NEW GENERATION OF EMERGENCY RESPONSE AND REAL-TIME DECISION SUPPORT SYSTEMS

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1. Introduction

With their computational power increased, the new generation of emergency response and real-time decision support systems (ER&RTDSS) represents major improvements in the ability to provide decision makers with timely and accurate assessments of the impacts of nuclear or chemical accidents on public health and the environment as well as increase ability for fast and accurate response in case of terror acts. However, it entails a complex structure of ER&RTDSS kernels which must be developed for management and control of the computational flow, task scheduling and data acquisition. In general an integrated ER&RTDSS consists of four functional modules developed for:

- interfacing to on-line biological/chemical/radiological monitoring and meteorological networks,
- atmospheric dispersion modelling,
- consequences simulation,
- decision support and emergency response planning and support in case of a real emergency.

The kernel of an ER&RTDSS has to provide a friendly interface to the user and ensure control over the computational module and a large amount of various data, coming usually from other dedicated systems operated in different computer environments. Some of these data are static or varying slowly - topographic data, elevation or land-use can be updated from time to time - but the majority of the data should be provided in real-time. It in particular concerns collection of accident information, meteorological and measurement data from the local networks along with meteorological data from national weather centers. This demands application of advanced software engineering techniques using adequate tools to cope effectively with:

- data exchange with other systems,
- meeting demands of real-time regime, e.g., through parallelization of algorithms,
- distributed processing,
- heterogeneity of the network,
- portability,
- software security,
- ability to integrate with other systems.

Below we review basic strategies and methods for dealing with the issues set out above. A particular emphasis is placed on aspects of these technologies that meet specific requirements of the ER&RTDSS.

One of the particular features of ER&RTDSS is the necessity of dealing with a great variety of data coming from other dedicated systems like meteorological and measurement networks or various types of geographical and statistical information. It necessitates both designing fast, reliable communication systems and integrating functions of different computer systems. To achieve that goal the following types of data exchange between systems can be considered:

- broadcasting: when information is sent in one direction, the receiver accept any information and whenever it is sent - no possible interaction between systems,
- file transfer: information is stored on a server accessible for a client; it may be organized in an automatic way,
- remote procedure call: the client can use functions available on a server building a distributed application,
- message passing scheme: cooperation between clients and servers is based on sending requests and receiving answers in the form of messages,
- callbacks: a small but convenient improvement of the previous items - the client sends a request to the server, which will reply to the client automatically when the data are ready for transfer,
- invoking a remote object method: in a sense this is similar to remote procedure call, but it takes advantage of object-oriented features like encapsulation, abstraction, polymorphism.

In a practical sense some of these methods can be implemented using the others: a remote procedure call on top of message passing scheme, invocation of remote object method on top of message passing scheme or remote procedure call.

Another important feature of ER&RTDSS is timely response, together with accurate predictions. This demands appropriate computer capacities, sophisticated mathematical models and high performance numerical methods that take advantage of recent advances in computer technology, in particular vector and parallel processing. The emergence of new generations of workstations has now made it possible to consider employing workstation clusters to achieve supercomputer power for a small fraction of the price of a supercomputer. In addition, many traditional supercomputer applications relevant for ER&RTDSS have benefited greatly in the move from the realm of the supercomputer center to the more direct local control of the end user. However, this leads again to distributed computing.

Security is another key factor of ER&RTDSS software. One should consider security within the Intranet or while connections to remote resources as well as stability and robustness of the whole system. Sometimes it may even denote opposite requirements: flexibility and openness needed for integration with other systems but still keeping all the elements of system security.

Portability also seems to be an important issue, at least from developer’s point of view.

All the above features of ER&RTDSS, as well as others not mentioned here, require special software techniques that should be used in the system development. In particular distributed processing, while preserving full security is a some kind of challenge for analysts, designers and programmers.

2. Review of some advanced software technologies

This section reviews the basic software tools for development of ER&RTDSS in a distributed environment.
A. Distributed Computer Environment (DCE) of Open Software Foundation (OSF) provides a common multi-vendor infrastructure for distributed applications. Key services supported by DCE are as follows:

- remote procedure call (RPC),
- directory service,
- security services.

DCE supports a few elements of the object-oriented approach and standard the interface is defined in C (not C++ or any other object-oriented language). There are also few object-oriented extensions of DCE provided by some vendors, such as OODCE from Hewlett-Packard or DEC’s DCE++.

B. CORBA (Common Object Request Broker Architecture) of Object Management Group (OMG) is a set of vendor-neutral standards for various distributed services. Unlike DCE, CORBA is explicitly object-oriented. CORBA standards define only interfaces, not actual implementations of those interfaces (as in DCE). CORBA supports callbacks via events (independently of the object’s interface), as well as exceptions (simplifying the implementation of security services). The OMG has also defined a COM to CORBA specification. CORBA can be build on top of DCE - such an implementation takes advantages of DCE services.

C. OLE (Object Linking and Embedding) is based on Component Object Model (COM) of Microsoft. COM specifies conventions and provides services for defining and using objects. It is based on Microsoft RPC, that is interoperable with DCE RPC. For distributed objects an extension of COM has been defined (Distributed COM - DCOM). Callbacks are supported by a specific interface. OLE, although originally standing for linking and embedding, is now a technology including lots of things from compound documents to database interfaces. OLE/COM is well suited for front-end application and it might be a good choice for distributed applications that are to be run on Microsoft platforms.

D. System Object Model (SOM) of IBM is CORBA compliant, language neutral and a multi platform object model. There is also a specification for distributed objects called DSOM (Distributed SOM). For compound documents IBM proposes an OpenDoc software architecture based on SOM.

E. Java of Sun Microsystems is a new object oriented, architecture-independent, multi threaded language that can change World-Wide-Web applications significantly. Java scripts (called applets) can be put directly into WWW page, allowing the user to change its behaviour dynamically. Analogously Java servlets stay on a server to meet user request. Java interfaces are similar to IDL (Interface Definition Language), which means that Java can be utilized in CORBA or any other distributed systems.

F. Message Passing Interface (MPI) and Parallel Virtual Machine (PVM) of Oak Ridge National Laboratory are examples of parallel distributed systems. These systems are mainly designed for increasing computational efficiency through parallelization of the algorithms and are typically based on a message-passing concept. Because communication between computers is also based on message-passing schemes they can be used in distributed environments. Systems built directly on object-oriented approach (for example POOMA, i.e., Parallel Object Oriented Methods and Applications of Los Alamos National Laboratory) are also available, as well as object-oriented extensions like OOMPI (Object Oriented MPI).

G. A variety of Relational Database Management Systems (RDBMS) have built-in distributed features, such as ORACLE, Informix, Sybase, Ingress, PostgreSQL and others. However, one should also consider OODBMS (Object Oriented DBMS), for example ObjectStore, Poet or Ontos. These systems directly deal with objects and in comparison with RDBMS are usually faster in real time transactions, which is of great importance for ER&RTDSS.

H. High Level Architecture (HLA) is general purpose software for distributed simulation systems, developed by U.S. Defense Modeling and Simulation Office. Using HLA, computer simulations can communicate to other computer simulations regardless of the computing platforms. Communication between simulations is managed by a runtime infrastructure (RTI). The HLA (defined under IEEE standards) consists of: interface specification (compliant with RTI), object model template and special rules. It can be used for building and running simulators, each one modeling some aspect of a complex system.

