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# Models and methods of risk assessment and control in dangerous goods transportation (DGT) systems, using innovative information and communication technologies

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► **To cite this version:**

Angela Maria Tomasoni. Models and methods of risk assessment and control in dangerous goods transportation (DGT) systems, using innovative information and communication technologies. Chemical Sciences. École Nationale Supérieure des Mines de Paris; Università degli studi di Genova - Italie, 2010. English. NNT : 2010ENMP1703 . pastel-00006223

**HAL Id: pastel-00006223**

**<https://pastel.hal.science/pastel-00006223>**

Submitted on 10 Aug 2010

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École doctorale n° 432: SMI-Sciences des métiers de l'ingénieur

## Doctorat ParisTech

# THÈSE

pour obtenir le grade de docteur délivré par

**l'École nationale supérieure des mines de Paris**

**Spécialité “ Science et génie des activités à risques ”**

*présentée et soutenue publiquement par*

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21 avril 2010

**Modèles et méthodes d'évaluation et de gestion des risques appliqués aux systèmes de transport de marchandises dangereuses(TMD) reposant sur les nouvelles technologies de l'information et de la communication (NTIC)**

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(PhD Thesis sponsored by UIF-UIFI)

“Science and Information Technology for System Monitoring and Environmental Risk Management” – XXII Cycle – DIST – UNIGE - Italy

“Science and Engineering of risk activities” – CRC – MINES PARIS-TECH – France

## **THESIS IN COTUTORING**

for the degree of

DOCTOR OF PHILOSOPHY

presented and publicly defended by

Angela Maria TOMASONI

## **MODELS AND METHODS OF RISK ASSESSMENT AND CONTROL IN DANGEROUS GOODS TRANSPORTATION SYSTEMS, USING INNOVATIVE INFORMATION AND COMMUNICATION TECHNOLOGIES**

Thesis Supervisor: Prof. Roberto Sacile

Co-Supervisor: Dr. Emmanuel Garbolino

## **Modèles et méthodes d'évaluation et de gestion des risques appliqués aux systèmes de transport de marchandises dangereuses (TMD), reposant sur les nouvelles technologies de l'information et de la communication (NTIC)**

**RESUME :** Durant ma thèse de doctorat, j'ai développé plusieurs modèles et méthodes d'évaluation des risques dans les systèmes de transport de matières dangereuses. En raison de la multiplicité des approches d'évaluation de risque, tous les modèles décrits, définis et utilisés sont fondés sur la définition classique du risque technologique - liés à l'activité de l'homme - la catégorie des risques accidentels, - ou d'un accident - d'un véhicule transportant des matières dangereuses.

Cette définition des risques est la même pour les conduites que pour le transport par route, mais différentes approches méthodologiques pour l'évaluation des risques de transport peuvent être abordées:

Au chapitre 2: une définition générale des marchandises dangereuses a été réalisée ainsi que différents types de matières dangereuses considérées. Ensuite, l'étude a été focalisée sur les hydrocarbures ainsi que sur les réglementations qui y sont liés.

Dans le chapitre 3, l'étude a porté sur la définition des risques dans le transport des matières dangereuses, respectivement, dans le cas des pipelines ainsi que pour le transport routier.

Au cours du chapitre 4, une description complète de la méthodologie d'évaluation des risques de pipelines a été réalisée. Par la suite, au chapitre 5, un modèle innovant et technologique a été utilisé afin de décrire un scénario d'accident du GPL par route et d'évaluer son impact sur la population concernée.

Au chapitre 6, j'aborde des modèles et des méthodes innovants pour l'évaluation des risques et le contrôle de la DGT par route. Cette méthodologie est basée sur une approche «Risk adverse decision making».

Au chapitre 7, une loi de contrôle optimale de la DGT a été développée et appliquée dans le cas d'une infrastructure critique, spécifiquement, dans le cas des tunnels. Enfin, le chapitre 8 a pour objectif de résumer mon travail en termes de résultats obtenus au cours de ma thèse.

**Mots clés :** systèmes de transport, marchandises dangereuses, modèles d'évaluation des risques, technologies de l'information et de la communication.

## **Models and methods of risk assessment and control in dangerous goods transportation (DGT) systems, using innovative information and communication technologies (ICT)**

**ABSTRACT :** All the models that I have described and defined originate from the classical definition of technological risk, specifically of accidental risk, that is related to human activities. The risk I have dealt with is so related to the failure – or accident – either of a vehicle on road or a pipeline, transporting dangerous goods (DG). Although different means of transportation do not deeply influence the basic definition of risk (which is more affected by the quantity, the type and the nature of the transported dangerous good), different methodological approaches may be used to evaluate the risk in transportation.

In Chapter 1, some preliminary basic concepts on industrial risk, its assessment and its characterisation in the transportation and logistic domain are introduced. On the ground of the basic assumption that “an accident may happen” both in road and in pipeline transportation, in Chapter 2 I have defined what a DG is, which type of DG I have considered in this study, which transportation modalities are generally used, and which of them I have chosen for my research activity, and finally, what the main relative regulations are present in France, Italy and in general in Europe. Chapter 3 deals with the risk definition in the transportation of DG, respectively, in pipeline and on road, starting from one risk definition, univocally based on the risks related to humans activities. Similarities and differences between pipeline and road transportation risk definition are also discussed. Then, in Chapter 4, an original methodology used to describe pipeline risk assessment has been defined and validated on a case study. In Chapter 5, an innovative and technological real-time approach which can be used to describe the effects of a DG accident scenario on road, and the population involved, has been described. Finally, I tackle specific models and methods of risk assessment and control in DGT on road, considering two different approaches: a risk adverse decision maker approach (Chapter 6); and an optimal real-time control of DGT flow towards a critical infrastructure, such as a tunnel (Chapter 7). Conclusions and future developments are reported in Chapter 8.

**Keywords :** transportation systems, dangerous goods, models of risk assessment, information and communication technologies.



To Davide and Elena

“Home, sweet home”.

John Howard Payne (1791-1852)



## Acknowledgements

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I would like to extend my most sincere thanks to:

**Pierre CARREGA**, full professor at University of Nice, who is an expert in Geography, Planning and Territorial Development, and in Environment and Sustainable Development, who is the first reviewer of my thesis;

**Riccardo MINCIARDI**, full professor at University of Genoa, who teaches Modelling and Control of Transportation Systems, Industrial Automation and Optimization and other courses;

**Domenico PIZZORNI**, Eni HSE manager, expert in dangerous goods transportation on road and in pipeline, because of a long career in PraOil Group before, and then in Eni Group – an international Oil Company with head office in Roma;

**Agostino POGGI**, full professor of Computer Engineering at University of Parma, who teaches Computer Networks, Distributed and Agent Systems and Software Engineering, and he is the second reviewer of this thesis;

**Jerome TIXIER**, teacher researcher, expert in Industrial Safety and Environment, Methods of analysis and evaluation of major industrial hazards in fixed plants; because of their role in my thesis jury.

**Emmanuel GARBOLINO** and **Roberto SACILE**, thesis directors, guidance and support for the development of this thesis.

Then, I wish to acknowledge:

**Italo-French University** (UIF) because I won a scholarship and contributions to joint initiatives in a VINCI programme for the realization of my PhD theses under the co-supervision of University of Genoa and Mines Paris-Tech.

**Roberta Valentina GAGLIARDI** and ISPESL (National Institute for Occupational Safety and Prevention – Department of Industrial Premises and Interaction with the environment) for the opportunity to develop the topic of transportation in pipeline considering aspects related to safety and security. **Stefania BRIATA**, and her staff of Eni Secondary Logistic, **Francesca POLLAMATTIOT**, and her staff of Eni Corporate - Health, Safety & Operational Environment - Major Emergencies, **Pierluigi TIMOSSO**, and his staff of Eni Primary Logistic, who gave helpful advice on dangerous goods

transportation data and information, for both modality of transportation, road and pipeline.

*Régine MOLINS*, “MINES ParisTech - Direction de la Recherche - Responsable Formation Doctorale”, and *Gérard COFFIGNAL*, “Directeur de l'Ecole Doctorale Sciences des Métiers de l'Ingenieur, Directeur de la formation doctorale Arts et Métiers ParisTech” for their welcome in Paris. *Yves LABOUREUR*, “Adjoint du Délégué - Chargé de la formation et de la recherché” of Mines Paris-Tech in Sophia Antipolis; *Frank GUARNIERI*, *Denis BESNARD*, *Valérie GODFRIN*, *Myriam PERRAULT LAVIGNE*, *Aldo NAPOLI*, *Samuel OLAMPI*, *Eric RIGAUD*, and all the other researchers, PhD students and technicians of the CRC, for their kindness and hospitality during my stay in Sophia Antipolis.

*Chiara BERSANI*, *Irene MARRAS*, *Fabio MERLO*, *Michela ROBBA*, *Massimo ROVATTI*, *Stefania TRAVERSO*, and *Eva TRASFORINI*, who not only provided comments, but also contributed images and figures that are included in the final thesis.



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## Abbreviations

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ADN: European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways;

ADR: the European Agreement concerning the international carriage of Dangerous goods by Road;

ALARP: As Low As Reasonably Practicable;

ALOHA: Areal Locations of Hazardous Atmospheres;

ANN: Artificial Neural Network;

BARPI: Bureau d'Analyse des Risques et Pollutions Industrielles;

BLEVE: Boiling Liquid Expanding Vapour Explosion;

CAMEO: Computer-Aided Management of Emergency Operations;

CFR: Code of Federal Regulations;

CYPRESS: Le centre d'information du public pour la prévention des risques majeurs et la protection de l'environnement;

CONCAWE: CONservatio of Clear Air and Water in Europe;

COTIF: Convention concerning International Carriage by Rail;

CSA: Canadian Standards Association;

Da.Go.T: Dangerous Goods Transportation (Project);

DG: Dangerous Goods;

DGT: Dangerous Goods Transportation;

DIST: Department of Communication, Computer, and System Sciences;

DM: Decision Maker;

DRIRE: Directions Régionales de l'Industrie, de la Recherche et de l'Environnement;

DSS: Decision Support Systems;

EEC: European Economic Community;

EEA: European Environmental Agency;

EFTA: European Free Trade Association;

ERA: Environmental Risk Assessment;

EU: European Union;

FD: full drop;

FERC: Federal Energy Regulatory Commission;

FMEA: Failure Modes, Effects, and criticality Analysis

FTA: Fault Tree Analysis;

