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Methodological framework for developing decision support systems (DSS) for hazardous materials emergency response operations

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Abstract

The production, storage, and transportation of hazardous materials are processes of vital economic importance for any advanced and technologically complex society. Although the production and distribution of hazardous materials is associated with economic development, there is a significant potential danger to the natural and social environment in the event of their accidental release, a fact that prompts for the development and implementation of methods and techniques that aim to improve hazardous materials risk management decisions. The objective of this paper is to present a unified framework for developing a Decision Support System (DSS) for supporting a vital function of risk management, namely the management of emergency response operations. The proposed framework recognizes the peculiarities of the hazardous materials decision-making environment which is characterized by: (i) multiple stakeholders, i.e., persons and organizations involved in and affected by hazardous materials risk management decisions; (ii) lack of a formal management structure for monitoring and controlling in a unified manner all Emergency Response Resources; (iii) lack of clear distinction and fragmentation of responsibilities of the actors involved in risk management operations; and (iv) dynamic/real-time decisions, i.e., risk determinants change over time. The proposed framework was used in order to develop a DSS for managing emergency response operations for large scale industrial accidents in Western Attica, Greece. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Risk management; Emergency response; Hazardous materials; Decision support systems

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1. Introduction

The production, storage and transportation of hazardous materials are processes of vital economic importance for any advanced and technologically complex society. All substances that pose unreasonable risk to health, environment and surrounding properties are characterized as *hazardous materials*. More than 3300 substances and their products have been characterized as hazardous materials; this list contains flammable, corrosive, radioactive, toxic, poisonous, and explosive substances and is constantly expanding to include new substances that exhibit the abovementioned characteristics [1–3]. The adverse impact of hazardous materials occur when hazardous materials are released in the environment. To reduce the *risk* associated with the handling of hazardous materials, it is important to develop *risk management systems* that involve procedures and actions for supporting strategic, tactical and operational decisions that aim in reducing risk along the following two dimensions [4]: (a) reduction of the probability of accident occurrence and (b) reduction of the consequences of a potential accident. The first objective is achieved by the implementation of accident preventive actions, i.e. (i) development and implementation of safety procedures for the production, packaging, storage and transportation of hazardous materials; these procedures aim to eliminate all factors that may cause an accident, i.e. human error, equipment/infrastructure failure, etc. and (ii) development of the appropriate infrastructure including development and implementation of regulations and inspection protocols that detect maintenance needs, deficiencies, and problems promptly, before causing any severe accident. On the other hand, the second objective (consequence minimization) can be achieved by the development and operation of a *hazardous materials emergency response* (HAMER) system, which aims at reducing the duration and the consequences of a hazardous materials accident.

The design and operation of a HAMER system is a complex procedure for a number of reasons.

(I) Hazardous materials accidents are rare and unpredictable events with very low probability of occurrence, but serious and sometimes catastrophic and unrecoverable consequences, and severe social impact.

(II) Decisions relevant to hazardous materials logistics operations influence, to a varying degree, multiple societal groups (stakeholders) with different and sometimes conflicting objectives.

(III) The area of responsibility, of the various stakeholders involved in the decision-making process, is ill-defined and the existence of gray areas of responsibility and managerial authority is common.

(IV) A number of emergency management decisions (i.e., decisions after the occurrence of an accident) are taken under time pressure and sometimes under limited data availability.

(V) The HAMER System is dynamic in nature and a number of factors that influence risk evolve over time and space.

(VI) The information needed for supporting decisions is coming from multiple spatially distributed sources.

(VII) The HAMER system requires the cooperation and coordination of multiple actors with varying degree of training and professional expertise.

The development of a Decision Support System for risk management decisions must take into consideration the abovementioned characteristics.

The objective of this paper is to present a methodological framework for developing a HAMER system and to illustrate its applicability for the development of a Decision Support System (DSS) for managing emergency response operations for large scale industrial accidents in Western Attica, Greece. This framework is primarily focused on the analysis and design of the HAMER system and covers the following stages of the DSS life-cycle: (a) identification of users needs, (b) development of functional specifications, and (c) system design. The paper describes all methodological steps that should be employed at the various stages of the system development, presents in a systematic manner the HAMER scope, characteristics, and requirements, summarizes ''WHAT'' the system should do in order to fulfil its goals and objectives, as they have been identified from the case study.

The rest of this paper is organized as follows: Section 2 presents the proposed methodological framework and the experience gained from the implementation of the proposed framework at the Western Attica Case Study; and Section 3 presents the concluding remarks of the paper.

2. The proposed framework for the analysis and design of the HAMER system

The proposed framework is based on the typical life-cycle used in the DSS development, which involves the following stages: (1) identification of user needs, (2) development of functional specifications, (3) determination of the system architecture, (4) system implementation and (5) evaluation/validation. Fig. 1 shows the input/output relationship between the phases of the project life-cycle. Two important observations can be made regarding the characteristics of the relationships between the various phases of the project life-cycle. The first observation relates to the decisive role of the ''identification of user needs'' phase on the subsequent phases. The second observation relates to the presence of a continuous feedback between the various phases of the DSS life-cycle and the involvement and interaction between the system developers and the system end users.