I. Dynamic Information Architecture System (DIAS) developed by Argonne National Laboratory (ANL). DIAS is a flexible, extensible, object-based framework for developing and maintaining complex multidisciplinary simulations of a wide variety of application contexts. Because DIAS is explicitly designed to be context-neutral, it supports simulations in essentially any domain (environmental, military, emergency response).

In order to assess which technologies can facilitate the development of ER&RTDSS software one should first consider the basic structure of such systems. The following three levels of ER&RTDSS have to be taken into account:

- management during emergency situation,
- simulation and analysis of emergency situation,
- collection of necessary information

Each of these levels can be divided into three sublevels:

- components, i.e., functional modules,
- management and controlling of the components,
- integration tools for dealing with different components.

The last two levels are often implemented by the same software tools.

Table 2.1. Software architecture of ER&RTDSS.

Level	Components	Management & control	Integration tools
Management during emergency situation	Front-end applications: • decision making support • emergency action support • public information	Graphic user interface	OLE, OpenDoc, Java
Simulation and analysis	Functional modules: • atmospheric dispersion modelling • environmental models • countermeasures and their evaluation	Process management	DCE, CORBA, COM, SOM, RPC, MPI (PVM), HLA, DIAS
Collection of information	1. Databases: • real-time (measurement and meteo monitoring) • static (geographical, topographic, statistical and others) 2. Communication (different protocols)	1. Transaction management (typically built-in in DBMS) 2. Protocols management	1. RDBMS, OODBMS 2. Transport Layer Interface (TLI)

Table 2.1 shows the structure of ER&RTDSS including software tools for each level. The most difficult part in implementation is the second level, particularly management and integration elements of ER&RTDSS, because

they are also responsible for communication with the two last levels. It demands utilizing such techniques and standards that are highly interoperable across different platforms. It seems that the current trends in the development of client-server applications show that such kinds of cooperation will be possible in the nearer future. It is, however, important that in order to create distributed systems the appropriate design based on clearly defined processes, objects, their interactions and taking into account fundamentals presented in Table 2.1 is necessary.

In the following sections some advanced emergency response and decision support systems used operationally are presented. This cannot be, at any case, treated as a full review, as there are a number of other systems worth mentioning (like JACE-CATS, AirQUIS and many others) – the idea was rather to show some working solutions. It should be however clear, that there exist a lot of possible solutions and very often there are no obvious advantages ones over others.

3. The RODOS: Real-time On-Line Decision Support System for Nuclear Emergencies.

The Chernobyl accident had a profound effect on emergency preparedness and post-accident management worldwide and, in particular, in Europe. Deficiencies in arrangements dealing with an accident of this magnitude at both national and international levels (e.g., in world food trade) led to many problems of a practical and political nature. Many lessons have been learnt, and considerable resources have since been committed, to improve emergency preparedness and post-accident management in order to avoid similar problems in future. Improvements have been made at national, regional and international levels and have been diverse in nature. However, more needs to be done to ensure a timely and effective response to any future accident.

Emergency management, more generally, has received increased attention following the tragic events in the U.S. in September 2001. Attacks with radiological dispersal devices (RDD), which spread radioactive material by aerosolising or dissolution in water reservoirs are currently under intense discussion.

A number of requirements emerge from these considerations; they include:

- the need for a more coherent and harmonized response in Europe and during different stages of an accident (in particular, to limit the loss of public confidence in the measures taken by the authorities for their protection);
- exchanges of information and data in an emergency so as to enable neighbouring countries to take more timely and effective action; and
- the necessity to make better use of limited technical resources and avoid duplication.

The RODOS project was established to respond to these needs. It was launched in 1989 and increased in size through the European Commission's 3rd, 4th and 5th Framework Programmes. Significant additional funds have been provided by many national R&D programs, research institutions and industrial collaborators. In particular, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) contributed to the project financially with a special focus on early emergency response. Up to 40 institutes from some 20 countries in the European Union, Central and Eastern Europe and the Former Soviet Union were actively involved in the project (Schulte et al., 2002).

As a result of these collaborative actions, a comprehensive decision support system (RODOS) has been developed which can be applied generally within and across Europe (Ehrhardt and Weis, 2000; Ehrhardt, 2004). It can be used in national or regional nuclear emergency centres, providing coherent support at all stages of an accident (i.e., before, during and after a release), including the long term management and restoration of contaminated areas. The system is able to support decisions about the introduction of a wide range of potentially useful countermeasures (e.g., sheltering and evacuation of people, distribution of iodine tablets, food restrictions, agricultural countermeasures, relocation, decontamination, restoration, etc.) mitigating the consequences of an accident with respect to health, the environment, and the economy. It can be applied to accidental releases into the atmosphere and into various aquatic environments. Appropriate interfaces exist with local and national radiological monitoring data, meteorological measurements and forecasts, and for adaptation to local, regional and national conditions in Europe.

The current version of the system (RODOS version PV 6.0) has been, or is being, installed in national emergency centres in several European countries for (pre-operational) use (Germany, Finland, Spain, Portugal, Austria, the

Netherlands, Poland, Hungary, Slovakia, Ukraine, Slovenia, and the Czech Republic). Installation is foreseen or under consideration in Switzerland, Greece, Romania, Bulgaria, and Russia within the next few years. Installation in the CEE and FSU has been achieved with support from the European Commission's ECHO, PHARE and TACIS programs, respectively. Installation of the system for (pre-operational) use in many national emergency centres is indicative of the success of the system and its potential for achieving more coherent and effective responses to future accidents which may affect Europe.

3.1 Structure and functions of the RODOS system

From the beginning, the RODOS system has been designed as a comprehensive system, that:

- incorporates state-of-the-art methods, models and data bases for assessing, presenting and evaluating the consequences of a nuclear accident,
- can be applied at all distances from the release site,
- takes account of the most important emergency actions and countermeasures,
- can be used from the moment that an accident threatens, through to long-term actions implemented months or years after an accident.
- provides information ranging from largely descriptive reports (Levels 0-2, see Table 3.1) to a detailed evaluation of the benefits and disadvantages of various strategies and their ranking according to the societal preferences expressed by the decision makers (Level 3, see Table 3.1).

Table 3.1. Levels of decision support systems.

Level 0: Acquisition and checking of radiological data and their presentation, directly or with minimal analysis, to decision makers, along with geographical and demographic information.
Level 1: Analysis and prediction of the current and future radiological situation (i.e. the distribution over space and time in the absence of countermeasures) based upon monitoring data, meteorological data and models, including information on the radioactive material released to the environment.
Level 2: Simulation of potential countermeasures (e.g. sheltering, evacuation, issue of iodine tablets, relocation, decontamination and food-bans, restoration), in particular, determination of their feasibility and quantification of their benefits and disadvantages.
Level 3: Evaluation and ranking of alternative strategies by balancing their respective benefits and disadvantages (i.e. costs, averted doses, reduction of stress and anxiety, socio-psychological aspects, political acceptability, etc.) taking account for judgements and preferences of decision makers.

