencies as well as details of the road network and the transportation facilities of the region are a significant part of the information compiled and maintained. In addition, the Data Base 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 Data Base to store data and information produced by 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 software used for the development of the IS is the Microsoft SQL Server.

The software for spatial analysis and representation of cartographic information is the Desktop GIS - ArcView 3.0 of ESRI. The collection of cartographic data can be achieved by any of the alternative procedures: extant maps through digitizing or scanning, photogrammetric procedures or terrestrial surveying measurements. The demands in accuracy and the level of detailed representation for these data depends on the object. The installations of high risk industries must be registered with the accuracy of the scale 1:500 or 1:1.000, especially the tanks, the storehouses and other characteristics of special interest. The surrounding areas of these industries and the neighboring activities have less accuracy demands, these of the scale 1:2.000 - 1:5.000, yet the broader area of interest can be registered with the accuracy of the scale 1:10.000, both for planimetry and leveling. Consequently the best solution is the combination of the above procedures, with an emphasis on the application of digital photogrammetric methods either for the updating of extant maps or for the compilation of new ones.

It is exactly because high accuracy is selectively needed and only in small parts of the whole area, that the possibility of applying simple photogrammetric methods, like rectification or monoplotting for the compilation of the general background, should be investigated as first alternative solution. After that, more detailed and accurate spatial information can be added to the particular parts of interest, by applying more complicated photogrammetric methods, such as stereoplotting using large scale airphotos or even terrestrial measurements. These information is classified in various levels of SIS correspondingly, so that their cartographic representation in appropriate views of diversified detail and significance, will be possible to achieve, through the graphical environment of the ArcView software:

- at first level, the whole of the area under study
- at second level, the neighborhood of an industry (i.e. at a distance of 2-4 km)
- at third level, the diagram of the industrial installation
- at fourth level, the particular storage tanks and its neighborhood, etc.

All the detailed characteristics of the installations are derived from the central Data Base by the starting of the systems operation. Any kind of updating done to the central Data Base is automatically represented to the cartographic system. The other way round, from the later is the Data Base supplied with spatial coordinates of points of interest (tanks, storehouses etc). The connection between these two operational units of the system is done through the SQL language. Figure 2. shows an example of the structure of a graphical user interface with simultaneous representation of cartographic information and elements of the database.

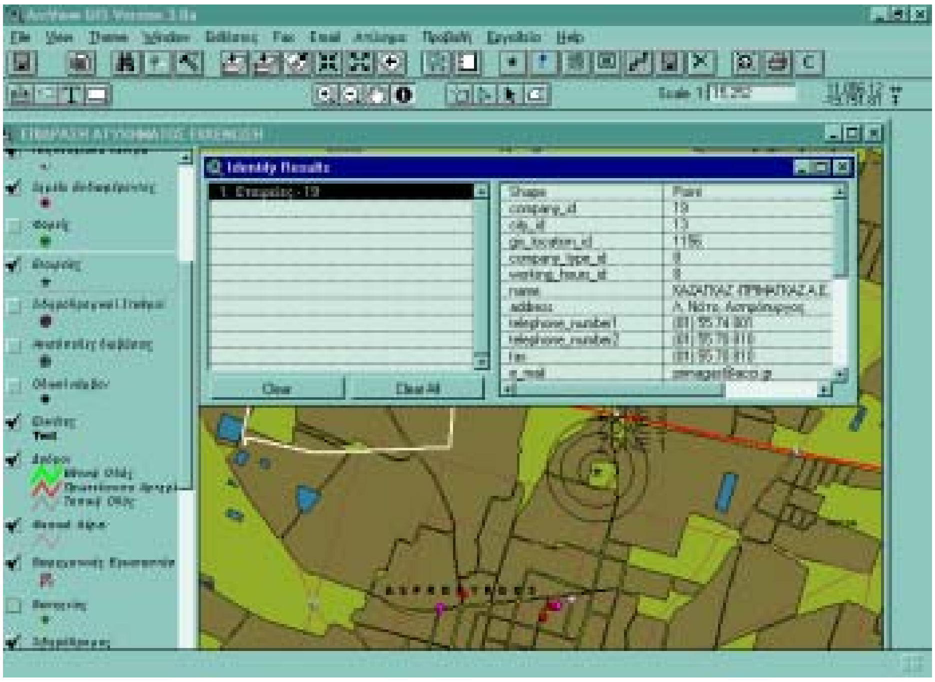


Figure 2. Graphical User Interface of the Information System

The main assistant tools that have been planned and developed for the IS are:

a. The accident simulation tool (AST), which performs the necessary numerical calculations that would quantify the extend of the consequences of an industrial accident. The type and the characteristics of the accident scenario studied is 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. Figure 3. shows a screen of the AST.