Each stage of the proposed framework and the relevant results from the implementation of the framework at the Western Attica Case are presented in the following sections.

2.1. User needs analysis methodology

The objective of the user-needs analysis is to identify the expectations, needs, and requirements of the various groups involved in and affected by HAMER operations. The decisive role of the user-needs analysis, requires the development and application of a methodological framework able to: (1) identify all actors (stakeholders) involved in and affected by emergency response operations, (2) identify the functions, tasks, and sub-tasks performed during emergency response operations, (3) identify the context within which emergency response functions are performed, (4) identify the communication difficulties between the various actors, (5) recognize the limitations of the users to

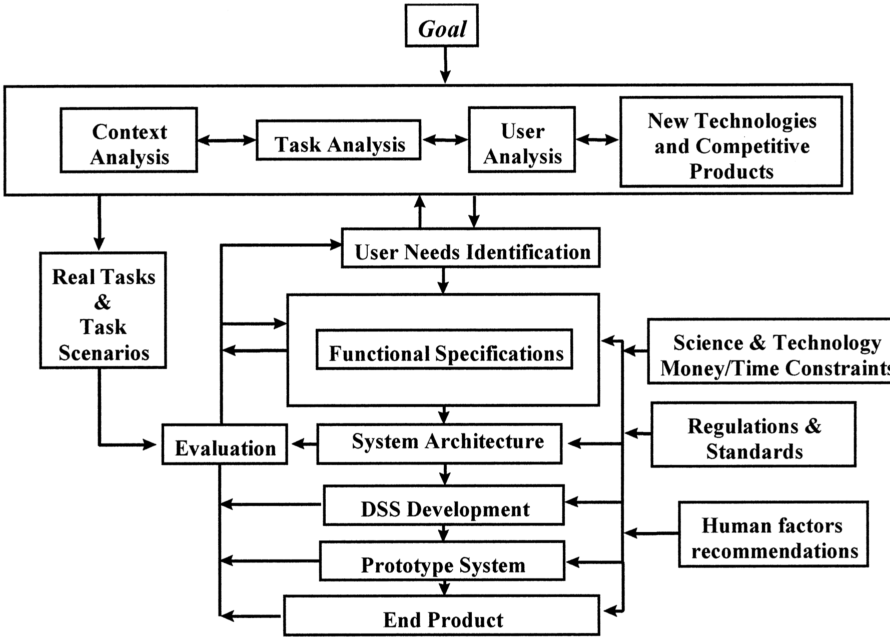

Fig. 1. The inputs and outputs of each phase of the DSS life-cycle [5].

identify explicitly their needs, (6) understand differences in goals, objectives, and priorities between the various actors, (7) understand the differences of accident management operations within a variety of legal, institutional, organizational, and technological settings across various users groups, and (8) synthesize user-needs and requirements in order to provide meaningful input for the subsequent phases of the system development life-cycle.

The user-requirement analysis methodology for the development of the HAMER system incorporates all the above characteristics and is shown schematically in Fig. 2 [6–9]; the starting point of the user requirements analysis is the identification and classification of the potential DSS user groups. In order to extract all user requirements in a constructive and methodologically correct manner, a questionnaire should be developed. This instrument is based on the outcome of an extensive state-of-the-art and state-of-practice review and on the expertise gained from the development of other emergency response systems, and is structured in a way that facilitates the objectives of the user needs analysis. Special emphasis should be given on the identification of the various public and private agencies involved in or affected by the operation of the system, on the determination of data and information flow between the various emergency functions and on the determination of system deficiencies and bottlenecks, and users expectations. A preliminary version of the questionnaire is tested in a group meeting with a subset of the system users. The reactions and comments of these users are used for the improvement of the questionnaire content and structure. The improved questionnaire is distributed to a greater set of users in order to collect the required