GHS: Globally Harmonized System of Classification and Labelling of Chemicals;  
GIR: Interdivisional Group of Radiochemistry and Radiation Chemistry applied to environment, health and industry, Italian Society of Chemistry;  
GIS: Geographical Information System;  
GMES: Global Monitoring for Environment and Security;  
GPS: Global Positioning System;  
HAZMAT: Hazardous Materials;  
HSELINE: Health and Safety Executive (HSE) Library and Information Services;  
HMTA: The Hazardous Materials Transportation Act;  
HMTUSA: Hazardous Materials Transportation Uniform Safety Act;  
HSE: Health, Security and Environment;  
IAEA: International Atomic Energy Agency;  
IATA: the International Air Transport Association;  
ICAO: the International Civil Aviation Organization;  
IChemE: Institution of Chemical Engineers;  
ICT: Information and Communication Technologies;  
IMDG: the International Maritime Dangerous Goods Code;  
IMO: the International Maritime Organization;  
INERIS: Institut National de l'Environnement industriel et des risques;  
IR: Individual Risk;  
JSA: Job Safety Analysis  
UIF: Italian-France University in Turin.  
LOC: Level of Concern;  
LOPA: layer of protection analysis;  
LPG: Liquefied Petroleum Gas;  
NATO-OTAN: North Atlantic Treaty Organization;  
MAL: Maximum Acceptable Level;  
MEEDDM: Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer;  
MHIDAS: Major Hazardous Incident Data Service;  
MIT: Italian Ministry of Transport;  
MMS: Minerals Management Service;  
MTBE: Methyl tert-butyl ether, also known as methyl tertiary butyl ether;  
NEB: National Energy Board;  
NL: Negligible Level;

NOAA: National Oceanic and Atmospheric Administration Office of Response and Restoration;

OD: Origin – Destination pair;

ONU: The United Nations Organization;

OEM: Office of Emergency Management;

PACA: Provence-Alpes-Côte d'Azur;

PET: Polyethylene Terephthalate;

PHMSA: Pipeline and Hazardous Materials Safety Administration;

PLL: Potential Loss of Life;

PNA: Peptide Nucleic Acid;

PRA: Probabilistic Risk Assessment;

PVC: Polyvinyl Chloride;

QARA: Quantitative Area Risk Assessment;

QRA: Quantitative Risk Assessment;

RADM: Risk Assessment Decision Matrix;

ReLaMP: “Regione Liguria Merci Pericolose” – Dangerous Goods in Liguria Region;

REX: Retour d'EXpériences;

RID: Regulation concerning the International transport by railway of Dangerous goods;

SDIS 13 : Service départemental d'incendie et de secours des bouches du Rhone ;

SIMAGE: “Sistema Integrato per Monitoraggio del Rischio e delle Emergenze”:  
Integrated System for Monitoring Risks and Emergencies;

SR: Societal Risk;

TIP: Transport Integration Platform;

TMDNIS: Transport of Dangerous Materials through Nice, Imperia Savona;

UNECE: The United Nations Economic Commission for Europe;

UN Recommendation: United Nations Recommendation;

UVCE: Unconfined Vapor Cloud Explosion.



## Foreword

---

Every day, dangerous goods (DG) are transported in different modalities from one or more origins to their destinations, all over the world, where people need DG to live, to work, but also to find out new frontiers. Every country needs DG for everyday civil life activities: for example to use energy, to transport goods and passengers, or simply to conduct a healthy and safe life.

For these main reasons, the contemporary generation is addicted to DG, and for this reason we have the duty to monitor and to control their overall supply chain from producer to consumer – including their transportation - using innovative information and communications systems - such as Global Positioning Systems, Geographic Information Systems, Decision Support Systems.

The awareness of DG production, loading, unloading, storage, and transport, gives us the challenge to use DG, firstly, in a sustainable way, (optimizing, preventing cost and time delays, avoiding waste), secondly, in a safe and sustainable way in order to reduce the human exposition to the possible harmful effects of such DG (reducing emissions and spills), and also to quantify the potential damage or consequences linked to its use, not only for us, but also for the future generations (avoiding accidents, injuries, and deaths).

These are some reasons for which I decided to face this world, the world of DGT, unknown for me before 2001, year of my first research to get my degree in Environmental Engineering with a topic dealing with “Definition of a methodology for real-time evaluation of risk from the transport of dangerous goods by road. Application to a case study in the transport of hydrocarbons in Liguria.”

After almost ten years, I have understood that the DG transport system has an extremely complex architecture and a stratified framework. DG transport is a complex system due to the aspect of "mobility and dynamicity" of its hazard, but also because of external and boundary conditions, and also for the mode of transport, (such as the nature of the materials transported, the state vehicle, weather condition, condition of transport infrastructure, proximity to urban centres, traffic density etc.). In addition, public authorities and the highway managers have a very fuzzy picture of flows of DG that go

through European Union territory. In addition, it is a complex subject to study in all its dimensions (scientific, technical, economical, sociological, environmental, etc.).

This system has different levels of research and investigation, and - at a strategic level - I should not leave out even a single part, otherwise I can not reconstruct the whole system. Otherwise, it is unrealistic to describe mathematically, or analytically the whole system with the hope to have only one and realistic and finite solution for such a complex problem.

A DGT, and the related risk, might be characterized by several aspects:

- The DG type and the related chemical-physical characteristics related to the hazard in its transportation;
- The transportation modality;
- The infrastructure used in the transportation;
- The human factors linked to the transportation (drivers, users, decision makers, public and private authorities and their policies);
- The territorial and geographical elements exposed to the transport considered;
- The meteorological, atmospheric, and environmental conditions monitored during the transportation.

In my PhD work, two transportation modalities, pipeline and road, have been taken into account, since they represent the most common modalities of transportation in Europe of DG, as well as in France and Italy.

The different methodologies that have been used throughout my PhD work are strongly oriented to an engineering vision of the hazard and of the related risk, where a numerical quantitative evaluation is required. To support this view, I have deepened and used methodologies and technologies oriented to Geographic Information Systems, Innovative Statistic Approaches, Mathematical Programming, Optimal Control and, in part, Game Theory.

Specifically, in first place, I have defined an on-line / off-line GIS for the quantitative definition of the vulnerability of a pipeline to third parties activities, corrosion and mechanical failures. The proposed methodology, which also includes

innovative statistical approaches based on artificial neural networks, has been applied to an important oil pipeline in the South of Italy.

Secondly, I have integrated the real-time information coming by the Eni tracking/tracing system used to monitor the transportation of petrol products on the roads of the European territory (currently about 400 vehicles) with a common tool (ALOHA) used to evaluate the hazard and the exposure according to different accident scenarios. This approach has been tested with some case studies in the North of Italy, where a LPG explosion and release scenarios were supposed on a highway.

In addition, I have also formulated two original methodologies - might be more theoretical than the previous ones - with some direct practical application. The first methodology, which originates from a work by Prof. Bell, Imperial College, London, aims to verify how a risk adverse behaviour in DG transport on road can contribute to a practical reduction of risk if a mixed strategy – that is spreading travels both in time and in space – is applied. This methodology is based both on a game theory vision of the problem and on a practical mathematical programming modelling approach. The second methodology is based on the computation of optimal control laws in the DG transport on road to define the DG optimal flow which must access throughout a critical infrastructure, such as a tunnel.

In my opinion, it is also important to underline that I have had the chance to relate my PhD work to an International context, as well as to access to the most recent “know-how” on DG transport. Specifically, my work on the vulnerability of pipelines is strictly connected to a National project, funded by University of Genova and by ISPESL, and it has also been performed in close collaboration with Eni. My work on DG transport risk on road has been developed in close connection with the VIFP EU project Da.Go.T, as well as with two ALCOTRA-Interreg projects between Italy and France.

In fact, my overall PhD work strongly reflects the effects of the co-tutoring between University of Genoa and Mines Paris-Tech. A part from the Interreg projects, I have had the chance to deepen and to compare the Italian and French regulations and organisations to face DG transport risk. During my stay at the Mines Paris-Tech, for example, I met representatives - or simply knew during my study in France - industrial stakeholders,

such as Albemarle, Arcelor, Arkema, Charabot, Mane Fils, Primagaz, SB Formulation, Shell, SNPE, Total; association stakeholders (CYPRES) and finally institutional stakeholders (BARPI, DRIRE of Midi-Pyrenees and PACA, INERIS, PACA Prefecture, SDIS 13).

I focused my attention on "industrial safety" and I spent an intensive period of three weeks where I met decision makers in the field of risk prevention and of crisis management during visits to industrial sites and conferences.

From a methodological viewpoint, my work strongly reflects some research studies I have followed in my hosting in the French institution, specifically as regards how DG risk is faced in several French companies as well as on some software tools, such as ALOHA, that are currently used in France, for example at INERIS. Indeed, as Mines Paris-Tech student, I went to INERIS for one day course on Industrial Risk Prevention.

In this occasion I was introduced on research, development and expertise of this institute. They described what kind of methods of risk analysis for complex industrial systems used, in order to give me practical know-how in the accidental risk topic. Finally, the overall research has been inserted and cofounded by the UIF - Italian and France University in Turin, (<http://www.universite-franco-italienne.org/>) that supported me for mobility in the joint supervision of my PhD thesis.

The main results of my PhD work have been discussed at International level in several contexts. Among others, in 2009, I discussed my PhD work on the risk adverse methodology at Imperial College, where Prof. Michael G.H. Bell led a specific NATO workshop on DGT. Other results have been also discussed in a similar NATO workshop co-organised by University of Genova and by Mines ParisTech in Genova in 2007. In these workshops, I have had the chance to discuss my work with the most outstanding scientists in the field such as:

Professor Rajan BATTA

Associate Dean for Graduate Studies, School of Engineering and Applied Sciences

Professor of Industrial and Systems Engineering

412G Bonner Hall - University at Buffalo (State University of New York) - Buffalo,  
NY 4260, USA.

Professor Michael.G.H. BELL,  
Centre for Transport Studies  
Imperial College London - Exhibition Road, London, SW7 2AZ, UK.

Associated Professor Bahar YETİŞ KARA  
Department of Industrial Engineering  
Bilkent University, 06800 Ankara-Turkey.

Professor Vedat VERTER,  
Desautels Faculty of Management,  
McGill University, 1001 Sherbrooke Street West, Montreal, Canada H3A 1G5.

During these four years of my PhD work I concretely handled a complex subject in all its dimensions (scientifically, technically, economically, sociologically and environmentally) and I managed a complex problem in a context of uncertainty. I worked in teams with people of various cultures and different occupations, in an international atmosphere of proficiency, skills and expertise.



# 1 Introduction

---

This thesis is based on the need to describe the DGT system to find solutions or answers in order to minimize the risks arising from transportation or maximize the level of security in freight transport. DG logistics is a complex system of which the DGT system is a specific subsystem which can be in turn be modelled in several other subsystems. In the thesis work, I have developed approaches and found optimal solutions of models - applied to some of these DGT subsystems - with assumptions, methodologies and targets ad hoc for each analyzed case study.