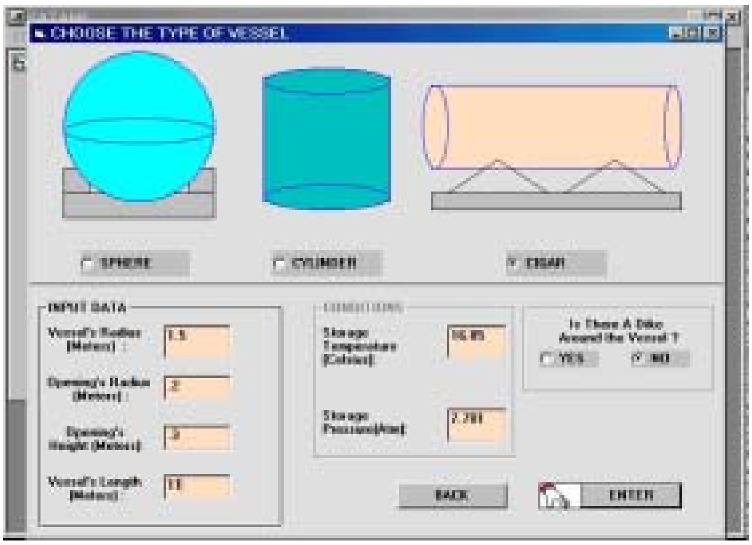


Figure 3. Accident Simulator Tool

b. The network analysis tool (NAT), which provides solutions to problems of effectively determining the shortest path within a specific road network for assembled population to abandon the affected region using mathematical programming techniques. The cartographic part of the IS performs all graphical tasks related to the operation of this tool, such as the roads, the road intersections, the location of the settlements, the location of the public buildings etc. The referring attributes are supplied by the central Data Base, that is the type and the condition of the road, the population density of each urban block, the type of the public building etc.

The IS, with the above described structure and tools, can automatically give the spreading of the consequences of a particular industrial accident. Being continuously supplied with data from the database it executes the proper spatial operations for the representations of areas with direct or indirect consequences of the accident, the way and rate of the toxic chemical pollution expansion. The later stage of this plan is the design of an advanced tool, the decision support system (DSS), for the timely provision of solutions at critical situations. So, this tool is responsible for proposing the appropriate course of actions that would enable the less possible harm on population, depending on the severity of the specific accident. The SIS provides solution for the worst possible case where the affected region should be evacuated.

3. APPLICATION TO THE THRIASSION PEDION

3.1 Basic characteristics of the region

The Thriassion Pedion consists of 4 municipalities with a total area of 344 sq.km. All the activity has been develop only to the flat part of the region (up to the level of 100m), which is surrounded by the mountains in the north and by the sea in the south, and has a total area of approx. 100 sq.km., which is the area under study. The urban areas are of a size of 15 sq.km., where approx. 60.000 inhabitants live there and the industrial areas are of a size of approx. 25 sq.km. In this area work 23.000 employees, 78% of them are occupied in industry and commercial enterprices. This percentage remains almost stable for the last 20 years, compared to the increase of the industrial units.

The Thriassion Pedion is the largest industrial area of Greece, since more than 1.050 industrial units of any kind are located there, some of which belong to the largest and most important of Greece. There are 57 industries for chemicals and gas petroleum products, some of them are located among areas of high population density. As an example it could be mentioned that 12 km out of the total 15 km coastline are occupied for the marine activity of these industries, with 13 piers, and trade activity of 5.500 ships. Relative to that, the traffic load on the extant road network is also huge, with total traffic rate of 30 million vechicles per year, 12 million of them travelling through the National Road that crosses the Thriassion Pedion.

In parallel, the existing social infrastructure concerning schools, sports activity, entertainment etc, in urban areas covers only the 33% of the needs, in the region, according to the international standards.

3.2 Compilation of the chartographic background

The chartographic characteristics that were considered necessary for the operation of the IS are:

- The coastline, the road network classified into 5 categories, starting from the National Road upto the non-asphalt roads, and the major road intersections
- The applied urban plans in the 14 various residence areas of the region
- The rest land uses (rural areas, forests, military installations, industrial areas, etc)
- The streams, the natural water network and the lakes
- The elevation contours, with a contour interval of 4 m
- Detailed topographic diagrams of the main industries and the Seveso industries
- The location of the rest industries
- The location of archaeological sites and the other protected regions
- The location of the Public Services and the possible places of population assembly (i.e. hospitals, schools, sports courts, hotels, etc).

