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Rare events: natural hazards and major accident industries

K e y w o r d s

Rare events, natural hazards, industrial accidents.

S ł o w a   k l u c z o w e

Zdarzenia rzadkie, zagrożenia naturalne, katastrofy przemysłowe.

S u m m a r y

This paper illustrates an integrated system (methodology and derived decision support system) for the management of hazards coming from rare natural events referring to major accident industries (Seveso II classified) and chemical process plants in general. Work done provides for a risk analysis approach and decision / emergency support. This work focuses on studying accidents related to severe natural events, presenting the case study of an Italian chemical plant (flooding risk).

1. Aims

Aim of this paper is presenting real cases of risk assessment related to rare natural events (floods, heavy rains, wind, etc.) involving chemical process industries and, in particular, major accidents (Seveso II classified) companies.

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Natural hazards are likely to produce major accidents if involving this kind of industries. This paper will deal with the flooding issues connected with heavy rains and floods. Regarding earthquakes and process companies a great literature is available and they will not be taken into account in these papers.

Risk assessment studies take into account the plant sitting and layout and appear to have a great importance in some Italian areas and regions having complex orography.

Furthermore during discussion of the paper the authors will present some accidents of this kind that affected process companies on the Italian territory and that could have lead to serious damages to process lines support structures, process equipment, hazardous chemicals lines, and the related lessons learnt.

In general it appears very important to site the new plants in proper (i.e. safe) locations, to protect the existing industries with suitable measures and to implement proper emergency planning for the surrounding territory.

Risk analysis and the subsequent decision support for the Authorities have to be defined considering primary objectives such as: localize and characterize the sites, select and group the scenarios, plan the mitigation intervents, foresee the abnormal flooding events and evaluate their consequences, plan the emergency and the operators training.

2. Introduction

Taking for example into account water problem treatment inside an industrial plant this appears to be a particularly important issue for several reason and in case of Seveso II classified companies it is fundamental.

In these companies it is common having two different sewers: an open clean storm water sewer and a closed contaminated storm water sewer.

Plant sewers are of particular importance and have to be dimensioned characterizing the rainfall.

It's quite important estimating the maximum 24h rainfall and the intervals between these max rainfalls.

Considering the characteristics of the surfaces (impervious, semi-pervious and pervious) it's also possible to assign a runoff coefficient to estimate the portion of the rainfall that is able to become runoff.

These considerations regarding the plant site & layout allow the estimation of the cumulative flow rate per unit area.

Furthermore sewers have to be dimensioned to take into account the large quantities of firewater used in case of fire (referring to the fire scenarios and the available fire protection systems and equipment).

These considerations have to be inserted into the Safety Report of the facility since they clearly define the fire water flow that in case of emergency would flow in all sections of the main sewer system.

Is this approach correct?

Yes it is, but this is not sufficient to consider several different events that assume particular relevance in some areas/regions (such as in complex orography sites) as stated in the previous paragraph.

For this activity it is important starting a precise and dedicated risk assessment.

Risk analysis helps to identify the level of risk of a particular hazard in the usual manner considering the frequency and the consequences.

In fact natural events can, sometimes, produce devastating effects on human settlements. These effects can grow dramatically if a major accident industry is involved.

This is especially true when a severe natural event hits a chemical process plant or a tank farm, due to the large quantities of hazardous substances that could be released, affecting people and environment.

Taking into account an accident occurred in USA closer to our problems we see the consequences of flooding coming from heavy rains in a refinery located 30 miles east of Houston.

In this case flood water covered this entire plant in depth ranging from two to five feet.

Process units have been shut in a timely manner and connected problems have been avoided.

Nevertheless the flood waters caused extensive damage, mainly to computers, electrical substations, switchgear, pumps, motors and building and at least 350 electric motors varying in size from 5 to 20 horsepower were completely submerged and required replacement while the larger electric motors with up to 1500 horsepower were disassembled, baked out and repaired.

The plant was shut down for approximately 2 months but it did not suffer for major accidents coming from the flooding for possible damages to supports, structures, racks resulting in greater emergencies or in pollution.

Having the reduction of natural events consequences as a primary goal, we are supposed to define a strategy to analyze the problem, find the vulnerabilities of the industry-natural event system and, possibly, remove them.