The DGT risk is related to the risk derived from human settlements – technologies, biological activities, socio-political behaviours – where an action and its consequence, or the binomial cause-effect, is strictly links to human factor, and all risk derived from human activities are called technological risk, (Rinatech, 2010).

When a dangerous event happens, caused by human error, and involving DG, the consequences cannot sometimes be reduced or contained. So, it is essential to apply preventive measure to reduce the probability of occurrence, or/and magnitude of the consequences.

To achieve this goal, it is possible to implement monitoring and control systems, using new and state-of-the-art Information Communication Technologies (ICT), sensors and failure (or leak) detection systems, alarms, but also using models and methods to develop possible scenarios or simulation.

Using simulations, it is possible to have more information about the DGT system behaviours in different situation, considering many decision makers, on the bases of different what-if hypothesis and taking into account different approaches.

In case of emergency management, or for planning activities, such as operative training, models and simulations could be useful for technicians, drivers, controllers, fireman, emergency operators and others DGT subjects.

In this context, in the following chapters, I propose some original models and methods of risk assessment in DGT systems, because of the multiplicity of approach that

could be followed to evaluate risk. I focused my attention on risk linked, not only to vehicles transporting DG incidents (or accidents), but also to infrastructures used for transporting DG, and the surrounding territory. This kind of risk is defined as an accidental risk, and the consequences associated to a DGT hazardous event can be, for example, explosions, thermal accidents, fires in urban areas, toxic releases and plums, air, or water or soil pollution, and acid rains.

All the models that I have described and defined are based on the classical definition of technological risk – related to human activities – categorized as accidental risk, where the risk is related to the failure – or accident – of a DGT vehicle or pipeline.

This risk definition is the same for the pipeline and road, but I can use different methodological approaches to evaluate the risk.

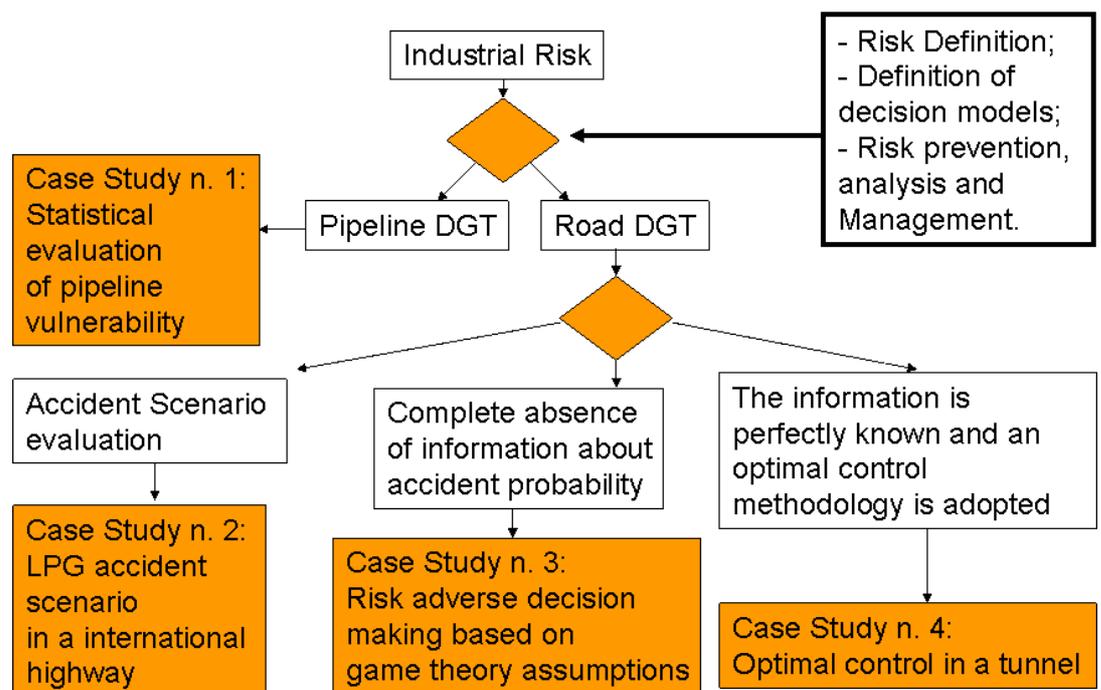


Figure 1. Thesis architecture: starting from DGT risk definition until mathematical formalization in case study solving.

## 1.1 Risk assessment

Generally speaking and as I mentioned in the foreword, the DGT system has a complex architecture, and there is not one way to evaluate risk. For the sake of simplicity I want to report what are the most common methods used in risk assessment.

Actually, the chemical industry makes use of eleven different procedures for hazard assessment, (Muhlbauer, 1996):

- checklists;
- safety review;
- relative ranking
- preliminary hazard analysis;
- “what if” analysis;
- hazard and operability studies (HAZOP);
- failure modes, effects, and criticality analysis (FMEA);
- fault tree analysis;
- event tree analysis;
- cause-consequence analysis;
- human-error analysis.

Examples of Qualitative Risk Assessment are:

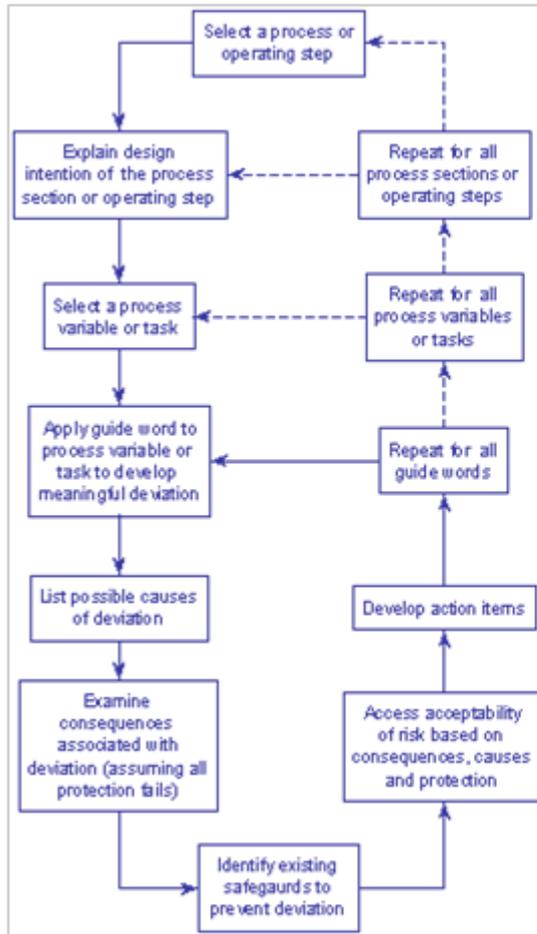
- Job Safety Analysis (JSA)
- Logic diagrams
- What-if/Checklist
- Failure Modes and Effects Analysis (FMEA)
- Hazard and Operability Study (HAZOP).

Each process has a cost, effectiveness and a degree of appropriateness for the system analyzed. With regard to the formal techniques used by industry and companies that transport DG, the methods mainly used are:

- hazard and operability studies (HAZOP);
- quantitative risk assessment (QRA);
- probabilistic risk assessment (PRA).

**HAZOP** - which is the acronym for **HAZard OPERability studies** - is a technique that must be performed by a group of experts, who know in detail the system that they intend to analyze. This is a very expensive process, both in terms of hours worked and number of skills involved. This technique requires a deep knowledge of the plant because the experts have to examine any possible failure or rupture, using a variety of keywords that drive this analysis.

(Figure 2 part A)



(Figure 2 part B)

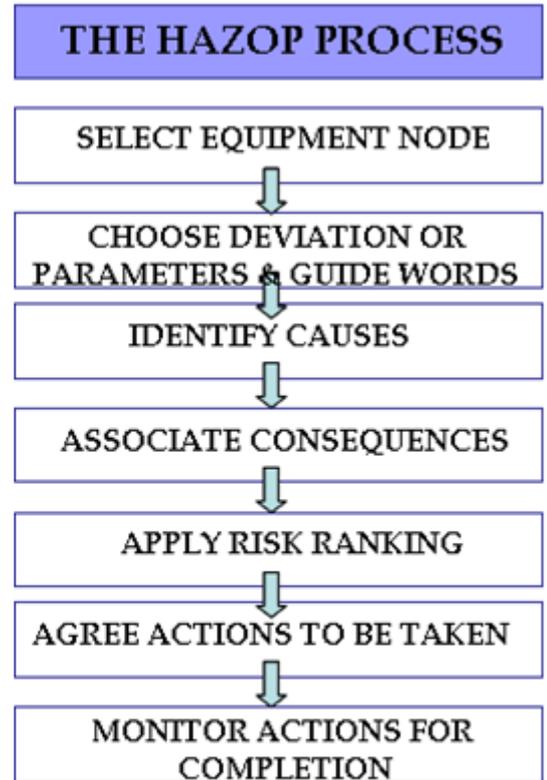


Figure 2. - Part A: HAZOP structured technique description, following a systematic study of a process, using guide words to discover how deviations from the design intent can occur in equipment, actions, or materials, and whether the consequences of these deviations can result in a hazard. - Part (B): A block diagram of the HAZOP process.

**QRA** is the acronym for **Quantitative Risk Assessment** and it is a strictly mathematical technique that numerically determines the absolute frequency of "accidents". This technique is used not only in the petro-chemical, but also in the nuclear and aerospace industries.

With this technique it is possible to quantify the risks on their own and the social risk related to a process, activity or system analysis, management plans for internal and external security for an industrial system concerned, (Muhlbauer, 1996).

Examples of Quantitative Risk Assessment are:

- Fault Tree Analysis (FTA)
- Probit statistical analysis
- In-process energy modeling
- Event probabilities
- Risk/cost trade-off.

**PRA** stands for **Probabilistic Risk Assessment** and is a technique obtained by linking the probability of individual events, such as failures or disruption of plant components and poorly functioning security system. The probabilistic risk assessment (or analysis / probabilistic assessment of safety) is indeed a complex and systematic methodology for assessing the risk associated with complex technological devices (such as aircraft or power plants), (Kumamoto and Henley, 1996).

The PRA is a well established technology, where PRA analysts aim to estimate parameters used to determine the frequencies and probabilities of different events modelled. The cause of an event is an accident. In a PRA model, the parameters are estimated - on the bases of data used to evaluate each of the parameters - and the uncertainties in estimation can be quantified using methods and sources of information that delineate the response of systems and operators to accident initiating events. In this context, performance and plant reliability are enhanced by monitoring equipment performance and evaluation of equipment trends. (Atwood *et al.*, 2003)

The probabilistic risk assessment usually answers three questions, (Muhlbauer, 1996):

- What can go wrong? What are the initial events that lead to adverse consequences?
- How likely is it? What are the likely consequences of this unwanted, or what is their frequency?
- What are the adverse consequences and how serious are the potential damage?