The system should be capable of coping with differences in site and source term characteristics, in the availability and quality of monitoring data, and in national regulations and emergency plans. In addition, the use of RODOS for training and education in radiological protection and emergency management has been one of the major objectives from the beginning. Another important requirement was that the system uses meteorological and radiological monitoring data and field measurements to improve the accuracy of its simulations of atmospheric and hydrological dispersion and radioecological processes.

Due to the complex requirements on the RODOS system, during planning and development only minor benefit could be taken of the experience gained with existing systems. Therefore, from the beginning the iterative "prototyping" concept was pursued, which led step by step to the completion and continuous improvement of the system.

The basic concept and design of RODOS were specified and agreed upon by participants at the outset of the project. The conceptual RODOS architecture (see Fig. 3.1) is split into three distinct subsystems, which are denoted by Analysing Subsystem, Countermeasure Subsystem and Evaluating Subsystem. Each subsystem consists of a variety of modules developed for processing data and calculating endpoints belonging to the corresponding level of information processing. The modules are fed with data stored in three different databases, comprising real-time data with information coming from regional or national radiological and meteorological data networks, geographical data defining the environmental conditions, and program data with results obtained and processed within the system. The interconnection of program modules, the input, transfer and exchange of data, the display of results, and the interactive and automatic modes of operation are all controlled by the specially designed RODOS Operating System.

The dialogue between RODOS and a user is organised in two different modes. In the so-called "automatic mode" the system automatically presents all information which is relevant to decision making and quantifiable in accordance with the current state of knowledge in the real cycle time. For this purpose, all the data entered into the system in the preceding cycle (either on-line or entered by the user) are taken into account in the current cycle. Interaction with the system is limited to a minimum amount of user input necessary to characterise the current situation and adapt models and data.

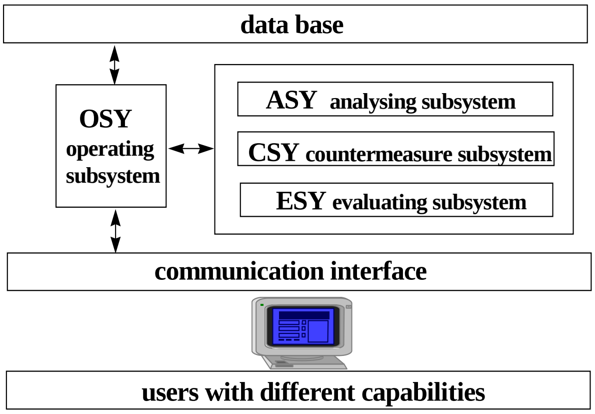

Figure 3.1. Conceptual structure of the RODOS system.

The diagnostic calculations are performed in the automatic mode with cycle times of 10 min. Prognostic calculations and simulations of emergency actions together with consequence assessments are repeated typically every 30 min. The automatic mode is limited to the near range around the nuclear facility, defined by an area of 160 km X 160 km; it is terminated after the cloud has left the calculation area and thus when “stable” conditions are reached (see Fig. 3.2).

Either in parallel to the automatic mode or alone, RODOS can be operated in the "interactive mode". In particular, all calculations at distances outside the 160 km x 160 km area are performed interactively.

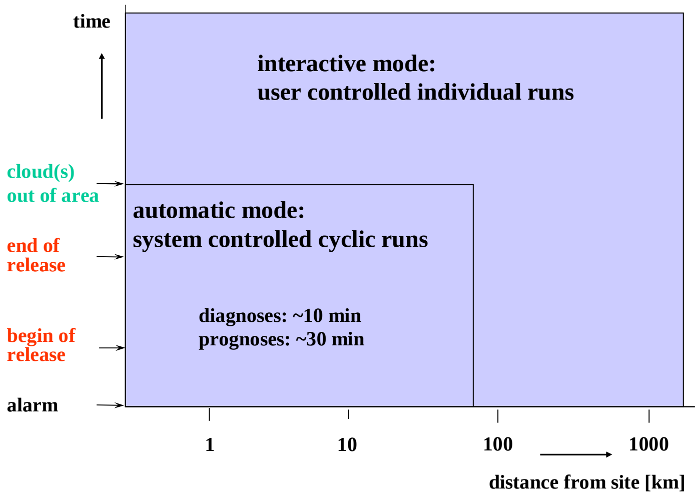

Figure 3.2. Operation of RODOS in different time scales and distances.

The dialogue between RODOS and a user is performed via various user-interfaces tailored to the needs and qualification of the user. The access rights of different user groups determine the type of user-interface, which allows increasing access to models, data and system parameters in a hierarchical structure. At the lowest level of access, there is an easily understood but very limited interface; at the highest, the full spectrum of interface tools is available for system administrators and operators familiar with the system’s content and structure.

3.2 Interfaces to plant safety, radiological monitoring data and meteorological information

The RODOS system offers appropriate interfaces to plant safety, radiological and meteorological networks:

- flexible input of source term information,
- accident source term data base for nuclear power plants, such as PWRs, BWRs, VVER440 and VVER1000,
- radiological real-time data:
  - stack emission data,
  - local monitoring data,
  - national monitoring data (incl. EURDEP, the European Data Exchange Platform),
- site meteorological data (multiple meteorological stations),
- meteorological forecasts of numerical weather models of national weather services,
- prognostic long range atmospheric dispersion calculations performed externally.

Parallel to the development of the RODOS system, prototype software tools have been developed within the STEPS/ASTRID and STERPS projects (Schulte et al., 2002) which, in the event of an emergency situation in a light water reactor, allow to follow up the progression of an accident from the moment it is detected, and to forecast the future behaviour of the reactor and potential releases. The source term, thus evaluated faster than in real time, can be used to predict with RODOS the potential and/or real radiological consequences. On the basis of the results of these prognostic calculations, decisions about precautionary emergency action can be initiated in a timely manner. Appropriate interfaces exist to directly transfer to the RODOS system the source term data estimated with the software packages mentioned above.

3.3 Diagnosis and prognosis of the radiological situation

Meteorology and atmospheric dispersion

RODOS provides continuously updated fast and comprehensive assessments of the radiation exposure of the population following accidental releases of radioactive material (or the threat of such a release) into the atmosphere and/or the aquatic environment. Calculations can be performed

(1) either with the incoming on-line meteorological data and prognosticated meteorological fields,
(2) or with historic and/or user defined meteorological information.

Case (1) corresponds to the typical real-time operation of the system. In the automatic mode, diagnostic calculations can be performed without time limitations, the 30 min interval prognostic calculations extend over a time period of 24 hours. In the interactive mode, the time period of the prognostic calculations is limited by the duration of the available meteorological forecasts.

In case (2), RODOS is used for calculating complete episodes of past or artificial accident situations with known information about meteorology and source term. These episodes can extend over a time period of up to 47 days. The main purpose of this kind of application is to educate and train current and future RODOS operators and users and to support the preparation and performance of local, national, regional or international exercises.

The dispersion and deposition of material released into the atmosphere is predicted by means of a nested chain of models. The models consistently simulate dispersion and deposition processes over two distinct ranges, the local scale within an area of 160 km x 160 km, and the far range up to several thousands of kilometers. The models included in RODOS were selected from among the many models available as those best able to meet the operational demands of the system.

