A modelling system for the simulation of industrial accidents

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Keywords: Industrial accidents, modelling system, emergency plans.

1 Introduction

Lombardy is the Italian region with the highest number of hazardous industrial activities as defined by the Seveso II Directive (96/82/EC). For this reason the regional Civil Protection Department developed an integrated modelling system for the simulation of industrial accidents.
The system is composed by a set of mathematical models capable to simulate the different aspects of an accident: the release of a vapour or a liquid from a failure in a tank, the dispersion of the liquid over the ground and its evaporation, the dispersion of the vapour, dense or light, in the atmosphere and the overpressure field or thermal radiation field caused by an explosion or a fire. All the models are linked to a shared database containing the physical and chemical properties of the substances. The same database contains also the information concerning the type and level of hazard of each substance (i.e. LFL, UFL, toxicity levels, …). The models can be used alone or in cascade; for example the user can simulate the release rate of a liquid from a tank using a model, its dispersion and evaporation over the ground using another model, the dispersion of the dense or light vapour in the atmosphere with another model, its ignition and the effects of the fire on the surrounding environment with another model again. The models that can be used in cascade are completely compatible, i.e. the output of a model can be used as input for another model.
The modelling system also implements the algorithms described by the US-EPA for the management of the offsite consequence analysis. These algorithms allow a fast evaluation of the hazards associated to a given industrial plant.
The system can simulate different types of accidents, among them: release of vapours and liquids, dispersion and evaporation of liquids over ground, atmospheric dispersion of passive and dense vapours, BLEVEs, fireballs, pool fires and UVCEs.

2 Modelling system

The modelling system is implemented as a module of LTK3 (Quaranta, 1996; Quaranta et.al, 1998), a user-friendly decision support system for environmental emergency situations. It has a client-server architecture that allows remote or local users to access the system. The system is characterised by database servers at back-end level, middleware Fortè at the application server level and Java at client level. It allows an easy insertion of data necessary for the models input and the interpretation of the results. All the simulation models are written in Fortran language.
The system allows the users to place and configure their own industries. The placement is done by moving the mouse pointer over the image of the Lombardy region and clicking in proximity of the correct point. Then the user can make a fine placement inserting the actual coordinates in specific form fields. When the industry is properly placed over the region, it is possible to configure it by inserting plants and tanks (Figure 1). Each tank is characterised by a substance, its quantity, thermodynamic properties such as storage temperature and pressure and other information. Each user can insert several industries over the region and save them in an appropriate layer. For example

a company with different production plants over Lombardy could build its own layer and investigate possible accidents. Each layer of industries can be viewed and managed by the owner or, if desired, made public to other users.

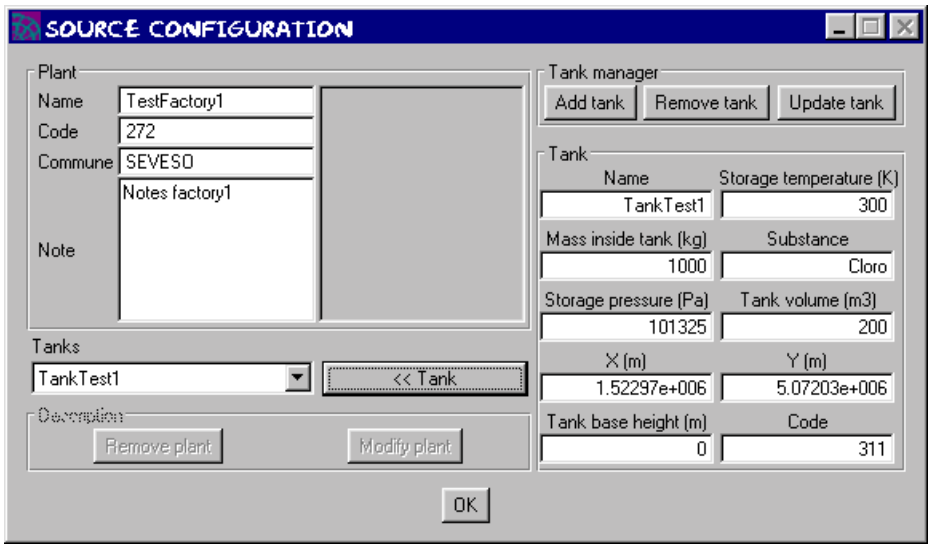

Figure 1 Form for source configuration.