The two methods normally used to answer these questions are the **Event Tree Analysis** and the **Fault Tree Analysis**.

The probability of failure or the probability of having an event - in terms of importance – is associated to the consequences of that event, and this relationship is plotted and qualitatively in the matrix of probability of hazard-effects shown in Figure 3.

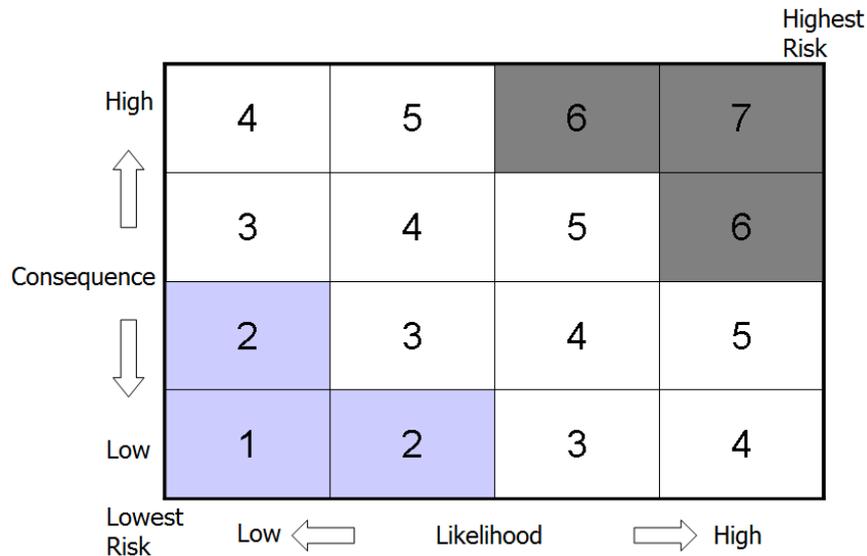


Figure 3. Likelihood-consequence risk matrix - (Muhlbauer, 1996).

**ERA**, an **Environmental Risk Assessment** is a process leading to problems that are caused by pollutants in the environment, and it is evaluate predicting whether there may be a risk of dangerous effects on the environment caused by a chemical substance, (EEA, 1998). “Environmental Risk Assessment (ERA) is the examination of risks resulting from technology that threaten ecosystems, animals and people. It includes human health risk assessments, ecological or eco-toxicological risk assessments, and specific industrial applications of risk assessment that examine end-points in people, biota or ecosystems”, (EEA, 1998).

There is an environmental risk only if there is an exposition to a hazard, and one - or more than one -outcomes associated to the exposition. First of all, to evaluate the risk a **hazard identification** is requested. Secondly, a **dose-response assessment** has to be evaluated: what is the link between exposure and severity, how many factors might influence this relationship, and what is the relationship between animal responses, human responses, high-dose and low-dose responses. Thirdly, the intensity, frequency and duration of an individual exposition is described characterizing an **exposure assessment**. Finally, a **risk characterization** is needed.

Identify, evaluate, and assess risk leading to environment is a complex task, because of its complexity in system architecture, levels of decision, and subjects – public or private - involved. Indeed, ERA depends, at least, on four sub-systems:

- Ecological risk assessment;
- Health risk assessment;
- Industrial risk assessment leading to facilities at strategic and planning level;
- Industrial risk assessment leading to supply chain and system utilities, such as transportation, at strategic, planning, operational or real time level.

Moreover, the economical efforts and the great amount of indirect costs associated to a risk evaluation have to be taken into account to better understand another level of complexity of this system.

Each sub-system can be characterized by many other smaller systems, in which others decision and subjects are involved. So, to conduct an ERA the socio-political, economical, territorial, industrial, and health systems have to share decisions and objectives having a common target: reduce the occurrence and severity of consequences in risk estimation on the environment. This is a management goal, in which communication and information must be shared to reach the goal. So, communication protocol and standards, tools, software or methods adopted have to be defined and the knowledge have to be shared in order to respect law and regulation in ER prevention, and protection. Also data acquisition, elaboration, and visualization should be in common at each level, and a continuous control and monitoring might be performed to update the levels of risk in each sub-system and also in the ERA system.

Only one subject has not the economic power, the skills, and the ability to develop an ERA, this kind of assessment must be managed by an ad hoc Authority, with an extraordinary political, decisional and economical power, that can coordinate all the other subject involved in the system analysed, considering also all the phases of a risk assessment, before the initial accidental event, during the accident and after.

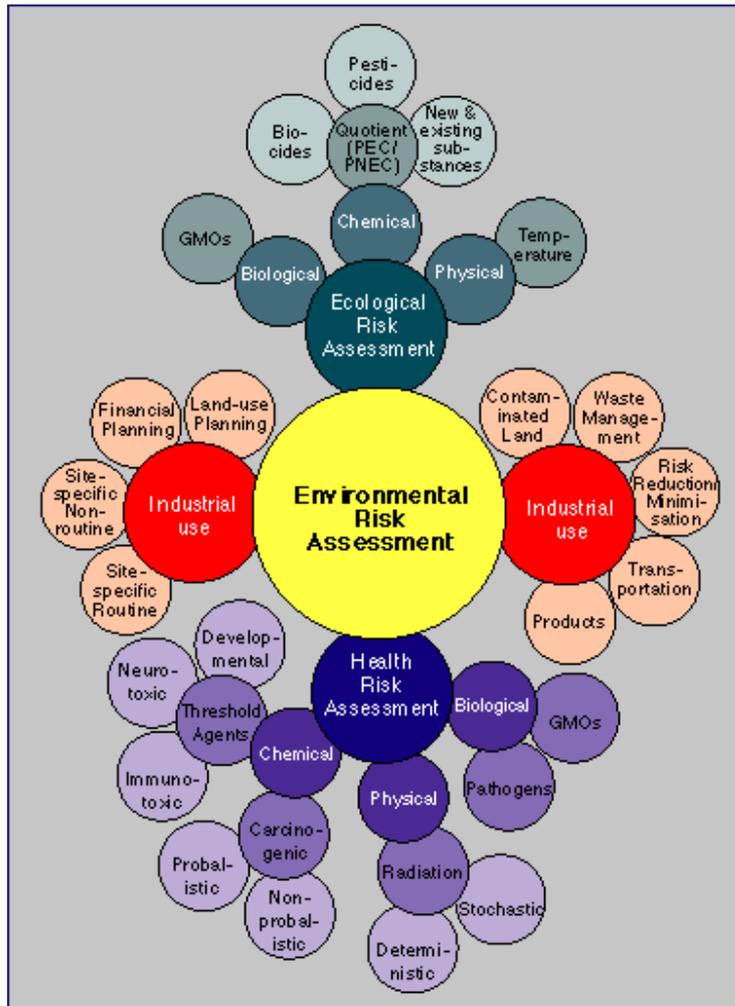


Figure 4. Typology of Risk Assessment - (EEA, 1998).

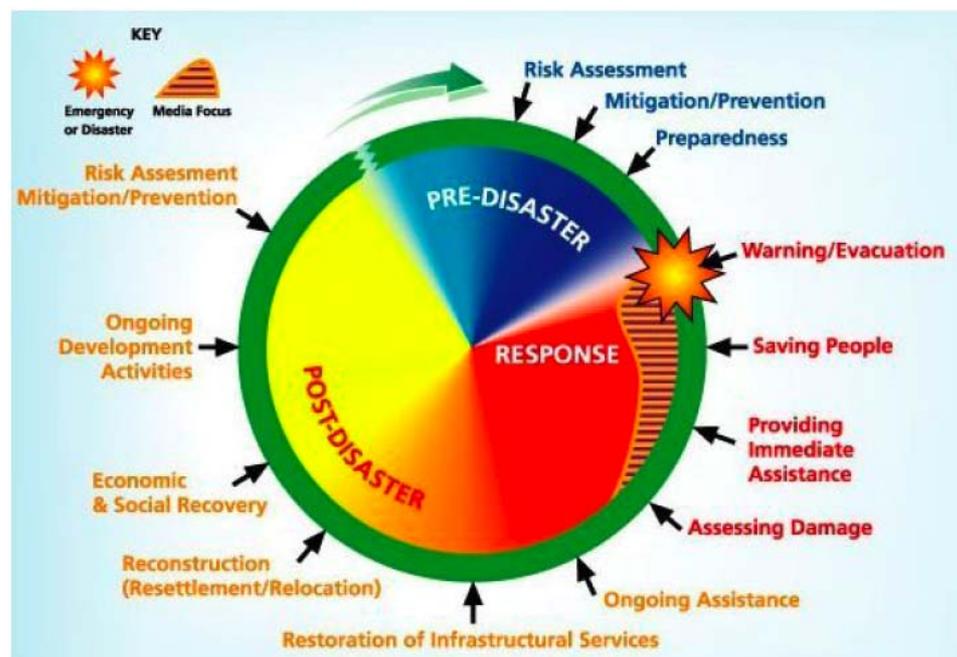


Figure 5. GMES Fast Track Emergency Response Core Service Strategic Implementation Plan\*  
 - Final Version, 24/04/2007 Author: Professor Bernardo De Bernardinis.

In the risk assessment definition, many are the concepts involved:

**Hazard** is defined as "the potential to cause harm", (Royal Society, 1992). Hazard is related to the intrinsic characteristic of a material, good, condition, or activity that has the potential to cause harm to people, property, or the environment, and it is often defined in terms of a probability, (EEA, 1998). For Gilles Dusserre (Analyse des risques TMD, 2010), hazard is the probability of an event that may affect the system studied.

**Elements exposed** are resources (goods, people) and the environment that may suffer damage, (Dusserre, 2003).

**Sensitivity** is the propensity to recover or resist damage assessment, (Dusserre, 2003).

**Vulnerability** is the measurement of the consequences of the event (hazard with a certain intensity) on the exposed elements involved. It can be defined as the sensitivity of the element exposed studied taking into account the ability of emergency response, (Dusserre, 2003).

**Danger** is define as all processes involved in the chain or sequence of events leading to an undesirable event which could have a destructive nature on population, ecosystems and goods, (Dusserre, 2003).

**Severity** is defined as the effect of an undesirable event on the targets point, or on the elements exposed. Can be defined as a function of the elements exposed and the vulnerability of those elements, (Dusserre, 2003).

**Probability** is defined as a value between 0 and 1 and in some words is the likelihood of a sequence of events to an event not desired, (Gilles Dusserre, 2003).

**Industrial risk** is defined as a function (usually the product) of the probability of occurrence and the phenomenon (occurrence) and severity of consequences, (Gilles Dusserre, 2003).