3. Defining the problem

3.1. The industry-natural event system

As we hinted above, we consider the major accident risk industry and the natural event as a single system. This means, of course, considering in this system, with the "site" word, not just the plant itself, but also its boundaries and contour conditions, like the surrounding terrain morphology and the presence of inhabited places.

This kind of approach allows keeping a wider view of the problem and it better combines with the structure of the real knowledge database used to store data, explained later.

Some words must be spent on problems involved in studying natural events related major accidents. The study of this kind of accidents has one more difficult compared to the study of equipment and/or human related accidents in these plants: they are, in most cases, rare but it is important to take care of what affirmed by the European Environment Agency: […] *in nineties an exceptionally high number of floodings that made a large number of victims and great damages* […].

Under the definition "natural events" go many different events with very different consequences that require each a different consideration.

According to domain literature we can include among rare events:

- Subterranean stress (earthquakes, volcanoes, tsunamis);
- Surface instability (landslides and avalanches, ground surface collapse);
- Weather/wind, storm, tornadoes, hurricanes, floods).

All of these events can have dramatic consequences but, in most cases, they are not all likely in the same place so, in one single place the study will focus only on some of them taking into account the specific features of the site.

The Italian experience shows that, according to which part of Italy we consider, the most frequent events are floods, landslides and, sometimes, earthquakes. Italy is not subject to the threat of hurricanes or tsunamis.

Catastrophic natural events, besides being rare, are not reproducible in laboratory, so it is not possible to have a case history as rich as the one available for equipments.

This brings to statistic data (coupled with simulation) as the only possibility to evaluate the frequency of occurrence of a certain event.

To say the truth, there are some other predicting techniques coming out, but at this moment they are not enough affordable and their previsions have a too short temporal horizon for our scopes, so we decided not to use them.

Since these events are very difficult to face when they happen, the first thing to do is to choose the right place to build a new plant, considering the hazards connected to natural events, thus avoiding too dangerous places.

It may appear obvious, but some times the best strategy is avoiding to put ourselves into a situation difficult to manage.

Obviously not always a chemical plant can be built in a perfect place, having all the characteristics we need so, if choosing a place completely catastrophic-natural-event-proof is not possible; we have to know and face the situation.

3.2. Objectives

The main objective, in order to face this issue, is minimizing the overall consequences of a devastating natural event hitting the plant we consider. This means, first of all, to save human lives, then to avoid damaging the environment, then to avoid damaging the plant and all others material structures, buildings and so on.

3.3. Risk assessment

Risk analysis has become an invaluable tool for determining the fire safety level of existing facilities, for assuring effective protection design (also avoiding costly subsequent redesign) and for effectively integrate rare events protection criteria and features into project specifications in case of new-plants construction.

From their experience in the industrial field where this kind of approach is commonly used to deal with industrial risks the authors started using, with the proper modifications, the same approach to deal with rare events risks in different realities in order to: better classify the present risks of the facility, take better-informed decisions protection systems design (and avoid painful redesign), comply with the existing regulations (where applicable), reach safer conditions with hazard reduction at the source, identify the really needed protection measures, save money.

The proposed methodology consists of a conceptual model divided into different and linked phases.

Starting from the system identification in terms of general layout of the facility, boundaries, etc. it is important to define the general intents, i.e. objectives and performance requirements.

Main scope of the work is reaching the defined objectives and the desired performance: stakeholders of the project, taking into account the regulations to be applied (considering also available technical standards, guidelines, laws), are asked to define the acceptability criteria and the tolerance thresholds before the application of the methodology.

Methodology (for flooding risk) is depicted in Fig. 1.