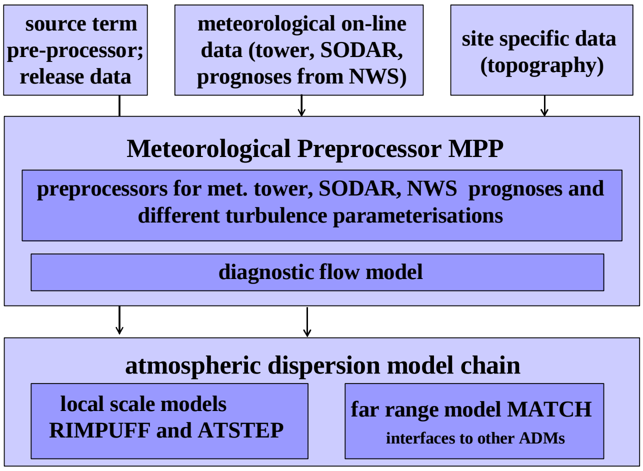

Figure 3.3. The local scale model chain and long range atmospheric dispersion model chain.

The local scale model chain comprises the local-scale Meteorological Pre-Processor MPP (Ehrhardt, 2004), the puff dispersion model RIMPUFF (Ehrhardt and Weis, 2000; Mikkelsen et al., 1984) and the elongated puff model ATSTEP (Ehrhardt and Weis, 2000) (see Fig. 3.3). MPP provides the local-scale system with actual and forecast local scale wind fields and local boundary layer variables by intensive pre-processing of the meteorological input data; if need be, a diagnostic flow model can be used. The state of the atmospheric turbulence can be characterised by different parameterisation schemes (Karlsruhe-Jülich, Mol, German-French modelling (Verlag, 1996)). Estimates of the current cloud position (diagnosis) are automatically updated every 10 minutes, the situation after cloud passage (prognosis) is recalculated typically every 30 minutes.

Figure 3.4. Example presentation of activity concentrations on ground surface.

Weather data and forecasts are provided in real-time via on-line connections to local meteorological observations (from on-site meteorological towers or SODARs) or via network connections to national or international meteorological services (NWS). Prognoses of ground-level air, dry and wet deposited concentrations including dose rates in half hour steps can be produced on the local scale for the time period, for which forecasted meteorological data are available.

The applicability to farther distances is mainly a result of the integrated far range atmospheric dispersion model MATCH (Langner et al., 1995) with an interface for accessing meteorological data of the Danish forecast model HIRLAM (Gustafsson, 1993). Through its coupling to the near range model chain, a complete model chain is realised and consistent dispersion calculations are possible from the near range to large distances in the European scale. However, interfaces exist to other numerical weather prediction models, such as those from the German Weather Service (DWD) and the ALADIN (http://www.cnrm.meteo.fr/aladin/scientific/scientif.html) model.

The hydrological model chain in RODOS is comprehensive (Raskob et al.,2004), covering the dispersion of material released into and through most aquatic environments (e.g., rivers, reservoirs, lakes, estuaries, coastal waters, seas, etc). In addition, transfer to various water bodies of material deposited from the atmosphere (e.g., by run-off from catchments) is modelled. Many models in the system have different levels of complexity and detail, thus enabling users to choose the most appropriate one, depending on the application and the desired output.

Exposure pathways and dose calculations

Exposures from all pathways of potential importance are assessed both during and after passage of a radioactive cloud (e.g., external irradiation from a radioactive cloud, external irradiation from material deposited on the ground and on the skin and clothing, and internal irradiation from the inhalation of airborne material and ingestion of contaminated food).

The transfer of radionuclides from the cloud to terrestrial foods as well as the resulting radiation exposure are modelled in the Terrestrial Food Chain and Dose Module, FDMT, which comprises the Food Chain Modules and the Dose Modules (see Fig. 3.5). Activity concentrations on soil, plants and other surfaces as input to FDMT are calculated in the Deposition Module DepoM. Activity intake by animals is considered using season dependent feeding practices. The products considered in the Food Chain Module can be adapted to the specific situation in the different parts of Europe; the default list of products presently comprises 21 feedstuffs (17 based on plants, 4 based on animal products) and 33 foodstuffs (17 plant products, 16 animal products).

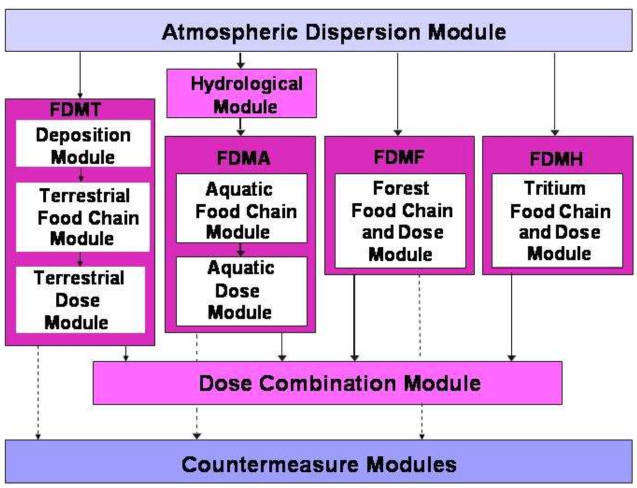

Figure 3.5. Food chain and dose modules integrated in RODOS.

The relatively large number of products results from the need to reflect properly the diversification of plant species in reality. The estimation of doses is performed via all external and internal exposure pathways of importance during and after the passage of the radioactive cloud; the endpoints are collective and individual organ doses for people of different ages.

Data assimilation

Another main focus of development was to implement data assimilation methods into the RODOS system. Data assimilation in general is the concept of combining measured data with model predictions for improving the diagnostic and prognostic results. The aim is to smoothly change from pure model output to a description of the radiological situation mainly based on monitoring data and measurements. Particularly, data assimilation is important for the food chain and dose modules of RODOS, since output of these modules is the main source of information for deciding on emergency actions and long-term countermeasures (see Fig. 3.6).

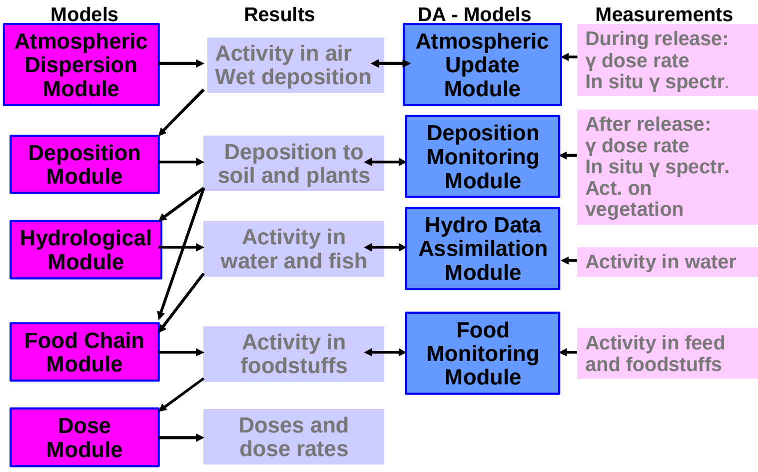

Figure 3.6. Data assimilation in RODOS.