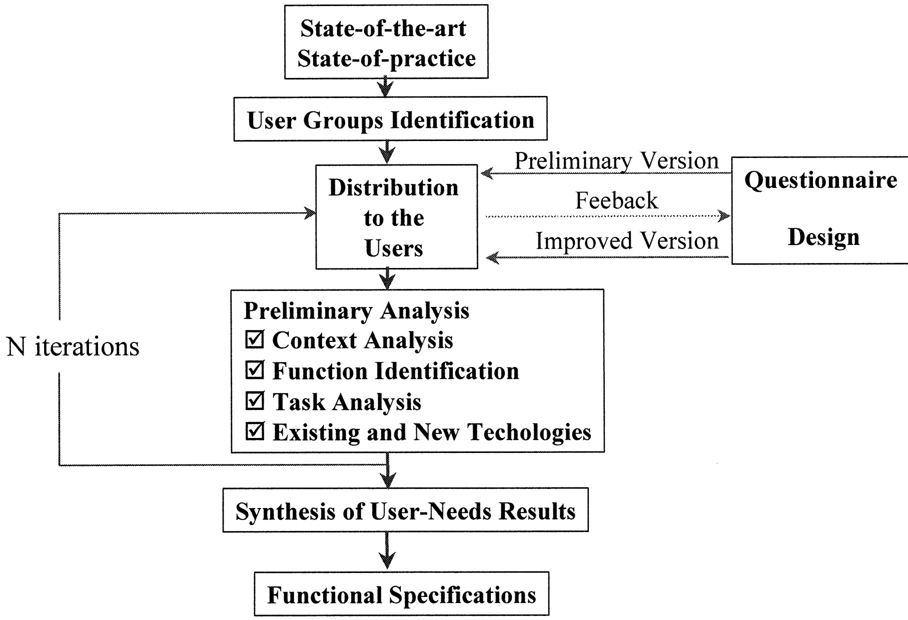

Fig. 2. The methodological framework for the user needs analysis.

information for the ''final'' analysis of user requirements. The questionnaire includes a wide spectrum of questions addressing the above issues and is organized in the following sections [6].

(A) *Respondent / organization / company information*: this part contains questions related to the company/organization profile and its role within hazardous material emergency management domain.

(B) *Operations undertaken by the organization / company*: this part contains questions related to (a) the actions performed during hazardous materials emergency management process, (b) the available resources for responding to hazardous materials accidents, and (c) the information flow and exchange.

(C) *Methods, policies, and systems adopted by the organization / company*: this part contains questions related to the different methods and techniques related to all HAMER subsystems. It also contains information related to the performance and the effectiveness of each system sub-component.

(D) *General system attributes and measures of effectiveness*: this part contains questions related to the measures of effectiveness used for evaluating the performance of the various HAMER sub-components.

(E) *Implications of advanced technologies*: this part contains questions related to the user requirement in terms of the computational environment to be used and the willingness to adopt new technological solutions for managing incidents. At the end of this section the responder has opportunity to provide a sketch of the existing and the desired generic system architecture.

(F) *Comments and ideas*: where the responder is free to express his/her ideas about issues that have not been covered by the questionnaire. Special emphasis is given on the identification of problems, bottlenecks and deficiencies.

The implementation of the abovementioned methodological framework in the Western Attica Case revealed that the following actors stakeholders/authorities/entities are involved in the operation of the HAMER [6,7]:

1. The industry in which the accident occurs (if the accident occurs during the transportation of a hazardous materials shipment, then the forwarding company is identified as one of the key actors),
2. The Fire Department,
3. The Police Department and Traffic Police,
4. The prefecture,
5. The medical assistance agencies,
6. The hospitals,
7. The Coastguard, if the accident occurs in or by the sea,
8. The general public,
9. The media,
10. Other neighbor industries.

The next step in the assessment of user needs is the identification of the functions performed by the various actors, which will be implemented during the development of the HAMER system. The functions of the HAMER system as they have been identified for the Western Attica Case are the following: (1) accident detection, (2) accident verification, (3) accident response, (4) accident suppression, (5) public safety and information Dissemination, and (6) accident rehabilitation. (More details about these functions are provided later in this paper).

The HAMER functions are further decomposed into tasks and sub-tasks using the following task analysis technique. For each of the above actors a task analysis table for processing and analyzing the completed questionnaire should be constructed [6–8]. This table contains information related to the following items: (a) actions performed, methods and techniques employed by each actor, (b) available human and technological resources, (c) information and data needs, (d) interaction with other actors, (e) problems, and (f) expectations (Table 1).

A task analysis table is filled for the each actor, all completed tables are synthesized and a consolidated table, is constructed. This table provides information for all the emergency response actors and aims in the:

1. Identification of the role of each actor
2. Identification of responsibilities allocation and responsibilities overlapping
3. Identification of methods, techniques and technological means for performing emergency response actions
4. Identification of data/information requirements and data flows and exchange (an example of table that can be used for the assessment of data flow is presented in Table 2)
5. Identification of technological means for data/information dissemination and exchange.

Table 1
An example of a task analysis table (this table is filled for each actor)

	Detection	Verification	Response	Suppression	Rehabilitation
Fire Department		• Phone call to the Industry	• Notification of other agencies	• Expertise for accident evolution forecasting	
		• Dispatching of two RUs	• Dispatching of additional resources	• Fire extinguishing	
		• Notification of all Fire Departments close to the accident area	• RU routing	• First aid to injured people	
				• Removal of hazardous materials,	
				• Etc.	

The results of the user requirements analysis for the HAMER System which will be used at the subsequent phases of the DSS development can be summarized as follows.

• The HAMER involves multiple actors with varying degree of training, different expertise and objectives.

• Resource allocation and the implementation of appropriate response actions are not the outcome of a well-defined decision making process; therefore, the system performance is strongly dependent on the experience and training of the responders.

