Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 152 (2008) 516–526
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

Results of the MITRA project: Monitoring and intervention for the transportation of dangerous goods

E. Planas [a,*], E. Pastor [a], F. Presutto [b], J. Tixier [c]

[a] *Centre d'Estudis del Risc Tecnològic (CERTEC), Departament d'Enginyeria Química, Universitat Politècnica de Catalunya, Diagonal 647, 08028-Barcelona, Catalonia, Spain*
[b] *M3 Systems, 1 Rue des Oiseaux, 31410 Lavernose, France*
[c] *Ecole des Mines d'Alès, Alès, France*

Received 17 April 2007; received in revised form 3 July 2007; accepted 3 July 2007
Available online 17 July 2007

Abstract

The objective of the MITRA (monitoring and intervention for the transportation of dangerous goods) project was to prototype a new operational system for monitoring the transportation of dangerous goods in Europe based on regional responsibilities. This concept, based on systems used in air traffic control, aims to provide civil security centres with real-time knowledge of the position and contents of dangerous vehicles circulating in their area of responsibility, and, in the event of a dangerous situation, to issue warnings, alerts and crisis management information, thereby allowing intervention teams to react immediately with maximum safety. The project was funded by the European Commission under the 6th Framework Programme (STREP – specific targeted research project – under the Information Society Technologies priority). It started on 1 September 2004 and ended on 31 October 2006. This paper presents the results of this project and the conclusions derived from the field tests carried out in Germany and in the French/Spanish border region in order to test the proposed operational system.

Keywords: Dangerous goods; Road; Rail; Transportation; MITRA; Risk

1. Introduction

Every day, numerous trucks and trains transport large amounts of hazardous substances. Several surveys have indicated an increase in the frequency of accidents in the transportation of hazardous materials [1,2]. For example, a study of 1932 accidents [3] occurring between the beginning of the 20th century and July 2004 shows that the 78% occurred in the last 20 years and 37% in the last decade. More than half the accidents happened in road (63%) and most of them happened in the developed countries. The most frequent accidents were releases (78%) followed by fires (28%), explosions (14%) and gas clouds (6%). Practically the majority of accidents (74%) were due to collisions.

The transportation of dangerous goods currently faces a number of problems. For example, in nominal situations, the European civil security authorities currently do not track the vehicles transporting dangerous goods in a given zone and are therefore unable to take preventive measures. This results in potentially dangerous situations. In alert and emergency situations, the European civil security authorities have no systematic knowledge of the nature and characteristics of the goods transported, nor the risks and effects associated with them. This may result in delays and/or inappropriate reactions to events, with the following human, economic and environmental consequences:

- Lack of adequate precautions, intervention procedures and schemes.
- Lack of specific protection equipment.
- Exposure of first rescue teams and civilian populations to unknown hazards.
- Late and incorrect information provided to civilian populations.
- Loss of lives, both in civilian populations and civil security intervention forces (especially the first intervention teams).

The objective of the MITRA project [4] was to specify and prototype an innovative operational platform for European civil

* Corresponding author. Tel.: +34 93 4011736; fax: +34 93 4017150.
E-mail address: eulalia.planas@upc.edu (E. Planas).

0304-3894/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2007.07.032

security centres aimed at monitoring dangerous goods transportation in Europe and supporting intervention in the event of an accident. This concept, derived from the air traffic control domain, provides civil security centres with the following:

- The location of dangerous goods circulating in their area of responsibility: real-time knowledge of the position and contents of vehicles (electronic cargo identification).
- Warning and alert displays in the event of dangerous situations. This can prevent accidents by allowing preventive measures to be taken.
- Crisis-management information that allows quicker, safer and more efficient intervention, including precise knowledge of the situation and its potential consequences. This can protect the lives of both citizens and intervention forces.

MITRA's innovation is the integration of satellite navigation systems, telecommunications networks, geographic information systems, risk-knowledge databases and risk-propagation models in a single system. All interfaces of the MITRA prototype system follow the INSPIRE (INfrastructure for SPatial InfoRmation in Europe) requirements.

The project resulted in a prototype consisting of three user monitoring terminals (UMTs), three on-board terminals (OBTs), the appropriate decision-support software modules and a risk-knowledge platform (RKP) containing all necessary information about dangerous goods and propagation models. The system was deployed in three major civil security centres (France, Germany and Spain) for field trials and a validation campaign, and was submitted to real-scale emergency scenarios.

MITRA was primarily designed to satisfy civil security needs in European countries. The participation of French, Spanish, German and Dutch civil security authorities was therefore essential to the success of the project. They provided the MITRA partners with first-hand, practical and operational knowledge of:

- Current legislation on the transportation of dangerous goods in the three countries participating in the project, as well as the framework in which it is applied.
- Vehicle-monitoring requirements of civil security authorities in the three countries.
- The operational crisis-management methods and procedures currently used by civil security authorities in the three countries.

2. MITRA services

MITRA services can vary according to the use and the "actor" involved. The diverse actors involved in the MITRA system are the following:

- *Operator*. Is the person sited in the regional control centre, which is in charge of monitoring the screen of the user monitoring terminal (UMT).
- *Consignor*. The enterprise that consigns dangerous goods either on its own behalf or for a third party. He or she will be in charge of providing the system with all the information related to the cargo and the pre-planned route for each of the planned transports. He or she will also provide the system with the information contained in the transport document.
- *Vehicle owner/carrier*. He or she will be in charge of providing the system with all the information related to the vehicle and tank characteristics for each of the planned transports before the transportation.
- *System administrator*. He or she will be in charge of maintaining the system and all the information needed for its correct operation. Among others, he or she will be in charge of ensuring that all the information included in the internal data bases is up to date.
- *Vehicle*. It will transport the dangerous good and, thus, will be monitored by the operator. In case of road transportation it includes the tractor and trailer and in case of rail transportation it includes the locomotive and wagons. The vehicle will carry part of the system (the on-board terminal and sensors) since it must send current information related to the transport, such as the current position and dynamic cargo information (like amount, pressure, temperature, etc.). All this information is transmitted via wireless applications.
- *Driver*. Person that carriages the dangerous substance/s. He or she drives the vehicle from the origin to the destination of the goods according to the pre-planned route.
- *First responder*. Reliable source of information. He or she could be a member of the first intervention team that provides first hand information of the accident characteristics. This information is communicated to the operator by radio or mobile phone.
- *Other information providers*. Any other provider of information. He or she could be a witness of the accident.