Data assimilation methods, including uncertainty handling, have been developed which are ‘primed’ either with the concentrations in air or the depositions predicted by atmospheric dispersion models, or with food contamination from the food chain modules, and update their diagnoses and prognoses as monitoring data (e.g. gamma dose rates, ground deposition or food contamination) arrive. The times after the cloud has passed are covered by techniques which allow estimates of contamination and of uncertainties to be made purely on the basis of databases of radiological monitoring data and measurements. Uncertainty handling and data assimilation have also been introduced in the river models to update the predictions of contamination downstream of measurements made upstream. Theoretical investigations exist for the other parts of the hydrological model chain.

Prototype real-time data assimilation modules have been introduced into RODOS version PV6.0 to improve the predictions for deposition onto different types of plants and for foodstuff contamination by assimilation of measurements. The implementation of data assimilation procedures in other modules of RODOS, such as those for the estimation of atmospheric and aquatic dispersion (see below), foodstuff contamination and radiation exposure, will be continued in the RODOS versions PV 7.0.

Customisation

The transfer of radioactive material to food (both commercial and natural) and, subsequently, to man is modelled with seasonal variations (e.g., state of crop growth) taken into account; special tools allow topical databases to be used in emergencies, thus improving the predictive power of the models. Differences in agricultural practice and climatic and soil characteristics are considered by adapting the databases of the models applied to various regions in Europe. This makes RODOS a unique tool in a consistent approach to dose assessment on a multinational level. Comparable models are used to assess exposures from radioactive material in different aquatic environments (e.g., drinking water, crop irrigation, fish consumption, etc.). Estimates are made of exposures of individuals (with average and special habits) and the population as a whole.

As the models for food chain transfer have been originally developed for Central Europe, an important task in connection with the customisation of RODOS for use in other regions of Europe is the adaptation of the many model parameters in the food chain and dose module FDMT. The selection of appropriate radioecological regions, with relatively uniform radioecological conditions, is predominantly determined by prevailing agricultural production regimes, growing periods of plants, harvesting times, feeding regimes for domestic animals, human consumption habits, etc. Typically, a country is subdivided into 1 to 5 such radioecological regions. Radioecological regions have been defined for Czech Republic, Hungary, Poland, Romania, one part of Russia, Slovak Republic, and Ukraine and the collection of the radioecological data has been completed to a large degree.

For several regions in Northern and Eastern Europe or in parts of the Alps, an additional specialised radioecological model has been developed for semi-natural (forest) pathways, FDMF. It considers transfer of radionuclides to mushrooms, berries and game and quantifies the internal and external exposure from contaminated forests. After reviewing the present status of tritium modelling for emergency response purposes, a simple module describing the transfer of tritium through foodchains, FDMH, has also been developed. The dose combination module, DCM, combines results from these and the FDMT food chain and dose modules.

3.4 Extent and implications of emergency actions and countermeasures

The RODOS system, in a coherent and comprehensive approach, simulates and estimates the timing and the extent and duration of all countermeasures which can be implemented to limit the health and environment impact of an accident. Intervention strategies adopted in various European countries can be implemented. All information available about the types of intervention listed below have been integrated and synthesized in the corresponding models and the databases associated with them:

- sheltering,
- distribution of stable iodine tablets,
- evacuation,
- decontamination of inhabited areas,
- temporary and permanent relocation, plus these agricultural countermeasures:
- banning foods, which may imply food disposal or stopping food production,
- food processing and storage,
- changes in the feed composition of grazing animals; factors for evaluation include the effect of supplying clean feed for a certain period after deposition, changes in the proportion of contaminated feed in the diet, and the use of different feedstuffs,
- administration of sorbents or boluses,
- soil treatment, such as the addition of fertilizer,
- change of crop varieties or crop species grown,
- change in land use from agriculture to forestry,
- decontamination of agricultural land by plowing and soil removal.

The areas of early emergency actions and later countermeasures defined by intervention dose criteria can be modified by the user via the graphical user interface and fed back into the system for repeated calculations. This is of importance particularly in countries with regulations concerning the size or extension of areas in which measures are to be implemented. For example, prescribed emergency planning zones and sectors necessitate the projection of the areas defined by isolines onto these fixed geometric areas. The same holds for countries, where decisions on agricultural countermeasures would only be taken for areas defined by administrative borderlines (districts). Software tools for automatically presenting RODOS results for administrative units will be available in the next RODOS version.

Measures to reduce radioactivity concentrations in freshwater fish and drinking water are also analysed for situations when streams, rivers and lakes have been contaminated. Measures range from changing the sources of drinking water supply to processing fresh fish to applying fertilisers to lakes in order to reduce the uptake of radionuclides by fish feeding in these lakes.

The relative merits and disadvantages (e.g., avoidable doses, health risks, costs, effort) of individual or combinations of emergency action and countermeasure can be assessed (e.g., sheltering indoors and taking iodine tablets as against immediate evacuation) and presented to those responsible for emergency management. In particular, the doses that would potentially be received by workers implementing countermeasures can be assessed for decontamination in inhabited areas, relocation of the population and agricultural countermeasures.

In order to explore the effectiveness of combinations of agricultural countermeasures, selected combinations of two options can also be considered for each food, however, with the underlying constraint that the combination is broadly feasible. For decontamination, the effect on the extent and duration of relocation and the need for, and duration of, food restrictions can be considered. In the case of relocation, the implications of relocation on the further use of agricultural land in the relocated area can be studied.

For agricultural countermeasures, a ‘decision mode’ has been defined to provide information on a number of countermeasure options and combinations of these options for a single food to the evaluating subsystem of RODOS to enable countermeasure strategies to be evaluated using a wide range of information including effectiveness, costs, health effects and feasibility considerations.

A database of technical information on decontamination and agricultural measures has been compiled for use in RODOS within Europe based largely on experience following the Chernobyl reactor accident in the Ukraine and other experimental research. This allows information about the costs of implementation, the manpower resources needed, and the quantities of waste produced to be estimated as well as the effectiveness in reducing contamination levels in the environment and radiation doses to members of the population. Technical, logistic and radio-ecological information pertinent to the implementation of countermeasures in individual countries has been collected. This has made it possible to give constructive guidance in the use of the RODOS database on countermeasure effectiveness and technical feasibility for specific areas of Europe.

3.5 Evaluation of countermeasure strategies

Whenever there is an option of two or more countermeasure strategies, a choice has to be made by the emergency management team. Evaluation techniques may support this task of the decision maker by proposing those courses and/or combinations of countermeasures, which are practicable under the actual or future conditions, and which are ranked by balancing of benefits and effort.

The MAV/UT-based software package, WebHipre (http://www.hipre.hut.fi/WebHipre), has been integrated in RODOS to enable users to compare and evaluate the benefits and drawbacks of different countermeasure strategies (e.g., risks, costs, feasibility, public acceptance, perceptions, social, psychological and political implications, and preferences or value concepts of decision-makers, etc). Rules, weights, and preference functions are encoded and applied to a list of alternative countermeasures providing a ranked shortlist to decision-makers together with the rules and preferences which determined the order of the list. Intuitive justifications of choices and underlying uncertainties inherent in the predictions are also provided. The evaluation software assists users in modifying rules, weights, and preferences and other model parameters as well as exploring the consequences of each change. The importance of this exploration cannot be emphasized too strongly. Any decision support systems helps decision-makers not by *making* the decision itself, but by *enhancing the decision-makers' understanding* of the problem, the issues before them, and their value judgments. Because of this improved understanding, they are then better able to make decisions (see Fig. 3.7).