In the context of **natural hazards**, the definition by UNESCO (1972) is generally adopted, which allows computing the risk on a set of territorial elements that may be damaged by a natural hazard, as a function (specifically, a product) of the likelihood of the hazard, of the value of elements at risk, and the so called vulnerability, that is the capacity of an element to resist to a hazard event.

**Risk** is most commonly defined as "The combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence" (Royal Society, 1992).

“**Risk** is used in everyday language to mean "chance of disaster", but hazard and risk are not the same. Risk is a function of hazard. [...] The distinction between hazard and risk can be made clearer by the use of a simple example. A large number of chemicals have hazardous properties. Acids may be corrosive or irritant to human beings for example. The same acid is only a risk to human health if humans are exposed to it. The degree of harm caused by the exposure will depend on the specific exposure scenario. If a human only comes into contact with the acid after it has been heavily diluted, the risk of harm will be minimal but the hazardous property of the chemical will remain unchanged”, (EEA, 1998).

In the risk evaluation it is essential to say that *the zero risk does not exist*. In the process of DGT there is always a level of acceptability, even if the perception of hazard, danger, and also of risk is not so easy to quantify.

“The risk assessment may include an evaluation of what the risks mean in practice to those affected. This will depend heavily on how the risk is perceived. Risk perception involves people's beliefs, attitudes, judgements and feelings, as well as the wider social or cultural values that people adopt towards hazards and their benefits. The way in which people perceive risk is vital in the process of assessing and managing risk. Risk perception will be a major determinant in whether a risk is deemed to be "acceptable" and whether the risk management measures imposed are seen to resolve the problem”, (EEA, 1998).

The notion of acceptability is most important in the risk study, but it is difficult to define because of its subjectivity depending on different dynamic factors. The evaluation of acceptability is not the same in each United Europe Country. The Netherlands used a probabilistic approach in risk definition, at a planning level, and the acceptability is determined as follow in Figure.6:

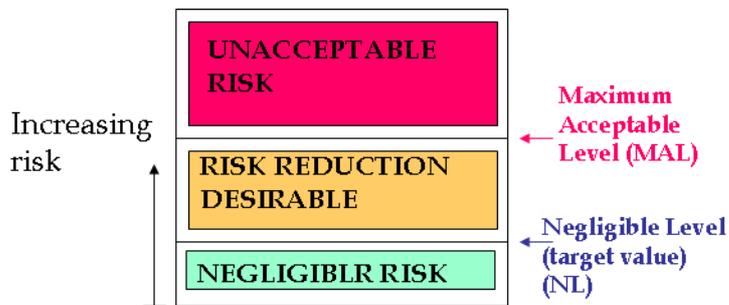


Figure 6. Risk management policy and criteria of acceptability in The Netherlands. (Ale, B.J.M., 1991).

To quantify the risk in term of cost-benefits trade off, the values of risk are determined by a political choice, derived from the art. 5, of the Seveso Directive 82/501/EEC, approved by Parliament (1990). Risk criteria have only been defined for people, and three regions of acceptability are considered:

- MAL (Maximum Acceptable Level) – should not be exceeded, irrespective of the economic or societal benefit that could result from the activity under consideration.
- NL(Negligible Level) – it is not sensible to try to further reduce the risk, in view of the fact that man and the environment are already subject to other risks resulting from nature or society.
- IN THE MIDDLE – risk needs to be reduced according to the ALARP concept.

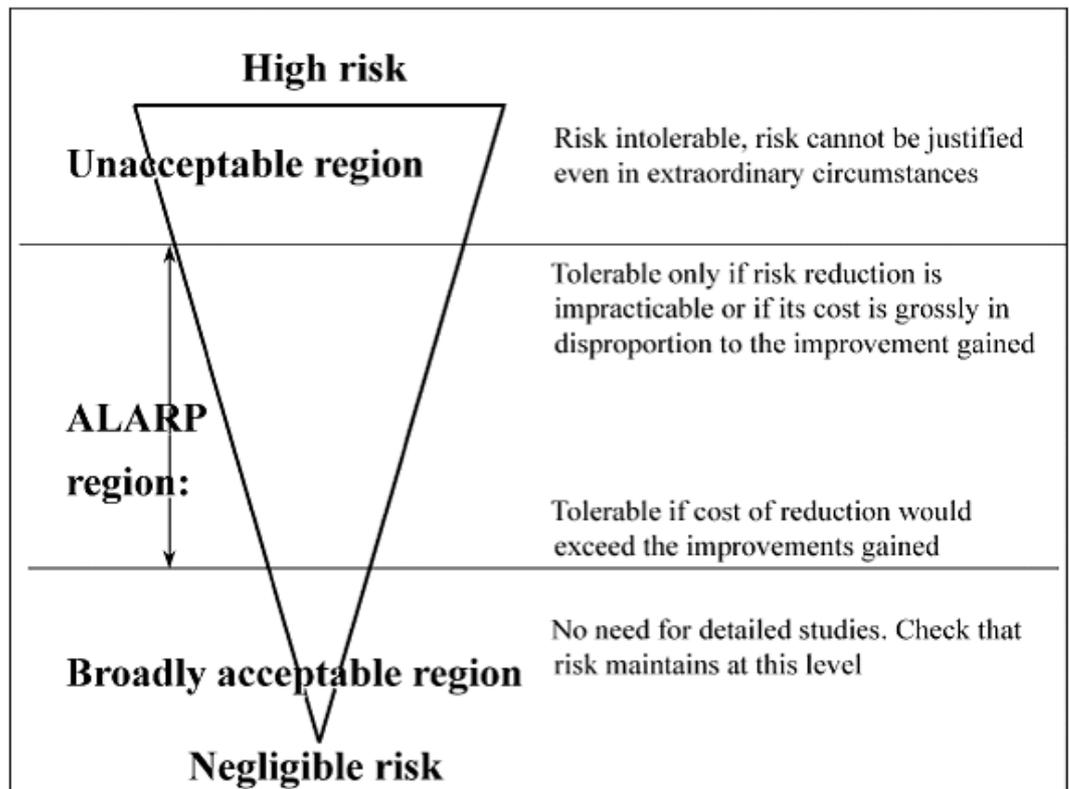


Figure 7. The ALARP region is defined in: Vrijling *et al.*, 1995; Vrijling *et al.*, 2004; and Hoj *et al.*, 2002.

Risks are “acceptable only if reasonable practical measures have been taken to reduce risks” (IAEA 1992).

The level of acceptability is quantified considering an Individual Risk (IR) to people, a Societal Risk (SR) to people, and a Potential Loss of Life (PLL).

INDIVIDUAL RISK (IR) is defined as the probability that an unprotected person, who permanently is located at a specific position in the vicinity of a risk source, is affected by the undesired consequences of an event, and he/she will be killed. IR is expressed as a period of year. It can be pictured on a map by connecting points of equal IR around a facility, the risk contours. (Ale, 2002).

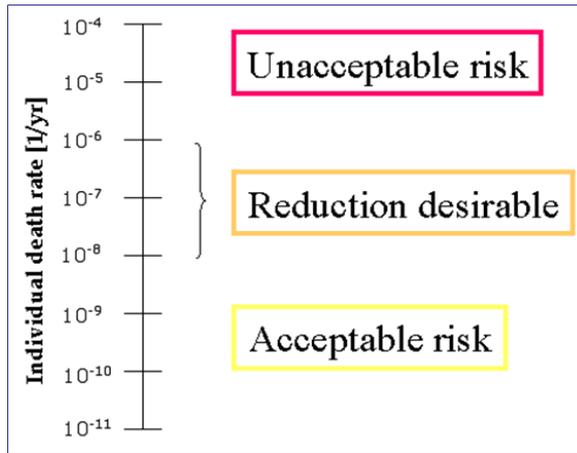


Figure 8. Provisional risk criteria for people, considering (IR) and its acceptable limits. (Ale, 2002).

SOCIETAL RISK (SR) is defined as the relationship between the number of people killed in a single accident (N) and the chance (F) that this number will be exceeded. It is the probability that in an incident more than a certain number of people are killed. Societal risk usually is represented as a graph in which the probability or frequency F is given as a function of N, the number of people killed. This graph is called the FN curve.

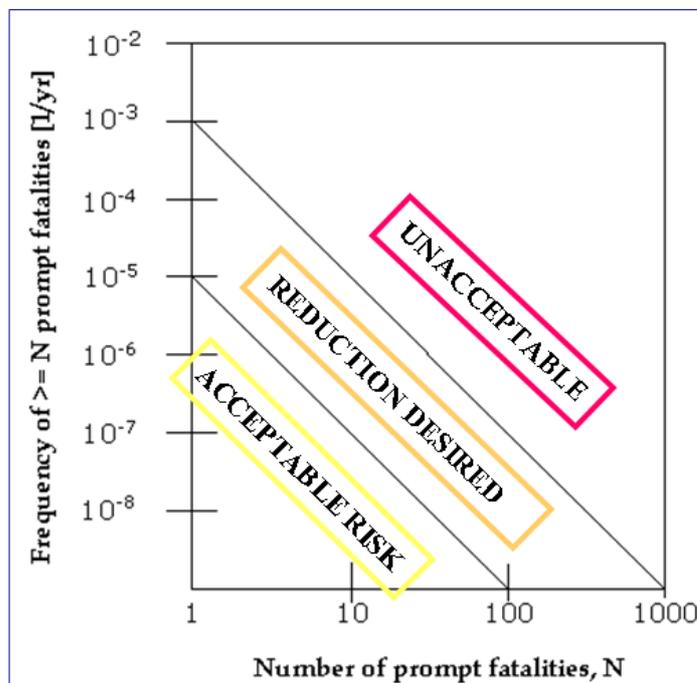


Figure 9. Provisional risk criteria for people, considering (SR) and its acceptable limits. (Ale, 2002).

POTENTIAL LOSS OF LIFE (PLL) is the expectation value of the number of people killed per year. It is the sum of all individual risks and it is the area under the FN curve.

The probability of a hazard referring to people has to be compared to its severity of consequences, and both the Netherlands, and French Policy, adopt a Risk Assessment Decision Matrix approach to determine qualitatively a level of risk. RADM can be employed to measure and categorize the risk. This procedure is based on probability and consequences parameters.

This approach is well assessed in fixed plants, subjected to SEVESO Directives, and for the evaluation of major technological risk. But, there is a substantial difference between the Netherland approach and the French one: while the accidents with a low probability are not considered in the first approach (probabilistic risk approach), the second one considers and studies all the accident scenario happened (deterministic risk approach).