The MITRA system considers two operational scenarios:

- *Nominal/alert*. A nominal situation is given when no accident happens. An alert situation is an event which can potentially lead to a crisis situation.
- *Crisis*. Situation requiring an action beyond the control of the driver, involving at least one of the civil security bodies (fire brigade, police, medical services, and civil protection) but not requiring the involvement of all public services.

Alert situations can be declared by different ways. For example, the operator will receive an alert in case it happens one of the following situations:

- The system detects a deviation from the pre-planned route.[1]
- The information provided by the OBT sensors detects a deviation from the cargo recommended status.
- The driver pushes the panic button.

[1] This case has not been implemented in the MITRA prototype.

Also, the operator is able to generate manually an alert after receiving information from the first responder, the driver or other information providers.

The operator of the MITRA system is also the actor who has to declare a crisis if a specific situation is considered by using the established procedures to take the decision.

The MITRA system will provide regional civil security centres with different services in nominal, alert and crisis situations (in the event of an accident or incident).

2.1. *Nominal and alert situations*

In nominal situations, the MITRA system provides real-time knowledge of the location of dangerous goods circulating in a given area:

- Current vehicle position.
- Cargo identification, characteristics and status (nature of the transported products).
- Potential risks and hazards posed by the vehicle and goods, and the particular precautions required.

The system also provides information about the area around the vehicle:

- Occurrence of extraordinary events.
- Geographical and physical characteristics of the areas the vehicle has to or might cross.
- Large human populations in the vicinity.
- Presence of social infrastructure (hospitals, schools, stadiums, etc.).
- Presence of other vehicles transporting dangerous goods in the vicinity.

The MITRA system enables two-dimensional (2D) or three-dimensional (3D) visualisation of selected areas. The default mode is 2D; the operator may switch to 3D mode, especially in case of an accident or incident, in order to better understand the situation and analyse the potential risks. 3D pictures make it much easier to understand the surrounding environment, especially in mountainous areas like the Pyrenees or the Alps. In emergency situations, operators can read and analyse 3D pictures more intuitively. This may prevent stress-related misinterpretations.

2.2. *Crisis situations*

The MITRA system provides all of the necessary information to react immediately with precise knowledge of the situation and subsequent risks. This information can help regional civil security centres make safe decisions and choose the best actions, in particular to protect the first intervention team, manage and coordinate the various teams on the ground, and optimise the resources deployed to fight the consequences of the accident. This information includes the following:

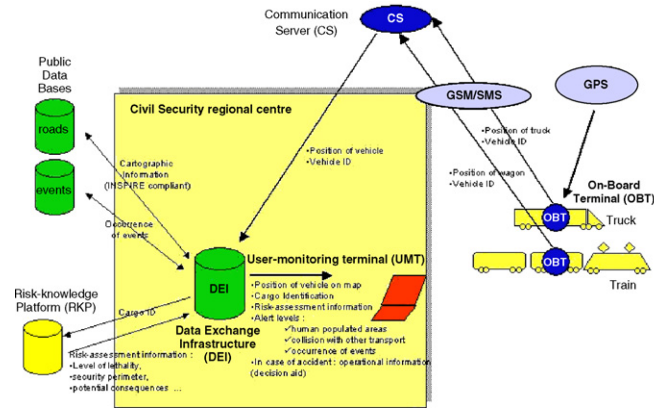

Fig. 1. MITRA prototype system architecture.

- The last known position of the vehicle, the precise identification of the cargo and the intervention procedures applicable to this cargo.
- Indications of the specific precautions to be taken, as well as the intervention schemes most suited to the type of accident.
- Estimation of the effects of the accident and its impact on the surrounding area (perimeters potentially affected).

3. MITRA prototype system architecture

The MITRA prototype system relies on the following main components (see Fig. 1):

- On-board terminal (OBT)
- Communication server (CS)
- Data exchange infrastructure (DEI)
- User monitoring terminal (UMT)
- Risk-knowledge platform (RKP)

The OBTs are installed in the trucks and trains circulating in the area controlled by the regional centre. The DEI and the UMTs are located on the premises of the regional civil security centres. The CS is located in Germany and the RKP is located in Spain.

The OBT receives the position of the vehicle from the GPS satellite navigation system. It transmits this position and the unique vehicle ID number to the CS via GSM/SMS,[2] together with the values of the OBT sensors, like temperature (T), pressure (P) or vehicle inclination, installed on the cargo trailer. The identification of the cargo carried by this particular vehicle is stored in the DEI prior to transportation. The DEI links the nature of the cargo to the vehicle ID. The CS multiplexes the incoming communications from all vehicles circulating in the area controlled by the regional centre and provides this information to the DEI. Depending on the nature of the cargo, the RKP is asked to send related risk-assessment information (effect zones for the various potential scenarios, specific required

[2] SMS: short message service; GSM: global standard for mobile communications.

precautions, substance information, etc.). Other types of information can be retrieved from external source databases, such as the occurrence of specific events, large human concentrations, school transportation, etc. The UMT provides the civil security authorities with a complete view of the current dangerous-goods transportation situation in the corresponding area.

When a vehicle leaves the area controlled by one regional centre and enters an area controlled by another, all information concerning this vehicle is handed over to the DEI of the next regional centre.