The available data for the collection of the above information were:

- Maps for general use at a scale of 1:5.000, in analog form, which cover the whole area under study and include the necessary leveling. The date of the last updating of the various mapsheets varies between 1975 and 1985.
- Recent airphotos with stereoscopic coverage of the whole area, at a scale of 1:15.000
- The ratified urban plans for the settlements, at scales of 1:500 and either of 1:1.000 or 1:2.000
- Analog or digital topographic diagrams of the industries of interest, with the accuracy of the map scale 1:100 – 1:500.

A recording of the industries of the Thriassion Pedion, made in the year of 1990, by the use of questionnaires and sketching of their location on the map series of 1:1.000 for the urban areas and 1:5.000 for the rest, compiled for the needs of Local Authorities, was also available.

According to the technical specifications of the IS, the creation of a three-level structure of the digital chartographic information was decided:

a. General map of the whole region under study. Its compilation contained two stages:
    - the digitization through the ArcView software and the structure into GIS-coverages of necessary information contained in the analog maps of general use (i.e. coastline, road network, streams, contours, etc)
    - the updating and completion of the digitized data using the recent airphotos. The continuous development of the region especially in the expanding of the industries and the human settlements, made some of the digitized data out of date (there were changes noticed even at the coastline data, due to the construction of new marine installations). The use of digital rectification was proved to be the most effective solution due to the following reasons:
        - the comparatively low accuracy demands
        - the availability of leveling data
        - the use of check points derived from the extant maps.