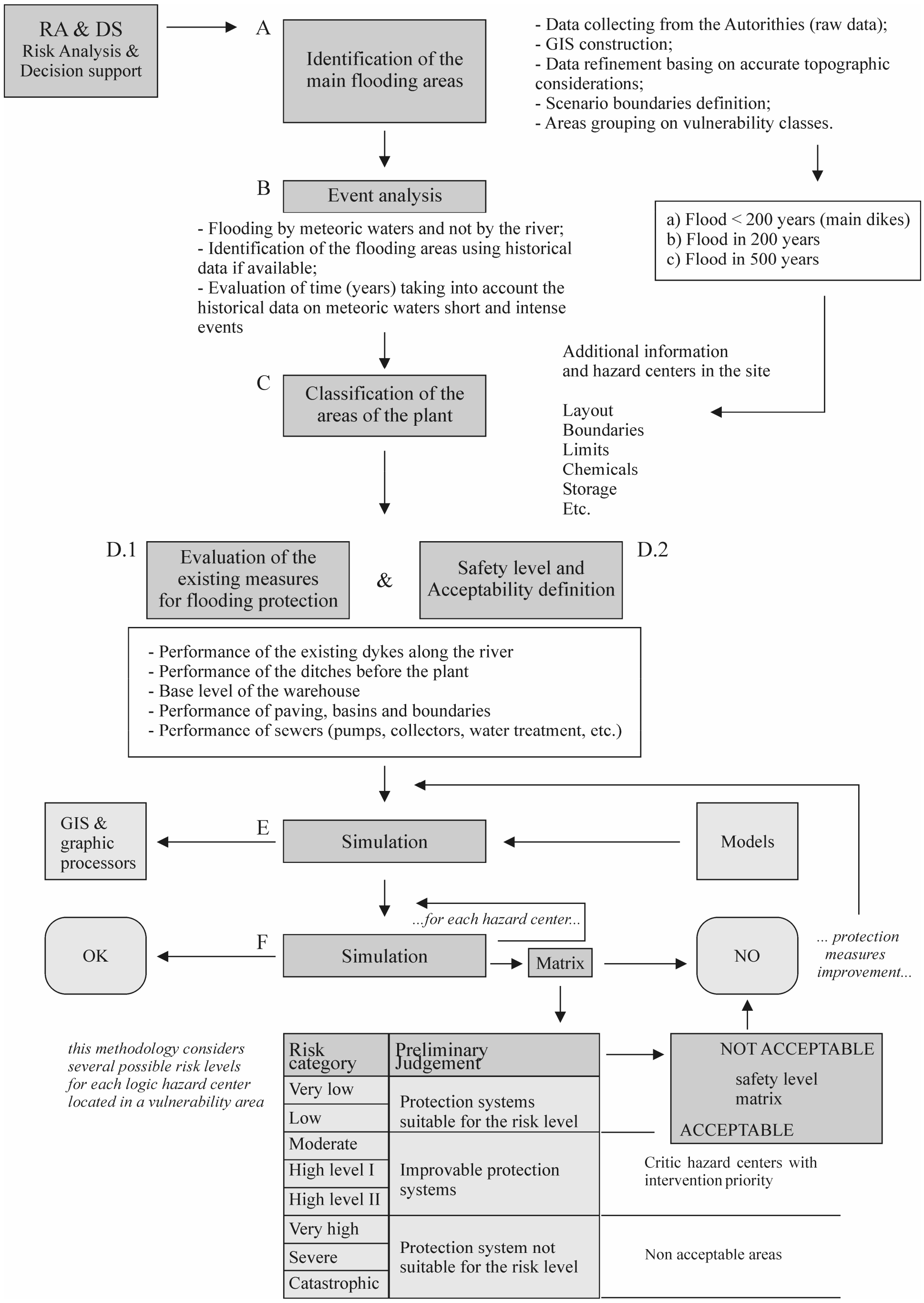

Fig. 1. Methodology (for flooding risk)
Rys. 1. Metodyka (ryzyko związane z powodzią)

3.4. An approach to the problem

Considering a new plant, we can identify three phases in which to divide the part of life cycle of it that start from its construction to arrive to the management of an accident:

1. Finding a suitable location to build the plant
2. Normal operation of the plant
3. Accident – Managing the emergency

We can work on phase 1 to decrease the probability of having to face an emergency and on phase 3 to decrease the effects of the natural event; after the explanation of how the full system is structured, we'll see how we can intervene in phases 1 and 3.

This is true for new plants. When dealing with an existing plant it's obvious that the place where to build it cannot be chosen.

In these cases a risk analysis on the existing situation can be done, finding directives to modify the parts of the plant more subject to risk.

Phase 3 is almost not touched by the fact of not starting from scratch.

What is important to notice is that, until this moment, damage coming from floods, earthquakes, and other natural events has not been considered when doing industrial risk analyses. But, evaluating the entity of this kind of damages during the last years, it's evident that they are relevant. We can, for example, refer to the famous MARSH report, that lists the 100 largest losses in terms of US dollars. We see that in the first 18 places we have damages going from 174 to 839 millions of dollars. As it's possible to see, losses can reach important values, so the further cost to be sustained for a risk analysis in this sense, and possible modifications to the plant, in most cases, is worth while.