After loading an industrial layer the user selects a specific industry and has the possibility to start the simulation phase. There are three types of operations that can be carried out: the calculation of industrial accidental indices, the use of the expert system and the simulation with a numerical model or with a chain of models. The calculation of accidental indices is based on the work of Suarez and Kirchsteiger (1998) with little modifications. These indices are useful to understand what is the main hazard posed by the industrial plant under study (release of substances toxic for water organisms, toxic in air, flammable and/or explosive) and then, for example, to decide what kind of detailed simulation has the priority.

The user interface of the expert system has been designed to be as friendly as possible and to give all the necessary help to the non expert user. This system gives as a result, for each type of accident, the area interested by a specific effect (e.g. concentration above the toxicity level of the substance for a toxic release, thermal radiation above the limit to damage a specified target for a fire, etc.). This area is plotted over the regional boundaries so that it is possible to organise all the necessary on site and off site preventing measures or emergency plans.

Since the mathematical models are more complex than the expert system, their use sometimes requires an expert user. Anyway the input interfaces of each model, as for the expert system, have been designed and developed in order to facilitate the user. For example the user does not insert the physical and chemical parameters of the substance involved in the accident, but simply chooses its name among those present in the substance database, then the system extracts the variables needed by the specific model. However, if the user needs to simulate an accident involving a substance not present in the database, it is possible to insert the variables needed by the model in a specific form. All the simulation models, the expert system and the algorithms for the calculation of the accidental indices share the substance database.

The georeferentiation of the industrial plants in LTK3 allows to represent the area interested by a potential accident over the actual topography. Other information layers can be added, including administrative boundaries (Provinces, Municipalities, …), water bodies, air quality monitoring stations and meteorological stations. Some of these layers allows to organise proper emergency plans, for example involving all the interested Municipalities, while other allow to choose the more

representative meteorological input for the models. The georeferetiation allows also to evaluate the possibility of domino effects.
After the simulations the system reads the unformatted output files of the models and the user can select the variable to show or, when the model gives 3D time variable results, which section and what time to display. It is also possible to perform zooming operations both on maps and on graphs.

3 Simulation models

The simulation models have been modified so that they can access a shared database containing the physical and chemical parameters of the substances. These variables have been obtained from different references. When not directly available, some of them have been calculated using proper relations indicated in literature (e.g. Perry and Green, 1997).
The models included in the system simulate the release term from vessels, the dispersion and evaporation of liquids above the ground, the atmospheric dispersion of light and heavy gases and the effects of fires and explosions. They are briefly described in the following.

3.1 SPILL

SPILL simulates liquid, vapour and two-phase releases from tanks. The algorithms of Lee and Sommerfeld (1994) are used for describing the liquid releases from small holes from various tank shapes. The main variables calculated by the model for this type of accident are liquid release rate as function of the time and leakage time. Vapour releases are simulated by means of the theory described in Woodward and Mudan (1991). The model calculates the time variable release rate and the thermodynamic quantities inside the tank. For a two-phase release the model determines the properties of the depressurisation and entrainment zones using the equations described in Fauske and Epstein (1988).

3.2 SPREAD

SPREAD is a mathematical model that simulates the dispersion and the evaporation of a liquid over complex topography with obstacles. The liquid spread over the ground is described using cellular automata (Miyamoto and Sasaki, 1997). The evaporation is calculated solving the equation of conservation of mass and energy. The energy balance equation considers the source term, the short term radiation from the sun, the long term radiation, the heat conduction from the ground or from obstacles, the heat convection due to the atmospheric wind and the evaporation term. Temperature is assumed uniform in the whole liquid pool, it depends only from time, not from space. The evaporation rate is calculated as indicated by Kawamura and Mackay (1987) with the mass transfer coefficient determined according to Mackay and Matsugu (1973).

3.3 DEGADIS

DEGADIS (Havens and Spicer, 1982) models the atmospheric dispersion of denser-than-air gas contaminants released into an atmospheric boundary layer over flat, unobstructed terrain. The model describes the dispersion processes which accompany the gravity-driven flow, contaminant entrainment into the atmospheric boundary layer, and subsequent downwind travel from the release. DEGADIS has been modified in order to read the substance database shared by the other models and to work properly inside the system.