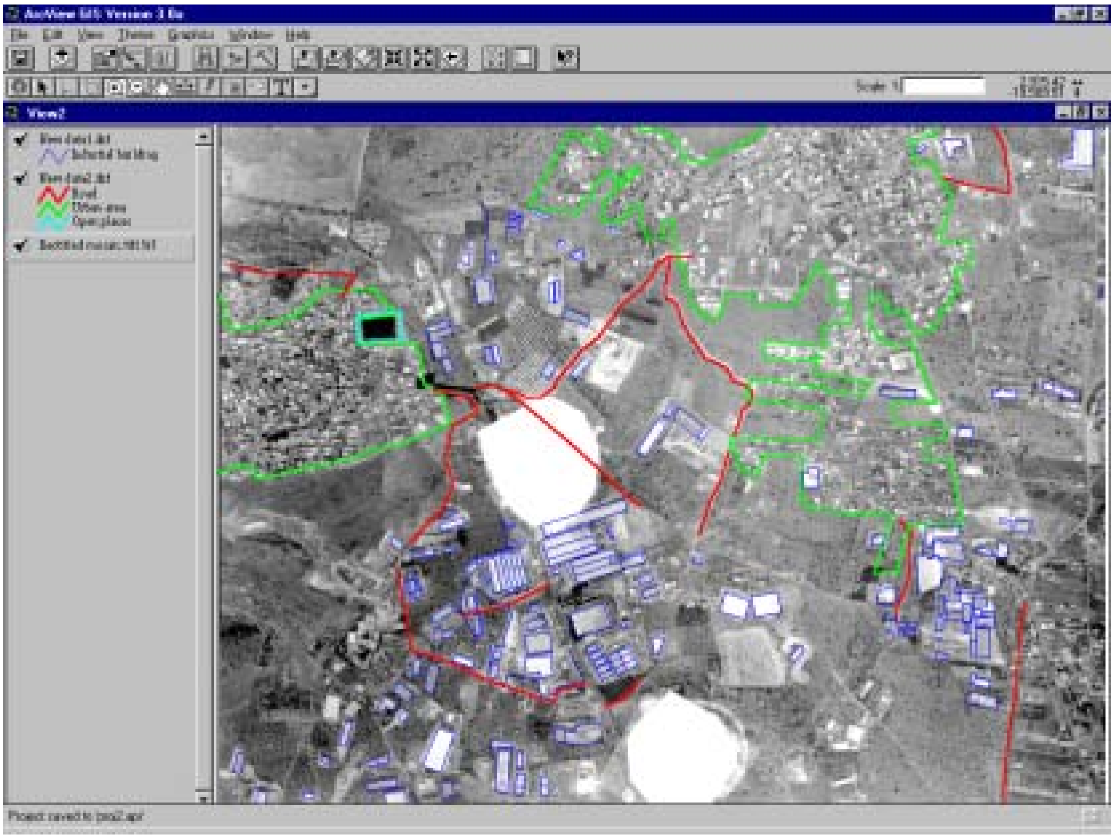


Figure 4. Digital updating of cartographic data from the rectified photomosaic

Twenty airphotos were used, which covered the whole region with significant side and forward overlap. From each photo a proper part around its center was selected (of a size of 7-12 cm on the image scale), so that a maximum error of 6 m on the ground (or 0.4mm maximum radial displacement on the image) to be achieved according to the equation:

$$\Delta r_{max} = (\Delta Z_{max} \cdot r) / (c \cdot m_p)$$

for c=152 mm and m_p=15.000

The photogrammetric rectifications were done by ARCHIS software of SISCAM, in MS-Windows environment. For each rectification 8-10 well defined points on the analog maps of 1:5.000 were used as control points. These points were crossroads, corners of large industrial buildings, points defined on the piers, characteristic boundaries of large land parcels etc.
A photomosaic was compiled for the whole region of study out of the rectified photos, by using the capabilities for raster geoprocessing of the module ARC GRID of GIS-software ARC/INFO of ESRI. The coordinate differences at the seams of images were within the accuracy demands, so giving the possibility of digitizing the necessary planimetric characteristics from the unique raster file. These characteristics were the updated coastline and the road network (with its classification), the land uses with detailed outlines of the urban areas, the new installations of the industries, the streams and hydraulic network and the archaeological sites. Figure 4. shows a screen of ArcView with a part of the photomosaic (the raster background) and the digitized vector information.

b. A detailed map of the surrounding area of each high risk industry. The additional to the above general map data were recorded in new coverages of the IS, for better manipulation of the data. The additional data were collected:
   - By digitizing the blocks on the existing analog urban plans, which are included to the areas of interest
   - From the topographic diagrams of the industries. Those of them in analog form were scanned and the rest were properly adapted to the chartographic background by using common points (i.e. boundaries, roads, diagram orientation etc)
   - From stereoplotting of individual parts of stereopairs for the surrounding areas of the high risk industries which are not covered by the extant diagrams. This process was applied into 4 stereopairs for the collection of a limited number of planimetric data (boundaries, buildings, narrow roads). As control points were used well defined points on the large-scale topographic diagrams of each industry. The plotting was done on the PC-based digital photogrammetric system VMAP. The discrepancies noticed between the photogrammetrically determined ground coordinates (X,Y) of check points and their coordinates as they are derived from the topographic diagrams, were less than 0.8m

c. Diagram of each high risk industry, with detailed representation of their buildings, their tanks, their storehouses and the plan of the whole area within the industy's boundaries. The geometric information was collected exclusively from the extant large-scale topographic diagram of each industry.

The descriptive information which is related to the chartographic data was collected from:

- Data aquired from public agencies, such as the National Statistical Service of Greece, about the population density per urban block and the employment, and the National Meteorological Service, about the winds, their direction, etc
- Existing studies for the industrial activity of the region
- Air-photointerpretation study (classification of the road network, land use, sport courts and military installations)
- Detailed data acquired from the industries (special characteristics of the tanks, the wastes etc) in combination with field research for the completion of information.

3.3 Accident simulation scenarios

For the good use of the geometric data and their attributes, several accident scenarios where planned, which were incorporated to the Accident Simulation Tool. All accidents involve hazardous materials storage tanks and systems referring to dispersion of toxic materials. For their manipulation, appropriate accident simulation programs were developed. Figure 5. shows a screen with the toxic dispersion caused by a fictitious fire at a particular tank of a chemical industry for certain meteorological data.