In applying the results of risk assessment to prevent this kind of damage, it's been noticed that normally it's impossible to give to every single part of the plant the highest level of protection, first of all for economic reasons.

So it appears necessary to decide where to focus the attention, in other words we have to identify the parts of the plant subject to the higher level of risk and bring them to lower levels. To do this, we have to make an analysis for every part of the plant, putting together information regarding different aspects:

- risk coming from terrain morphology;
- risk coming from plant related aspects, like type of equipment or chemicals used;
- decreased risk coming from measures of protection taken.

In order to better conduct this analysis it's necessary to have an instrument that allows organizing information according to a layer based approach.

This instrument has been identified in GIS technology, and its characteristics will be explained in the next paragraphs.

4. Structure of the DSS system

A conceptual model has been defined and translated into a coherent performance-based methodology based on hazard centers identification, vulnerability classes, risks classification and acceptance criteria matrices according to the identified methodology.

An integrated knowledge management tool and Decision Support System (DSS) has been built on it. The structure of the software system is depicted in Fig. 2.

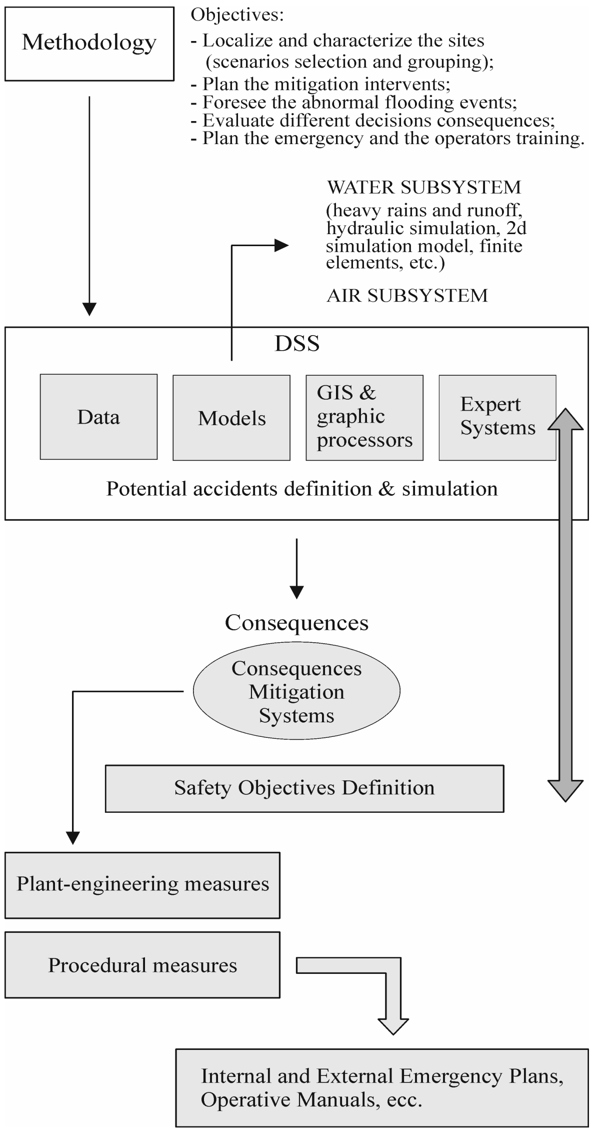

Fig. 2. Structure of the software system
Rys. 2. Struktura systemu oprogramowania

A DSS is, in general, offers several features, from the assistance in the evaluation of the situations, to the identification of alternative scenarios, to the analysis of the structure of particular contexts, the evaluation of the analysis results, their representation and their judgement taking into account reference values.

The DSS built by the authors is composed by four main components:

– GIS tool and graphic post-processors for dynamic visualization;
– data base management system (DBMS);
– model base management system (MBMS) and simulation models (SM), hydraulic, finite elements, etc. divided into homogeneous subsystems (Water/Air);
– dialog generation and management system (DGMS).

These components represent the decisional environment and the DGMS is the component that directly interacts with the decision maker.