• The analysis of the organizational and legislative structure of the HAMER revealed the existence of responsibilities overlapping that limits the coordination and cooperation of the various actors.

• The system performance depends to a great extent to the availability and timeless processing of both static and dynamic data.

• All decisions are taken under time pressure and stress, that limit the time available for data entry.

• The HAMER system requires the cooperation and coordination of other emergency response systems such as the police, the fire department, medical assistance, coastguard, etc. Each of the emergency response systems has its own procedures and organizational structure.

Table 2
Table for assessing data exchange between the various actors: an example

Data exchanged	Origin	Destination
Accident characteristics (nature and severity)	⇒ Industries ⇒ Prefecture ⇒ Fire Department	⇒ Prefecture, Fire Dept, Coastguard, Police, Municipalities, Medical Assistance, Other Industries
Accident location	⇒ Industries ⇒ Prefecture ⇒ Fire Department	⇒ Prefecture, Fire Dept, Coastguard, Police, Municipalities, Medical Assistance, Other Industries

- The HAMER system aims to harmonize and coordinate the procedures of the involved agencies and *not* to alter their organizational structure.
- The assessment of the accident evolution and expected impact, and the consequences that result from the application of different response actions and measure are of great importance for the decision makers.
- Information/data is exchanged between spatially distributed agencies.
- The HAMER System should support the following decisions: (a) assessment of accident consequences and accident evolution, (b) development of the appropriate emergency plan, (c) identification and notification of required response actors, (d) determination of the appropriate response actions and the required resources, (e) dispatching and monitoring of the responses, (f) selection and implementation of evacuation plans.
- The following inefficiencies and bottlenecks hamper the smooth and coherent provision of emergency services to the citizens:

⇒ Fragmentation of inter-agency communications

⇒ Duplication of effort in developing components of technological systems that support similar emergency management functions

⇒ Sub-optimal utilization of emergency management resources, i.e., manpower, equipment, etc.

⇒ Lack of co-operation among actors.

The next stage if the DSS life-cycle is the transformation of user needs and requirements are transformed into functional specifications, which are presented in Section 2.2.

2.2. Functional specifications

The user requirements, presented in the previous section, are transformed into Input-Process-Output Requirements which form the basis for the development of the HAMER functional model. The functional requirements of the HAMER system are summarized next.

2.2.1. Function: detection

The DETECTION function operates as follows: The HAMER system is notified about the occurrence of the accident, determines accident location, dispatches a Response Unit (RU) at the accident scene, and activates the VERIFICATION function

Input Data: Accident Location, Accident Characteristics

Processing:

⇒ Representation of the accident location on the digital map

⇒ Determination of the response actors, along with their location, telephone numbers, contact persons, etc.

⇒ Determination of the RU to be dispatched for accident verification

⇒ Routing of the RU

Output:
⇒ Visualization of accident location on digital map
⇒ Dispatching of RU for accident verification

2.2.2. Function: verification

The VERIFICATION function assesses the accident evolution, estimates the accident evolution, selects the appropriate emergency response plan, determines the resources needed for the accident treatment, and notifies the appropriate actors.

Input Data:
Accident Characteristics (more detailed)
Weather and Environmental Conditions
Expertise from other relevant accidents
Physical and chemical attributes of the released substance

Processing:
⇒ Estimation of accident consequences
⇒ Assessment of accident evolution
⇒ Estimation of Accident Severity
⇒ Determination of response actors to be notified
⇒ Determination if evacuation plan is needed

Output:
⇒ Selection of emergency response plans relevant to the accident
⇒ Notification of appropriate actors
⇒ Visualization of impact contours

2.2.3. Function: response

The RESPONSE function determines the resources to be dispatched at the accident site and for each RU determines the route the route that minimizes the travel time from its initial location to the accident scene.

Input Data:
Available resources
Accident characteristics (updated)
Weather and environmental conditions (updated)
Traffic conditions at the adjacent transport network

Processing:
⇒ Dispatching of the appropriate RUs
⇒ Routing of the RUs

Output:
⇒ Visualization of the RUs to be dispatched
⇒ Visualization of the routes for each RU

Function: Suppression. The SUPPRESSION function determines all actions and procedures needed to be implemented at the scene of the accident to minimize its consequences.

Input Data:
Expertise from other relevant judgement
Experts judgement

Processing:
⇒ Routing of ambulances for transporting injured people
⇒ Access to historical data for extracting expertise from relevant accidents
⇒ If additional expert judgement is needed, determination of a contact list of experts that can contribute
⇒ Determination of the availability of additional resources

Output:
⇒ Recommendations for on-scene actions
⇒ List of experts
⇒ Location and availability of additional resources. These resources can be dispatched if additional forces are needed
⇒ Visualization of optimum routes for transporting injured people

2.2.4. Function: public safety / info dissemination.

The PUBLIC SAFETY / INFO DISSEMINATION function implements the evacuation plan, determines the areas that should be evacuated, the evacuation routes, and sends the appropriate messages to be broadcasted by the media.