3.1. *Maintenance of the system*

The system administrator will make the maintenance of the internal databases and also ensure that all the external data bases such as extraordinary events, provide updated information all the time. The administrator will also configure the OBT terminal through the CS interface (e.g. introduces the emergency values of temperature and pressure of the substances transported. These values are needed to trigger the automatic alert based on the T and P values measured by the OBT sensors.).

Pre-trip information has to be introduced in the system before each trip. The consignor will provide information about the cargo (type, characteristics, quantity and emergency values of P and T), the pre-planned route and the transport document. The vehicle owner will provide information about the vehicle and tank characteristics.

4. The RKP

In an accident situation, safety services sometimes have difficulty collecting information on the exact nature and quantity of the material(s) involved and quickly determining effect distances. Some existing databases give distances (generally only one) but do not cover all possible situations. These distances generally refer to the worst-case scenario and may be difficult to apply. In case of an accident, the RKP provides useful information on the risks associated with the dangerous substances carried by vehicles and offer effect-assessment knowledge. The content of the RKP is based on two types of information (see Fig. 2):

- *Qualitative/static information.* Main characteristics of the goods transported, applicable precautions and intervention procedures, suitable equipment and means to dispose of the cargo, and recommended emergency first-aid treatment.
- *Quantitative decision-making information*. Local information provided by the first responder and internally available information, including the effect distances for several predefined scenarios.

For each type of scenario, different model types are used to assess effect distances depending on the phenomenon (fire, atmospheric dispersion or explosion) and the effects (thermal, toxic or overpressure). In all cases, three parameter types are considered: source term, environment and atmospheric conditions. Table 1 shows the most important parameters implemented in the MITRA system and the origin of the input in each case (DEI/OBT, first responder or default value).

The RKP does not include the effect-model equations but rather the pre-calculated effect distances for a set of representative scenarios. Therefore, when an accident occurs the first responder has to provide to the UMT operator with real on-site information. The UMT operator will ask the first responder (by radio or mobile phone) a set of questions according to the following steps:

1. *Environmental conditions*. One of the following options can be selected:
   - urban, industrial site or forest;
   - open countries.

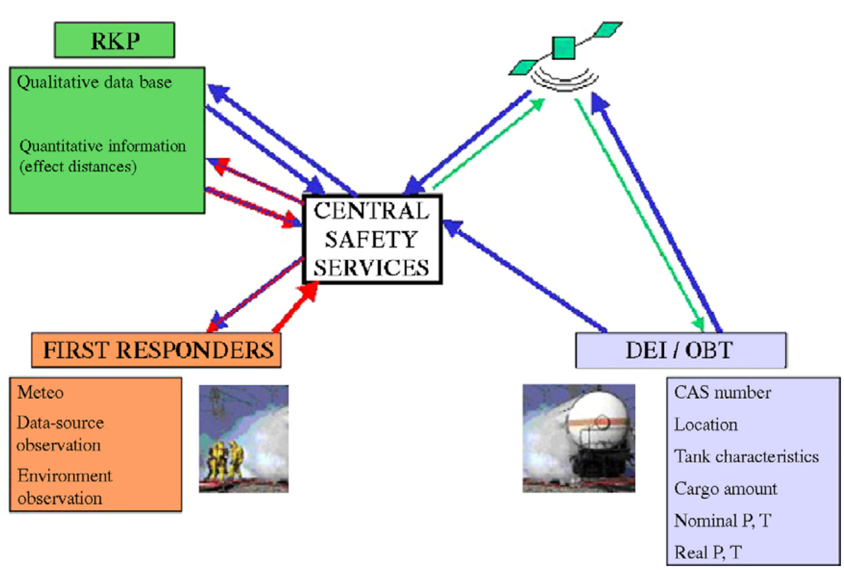

Fig. 2. Relationship between DEI/OBT, first responders, RKP and central safety services.

Table 1
Input parameters required for the identification of the scenario

	DEI/OBT	First responder	Default value
Source term parameters			
Chemicals characteristics	X		
Type of tank	X		
Quantity of chemicals	X		
Storage pressure	X		
Storage temperature	X		
Release conditions: explosion, leak, fire, etc.		X	
Hole diameter		X	
Pool diameter		X	
Height of breach/tank			X[a]
Height of release			X[b]
Jet direction			X[c]
Environment parameters			
Near field			X[d]
Ground roughness		X	
Topography, obstacles			X[e]
Atmospheric conditions parameters			
Wind speed		X	
Atmospheric stability		X	
Ambient temperature			X[f]
Ground surface temperature			X[g]
Solar flux			X[h]
Air relative humidity			X[i]

[a] Default value = 0 m.
[b] Default value = 1 m.
[c] Default value = horizontal.
[d] Default value = free jet.
[e] Default value = none.
[f] Default value = 20 °C (day), 15 °C (night).
[g] Default value = 20 °C.
[h] Default value = 70%.
[i] Default value = 500 W/m^2.

2. *Weather conditions* (day or night). Then depending on the parameter chosen:
   - if day is selected, then follow with step 3;
   - if night is selected then the cloud cover parameter is disabled, then go directly to step 4.
3. *Cloud cover* parameter. One of the following options has to be selected:
   - thin;
   - moderate or complete;
   - fog.

   Then depending on the parameter chosen:
   - if fog is selected, then the wind speed parameter is disabled. Go directly to step 5;
   - else continue with step 4.
4. *Wind speed* parameter. One of the following options has to be selected:
   - high or medium wind speed (> 5m/s);
   - low wind speed (< 5m/s).
5. Select the *breach size* together with the *pool size*. For the breach size one of the following options has to be selected:
   - no;
   - small (1/2 in.);
   - large (2 in.).

   For the pool size one of the following options has to be selected:
   - no;
   - small (3 m);
   - medium (10 m);
   - large (max).
6. Finally indicate whether there is a fire (yes or not) and whether the container is exposed to fire or destroyed (yes or not) parameters.
7. In addition, optional information related to the possible number of victims and to the visual damages can be indicated.