Severity of consequences		Probability of Hazard					
		F Impossible	E Improbable	D Remote	C Occasional	B Probable	A Frequent
<b>I</b>	<b>Catastrophic</b>						
<b>II</b>	<b>Critical</b>						
<b>III</b>	<b>Marginal</b>						
<b>IV</b>	<b>Negligible</b>						
<i>Risk code/ Actions</i>	<b>1.</b> [10 <sup>-2</sup> ] <i>Un-acceptable</i>	<b>2.</b> [10 <sup>-3</sup> ] <i>Undesirable</i>	<b>3.</b> [10 <sup>-4</sup> ] <i>Acceptable with controls</i>	<b>4.</b> [10 <sup>-5</sup> ] <i>Acceptable</i>			

Figure 10. Risk Assessment Decision Matrix (RADM) - Official Journal of France Republic – Regulation 7 October 2005. (Reniers *et al.*, 2005).

In Italy, four levels of risk are taken into account, (Fabiano *et al.*, 2002). The risk is divided into "Acceptable", "Region of tolerability: type A", "Region of tolerability: type B" and "unacceptable." The criteria for assessing the degree of risk are not standardized at the European level.

To compare the RADM criterion with the Italian one, Italian analysts processed ISTAT data for 20 years of accidents, showing that the rate of IR is between  $10^{-3}$  and  $10^{-4}$ , precisely, the IR for DGT accidents is about  $5 \times 10^{-4}$ ; while the SR is modeled with an approach that uses the frequency curve of deaths, (F/N curves), related to transport, as established by the Netherlands standards, and adopted by Italian case study (Fabiano *et al.*, 2002).

For SR, the limits are set as a guidelines: They are also set as a limit per kilometer of the route,  $F=[1 \times 10^{-2}/\text{yr}]$ . In addition, advisory limit is given for fixed installation and transport, and it should be noted that in spatial planning the limit for transport will only be observed within 200 m from the route.

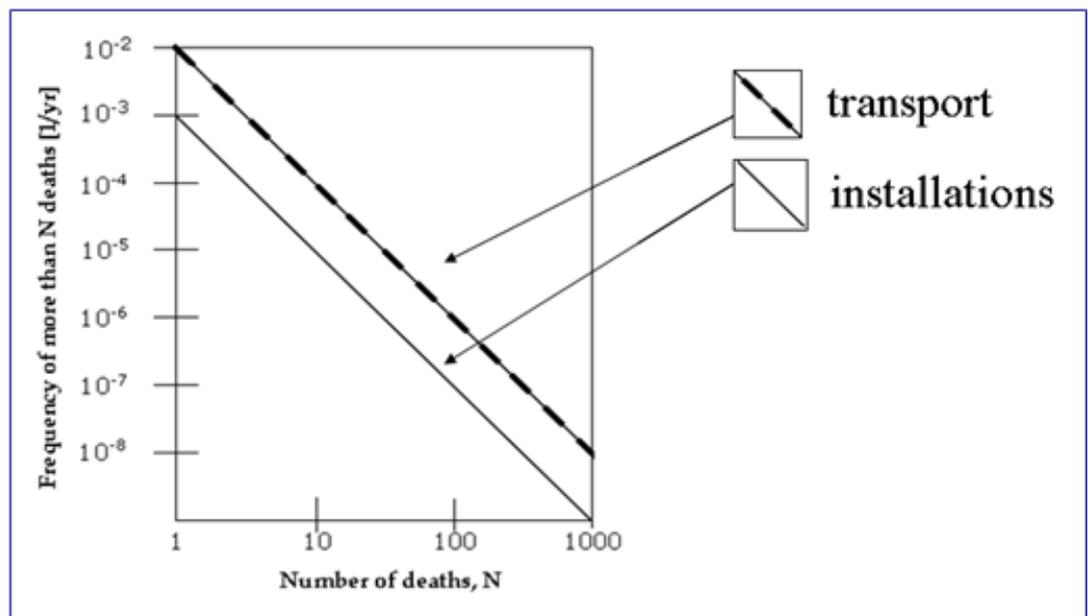


Figure 11. Advisory limits referring to societal risk, where transport SR and installation SR are compared. (Ale and Piers, 2000); (Ale, 2002).

“Risk management is the decision-making process through which choices can be made between a range of options which achieve the "required outcome". The "required outcome" may be specified by legislation by way of environmental standards, may be determined by a formalised risk-cost-benefit analysis or may be determined by another process for instance "industry norms" or "good practice". It should result in risks being reduced to an "acceptable" level within the constraints of the available resources”, (EEA, 1998).

On the other hand, actually, this methodology, both in France and in Italy, is not systematically adopted in DGT, because of lack of data in frequency or probability of

accident evaluation, but I hope that in a near future it might be adopted in French using a deterministic approach, collecting all the accident scenario happened in DGT.

Risk Evaluation	Criteria	Description
Acceptable risk	$P < (10^{-5} / N^2)$	Verify that risk remains at this level, no need for detailed study.
Region of tolerability: type A	$(10^{-5} / N^2) < P < (10^{-4} / N)$	Tolerable risk. If cost of reduction would exceed the improvements achieved.
Region of tolerability: type B	$(10^{-4} / N^2) < P < (10^{-3} / N^2)$	Tolerable only if risk reduction is impracticable or the cost is disproportionate in relation to the improvements obtained.
Unacceptable risk	$P > (10^{-3} / N^2)$	Risk intolerable: risk cannot be justified even in extraordinary circumstances.

**Table. 1. Risk acceptability criteria. P is the cumulative frequency in one year, and N is the number of deaths. Analysis performed by Dutch studies. (Hoj and Kroger, 2002).**

Also in Italy many DGT Companies are implementing tools and technologies able to detect accidents or abnormalities during the routing, for reasons of safety and security, and those observed data represent a set of accident really happened, that could helps analyst to define classes of probability of hazard, and new IR, and SR limits.

The risk definition is also a hard task because of not only the socio-political context, but also the economic and utilities and services - leading to the dangerous activity - can influence the risk estimation.

In this context, especially in France, the so called “retour d’expériences”, or “REX”, is a sort of feedback after an accident scenario really happened, it is an “experience feedback”. Lessons learned from past experiences or dangerous events, especially the most serious ones, are highly instructive to prevent recurrence of accidents and increase the level of safety related to the systems analysed, (Van Wassenhove and Garbolino, 2008).

Indeed, negative REX focuses on accidents, failures, technical problems, and errors, which have consequences on the system considered, and it is an essential tool in the risk management. On the other hand, positive REX focuses on good practices and techniques implemented. In our study, REX is a methodology for understanding safety dimension after a dangerous event, to prevent future accidents, and helps people to be ready and arranged for the effects of a similar event. It is also an approach to both individual and collective level, where each operator (or generally, a subject) is invited to share his experiences and to benefit from the other actors, (Van Wassenhove and Garbolino, 2008).

“One of the major difficulties concerning the use of risk assessment is the availability of data and the data that is available is often loaded with uncertainty”, (EEA, 1998).

To this end, there are many databases that collect all accident and incident occurred in the past; some of them are public and their access is direct, others are private and have an authorized or restricted access:

- ARIA, ([http://www.aria.developpement-durable.gouv.fr/barpi\\_3252.jsp](http://www.aria.developpement-durable.gouv.fr/barpi_3252.jsp));
- HSELINE, ([http://www.datec.lavoisier.fr/fr/not\\_bdd.asp?bdd\\_id=628](http://www.datec.lavoisier.fr/fr/not_bdd.asp?bdd_id=628));
- ICHEME, (<http://www.prosim.net/fr/resources/liens.html>);
- MHIDAS, (Major Hazardous Incident Data Service: <http://www.highbeam.com/doc/1G1-10875699.html>) ;
- TNO, ([http://www.tno.nl/content.cfm?context=markten&content=product&laag1=186&laag2=151&item\\_id=443&Taal=2](http://www.tno.nl/content.cfm?context=markten&content=product&laag1=186&laag2=151&item_id=443&Taal=2)).

Studying an accident - a failure or generally a dangerous event - after its occurrence prepare technicians, and all the subject involved, for estimation of damages, for establishing an event chronology, for a realistic hypothesis of accident scenario evaluation, for identifying barriers, and defence in depth, but also for quantifying the organizational and human dimensions, and, finally, for defining recommendation.

The right management of DGT is a hard task and get complicated because of many subject, who have to take different decisions, with objectives that are partially orientated to risk reduction.

Surely, to manage DGT system:

- first of all, a good knowledge and skills in transportation types and dangerous goods identification is required;
- secondly, principal risk leading to DG and its transport are taken into account;
- thirdly, not only, the nature of risk and the principal dangers and consequences leading to DGT, but also the principal causes of accident are taken into account;
- fourthly, perusing and investigating accident reports need to better understand the dynamics of an event, to be more able to prevent, act and deal with future incidents or accidents;
- fifthly, preventive actions and disaster relief are to be taken into account in the management chain;
- sixthly, the emergency organization is a tricky task not only at a planning level, bat also at operational and real time levels;
- seventhly, prevention through training of stakeholders is an effective goal to risk prevention at a public and private level of liability;
- eighthly, informing people before, during and after an event using codified instructions is to be hoped;
- finally, a compensation could be foreseen, and provided for low, deriving from DGT accidents.

“Risk assessment is carried out to enable a risk management decision to be made. It has been argued that the scientific risk assessment process should be separated from the policy risk management process but it is now widely recognised that this is not possible. The two are intimately linked” (EEA, 1998).