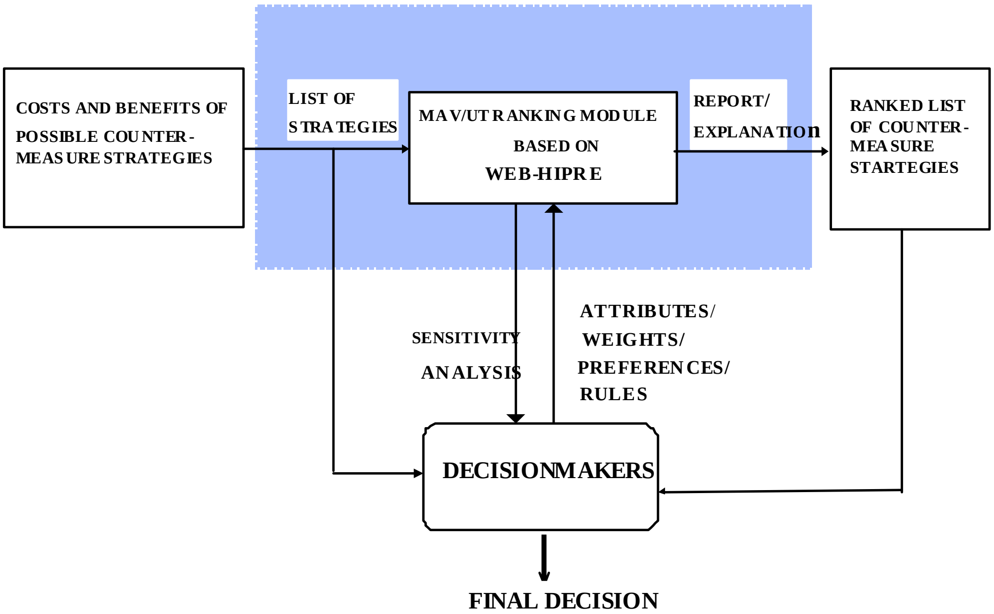

Figure 3.7. Evaluation of countermeasure strategies.

The description of the RODOS system was possible due to courtesy of colleagues from Forschungszentrum, Karlsruhe (Germany), in particular Wolfgang Raskob.

4. The SWAR: Emergency Planning and Response System for Chemical Plant

The main objective of an on site emergency plans in case of a chemical accident is to minimise consequences for people and environment by quick undertaking of appropriate emergency action. This in turn depends strongly on scenarios of the accident. It is particularly important that well-defined duties of particular services and co-ordinator are precisely described. In case of accidents with off-site consequences there is also a need of a co-operation between local and on site authorities and rescue services. Therefore the following groups of information are essential to account for by any decision support system supporting decision making in an emergency:

1. Regulations in force, which constitutes the basis for developing preparedness plans.
2. Information about localisation and types of activities in chemical plants.
3. Potential accident scenarios and their consequences for people and environment.
4. Databases containing information on available means and forces that can be used in rescue operations.
5. Rules for proceeding in case of an accident.
6. Rules to follow up actions.
7. Diagrams and digital maps.

As a result of these demands the computerised system SWAR (Borysiewicz and Potempski, 2002) has been designed to integrate the following elements:

- Databases containing information about: sources of hazards (materials, objects), employees in particular objects and forces and means to be used in rescue actions. These data should be integrated with digital maps under a GIS system.
- Database of basic chemical and physical properties of chemical substances, important for analysis of hazards.
- Numerical maps of the plant and its vicinity.
- Module for collecting information from meteorological services and other real-time monitoring systems, including monitoring of concentration of dangerous substances
- Modules for diagnosis and prognosis of accident scenarios, which use information from real-time monitoring systems and/or simulation programs.
- Module for visualisation of pollution transport in the environment, indicating endangered areas, and for preparation of reports.
- Module for alarming personnel and warning people in the vicinity of the plant, and inform appropriate authorities.
- Module for support of co-ordination of the action and exchange of information between groups of rescue teams.

The computerised system for emergency planning and response for chemical plant has been designed for:

- providing capabilities for computer aided emergency planning,
- providing sufficient means to co-ordinate emergency actions via a computer network,
- easily handling diversity of hazardous sources and scenarios by: assessing releases (substances and energy),
- predicting dispersion in the environment and assessing consequences,
- assessing quickly required emergency response (forces, vehicles, equipment),
- presenting results in a form of text, diagrams, drawings and maps,
- providing an easy access to the relevant information via a WWW site,
- providing means for training and simulation of any situation.

Therefore the most important functions of the system SWAR relevant for a crisis management can be described as follows:

- diagnosis and prognosis of emergency (real time estimates of endangered areas, transport in the environment, potential consequences to people and environment),
- support of emergency response with use of a distributed computer network,
- automating alarming of personnel to be involved in emergency actions,
- assisting in action to be taken, by the co-ordination staff, responders and endangered personnel with use of computer network,

- collecting real time data from chemical meteorological, hydrological, fire detection and visual monitoring systems, and from measurements of parameters determining the state of buildings and waste dumps,
- GIS based graphical presentation of data,
- collecting and updating plant specific data (safety related design, operational and organisational information),
- generating subject oriented layers of digital maps.

Programs for analysis of accident scenarios implemented in the system SWAR cover a variety of emergency situations related to possible releases of toxic materials, explosions and fires (solid material fires, pool fires etc.). For completeness the contamination of water bodies is also taken into consideration, particularly in case of floods.

The system can operate in three main modes (see Fig. 4.1):
- administration,
- preparation of emergency plans,
- action.

4.1. Design of the SWAR system

The SWAR system has been designed in order to work out an optimised decision, for which the following key factors play important role:
(a) accurate information on accident,
(b) proper assessment of current status and prognosis of development of situation,
(c) proper information on availability of means needed for emergency action like rescue teams, technical and medical equipment, means of transport etc.,
(d) reliable and fast communication system between decision makers, persons responsible for management of crisis situation, rescue teams and people in affected areas.

Figure 4.1. Modes of operation of the system SWAR.

The first two elements (a) and (b) are related to appropriate monitoring network and models for assessment of emergency situation. The element (c) is supported by GIS-like systems available at crisis centres. The last factor (d), however is, to much extent, a question of proper organisation of decision making process and management during emergency action. It seems also that often there are some kind of gaps between items (a)-(b) and (c)/(d) or may be particularly between (d) and other factors mentioned above. Therefore more integrated approach has been proposed in the SWAR system. It should be also mentioned that the last element (d) is usually the weakest point in the whole system. This is often caused by not clear organisation and division of responsibilities between persons engaged in the decision making process and management. The problem of communication has also some technical aspects. This can be solved by using more advanced techniques like satellite technologies and centralised computer communication systems of new generation, which allows for fast and reliable sending and receiving messages not only in form of text but also images or films. It is however interesting, that the same communication system can stand as a basis for integrating all elements (a)-(d) of the system. Such an approach has been investigated in the SWAR system. The main idea has been based on design of central message server, which allows for:

- bringing up to date information about current situation on numerical maps coming from decision support and monitoring systems,
- bringing up to date information about current status of emergency action,
- communication by sending and receiving messages, images, maps etc.,
- rapid access to all elements of contingency plans, defining responsibilities and possible actions of the key actors of the emergency scene.