Once the UMT operator has introduced all the responses to the system, the RKP selects the scenario most similar to what is happening. Six algorithms have been developed for this purpose:

- The first algorithm specifies the tank characteristics.
- The second algorithm defines the environmental and atmospheric conditions.
- The third algorithm chooses from among several phenomena (pool, leak, container exposed to fire or container destroyed).
- The last three algorithms, called *pool*, *leak* and *container*, respectively, describe how to obtain specific phenomena such as pool fire, unconfined vapour cloud explosions (UVCE) or toxic cloud.

Detailed information about these algorithms and how they are used can be found elsewhere [5,6]. From the information given by the first responder and the algorithms developed, it is possible to know which kind of specific phenomena (pool fire, vapour cloud explosion, flash fire, toxic cloud, jet fire, etc.) can take place in a given situation. Then end users obtain a set of distances (reversible, irreversible and lethal/domino effect) for the effect (overpressure, thermal radiation or toxic) generated for each of the specific phenomena linked to the situation in question. Table 2 shows the threshold values for radiation and thermal effects. Only three toxic substances have been implemented in the MITRA prototype. Table 3 shows the threshold values for these substances, some of which correspond to French legisla-

Table 2
Definition of the thresholds (radiation and blast effects) for the various levels of effects considered [6]

Level of effects	Radiation (Kw/m^2)[a]	Instantaneous radiation	Blast (mbar)	Description
1	1.8		30	Reversible effects
2	3		50	Irreversible effects
3	5	0.5 LFL	140	Start of lethality and/or domino effects

[a] For an exposure time equal to or greater than 60 s.

Table 3
Definition of the thresholds (toxic effects) for the various levels of effects considered. Values in italics correspond to the toxicity parameter *n*

Substance	Reversible effects		Irreversible effects		Lethal effects	
	30 min	60 min	30 min	60 min	30 min	60 min
Acrylonitrile	10[a]	10[a]	37[b]	22[b]	236[b]	139[b]
n[c]	–	–	1.32	1.32	1.32	1.32
Ammonia	30[d]	30[d]	500[b]	354[b]	4767[b]	3400[b]
n[c]	–	–	2.00	2.00	2.03	2.03
Chlorine	0.5[d]	0.5[d]	25[b]	19[b]	160[b]	110[b]
n[c]	–	–	2.30	2.30	1.98	1.98

[a] ERPG threshold, ppm.
[b] French threshold, ppm.
[c] According to the dose equation: Dose = $C^n \times t$, where C is the concentration, t the exposure time and n is a characteristic toxicity parameter of each substance.
[d] AEGL threshold, ppm.

tion values [7] while others correspond to emergency response planning guideline (ERPG) [8] or acute exposure guideline levels (AEGL) values [9], since European legislation does not indicate standard values. Nevertheless, in future implementations of the MITRA system, these values could be changed if new or different threshold values appear.

5. Visualisation tools

The UMT software is a fully featured information system designed for mapping and working in geographical space. It is based on a Windows MDI (Multiple Document Interface) and consists of several sub-components (see Fig. 3):

- The *Control Panel area* is the main menu of the MITRA UMT application.
- The *Lists area* manages lists of all processes (building, updating, displaying) carried out for all items handled by the user (vehicles, layers, hospitals, crises, etc.).
- The *2D GIS map area* shows geo-referenced information and also provides some essential mapping functions.

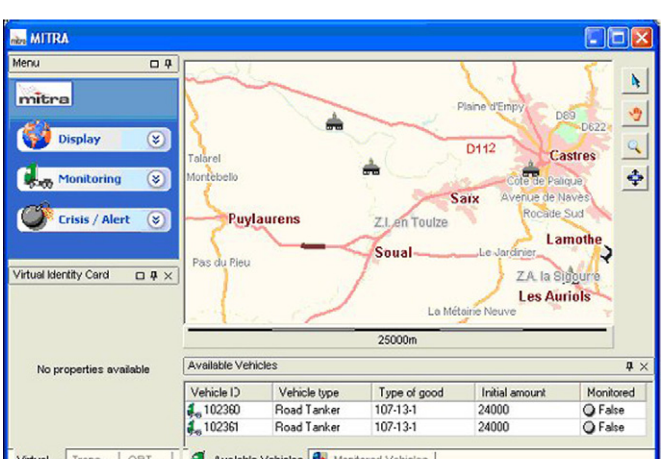

Fig. 3. Main graphical user interface.

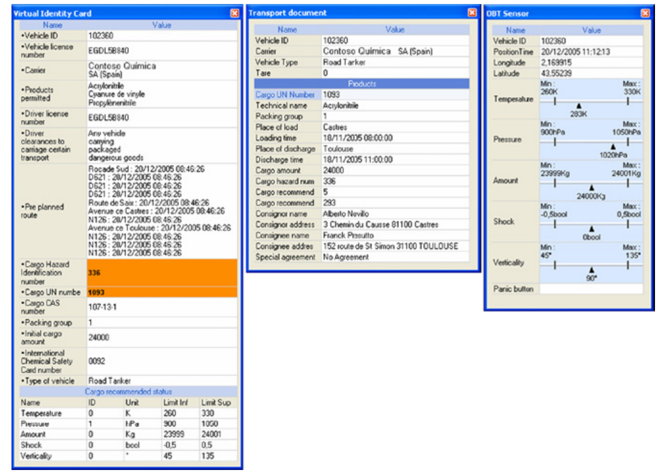

Fig. 4. Information that can be displayed in the *Properties sheet area*. Left: virtual identity card; middle: transportation document; right: OBT sensors.

- By means of property sheets and dialog boxes, the *Properties sheet area* builds, updates and displays all text information given to or collected from the user.