A GIS (Geographic Information System) is a comprehensive set of advanced tools, data and procedures that simplifies data gathering and archiving and produces maps and/or different other kinds of representations able to give the users (according to their role and responsibilities) descriptive information about existing elements (objects) or dynamic events (even in real time). GIS well known technology incorporates the software procedures to:

1) represent geography;
2) georeferencing the stored items associating them to a precise location;
3) organize data on different levels of model abstraction and with different archiving methods (vector, raster, network, TIN, etc.);
4) treat these data using object-oriented concepts;
5) create and maintain geographic databases (storage, indexing, security, query);
6) visualize data (elements, decisions, changes, etc.) on a rich GUI (Graphical User Interface).

Since the DSS is not an only rule-based tool it greatly differs from the general known expert systems, but, in some way, a part of it is quite similar.

DSS supports the users in the main three phases of the decisional workflow: formulation, analysis and interpretation.

The methodology and the DSS has been applied to several real cases and shared with the various Authorities having jurisdiction.

A derived simplified version of the tool is being constructed in order to allow its use during real emergencies and land use planning.

4.1. The knowledge base

As we said before, we think at all the objects involved in our study as a single system, so it becomes natural thinking to put all the information we need in a unique objects database.

Regarding the geographic related information, the database works in conjunction with a GIS system. The native layers structure of GIS systems facilitates the manipulation of data being inserted in the objects database.

Moreover, it becomes easy, accessing the stored information, to generate maps following precise rules. Data are organized in layers and themes connected to one or more common parameters.

Besides geographic information, we need to store all the plant related data. To do this, we define a list of classes of objects, and for each class we define the associated properties.

For example, we can define the class "Column Equipment", assigning it some properties, like "hazardous chemical hold up" or "position". Then we define an object, for example giving it an identifying code, like "C1_Column", and we assign it to the previously defined "Column Equipment" class. This way, the new column "C1" has all the properties defined for that class of objects, this means also to define the operations that can be done with/on that object (with a so-called Object Oriented approach).

Of course, it is not possible, and not necessary, to achieve such a level of detail (i.e. in other words we don't have to insert into the database every single component that constitutes the plant). We must use the lower level of detail compatible with our needs.

The level of detail is decided with a preliminary risk analysis.

Besides defining all the objects it is necessary to define the connections among objects. The type of connections an object can accept is defined when its structure is defined, is part of its properties.

When all the objects and the connections in our system will be defined, we'll have a complex structure made of a net of interconnected nodes.

4.2. Simulation

Another core module of the system is the simulator, used intensively during the risk analysis, even in an iterative process to evaluate different scenarios and protection measures combination.

In fact risk assessment is used to evaluate possible accidental scenarios before they take place, thus removing in advance the greater hazards or, if it's not possible, at least decreasing the negative effects.

The results of simulations and risk analyses are used during the project phase to indicate the best solutions according to safety criteria, and are used every time a modification in the plant occurs.

After this, results of simulation are stored into the database too, so that they can be used in case of accident for case based reasoning.

The examined event isn't the rupture of an equipment, or something else we are used to deal with generally speaking about industrial risk, but a natural disaster and its consequences (general industrial risk consequences models are not useful in this case while they could be quite helpful in identifying domino effects coming from the natural events consequences on the equipment, such as toxic releases, jet/pool fires, etc.).

This means, as already hinted, that we have to take the characteristic data from statistics and historical analyses and these data can be difficult to find: simulation of credible events is the best solution to find available protection measures combinations.

In case of working on a pre-existing plant, it's obvious that the freedom of intervention is limited, first of all because it's not possible to choose the location of the plant or to delocalize some parts of the plant.

Secondly, in most cases, some features of the equipment that could help in case of a catastrophic natural event cannot be decided, because the requested modifications to the plant would be too expensive in terms of money and of equipments shut-down time.

So, we are limited to minor changes, of course this does not mean we cannot do anything. We can still use the system, inserting all plant relative data into the database to conduct a risk analysis simulating the effects of the natural events we're interested in, and obtain indications on what to do to decrease the risk.

As we said before, we need to see the problem in a layer organized way. GIS technology allows extracting information from the database and representing it showing only the parts we need.

Suppose we are analyzing the risk associated to flooding for equipment. With GIS, we extract from the database terrain related information, equipment and process information and information about available protections, then we are able to conduct a simulation taking into account all these data in order to obtain a risk index for each combination and for various parts of the plant.