Input Data:
Decision that evacuation is needed
Traffic conditions
Population density and characteristics
Accident characteristics
Candidate locations for hosting the population from the evacuated area

Processing:
⇒ Determination of Evacuation Area
⇒ Determination of Evacuation Routes
⇒ Assignment of the available vehicles on the transport network
⇒ Determination of population concentration points
⇒ Determination of the appropriate messages that should be broadcasted for informing the general public

Output:
Visualization of the evacuation area
Visualization of the evacuation routes
Media notification

2.2.5. Function: rehabilitation

This Function was out of the scope of the reported case study.

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

• The DSS should be able to handle both static and real time data (i.e. data that evolve over time).

• The DSS model base should contain mathematical models and empirical rules that should be able to provide estimation of the impact and the consequences of the accident, and to optimize the use of the available resources.

• The model base should contain empirical rules for associating the appropriate response actions to the accident characteristics.

- The model base should be able to operate under limited data availability, and should take into consideration that the quality and the quantity of data evolves over time.
- The model base should contain mathematical models and algorithms for implementing evacuation plans.
- The database should be able to retrieve information from external sources or from databases spatially distributed, for example extract experience from the specific type of accident from other agencies located abroad.
- The human machine interface (HMI) of the DSS should be user friendly, should operate under a graphical environment, and should *not* require a large amount of input data.
- The graphical user interface (GUI) of the system should be GIS based for representing the spatial data of the system.
- The system should take advantage of the innovative telematics, networking, and communications technologies.

2.3. System design

Following the basic model for DSS development, the HAMER consists of the following structural elements:

1. Model base, that contains all mathematical models, algorithms, rules and knowledge that can be utilized for minimizing accident duration and consequences.

2. Database, that contains all data needed for the system operation.

3. A GIS-based GUI.

The structural elements of the proposed DSS are presented in Sections 2.3.1, 2.3.2 and 2.3.3 and illustrated in Fig. 3.

2.3.1. Model base

The selection of the appropriate models to be included in the model base is subject to the application domain and the problem characteristics. The scope of this paper is to present the classes of models that should be included in the HAMER system in order to fulfil the abovementioned functional goals and specifications. It is important to emphasize that the fact that the detailed presentation of the models included in the model base is out of the scope of this paper.

In particular, the model base contains the following types of mathematical models, rules, and algorithms:

(1) Models for estimating the impact and the evolution of the accident: This set of models is used for assessing the following problem: *Given the type of hazardous materials, the weather and environmental conditions, the characteristics of the facility (if the accident occurs in the vicinity of a stationary facility), the characteristics of the area around the accident site (i.e. population density, environmental sensitive areas, distance from adjacent facilities, traffic conditions, etc.), determine the impact area, the severity of the accident, and predict the evolution of the accident*. The models included