Additional information on each vehicle in the database can be consulted in the *Properties sheet area*. When a vehicle is selected, the related additional information can be displayed for the following (see Fig. 4):

- virtual identity card;
- transportation document;
- OBT sensors (only if monitored).

The main feature of UMT software is access to precise real-time knowledge of the cargo characteristics, associated potential hazards (flammability, explosion, chemical and bacteriological hazards, etc.), potential effects (zone of dispersion, lethality, pollution, contamination, etc.) and applicable procedures and measures. At any time during a nominal, alert or crisis situation, the user may want information on the potential hazards of the cargo transported by a given vehicle. Depending on the situation, the information issued by the RKP may vary. This information includes the following:

- Static RKP data, which is available at any time, in any situation, and gives real-time information to local emergency call services. This data is divided into several parts by CAS number (see Fig. 5):
  - ○ substance identification;
  - ○ physicochemical characteristics (substance behaviour);
  - ○ hazard identification: generic information;
  - ○ hazard identification—acute toxicity threshold;
  - ○ first aid;
  - ○ intervention in terms of medical aspects and the fire brigade's tasks;
  - ○ transportation conditions;
  - ○ effect distances for the worst-case scenario for the substance involved.

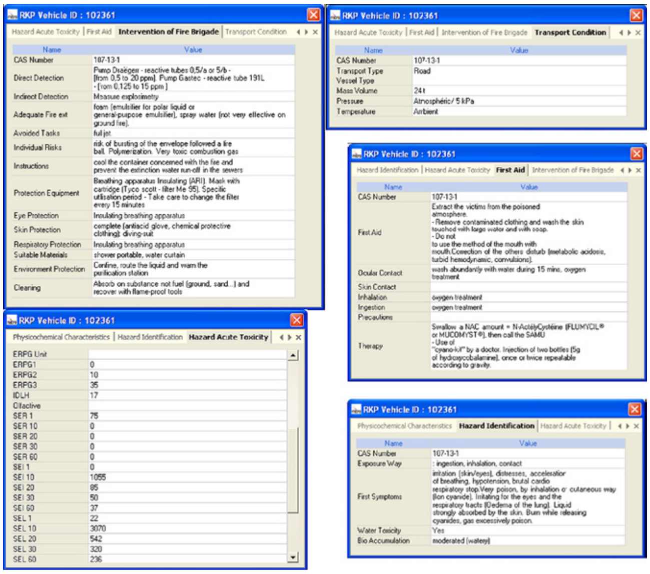

Fig. 5. Static RKP data.

- Dynamic RKP data, which includes effect distances in crisis situations. Based on simple on-site observation by a first responder (a non-chemical specialist), effect distances for various hazardous scenarios (fire, explosion, toxic release, etc.) are established for the following:
  - overpressure effects;
  - thermal effects;
  - toxic effects;
  - worst case.

In a nominal or alert situation, the potential affected area corresponds to the static part of the RKP and the worst-case effect distances are used to display the three circles corresponding to lethal, irreversible and reversible effects (see Fig. 9, corresponding to the field trial). The three effect distances are drawn on the map in different colours. Inside each effect circle, the distance is displayed in meters.

In a crisis situation, the potential affected area corresponds to the dynamic part of the RKP. The user can choose to display one of the real situation effect distances on the map (see Fig. 10, corresponding to the field trial):

- overpressure effects;
- thermal effects;
- toxic effects 30 min;
- toxic effects 60 min;
- worst situation.

More detailed information about the UMT software can be found elsewhere [10].

6. Validation campaign: rail and road field tests

A MITRA validation campaign was organised in order to verify that the MITRA system meets user requirements, in particular that the rescue teams and intervention forces are satisfied with the information provided by the MITRA system and that information can be efficiently exchanged between the various stakeholders involved in the interventions. This campaign consisted of two main events:

- *Road and rail field trials in Germany*. These field trials, held in the region south of Munich, involved the following activities:
  - Assessing positioning accuracy and communication reliability in urban, rural and mountainous environments.
  - Road and railway testing at a live demonstration on 8 March 2006.
  - EGNOS (European geostationary navigation overlay service) SISNeT[3] (signal-in-space via internet) testing.
  - Galileo simulations, to analyse the impact of signal availability on the performance of the currently used satellite-based navigation system GPS and the potential improvements to be expected with the use in the future of coming European navigation system GALILEO on the monitoring of dangerous goods.
- *Road field trials in the cross-border area between France and Spain*. These field trials, held on 19 April 2006 in Perpignan, Le Perthus and Barcelona, involved the following activities:
  - Involving intervention teams in the field trials so as to obtain operational feedback on the operation of MITRA in real conditions.
  - Checking and validating cross-border cooperation between France and Catalonia, as well as the interoperability of the two regional civil security centres involved in the field trials (Perpignan, Barcelona).

The following sections describe the French/Spanish field tests in detail. The field tests in Germany are not described as their objectives focused more on communications than on risk-management aspects of the system.

6.1. French/Spanish field trials

The objective of these field trials was to verify that the functionalities and services of the MITRA system corresponded to the operational needs of the rescue teams and intervention forces. The following means were deployed for the French/Spanish field trials:

- The M3S test vehicle (Opel Zafira) was equipped with one OBT, thus simulating a tank truck carrying 1 t of chlorine. The

[3] The potential users of MITRA requested a horizontal position accuracy of better than 5 m. Such an accuracy cannot be achieved with GPS alone. Only with satellite-based augmentation systems (SBAS) this accuracy can be reached. However, the use of SBAS signals transmitted by GEO satellites has its limitations. In urban or mountainous areas, the visibility of the GEO satellites is frequently interrupted, which strongly reduces the availability of SBAS signals. To overcome this problem, the European Spatial Agency has started the SISNET project with the goal to provide EGNOS correction data via the Internet. With modern wireless technologies such as GPRS it becomes possible to receive and use the EGNOS data on a continuous basis even in areas with bad sky visibility.