After we've done this for each part of the plant, we are able to construct a map with all the risk levels associated to them.

Then we decide which the maximum acceptable risk level is and we begin to work on those parts having higher levels to bring them to acceptable levels.

This is an iterative process, in fact we start with a simulation, we see that the risk level is too high, so we insert some modifications into the system and run the simulation again, if we didn't solve the problem we have to try with different modifications until we find a suitable solution.

We could also find that different solutions help in solving the problem; in this case we have to decide which is the best one according to security and economic considerations.

4.3. Emergency management

The decision support module of the DSS could be also giving the aim of guiding people to take decisions during the emergency.

Everybody knows that when people are in a situation of danger their ability to take decision decrease, when they are not completely in panic. On the other side, right in these moments the greatest decision taking ability is required.

To help people in becoming confident with the operations they should do during emergency they are demanded to make training and exercitations, this is mandatory in Seveso II classified industries. This training activity has to be conducted with a proper tool. But even this may be not enough.

So, the Decision Support System can be of great help, not only helping people to take decisions and to evaluate the situation more easily, but also automating a list of operations to be done.

In fact, it can automatically notify the event to a list of interested persons and authorities, sending email and faxes. It can also be used to notice media (radio and TV) of the fact so that they can contribute to warn the surrounding population.

More precisely, the DSS is projected to achieve a list of objectives, the main ones are:

– to acquire the warning of incidents in real time,
– to make sure the received warning corresponds to a real emergency and is not a fake,
– to continuously receive up-to-date information of what is happening,
– to recover in a very short time archived information regarding risk scenarios,
– to elaborate scenarios of possible consequences of the accident in real time, only for the cases that allow it,
– to define operations to be done relatively to what is happening,
– to determine which is the population involved and to alert it using the provided systems (telephone, radio, TV, etc.),
– to alert and send to the accident place the opportune emergency teams.

First of all, a preliminary analysis of the suitable site must be done, evaluating the consequences of various simplified scenarios.

When the site has been chosen the plant can be built and a precise risk analysis must be done, all the geographic information must be inserted into the database, using the GIS support. During the risk analysis the simulator takes from the database all the information needed regarding geography and plant structure.

When an accident occurs, the DSS becomes active and helps facing the emergency. It connects to the database to look for similar scenarios and to reach all the other information needed (Case Based Reasoning).

If we look more in depth at the functioning of the DSS, we see that it works following a logical scheme like the one presented in Fig. 2.

It reacts to external events input by the users according to a set of predefined rules.

5. Case study

The system hereby presented has been successfully employed in studying the case of a chemical plant located in Italy. The plant is situated in a valley, and has a river near it.

The path followed to investigate these problems in this real case study and the needed protection measures have been defined by using the developed methodology and decision support/simulation software.

This case deals with a Chromate compounds production industry (Seveso II classified).

Fig. 3 shows a simplified map of the zone, elaborated by the simulator in conjunction with the GIS system.

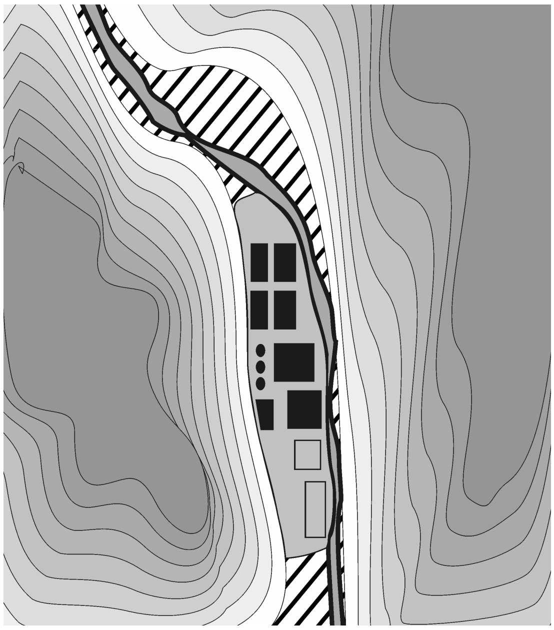

Fig. 3. Map of the plant and the surrounding area
Rys. 3. Mapa zakładu i jego otoczenie

This industry is composed by process units, raw materials warehouses, product warehouses and waste storage. The industry is located at the sole of a valley near a river.