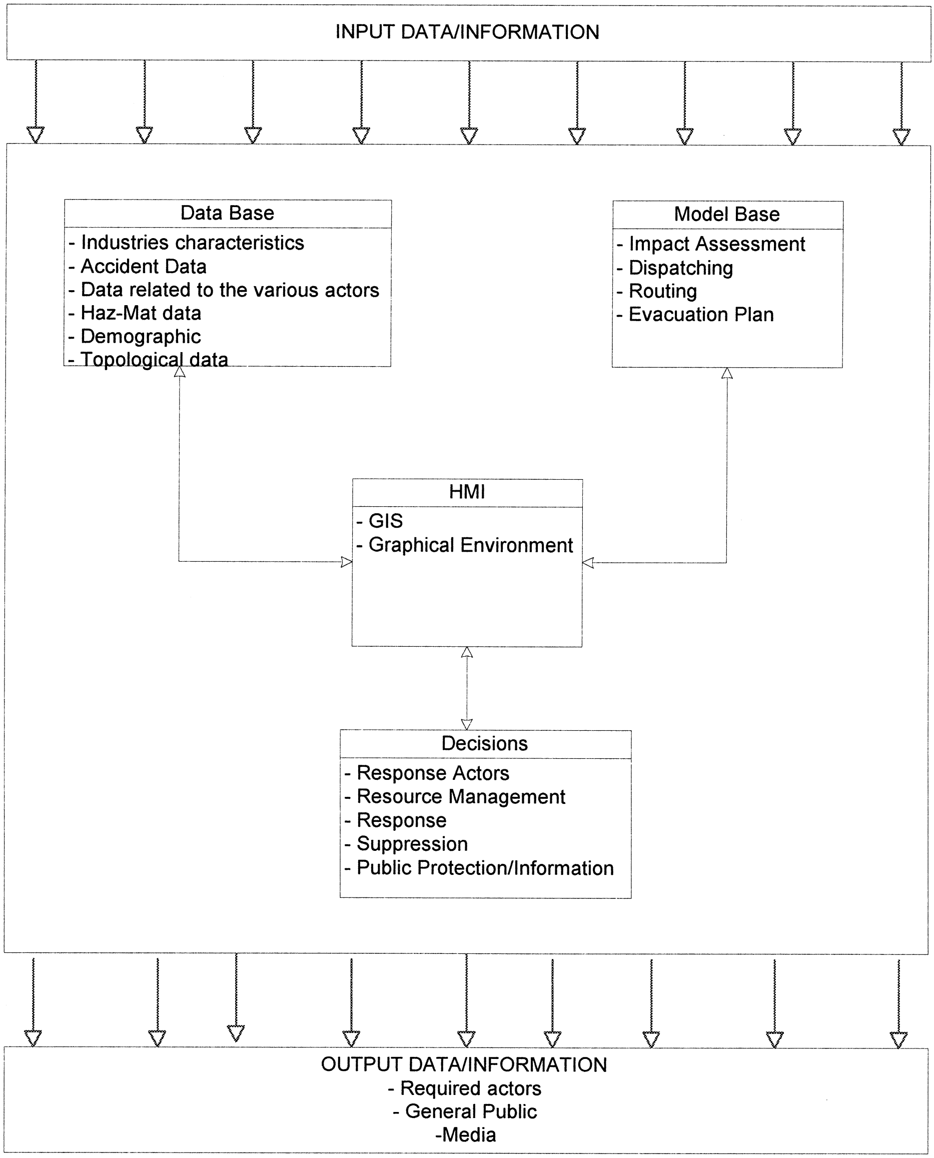

Fig. 3. The structural elements of the HAMER system.

in HAMER system should have the ability to capture the dynamic nature of the accident, and update their output when some of the input parameters change.

(2) Rules and knowledge for assessing the impact and the evolution of the accident: The HAMER system must be able to support emergency response operations under data unavailability, which is observed if some of the input data are not available or if the level of details of the available data is not adequate for the models to operate. To

overcome this problem the proposed system contains a rule based system that extracts knowledge from other similar accidents and from the safety plan of the facility.

(3) Rules for the dispatching of the appropriate response units: The objective of this set of rules is to solve the following problem: *Given the location, the characteristics (i.e. severity, impacted area, expected consequences, etc.), the RUs' location, determine the RU needed for responding to the accident*. The dispatching rules are collected during the assessment of user requirements, through personal interviews with the various users involved in the HAMER operations, and through published sources. The dispatching rules and policies implemented by the various agencies exhibit some differences. As mentioned a number of times before, the objective of the HAMER is *not* to alter the organizational structure of the responding agencies, but to harmonize and integrate their operational procedures in order to accommodate their common goal: *the reduction of accident consequences*. The harmonization guideline should be applied for the development of the HAMER dispatching rules.

(4) Algorithm for Routing RUs, that addresses the routing problem defined as follows: *Given the location of an incident, the location of the RU, the roadway network topology data determine the route that the RU must follow in order to minimize travel time, i.e., the time elapsed between the moment of dispatching until the moment the RU arrives at the accident scene.* The routing algorithm is a shortest path algorithm, that is able to identify quickly the route that each RU has to follow for arriving at the accident site at the minimum time; the algorithm takes into consideration the size of the RU (it excludes links that cannot accommodate the dimensions and the weight of the RU) and the traffic conditions on the roadway network.

(5) Mathematical models for determining optimum evacuation plans by solving the following problem: *Given the population distribution of the evacuation area, a set of candidate destinations for transporting the inhabitants of the evacuated areas, the topology and the capacity of the roadway network, and the available vehicles, identify the set of destinations where the population centers should be transported, determine the routes that should be used and the relevant traffic volume that should be assigned to the each route, and specify the optimum signal setting and traffic management actions, in way that minimizes the evacuation time.* The following types of algorithms should be employed:

⇒ Algorithms for identifying evacuation routes and assigning optimum traffic volumes

⇒ Algorithms for dynamic rerouting of on-coming traffic to prevent secondary accidents.

2.3.2. Database

The database contains all data needed for the operation of the HAMER which can be classified into two distinct categories: (a) static and historical data that do not change during the accident evolution, e.g. transportation network, industry plans and facilities layout, etc. and (b) dynamic data that may change over time, e.g. accident characteristics, environmental conditions, RU location, etc. The data elements that should be included in the HAMER database are summarized in Tables 3 and 4.