OBT, which had a panic button for the driver, was installed on the passenger seat.

- Three UMTs were deployed in parallel at different sites in order to monitor the field trials:
  - One UMT was deployed at the Service Départemental d'Incendie et de Secours des Pyrénées-Orientales (SDIS 66, Perpignan). This UMT had a French human–machine interface and enabled French intervention forces to follow the execution of the field trials. One part of the MITRA team, stationed at SDIS 66, played the role of the French UMT operator, i.e. received the OBT alert and informed the SDIS 66 fire-fighters.
  - One UMT was deployed at the Centre d'Emergències de Catalunya (CECAT, Cerdanyola del Vallès, Barcelona). This UMT had a Catalan human–machine interface and enabled Catalan intervention forces to follow the execution of the field trials. A second part of the MITRA team, stationed at CECAT, played the role of the Spanish UMT operator, i.e. received the OBT alert and informed the CECAT fire-fighters.
  - Another UMT was deployed in the Reception Room of the cross-border city of Le Perthus. This UMT had a French human–machine interface and enabled the third part of the MITRA team, stationed at the accident site, to follow the execution of the field trials.

The M3S test vehicle simulated the movement of the tank truck along its journey from Perpignan to Le Perthus, located approximately 20 km south of Perpignan in a mountainous area. In Le Perthus, a collision with a light vehicle was simulated.

In order to test the reaction of intervention teams under real operational conditions, a real tank truck was used and a real light vehicle (previously extracted from an accident) was wrecked in Le Perthus. The day before the French/Spanish field trials, the French SDIS 66 fire-fighters in Perpignan loaded the real tank truck and wrecked light vehicle onto a low loader and brought them to the accident site in Le Perthus in order to simulate the damaged truck and vehicle. The tank truck was filled with one ton of water (with a small amount of liquid bleach) in order to simulate the chlorine cargo. A breach was opened in the tank and a pool of water formed in the car park. This pool simulated the pool of chlorine.

When the M3S vehicle arrived in Le Perthus, it stopped in the car park where the accident was being simulated. The driver of the vehicle (a person from M3S) pressed the panic button of the OBT to simulate the collision with the light vehicle. The Spanish CECAT fire-fighters asked for these French/Spanish trials to be strictly confidential, since they wanted to use them as a pilot exercise. As a result, the fire-fighters sent to the accident were not informed that it was simulated. This ensured that they behaved as if the accident were real in order to test the reaction of the teams under real conditions. The scenario used for these French/Spanish field trials aimed to test the following issues:

- Panic button alert transmission to the SDIS 66 and CECAT control centres and simultaneous viewing in both control centres.
- Knowledge of the accident situation:
  - o exact location of the accident.
  - o identification of cargo (nature of product, initial amount, etc.).
- Ergonomics of the UMT and human–machine interface.
- Pertinence and relevance of the information provided by the RKP (recommended emergency treatment, intervention procedures and precautions).
- Relevance of the effect distances calculated by the RKP.
- Engagement of the intervention teams on the basis of the information provided by the MITRA system to the operational centre.
- Collection and exploitation of the information provided by the first responder to the fire control centre.
- Transfer of information from the fire control centre to the intervention teams (additional information to improve the efficiency of operations).
- France/Spain cross-border cooperation.

6.1.1. Field trial evolution

At 9:00: The simulated tank truck leaves Perpignan and drives southbound towards Spain.

At 9:15: The movement of the simulated tank truck driving southbound towards Spain is monitored on the French UMT deployed at the French fire brigade in Perpignan (SDIS 66). The operator interrogates the RKP, available both in French and Catalan, in order to obtain information about the transported substance and its physicochemical characteristics (see Fig. 6).

At 9:58: As the tank truck approaches Le Perthus, the situation is still normal (i.e. the accident has not happened yet). The onboard sensors (pressure, temperature, shock and verticality) are still normal and the panic button has not yet been pressed (see Fig. 7).

At 10:05: The tank truck arrives in Le Perthus and the collision between the tank truck and the light vehicle occurs. The driver of the tank truck presses the panic button

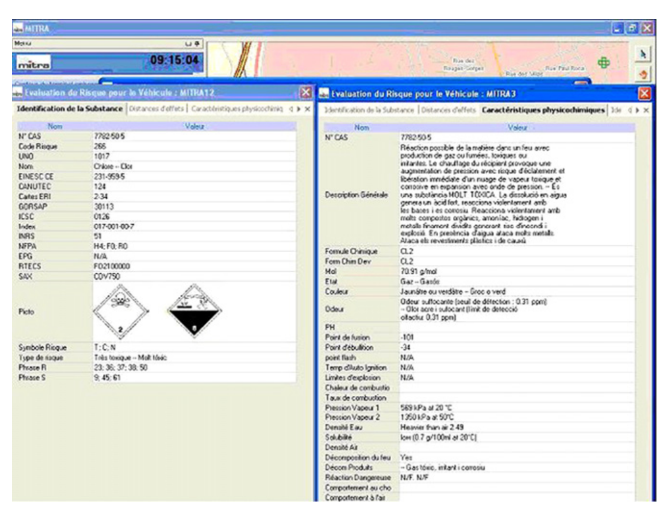

Fig. 6. View of static RKP data (substance identification and physico-chemical properties) during the French/Spanish field trial.

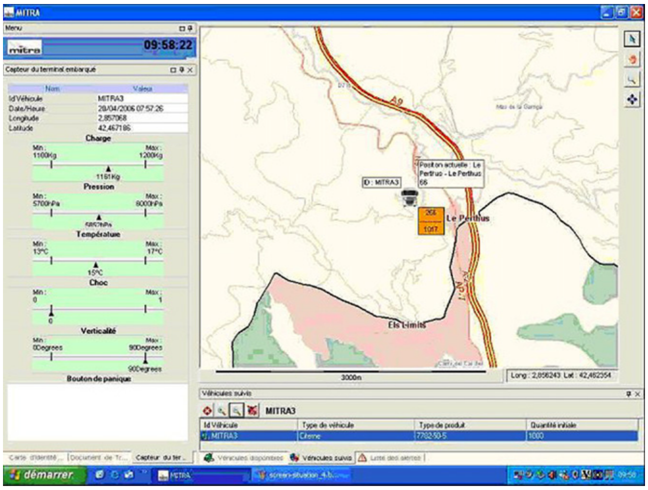

Fig. 7. UMT main screen shown when the tank truck is approaching Le Perthus (nominal situation).