3.4 MDGP

MDGP (Bellasio and Tamponi, 1994) is a non-stationary 3D Eulerian model that simulates the dispersion of heavier-than-air gases accidentally released into the atmosphere. By using the finite volumes technique, MDGP solves numerically the non-stationary partial-derivative differential equations of pollutant's mass and energy conservation. Peculiarities of this model compared to other ones of the same class include the modification of the wind field induced by the heavy gas cloud and the heat exchange between the heavy gas cloud and the ground.

MDGP, as DEGADIS, can be used to forecast the consequences of accidents that may happen in industries storing and/or processing hazardous substances that become heavier-than-air gases once released into the atmosphere.

3.5 TOXFLAM

TOXFLAM is an improvement of MRBT (Bianconi and Tamponi, 1993), an analytical model describing the atmospheric dispersion of inert or linearly-decaying substances with air density, released at variable rate. TOXFLAM is based on a general solution to the diffusion equation that describes instantaneous, finite or continuous releases. TOXFLAM accounts for the finite height of the planetary boundary layer and uses a mean wind speed obtained from the integration of the wind profile that accounts for the land use. The non-stationary mathematical solution implemented makes TOXFLAM more general than other regulatory models based on the Gaussian solution. TOXFLAM computes the concentration field at any time, the maximum reachable concentration at any location, the average concentration over a finite time period (dose) and the infinite exposure.

3.6 EXPFIRE

EXPFIRE (Bellasio, 1999) is a mathematical model for the simulation of the consequences of fires, explosions and BLEVEs. It can predict the overpressure levels due to BLEVEs and to the explosion of an unconfined vapour cloud (UVCE). In case of BLEVEs, EXPFIRE also computes the range of projectiles as a function of their mass. The model incorporates also the algorithms to estimate the thermal radiation due to pool fires, jet fires and fireballs.

3.7 Model connections

The simulation models have been developed or modified in order to allow a "dialogue" among them: the output of some models can be directly used as input by other models, so that starting from the simulation of the release term the user can arrive to the evaluation of the accident effects. However each model can be used alone to simulate a specific problem. An example of possible chains of models is illustrated in Figure 2. For a release in vapour phase, SPILL calculates the release rate used as input by TOXFLAM, if the vapour is lighter than air, or by MDGP if the vapour is denser than air. For a liquid release SPILL determines the release rate which is given in input to SPREAD; this model calculates the dispersion and the evaporation of the liquid and the evaporation rate can be used as input by one of the three atmospheric dispersion models. Finally a two-phases release described by SPILL can be used as input by DEGADIS or MDGP. These two last models, when describing a flammable vapour, calculates the mass above the lower flammability limit and the mass between the lower flammability limit and the upper flammability limit. These quantities are used as input by EXPFIRE for determining the effects of fires or explosions.

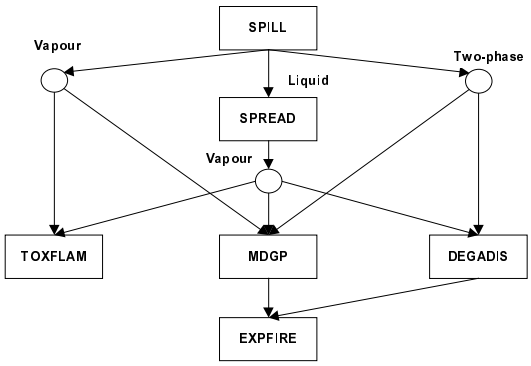

Figure 2 Example of possible model chains managed by the system.

4 Expert system

The expert system (ES) implements the algorithms described by the US-EPA (1999) for the determination of the area at risk for human beings and materials upon hazardous releases. The algorithms are simpler than those of the aforementioned mathematical models in order to give real time predictions. These predictions are always conservative because the worst conditions for dispersion are considered. The ES requires less input data than the models and guides the user among the possible selections. The accidents managed by the ES include the release of a toxic vapour, the release and evaporation of a toxic liquid, the release of a flammable vapour, the release and evaporation of a flammable liquid. When simulating a toxic or flammable vapour release the ES calculates the distance beyond which the concentration falls below the level of concern (e.g. LC50 or LFL). The user can also simulate other accidents as for example pool fire, fireball and UVCE. In these situations the user selects the target onto which damages must be evaluated and the ES calculates the distance beyond which the thermal radiation or the overpressure fall below the critical values for that target.

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