Thus the central message server plays the key role for integration of all modules in the system. Therefore the whole system is composed of (Fig. 4.2.):

- set of tools and functional modules located on the server,
- graphical user interface,
- central message server with connection to monitoring systems, GIS maps and databases, and WWW server.

It should be stressed that such design makes possible to apply distributed and/or parallel computing, as the SWAR modules can communicate via central message server as well. Software tools useful for development of the system are based on client-server and object-oriented methodologies.

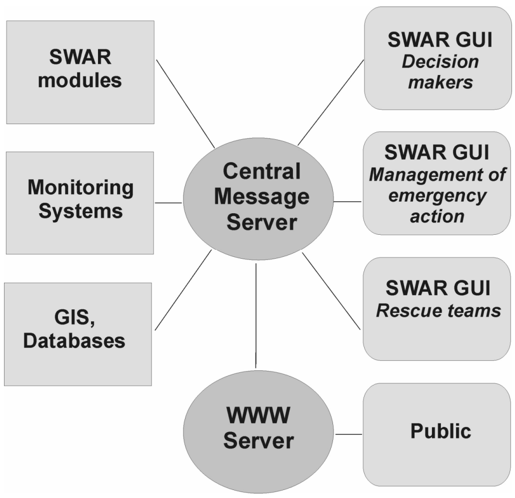

Figure 4.2. Structure of the SWAR system.

At the current stage of development the SWAR system consists of:

- Databases on: sources of hazards (materials, objects), employees in particular objects and forces and means for rescue actions - data integrated with digital maps under a GIS system.
- Database on basic chemical and physical properties of chemical substances.
- Digital maps of the plant and its vicinity.
- Module for collecting information from meteorological services, monitoring of concentration of dangerous substances etc.
- Modules for diagnosis and prognosis of accident scenarios, with use of information from real-time monitoring systems and/or simulation programs.
- Module for visualisation of pollution transport in the environment, indicating endangered areas, and for preparation of reports.
- Module for alarming personnel and warning people in the vicinity of the plant, and inform appropriate authorities.

- Module for support of co-ordination of the action and exchange of information between groups of rescue teams based on dedicated protocol.

A specialised unified model for pollutant dispersion in atmosphere (UMPDA) has been included into SWAR system as a module both for scenario calculation for emergency planning and for supporting emergency response in real-time. Usage of the central message server allows for fast and reliable exchange of data between all modules of the system. It means, that on-line meteorological data are transferred to the UMPDA module via central message server and can be used as input data. Similarly emergency zones calculated in the UMPDA model can be automatically sent to Web server and become visible for all user connected to the network. Basing on UMPDA calculations proper decisions important for emergency action can be undertaken and realised. Then the whole action can be co-ordinated and managed using SWAR system like. One of the attractive issue is a possibility of making analysis of crisis situation as well as preparing proper decisions by group of experts by persons not directly present in emergency centres.

The SWAR system uses digital maps, which can be stored in most popular GIS, like ArcInfo, MapInfo or Microstation. However it's possible to add information strictly relevant for supporting emergency response. This includes data on:

- technical equipment for rescue teams,
- organisation structure,
- external forces and means,
- all documents related to emergency preparedness,
- typical scenarios and their possible consequences,
- more detailed description of tasks of rescue teams stored in the form of control lists, which allows for better planning and controlling the situation.

Some of data can be linked to spatial objects. This is realised by defining attributes of the relevant object. The system is flexible as system administrator can add not only attributes or objects but also classes of objects via their attributes. All these operation can be made using Web browser. All documents are stored as html files, so they can be accessed independently of the system as well.

Summarizing, the SWAR system has been designed to integrate all key elements in the decision making process via central message server, which enables automatic transfer of all data between modules of the system as well as provides tool for information exchange and co-ordination of the emergency action. The new version of the SWAR system allows for more realistic assessment of situation after accidental release of chemical substance. A very promising feature of the system is also support of emergency response based on network capabilities, which makes management of rescue action more effective.

The key advantages of the UMPDA model with respect to other typical dispersion models can be summarised as follows:

- a single model for the entire dispersion regime from the point of release to the far-field dispersion including possible rainout and pool re-evaporation; this eliminates discontinuities and matching problems;
- a very extensive verification and validation to ensure that the model shows the correct behaviour and produces accurate predictions.

The UMPDA is integrated within the user-friendly and well-established SWAR computer network based decision support system for emergency response in case of chemical accidents. This enables plotting, linking with discharge/fire/explosion models, toxic/flammable impact and risk calculations. The results of UMPDA calculations can be used in other modules of the SWAR system both for emergency planning and for supporting emergency response in real-time.

5. The FEMIS: Federal Emergency Management Information System

Automation can assist emergency managers in successfully responding to the enormous task of implementing plans under the pressures of time, risk, and inadequate information.

The Federal Emergency Management Information System (FEMIS) (description of FEMA in this section is based on (http://www.pnl.gov/femis)), developed at the Pacific Northwest National Laboratory, USA (PNNL), is an automated decision support system that integrates all phases of emergency management. FEMIS is unique in that it is planning based. During an actual response, emergency personnel can retrieve and execute plans created under non-emergency conditions. FEMIS was specifically designed to support operations in response to an accidental chemical agent release and has been expanded to include capabilities for use with other hazards.

The system utilizes a client-server platform to support multiple users, distributed data, and multiple operations centers. FEMIS uses a UNIX central data server and Windows-based PC clients.

5.1. Features of FEMIS

FEMIS tightly integrates the preparedness, response, mitigation, and recovery phases of emergency management. During the planning process, planners use hazard analysis modelling, demographic information, and community conditions to assess vulnerability. Protective action strategies are developed using emergency information such as facilities and traffic control points that may be impacted, as well as other geographic information. Scenario datasets allow planners to create as many separate plan task lists as vulnerability analyses indicate are needed.

During response to an actual emergency, the response decisions are tracked in the FEMIS navigator. Current hazard analysis, including decisions concerning threatened areas and zones at risk, is available. The current community conditions, linked with the planned protective action strategies for this hazard situation, allow FEMIS to suggest the best-fitting plan task list to use in response. After the task list is selected, multiple users can change status for individual tasks, making an overall status available to all users. Any changes made to the task list during a response can be saved for analysis and possible plan improvement.

FEMIS can generate and deliver reports online, using system data and graphics such as maps. Hazard analysis modelling provides output in the form of text reports, static graphical reports displayed on the geographic information system (GIS), and the GIS displays animation over time. Estimates of the population at risk are provided based on census data and the threatened area, and a report of the population and facilities that are potentially at risk can be run.

In daily operations and response, FEMIS enhances communications by replicating current information between jurisdictions. Decisions and activity information are conveyed several ways:

- Shared reports provide a method to transfer information between individuals and EOCs in free-formatted text.
- Pre-defined status boards display task status, shelter use, evacuees, casualties, and meteorological information.
- Site-Defined Status Boards let users create a status board of their own design to be used by their own jurisdiction or to be shared with other jurisdictions.
- User-defined points and polygons allow users to share geographic information between jurisdictions.