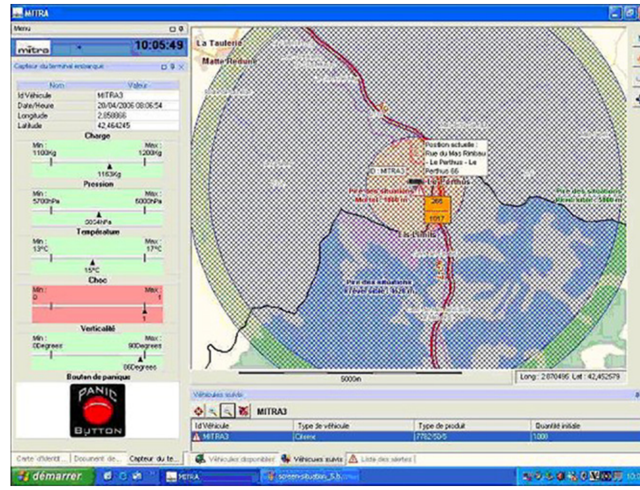

Fig. 9. Worst-case effect distances for chlorine shown automatically in an alert situation.

of the OBT. A pool of chlorine appears in the car park (see Fig. 8). The driver of the light vehicle remains trapped in the vehicle.

At 10:05: The operators at the French fire brigade (SDIS 66) and at CECAT in Barcelona view the *shock alert* and the *panic button alert* on the UMT. The MITRA system automatically calculates the *worst-case effect distances* (see Fig. 9).

At 10:05: A local witness calls the 112 emergency number and provides information about the local conditions of the accident. This information is entered in the MITRA system by the operator at SDIS 66 in order to calculate the effect distances associated with the local conditions of the accident (see Fig. 10).

At 10:07: The first Le Perthus rescue teams (fire-fighters and gendarmerie) arrive at the accident site and define a safety perimeter.

At 10:12: The rescue teams from La Jonquera (Spain) arrive at the accident site.

At 10:13: The operator at SDIS 66 views the cargo alert on the UMT, which indicates a cargo leak.

At 10:20: The Le Boulou rescue teams arrive at the accident site.

Fig. 8. Scenario representing the collision between the tank truck and the light vehicle with a detail of the chlorine leak.

10:20–10:45: The Le Boulou and La Jonquera rescue teams perform their operations in close transborder cooperation. The victim is extracted from the wrecked light vehicle.

At 10:45: The Cellule Mobile d'Intervention Chimique (CMIC) arrives at the accident site and performs operations related to chemical risks (shutting off the leak).

6.1.2. Field trial analysis

The conclusions of the French/Spanish field trials presented hereafter are based on the operational feedback and comments of the French and Catalan fire-fighters:

- The *panic button alert* was automatically transmitted by the MITRA system to both the French fire-fighters (SDIS 66) and the Catalan fire-fighters (CECAT). The alert was transmitted within 2 min of the accident. The fire-fighters considered

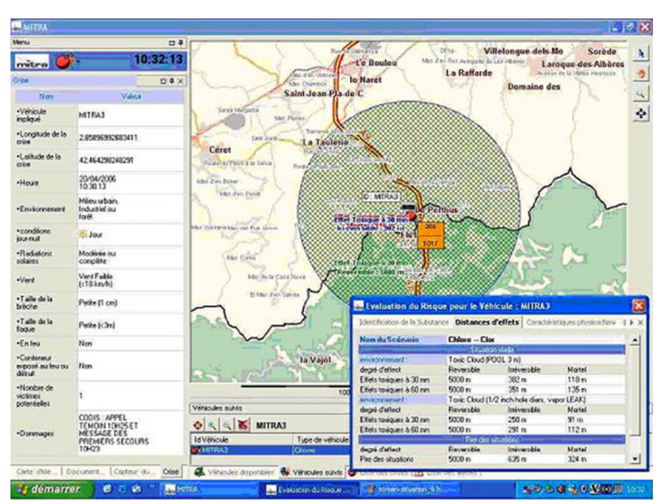

Fig. 10. RKP-generated effect distances corresponding to the local conditions of the accident.

this time delay satisfactory and compliant with the current operational procedures.

- The alert was viewed simultaneously by the French fire-fighters (SDIS 66) and the Catalan fire-fighters (CECAT). This demonstrates that several UMTs can be operated simultaneously in different countries.
- The fire-fighters considered the ergonomics of the UMT, and especially the human–machine interface, satisfactory. In particular, they noted that the human–machine interface complied with their current operational procedures.
- In the event of an accident, the MITRA system gave the fire-fighters improved knowledge of the accident situation by providing them with:
  - The exact location (address and GPS coordinates) of the accident.
  - The identification of the product involved (nature of product and initial amount).
  - Recommended emergency treatment.
  - Adapted intervention procedures and precautions.

  This enabled the fire-fighters to increase the efficiency of their operations.
- The 112 emergency call by the local witness was successfully received at the SDIS 66 in Perpignan and enabled the collection of useful information on the local conditions of the accident (wind, weather, breach size, pool size, etc.). The SDIS 66 transferred this information to the intervention teams at the accident site, thus enabling them to improve the efficiency of their operations and react immediately without risk. This information may eventually save the lives of both fire-fighters and civilians.
- Based on the information provided by the MITRA system, the fire-fighters were able to engage a sufficient number of intervention teams in a manner appropriate to the situation.
- Cross-border cooperation between French and Catalan fire brigades and intervention forces was demonstrated for the first time in the context of a common cooperation protocol.