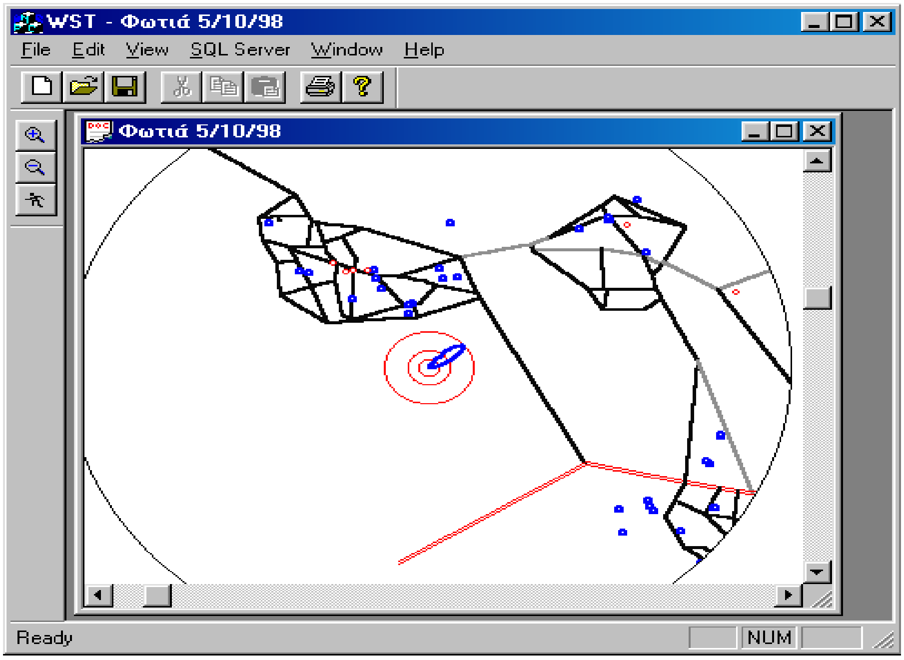


Figure 5. Toxic dispersion simulation tool

This information is supplied to the Decision Support System where combined with the geographical characteristics of the region and other data of the IS (such as the installations of neighboring industries, the population and the number of employees in the adjacent urban areas) shows the results of the accident with an efficient graphical way. Figure 6. shows such a representation with the expansion zones of the toxic pollution.