Table 3
Summary of the static data included in the DSS database

Static data		
Information stored	Description	Comments
Transportation network	Contains the output of the transformation of the transportation network to a mathematical graph. Consists of a set of nodes and links along with their associated attributes.	The mathematical network is constructed based on specific network representation rules.
Spatial data	Contains information related to the population density, the location of special population groups such hospitals, schools, etc, the location of candidate location for accommodating the population evacuation, the location of environmentally sensitive points such as lakes, rivers, etc.	This information is used for the assessment of the accident impact and consequences, the implementation of evacuation plans, etc.
Historical accident data	Contains historical accident related information. Data related to hazardous materials accidents that occurred in the past, i.e., type and quantity released, weather and environmental conditions, accident impact and evolution, emergency response actions implemented, etc.	All this information is used for supporting decisions under data unavailability conditions.
Traffic conditions of the roadway network	Contains historical information related to the travel times between adjacent nodes of the mathematical network. These times differ depending on the time of day and year (a set of tables is stored). If appropriate instrumentation exists, theses traffic conditions can be real time data.	This information is used by the routing function which depending on the time of day, and other conditions (i.e., weather, season, etc.) selects the appropriate table for supporting routing decisions.
Data related to the facilities that produce, pack, and store hazardous materials	Contains information related to the location, the layout, the type and the quantity of the hazardous handled, and the safety and emergency plans of the facility.	This information is used for the assessment of the accident impact and evolution, and for the determination of the required resources and actions for responding to the accident.
Data related to the response actors.	Contains information related to the location, the human and technological resources, and telephone numbers of the response actors.	This information is required for the notification of the appropriate response actors, and for the determination of the resources needed for responding to the accident.

2.3.3. Human machine interface

The development of the HMI is based on the user requirements and their subsequent transformation into functional specifications, and other special needs revealed during the development phase. The HMI is GIS-based (to handle all spatial data and perform the relevant operations), operates on a PC and performs the following operations: (a) interacts with the user, (b) serves as a front end for entering real-time information into

Table 4
Summary of the dynamic data included in the DSS database

Dynamic data		
Information stored	Description	Comments
Accident location	Contains the accident location associated with the mathematical graph	This information is used by all functions.
Accident character istics	Contains all information related to the type and the severity of the accident, i.e. type and quantity of released substance	This information is supplied by the verification function.
Weather conditions and environmental conditions at the scene of the accident	Contains information related to the weather and environmental conditions at the scene of the accident, e.g. temperature, wind direction and speed etc.	This information is required for the determination of accident severity and impact assessment.
Output of the various functions	Contains the output of the various functions	This information is displayed on the system console by the HMI.

the system, (c) provides features for extracting and displaying all information stored in the data base, (d) illustrates the application site including the mathematical network representation, and all facilities that may be important for the system operation, e.g. hospitals, industrial plants, etc. (e) performs all required associations with real time

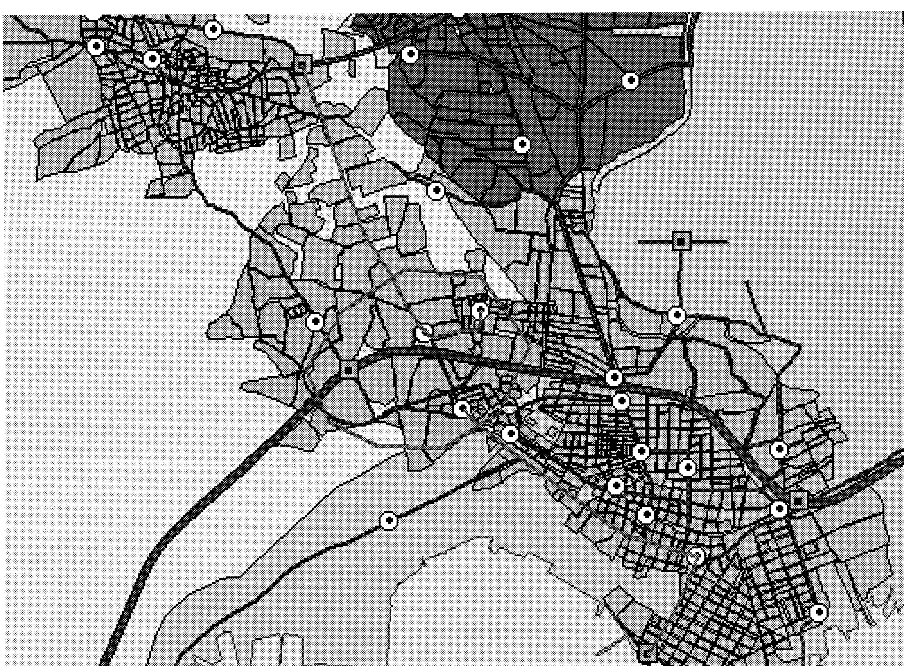

Fig. 4. Sample output of the HAMER system: evacuation plan.

Table 5
Association of real world decisions and actions to system operations and system output