As a conclusion, the French/Spanish field trials clearly demonstrated the interest of the MITRA system for fire brigades and intervention teams. During the various debriefings, the fire-fighters emphasised the benefits of MITRA, thus showing that the system efficiently fulfils real and identified needs. In addition, these field trials demonstrated the need to capitalise on the results of the MITRA projects in order to push toward the industrialisation and operational deployment of the system.

The main areas for improvement identified by the fire-fighters were related to the effect distances provided by the RKP:

- The *worst-case effect distances,* which are sometimes very large, might not satisfy the needs of intervention teams under real conditions because the size of the effect distances might worry the operator in the command centre, who might therefore trigger the intervention of too many rescue teams. Likewise, the operator in the command centre might also not 'believe' the calculated effect distances and therefore fail to trigger sufficient intervention teams.
- The *effect distances* (worst-case or based on the local conditions described by the first responder) provided by the RKP are calculated only in 2D and not in 3D and thus do not take into account the numerical terrain model. The fire-fighters would appreciate the availability of 3D visualisation.
- The fire-fighters noted that some fire brigades have already developed their own models for calculating effect distances. These models are different from those used by the RKP. As a result, the legitimacy of the MITRA effect distances under operational conditions might be questioned by some fire-fighters.

7. Conclusion

The MITRA system was developed by a European consortium and was one of the first initiatives to bring together civil-protection and crisis-management organisations. Therefore, MITRA helped structure risk-management exchanges and cooperation between EU member states. The MITRA system demonstrated what today's technology can do and provides a preview of what might be possible in the future (e.g. using Galileo or next-generation communication systems).

MITRA will provide institutional authorities with the necessary tools to improve emergency response by providing knowledge of the characteristics of dangerous goods and of the associated risks and effects. More importantly, it will provide real-time expertise and support to decision-makers and emergency teams.

Two field tests were carried out, in Germany and in the French/Spanish border region, in order to assess the various functionalities of the MITRA system. During both field tests, the functionalities described in this paper worked properly without any problems and the invited user communities provided quite positive feedback. In general, the MITRA system proved helpful in monitoring the transportation of dangerous goods and providing operational support to rescue forces in the event of an accident or other emergency. Cross-border cooperation between French and Catalan fire brigades and intervention forces was successfully demonstrated for the first time in the context of a common cooperation protocol.

Deploying MITRA in regional civil security centres in Europe is expected to:

- Improve the safety of dangerous-goods transportation in Europe by providing alerts in the event of potentially dangerous situations (accident prevention), thus making it possible to save the lives of intervention forces and civilians.
- Improve the efficiency and speed of operations and interventions in the event of an accident by providing the necessary information to support the decision-making process of intervention/rescue teams.
- Help improve interoperability between regional civil security centres based on INSPIRE interface requirements.
- Pave the way for changes in European legislation on dangerous-goods transportation.

References

[1] P. Haastrup, L. Brockhoff, Severity of accidents with hazardous materials: a comparison between transportation and fixed installations, J. Loss Prev. Process Ind. 3 (1990) 395–405.

[2] J.A. Vilchez, S. Sevilla, H. Montiel, J. Casal, Historical analysis of accidents in chemical plants and in the transportation of hazardous materials, J. Loss Prev. Process Ind. 8 (1995) 87–89.

[3] A. Oggero, R.M. Darbra, M. Muñoz, E. Planas, J. Casal, A survey of accidents occurring during the transport of hazardous substances by road and rail, J. Hazard. Mater. A133 (2006) 1–7.

[4] Contract no. FP6-511361, MITRA (Monitoring and Intervention for the TRAnsportation of Dangerous Goods), Commission of the European Communities, Information Society Directorate General, Specific Targeted Research Project (STREP), date of signature July 26, 2004.

[5] J. Tixier, A. Dandrieux, F. Fontaine, R. Bouet, E. Pastor, E. Planas, Development of a risk knowledge platform dedicated to accident of dangerous goods transportation, in: Proceedings of the European Safety and Reliability Conference 2006, vol. 1, Estoril, Portugal, September 18–22, 2006, pp. 117–122.

[6] E. Pastor, E. Planas, R. Bouet, F. Fontaine, J. Tixier, D 2.2. Methodology for consequences assessment, public deliverable of the MITRA project (FP6-STREP-511361), http://www.mitraproject.info/html/download.html.

[7] Ministère de l'Ecologie et du Développement Durable (France), Arrêté relatif aux valeurs de référence de seuils d'effets des phénomènes accidentels des installations classées, October 2004.

[8] American Industrial Hygiene Association (AIHA), Emergency Planning Guidelines 2002 (Complete set and updates to 2006).

[9] (a) National Research Council (USA), Acute Exposure Guideline Levels for Selected Airborne Chemicals, vol. 1, The National Academies Press, Washington, DC, 2000;
(b) National Research Council (USA), Acute Exposure Guideline Levels for Selected Airborne Chemicals, vol. 2, The National Academies Press, Washington, DC, 2002;
(c) National Research Council (USA), Acute Exposure Guideline Levels for Selected Airborne Chemicals, vol. 3, The National Academies Press, Washington, DC, 2003;
(d) National Research Council (USA), Acute Exposure Guideline Levels for Selected Airborne Chemicals, vol. 4, The National Academies Press, Washington, DC, 2004;
(e) National Research Council (USA), Acute Exposure Guideline Levels for Selected Airborne Chemicals, vol. 5, The National Academies Press, Washington, DC, 2007.

[10] W. Vigneau, M. Rodriguez, D 4.2b User Monitoring Terminal (UMT) User Manual, public deliverable of the MITRA project (FP6-STREP-511361), http://www.mitraproject.info/html/download.html.