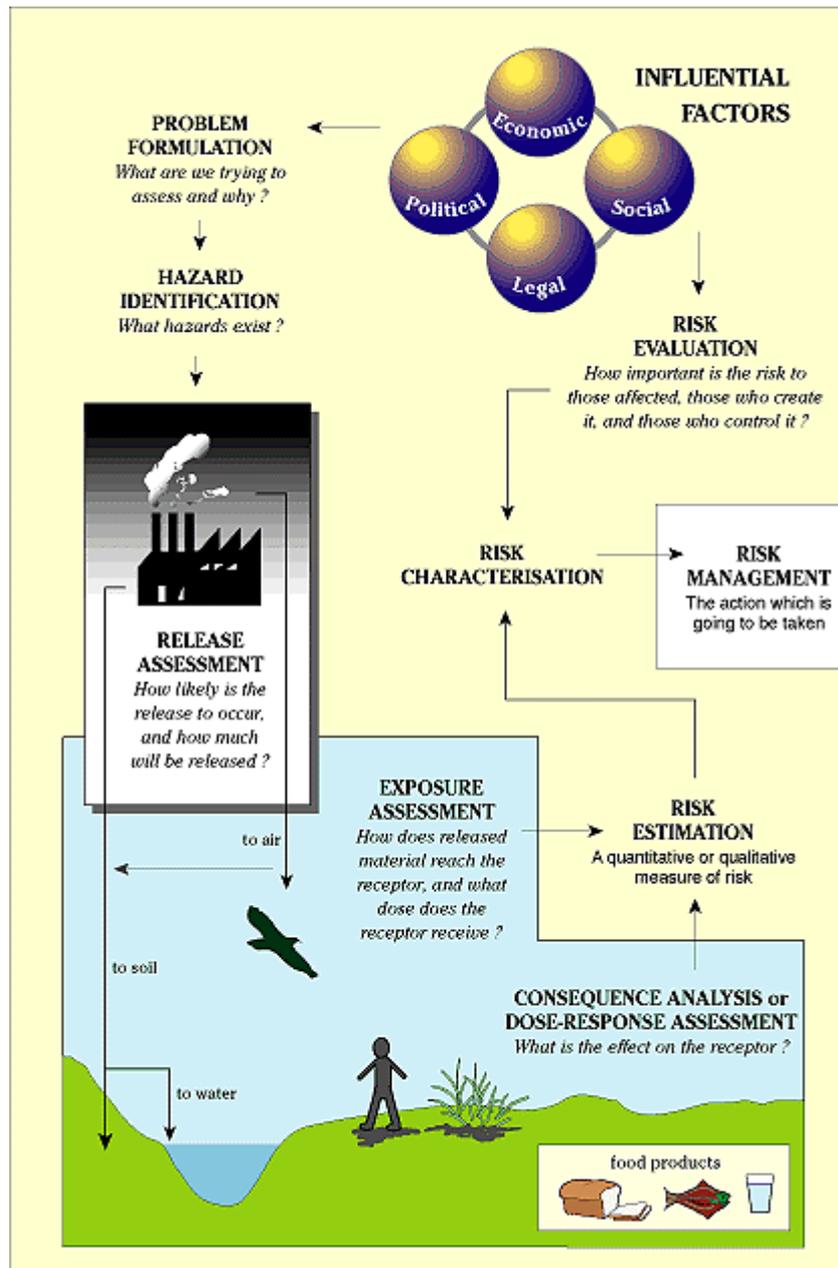


Figure 12. The elements of risk assessment. (EEA, 1998).

## 1.2 Systems and Models to support decisions

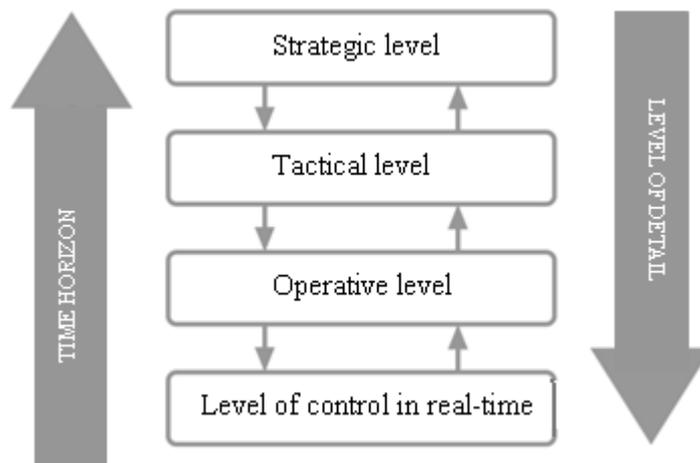
To narrow the gap between scientific risk assessment and policy risk management process models designed and implemented to support stakeholders in the decisional process exist.

The DGT topic and especially the accident prevention and crisis management interest a huge panel of decision makers. We all recognize that some decisions are more important than others, whether in their immediate impact or long term significance.

The significance of a decision is a measure of understanding, and especially the knowledge about how much resources and time to spend on a decision is a crucial point. So, the decisional process could be divided in levels of decision, on the bases of time and space information and priority. To project an informative system able to manage the infrastructure of the transport of dangerous goods, (for example, as done in the TMDNIS project), it is useful to refer to a classification hierarchy of the decisional levels that may be associated with the management of that type of transport. This classification consists of four levels:

- The strategic level;
- The tactical level;
- The operative level;
- The level of control in real-time.

The four levels are ordered according to the time horizon (in decreasing order) considered and the level of detail of the model used (in increasing order, see Figure 13 and Table 2).



**Figure 13. The four decisional levels.**

In the **strategic level** decisions are taken on models on a national scale with a time horizon of a few years (generally 5-10 years); it mainly regards the dimension of the infrastructure of the transport as well as the definition of the types of dangerous goods that can be transported in the considered infrastructure. These decisions are made based on an estimate of the demand for transport (scenario) for the time horizon considered. This level of planning due to its nature requires a long time and enormous resources and

has the Public Administration as its main component, which could require the collaboration of external experts, also private, who could be involved in the creation and/or the running of the activity or service.

In the **tactical level** a time horizon of a few months or a maximum of one or two years is considered, decisions are made on a model with a level of detail corresponding to a multi-regional geographic area. The choices made at this level are substantially connected to the planning of the transport of the average period. At this level therefore how much and which dangerous goods can be transported in the considered territory in the chosen period of time is defined. These decisions are made based on accurate estimates of the demand for the transport of dangerous goods and based on the infrastructure network configured at the strategic decision level. At this level who makes the choice could also be private and, even under the control of the Public Administration, is assigned the management of the transport of dangerous goods.

The **operative level** considers a time horizon of a few days and the activities of this level are aimed at the scheduling of the transport in the present week/month. The decisional models are at a regional level or, at maximum, a multi-regional level; the definition of the transport can be based on specific algorithms of scheduling, strategies of the route of vehicles or specific heuristics defined for the problem under consideration, and must take into account the risk levels connected to the infrastructure in order to minimize the risk deriving from the transport of dangerous goods. This level can be managed directly by the local Administration, by the managers of road infrastructures and by single transport companies.

The **level of control in real-time** is aimed at the continuous monitoring of the transport resources through suitable hardware instrumentation installed in the vehicles and in the infrastructure; potential decisions in the control of this traffic are taken on a local scale and regard a time horizon of a few seconds, minutes or at most some hours. The strategies present at this decisional level are necessary to contrast any hitches in the transport network such as the temporary unavailability of infrastructure or excessive density of vehicles that transport dangerous goods in a certain stretch of the network. This phase is initially run by the transport companies able to interact with the vehicles in

a fast and efficient way, but with the view of preventing risk the local Administration and managers of road infrastructure would also need to participate in this phase.

	Time Horizon	Level of Detail
Strategic level	Years (>2)	national scale
Tactical level	months, years ( $\leq 2$ )	multi-regional scale
Operational level	days	regional scale
Level of control in real-time	seconds, minutes, hours	local scale

**Table 2. The four decisional levels.**

The various subjects involved in the decisional process regarding the transport of dangerous goods, and above all in the evaluation of the risk derived from it, are not always clearly distinguishable and the roles assigned to them can be in a certain way interchangeable.

The problem can in fact be faced by the different decision makers involved:

- From the point of view of the manager of the network;
- From the point of view of the user of the network;
- From the point of view of the public body or the administration that has a social objective in the network.

The decision maker can furthermore be identified:

- In the transport company that is materially and daily occupied with the distribution of the high risk products along national and international roads;
- In the concessionary companies of the road infrastructure that are therefore interested in the management of the flow from both a viability and safety point of view;
- In the public administrations of the territory involved, to which are assigned the roles of supervision of the materials transported, safety and prevention.

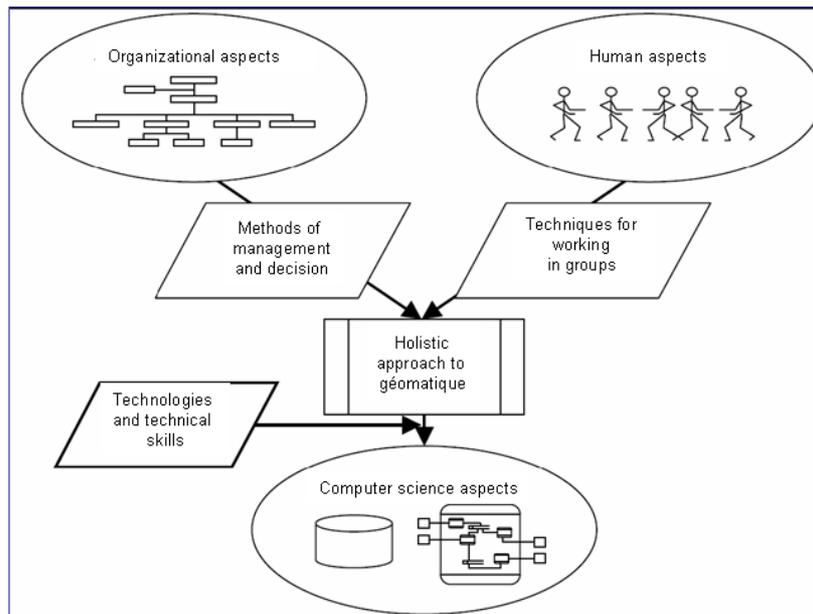
The complicated decisional process regarding the problems of management and the evaluation of the risk derived from the transport of dangerous goods therefore involves different components who should communicate, converse and comprehend each other with the aim of maintaining a correct and efficient organization.

In this decisional process at different levels of importance, using models and methods to describe a system studied - and then collecting the output of models and methods into a decision support system - help decision maker to spent less time, and resources (man and tools) in the decision process, and what is more, the decision, that is subjective for definition, could be taken on the bases of an objective and technical support.

Jean-Jacques Chevallier (1993, and 1994), for example, said that "A Decision Support System (DSS) is a Geographic Information System (GIS) tool, which support a complex activity or a process of developing and evaluating scenarios, to identify the best actions according to a well assessed situation, clear objectives, and criterions or standards. [...] A DSS must allow the possibility of integrating applications:

- For identifying, describing and manipulating a set of data to reach decision on the bases of actions, scenarios, and assessments;
- to jointly use original data and different forms of data representation;
- to link databases and geo-referenced data to applications and software specialized in developing simulations and specific analysis leading to the studied problem;
- to have tools to evaluate, compare scenarios, and then using techniques of multi-criteria analysis."

An interesting approach to fill the gap between science and policy is presented by Chevallier and Caron, (2002), where only developing information and data well structured and linked to organizational aspects, human aspects and Communication and Computer Science aspects it is possible to share information and manage it from a local or territorial point of view, in other words using a "géomatique" infrastructural approach.



**Figure 14. Chevallier and Caron (2002) approach to share and manage data from a territorial point of view.**

Another example is reported by Walliser, (1977), where the concept of models and methods are strictly linked to the concepts of system. Indeed, one system can be divided in sub-systems to be modelled, and each sub-system interacts with the others. The overall system can be known through models, and the various sub-systems components play their parts at different levels, and interact to describe and define the real system analysed.

In describing the overall system we have to take into account the data variability, the environment diversity, the complexity of the physical-chemical processes involved in the system considered, static and dynamic aspects involved in system description and in the DGT process.