Real-world decisions and actions	HAMER operations	HAMER Output
Detection		
· Accident detection	· Archive accident characteristics	· Illustration of accident location on GIS map
· Severity assessment	· Locate accident on GIS map	· Address, phone, name of agencies to respond
· Fire department notification	· Notify appropriate agencies	
Verification		
· Operations center notification	· Select the relevant emergency response plans	· Catalogue of all relevant emergency response scenarios available in the Database
· Severity assessment		
Response		
· Assessment of required resources	· Update real time data	· Data visualization
· Agencies notification	· Assess impact and severity	· Catalogue of all available resources
· Dispatching of RUs	· Select a more detailed emergency plan	· RU dispatching and Routing
	· Determine response actions	
	· Access the available resource data	
	· Project all required data on the GIS map	
	· Dispatch additional resources	
Suppresion		
· Medical Assistance	· Retrieve personal data of experts	· Presentation of the appropriate hospital
· Injured people transportation	· Monitor Meteorological conditions	
· Fire extinguishing	· Retrieve data related to the available hospitals	· Personal info of experts
		· Presentation of the output of the impact assessment models
· Traffic re-routing		
· Provide right-of-way to RU	· Impact assessment and evolution forecasting	· Guidelines for on-scene actions
· Accident evolution forecasting		
Public safety info dissemination		
· General public notification	· Determine evacuation area	· Illustration of evacuation area, evacuation routes, and concentration points on GIS
· Drivers notification	· Identify evacuation routes	
· Media notification	· Distribute vehicles at the various links	
· Implementation of evacuation plan (if needed)	· Determine concentration points	

and/or historical information with the mathematical graph, (f) displays the contours that illustrate the impacted area, (g) displays the RU that has to be dispatched for servicing a specific incident (i.e. the output of the dispatching function) along with the optimum route (the output of the routing function), (h) displays the list of response (i.e. the output of the suppression function), and (i) presents the evacuation plans. The proposed HMI, menu driven and provides on-line help at every stage of its operation.

Fig. 4 presents a sample output of the system that illustrates the implementation of evacuation plan (the blue polygon shows the area to be evacuated, the black and white bullets show the population centers, the green squares correspond to the destination points, and the purple line correspond to the routes that should be used for the transportation of the evacuated population).

2.4. System operation

The HAMER developed for the Western Attica Case Study is based on the user and functional requirements as they have been presented in the previous paragraphs. The scope of the developed DSS is to support decisions at all phases of an industrial accident with special emphasis on the suppression of the event. The major functions of the developed system are: (a) impact and consequence analysis and assessment of the phenomenon evolution, (b) development of alternative emergency response plans for optimizing the utilization of human and technological resources and (c) handling of all data and information needed for the system operation. In particular, when an accident is verified, the system performs the following operations: (a) notifies automatically all required response actors and forwards all accident information via e-mail and fax, (b) assesses the accident impact and consequences by applying the appropriate mathematical models, (c) provides to the operator a vast amount of data, e.g. location of important points such as hospitals, location of neighboring industries, hazardous materials chemical and physical characteristics, personal information of experts that can contribute in the development of the emergency response plan, (d) produces emergency plans for responding to the accident, and (e) produces evacuation plans. The developed system has the ability capture the dynamic nature of the problem and modify its output if some of the input data are altered during the phenomenon evolution, displays all spatial data on a GIS digital map, is easy to use and operate. Table 5 illustrates the operation of the HAMER system by associating real word decisions to system operations and system output.

3. Conclusions

A unified framework for developing DSS for hazardous materials emergency response operations was presented. This framework was implemented for the development of an emergency response system for responding to large-scale industrial accidents in Western Attica, Greece. The concluding remarks fall into the following categories: (a) conclusions related to the proposed methodological framework, and (b) conclusions that spring from the Case Study experience.

- The proposed framework has been tailored to capture the peculiarities of the hazardous materials emergency response problem, i.e. the existence of multiple stakeholders, the dynamic nature and the severity of hazardous materials accidents.
- The proposed framework provides the capability to identify the role of each actor, responsibilities overlapping and fragmentation, information flow and data needs and requirements, and to develop procedures for harmonizing the functions performed by the various actors, and transform these requirements into functional and design specifications.
- Continuous interaction between the system developers, the relevant decision makers, leads to the successful completion of the system and to a wide acceptability of the models and technologies, by the people involved in the hazardous materials emergency response operations, and gives the opportunity to exchange ideas, establish better communication and improve their cooperation.

The system developed for the Western Attica reduces the risk associated with hazardous handling by reducing the duration and the consequences of a hazardous material accident. In order to achieve these goals, the system employs a number mathematical models and empirical rules in conjunction with the capabilities provided by Data Base Systems and GIS technologies, and has the capability to operate under limited data availability, and to handle dynamic data. The latter feature is really important because risk determinants and accident characteristics change significantly over time and prompt for new response actions; the system collects, processes, and disseminate and real time and dynamic data and changes its outputs when the relevant input data change. The use of the GIS platform proved to be an effective tool for displaying spatial data, performing operations based on spatial data, e.g. estimation of impacted area, of the evacuation area and population, determination of the candidate evacuation routes, etc, and for helping the decision makers to visualize the modeling results.

Hazardous material accidents are rare events and consequently the expertise of the responding agencies is limited, and the developed system can be used as a training tool for simulating emergency response operations and evaluate the effectiveness of different strategies and decisions. The success of the system operation depends to a great extent on system maintenance and updating. Data related to: (a) the industry characteristics, e.g. type of substances handled, safety plans, etc. (b) the available resources, e.g. number, type and location of response units, personal information of experts, etc. should be periodically checked and updated.

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