Taking into account the natural hazards of the list the preliminary analysis addresses the events that can involve the company resulting in major accidents (environment damage).

These accidents are connected by two different kinds of flooding:

– flooding by meteoric waters from the slopes;
– flooding by the river itself.

Its major problem is the great quantities of chemical substances stocked there since, in case of flood, pollutant substances could melt into water and pour into the river to the sea (about 2 km from the plant).

In fact, the preliminary study showed that the area was subject only to flood risk, so the work focused only on this aspect.

Of course, the plant already had its system of containment basins and draws, some of them routing water to the river and some to the treatment plants for contaminated water.

After being treated, contaminated water is drained to the river too. Notice that periodically water coming from the treatment plant is analyzed to be sure that it doesn't contaminate the river, so this solution of draining cleared water to the river doesn't represent a menace for the environment.

The thing that had to be studied was if all these systems could stand a flow of water as great as the one we could have in case of a major rainfall, intending with "major rainfall" one as great as the greatest ones we could find in the historic records of the area given by the Authorities.

In these cases floods had to be expected, since all the water coming down from the mountains around flows down into the valley, making the river level to grow and possibly flooding the area.

To do the job, first of all, historical data on rainfall have been collected, taking into account to obtain data about the height of the river and its flow and waters' speed during heavy rainfalls, thus being able to evaluate until when the river could be of help in draining water (of course, clean water only), and when it began to overflow, representing another problem instead of a help.

Then a three-dimensional map of the plant (with a suitable level of detail according to the indications in the previous paragraphs) and the surrounding area has been put into the database, thus allowing simulating the flow of water around and inside the plant.

All these data have been represented through classes of interconnected objects.

The simulation showed that some modifications had to be done, because there was the risk that some pollutant could be drained into the river in case of natural event.

Particularly, two aspects have been taken into account:

1) preserving the separation between contaminating substances and water;
2) saving equipments from being flooded with other domino effects.

The simulation showed that complete isolation of the whole plant from waters descending from the sides of the mountains was impossible, because it would have comported to build something like a wall going all around the plant, perfectly water sealed. Even if this would have been done, there was the great problem that in case of emergency the plant would have been completely isolated from the outside, a not even thinkable way.

So the strategy that has been chosen was to heavily protect only the most valuable equipments, and those that could represent a menace for the environment.

Then, an analysis of how substances where stocked showed that the risk of water contamination could be easily solved modifying the positioning of some substances and providing forced water drain is some parts of the warehouses, relocating them in different hazard centers, having a better flooding risk level.

To assure water could not reach chemical substances in some cases the heights where the substances were stored had to be changed.

To save the equipment some barriers to water have been constructed, providing emergency pumps to drain water that could flow inside, this because in most cases it's impossible to guarantee perfect watertight.

There is a total of three main pumps, two electrical and one diesel, to assure proper functioning even without electrical power. A power unit is also present to guarantee the functioning of all the informative system during emergencies.

After these 'material' changes, some modifications to the management of emergencies have been introduced too.

Several simulations have been conducted in order to evaluate different combinations of protection measures.

Plant management staff evaluated these combinations taking into account the economic impact of them and the possible drawbacks of the new barriers building around the plant from the productivity point of view.

Periodic inspection of protection measures, description of them, and the new management procedures have been inserted in the safety management system for major accidents prevention of the plant and in the safety report of the facility.

Praca wpłynęła do Redakcji 26.03.2006 r.

Zdarzenia rzadkie: zagrożenia naturalne a wielkie katastrofy przemysłowe

S t r e s z c z e n i e

W artykule przedstawiono zintegrowany system (metodyka i oparte o nią systemy wspomagania decyzji) zarządzania ryzykiem, związanym z zagrożeniami wywołanymi przez rzadkie zdarzenia z przyczyn naturalnych, mające potencjalnie wpływ na przebieg poważnych katastrof przemysłowych (klasyfikowane w Dyrektywie Seveso II), a ogólnie katastrof instalacji procesowych w przemyśle chemicznym. Wykonana praca przyczyniła się do opracowania metodyki analiz ryzyka oraz wspomagania decyzji w sytuacjach awaryjnych. Niniejsza praca koncentruje się na badaniu awarii spowodowanych przez niebezpieczne zdarzenia naturalne, przedstawiając studium pewnej instalacji chemicznej we Włoszech (ryzyko związane z powodzią).