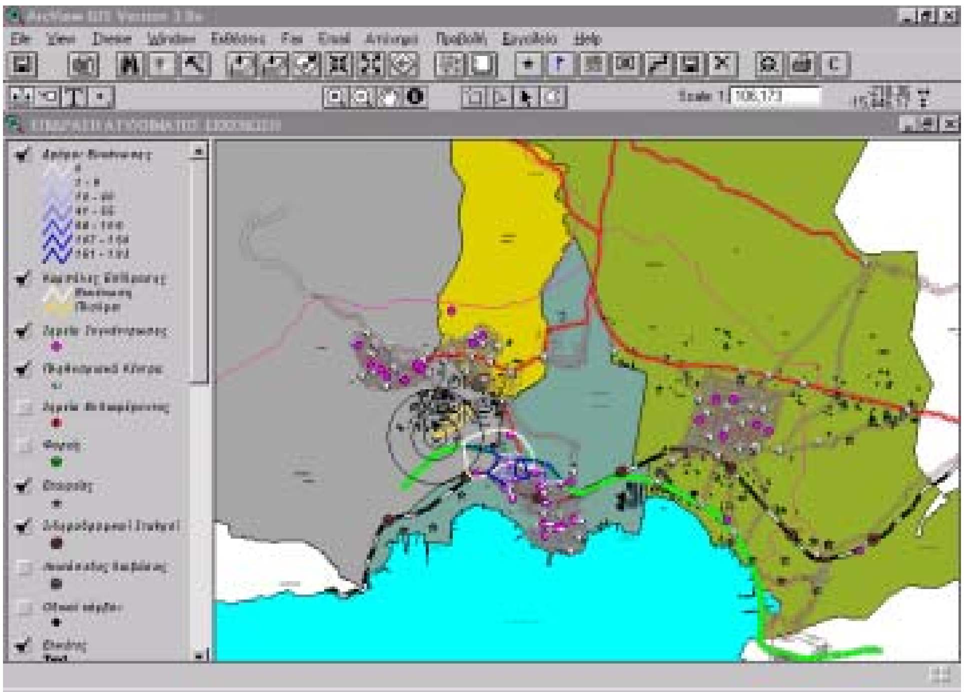


Figure 6. The basic screen of the DSS tool

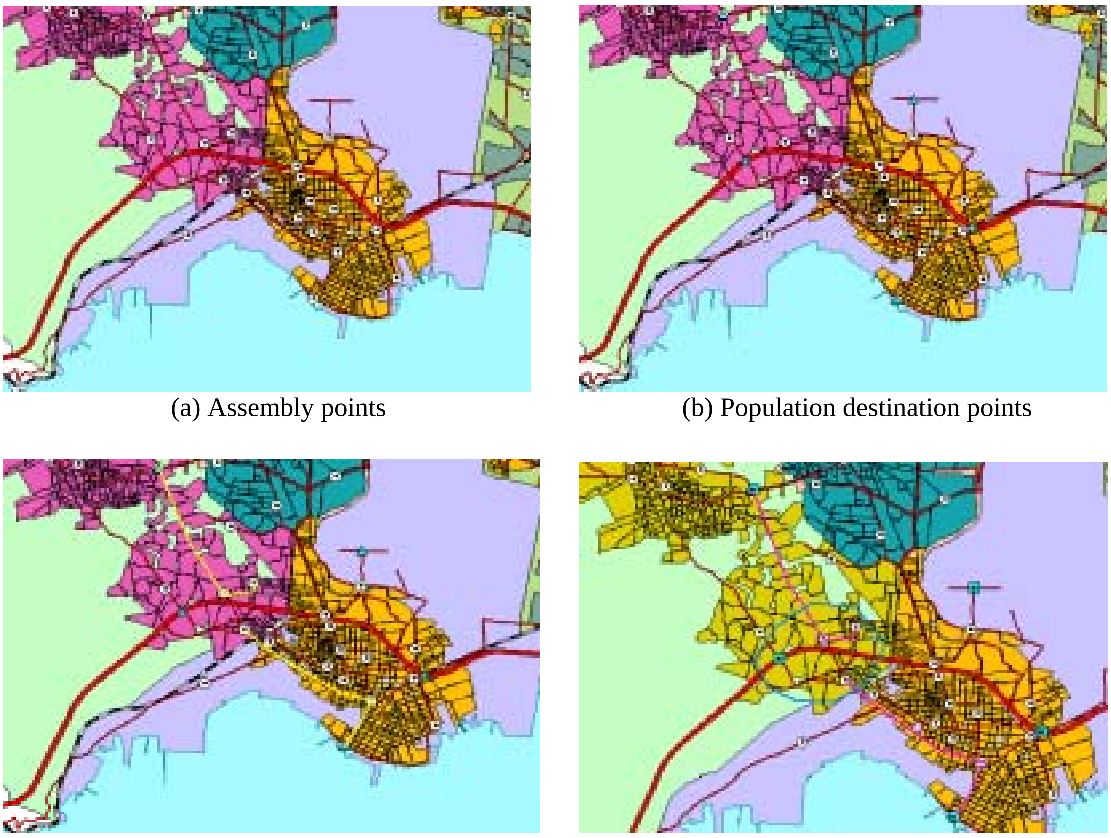
In the case that, it will be estimated that the people's life there is in real danger, the system goes further and provides us with the optimum evacuation procedure:

- Defines the assembly points and the population destination points, according to the extant data in the central Data Base (public buildings, open spaces etc)

- Calculates and represents the area that must be evacuated according to a particular time schedule
- Executes network analysis for the regional roads and their supply capacities
- Defines and represents graphically the evacuation paths that must be followed.

Figure 7. shows a graphic representation given by the IS for the above procedure for the fictitious fire accident under study.

Similar simulation scenarios were developed for various cases of accidents in the region, for the better checking of the AST operation and the proving of the IS's efficiency.



(a) Assembly points (b) Population destination points

(c) Evacuation area (d) Evacuation paths

Figure 7. Evacuation procedure for a specific industrial accident

4. CONCLUSIONS

To confront large-scale industrial accidents especially in the regions close to urban areas, the installation of an operational center at the local authorities responsibility is significantly useful. The system which was developed has low hardware demands, so its operation is cost-effective and simultaneously it gives solutions for the successful confronting of such a distraction. The IS combines open architecture and user friendly interactive operation. It constitutes a combination of a GIS with an external Data Base and a DSS for the better use of information, with appropriate tools for the manipulation and visualisation of the data. The most expensive part for the operation of the system is the creation of the chartographic background. The methods of collecting, entering and updating of the geodata is critical for the reliably effective confronting of the accident. The right application of digital photogrammetric methods is the best alternative solution for the certain map scales and accuracy demands. Usually the large industries lie in open space and flat areas where digital rectification in combination with the data from extant maps can provide quick and cost-effective solutions for the compilation of the chartographic background. The additional data can be derived from the individual topographic diagrams of each industry.

For the beginning of the operation of the IS 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 further various meteorological and regional details and proceed to the evaluation of the consequences, the determination of the extend and the region of the affected part of the adjacent area and be guided to take actions for the protection of 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.

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