Web Operational Status Boards (Web OSB) are a web-based tool that allows emergency managers to identify highly dynamic status information and disseminate appropriate information within an EOC, to multiple EOCs at a site, and to users outside the EOC who need to know the information (shelters, schools, hospitals). Web OSB supports "on-the-fly" planning and response activities using Site Defined Status Boards or Shared Reports.

Users can view, add, or edit Site Defined Status Board contents using a browser. Status board structure changes can be made using the FEMIS Site Defined Status Board Designer. Both structure and content changes are seen by users when they update their window.

FEMIS exercise mode duplicates its operational functionality and data to allow users to train on the same system and use the same data they will use in day-to-day emergency management operations without interrupting daily operations.
Local, state, and federal emergency management (EM) experts developed the requirements for FEMIS. FEMIS is built on a suite of commercial-off-the-shelf (COTS) software products, including ArcView and Oracle. The U.S. government provides the hazard analysis model.

The general hazard capabilities have been packaged into a separate product called EMA*DVANTAGE* (Emergency Management Advantage). This system provides a decision support architecture that can be directly applied to a site's general emergency management needs or expanded to create a system for a specific hazard.

EMA*DVANTAGE* is being used to support EM projects, such as PEMEX and Earth Alert.

For PEMEX, EMA*DVANTAGE* was tailored to support EM activities at oil refineries in Mexico. In addition to making the software bilingual and providing site-specific equipment and chemical databases, the system was expanded to include several new models. These models include: toxic release, fire, HF, and Bleve. Electronic plans were constructed to directly support the daily operations and response activities at the Minatitlan Refinery.

For Earth Alert, a National Aeronautics and Space Administration (NASA) project, PNNL expanded EMA*DVANTAGE* to transfer information and decisions to wireless devices called E-Gloves. The E-glove integrates a PDA (personal digital assistant), wireless modem, and global positioning system (GPS) device into a single unit. This system transfers messages to the E-Glove based on the user's subscription, such as the locations of wireless users, weather conditions, traffic conditions, ad-hoc messages, and damage assessment information.

EMA*DVANTAGE* supports hazard modelling. The architecture integrates hazard models with GIS displays. It also assists in making a protective action decision that is based on the time a potential hazard may impact a response zone or designated facility. Current models include heavy gas dispersion, jet fire, pool fire, flash fire, explosion (with overpressure and debris estimates), and water-borne spills.

In order to integrate a new model into EMA*DVANTAGE*, we work with the client to identify the model, the user-oriented interface needed to provide inputs, how the model will graphically and textually display results, and finally how the model will be used in the clients decision making process.

The result of modelling is a threat area, which is a geographic region depicting the area that will likely be impacted by the potential hazard.

EMA*DVANTAGE's* general hazard component allows a user to loosely-couple a model with its architecture by a direct link to the model from the EMA*DVANTAGE* interface.

As a result of the modelling integration, EMA*DVANTAGE* can assist the user in identifying the zones and facilities that are at risk. Risk identification also includes identifying sirens, traffic control points, and other site-specific elements of emergency management that are in close proximity to the hazard that will be involved in mitigating the hazard.

Electronic plans are selected based upon the protective action decisions and the community conditions. The plan contains the activities and tasks that need to be performed to successfully complete the protective action decisions. A task within the electronic plan contains general information about who in the EOC is responsible for the task, what actions need to be done, and what resources are needed to complete the tasks.

The task can also identify the geographical location where the task is to be performed as well as the people to contact outside of the EOC. Tasks within a plan can be given desired start and finish times.

When a task is executed, the actual start and actual finish times are kept in a log for later review. Some of the information in the plan can be linked to a task. Many users can view and work on an electronic plan at the same time.

MA*DVANTAGE* allows an authorized user to make an emergency declaration. An electronic notification automatically notifies the EOC and other users outside of the EOC that are using EMA*DVANTAGE* about the emergency. Depending on how the EOCs operate, this function can be used as an initial warning system for other EOCs and personnel.

MA*DVANTAGE* provides the capability to develop, manage, and quickly access information about the facilities, resources, and personnel needed to support an EOC's emergency management activities. This allows emergency managers to identify those agencies, departments, and personnel that are involved in emergency management at the EOC as well as in the local community. It also allows the emergency managers to track facilities and resources of specific interest to the EOC. The information management components of EMA*DVANTAGE* include but are not limited to:

- Agencies and departments involved in emergency management.
- Personnel that are responsible for manning the EOC and/or responding to a specific hazard.

- Personnel residing outside of the EOC that provide assistance to the general public during an emergency such as fire, police, and doctors.
- People in the community that provide resources.
- Facilities that may be effected by the hazard.
- Facilities for which special protective actions are needed, such as hospitals or schools.
- Facilities that are involved in providing resources and/or are involved in providing shelter to the community.
- Traffic Control Points to support emergency responders.
- Sirens to support public alert and notification.
- Meteorological towers to provide real time weather information.

A key component of the EMA*DVANTAGE* architecture is to allow a user to quickly access needed information about a facility, traffic control point, siren, or other element of emergency management. This includes the access and display of information directly from the geographic information system (GIS).

Protective action decisions are made by proximity to the hazard. They can also be based on impact time. Site and community conditions can also be factored into the decision making process.

The premise of EMA*DVANTAGE* is to provide both the emergency manager and responder with quick access to information. The types of information that can be quickly accessed include information about the emergency, the geographic area at risk, the electronic plan being implemented, the shelters being activated, and the people and materials being used to respond to the emergency.

To provide such information, EMA*DVANTAGE* provides predefined status boards and reports as well as single click access to view map displays. The list of predefined status boards and maps include but are not limited to:

- Emergency Declaration status board.
- Electronic Plan status board.
- Casualty status board.
- Evacuees Registration and Reunification status board.
- Shelter Activation status board.
- Meteorological and weather status board.
- Threat and Risk Area reports and/or map displays.
- Current Status of Other EOCs map display.
- Chemical plume displays.
- Protective Action Decision map displays.

EMA*DVANTAGE* allows EOCs to tailor status boards to fit its specific needs. This capability has been used extensively at EOCs and is one of the greatest strengths of the system. User defined status boards can contain text, numbers, locations, dates, and other types of information that are named and organized by the user. This information can be entered and shared between users as well as between EOCs. This capability allows an EOC to tailor EMA*DVANTAGE* to fit their specific needs because it is flexible enough that pre-created status boards and situation reports can be updated "on-the-fly" during an incident in response to the actuality of the situation.

During daily operations or in response to a natural or man-made incident, timely sharing of information in needed between:

- emergency operations centers, incident command centers, and mobile command centers;
- joint information centers;
- schools, shelters, hospitals and other key public facilities;
- the general public;

Operations Status Board (OSB) directly supports the timely sharing of information between all of the components of a sites extended emergency response program. OSB has the ability to add, display, and update dynamic status information simultaneously at all locations involved in emergency management.

OSB allows a command center to create its own local Web site to support information sharing via the Internet. The OSB designer has been developed to address security, data updates from multiple users, notification, and rapid implementation issues associated with the dissemination of highly dynamic information between multiple users and jurisdictions.

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