In this approach an hard task is to test and apply the various models making up a models system, where data variability, models complexity, time and space scale, can change rapidly, so we needs a very large set of hypothesis, for a great variety of possible scenario, and the models system have to satisfy all the scenario hypothesis in an effective and efficient way. Too much effort in time, skills and cost are required to reach this goal, so one reasonable target is to collect and integrate al the models – describing the system - in a decision support system architecture, for managing them, at an appropriate scale of space and time, to take a decision as optimal as possible at a specific level of decision.

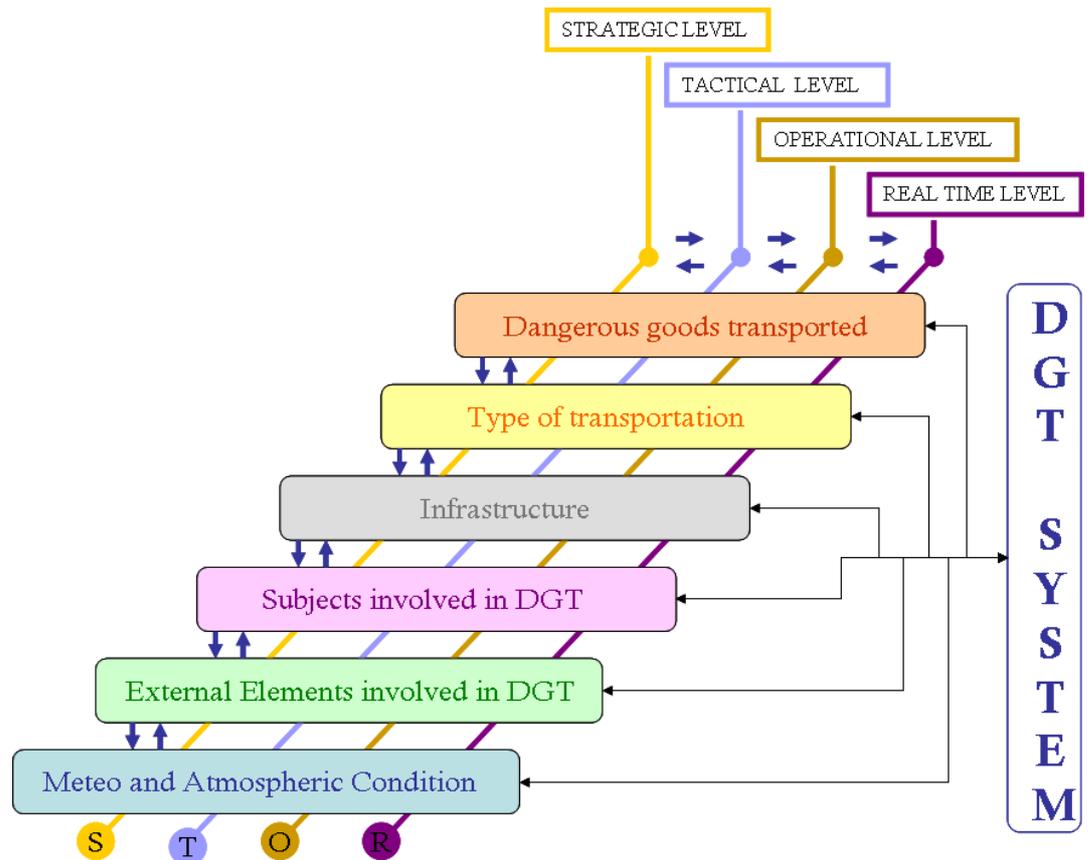


Figure 15. DGT System architecture. This system can be divided into its sub-systems, that are connected each others, and a decision process can be follow to find an optimal solution for the DGT system.

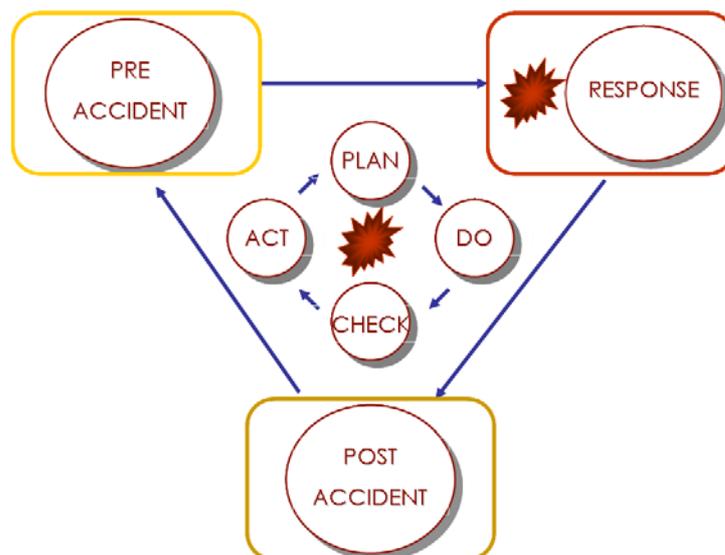
But the only way to control and master the overall system, and the evolution of risk is using methodologies and models that describe the risk assessment.

Using the DGT system architecture in the occurrence of a dangerous event, three are the principal phases of management:

- A strategic one, a pre-accident phase - where the subjects involved have to define plan of intervention, contingency plan, action plan, regulations to prevents risk, as well as a shared and well assessed territorial governance knowledge about the resources available, and time for intervention in case of an accident have to be defined;
- An operative and real time one - the response phase - during the accident occurrence, where all the subject involved in the DGT accident chain have to act on the bases of standards, protocols, and regulations for the emergency response;
- An operative or tactical phase – the post-accident phase– when the consequences of the accident have been estimated and perceived and the plan, defined in

the first phase have to be enforced, people have to be supported to react to the dangerous event, (medical treatment, evacuation, assurance compensations, expropriations).

In this process of management the risk in the DGT system, a continuous prevention, monitoring, control and check plan - on the bases of Deming cycle –is the core for an effective and efficient risk management system, to improve safety and reduce risk in DGT, as shown in Figure 16.



**Figure 16. Risk management in case of a DGT accident event.**

So the principal and not negligible aspect of this study that I want to highlight is that the risk characterization needs a decision system to support policy and regulations, encouraging clear, transparent, reasonable, and consistent risk characterizations. In this study I want to emphasize that the interface between carriers, infrastructure owners or managers, territorial Authorities, risk assessors, risk managers, technicians, and stakeholders is critical for ensuring that the results of the assessment can be used to support a management decision.

### **1.3 PhD thesis structure**

In the current chapter, I wished to highlight a general description of DGT, starting from risk assessment techniques, definitions link to risk, perception and risk acceptability, going through the tricky risk management and the “experience feedback”, until the crucial point: how relate subjective decision and scientific methods in risk estimation. According to time horizon, and level of detail, it is possible describe the DGT

system according to analytical model formalization - as I have done - but also using, for example, a knowledge base approach, or using a “géomatique” infrastructural approach.

A scientific approach, based on analytical models, could be supported by information communication technologies, able to connect models with a realistic representation of the system studied - such as a DGT routing into a portion of territory - to evaluate and quantify a certain level of risk.

This last concept is on the bases of this PhD work, and using this basic assumption that “an accident could happened” I have developed more than one models and methods of risk assessment in DGT systems. I focused my attention on risk, susceptibility and hazards links, not only to vehicles transporting DG and their incidents (or accidents), but also to infrastructures used for transporting DG, and the surrounding territory.

In Chapter 2 what a DG is and which DG type is considered in this study, has been defined. Which modalities are generally taken into account, and which of them have been chosen for this research activity, have been described. Finally, what are the regulations and laws, for each type of transport, have been introduced.

Chapter 3 deals with the risk definition in the transport of DG, respectively, in pipeline and on road, starting from one risk definition, based univocally on the risks related to humans activities, until exposing similarities and differences between pipeline and road transport risk definition.

Chapter 4, then, identifies how many pipeline segments are highly potentially at risk of failure. This chapter tackles a dual problem: firstly, to describe the most significant causes that may lead to a pipeline segment failure; secondly, to evaluate the occurrence of these causes leading to a failure, according to technical characteristics of the pipeline, infrastructures, territorial elements, and land use activities in the pipeline neighbourhood. A quantification of risk, based on an Artificial Neural Network (ANN) statistical approach has been implemented, and the methodology use to describe pipeline risk assessment has been tackled.

Chapter 5, subsequently, handles an innovative and technological model used to describe a DG accident scenario by road, and the population involved. Specifically,

Chapter 5 described the complex problem of integrating real-time data information about the tracking of a DG vehicle with classical risk evaluation methodologies in order to describe possible accident scenarios. The application described as case study deals with the transport of a hydrocarbon dangerous goods, where the accident consequences may involve the population exposed along the infrastructure used for transportation.

Chapter 6 describes the definition of models which enhance the overall transport planning process because of the increasing need for sustainable freight transportation due to economic, environmental, and risk aspects. The crucial point is that, as far as DGT is concerned, current decision making tools do not sensibly differ from traditional planning tools for general freights, that is they support decision makers in the computation of the best route based on the economical factors related to covered distances and transport operational costs.

The approach based on “risk-adverse” in the routing of hazardous material is used for problems whose aim is to find the best and safest routes to connect various origin-destination (OD) pairs, taking into account the objective of minimizing either the maximum risk or the maximum exposure. In chapter 6, it is also demonstrated that further improvements can be obtained scheduling the deliveries with different delays, that is spreading the risk both in space and in time. The improvement is particularly relevant when the vulnerability of the network is also time dependent.

Chapter 7, as chapter 6, tackles one specific model and method of risk assessment and control in DGT by road, considering an optimal control of DGT flow approach in a critical infrastructure, and a preliminary study as regards the possibility to define optimal control strategies for the DG traffic flowing towards one critical road infrastructure (e.g. as in the case study a tunnel) at the macroscopic level is introduced.

Chapter 8 describes, finally, not only the limits of models, improvements, and comparison between methodologies, but also an overall conclusion for this PhD work as well as future possible developments.



## 2 Dangerous goods transportation

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DGT includes all goods - liquids, gasses, and solids - that include radioactive, flammable, explosive, corrosive, oxidizing, asphyxiating, biohazardous, toxic, pathogenic, or allergenic materials (Berman *et al.*, 2007), (DGT, 2010) and (Zhang *et al.*, 2000). All substances that induce severe risk for health, that can harm people, environment and surrounding properties, or other living organisms, are characterized as DG (Zografos *et al.*, 2000). DG are all the substances and materials described in Annex A and B of the ADR, the “Accord Européen relative au transport international des marchandises Dangereuses par Route” (ADR, 2009). The MEEDDM, in France, defines DG all products highly toxics, explosives, and pollutants, but also a great variety of materials and products using every day.

Class 1	Explosive substances and articles
Class 2	Gases
Class 3	Flammable liquids
Class 4.1	Flammable solids, self-reactive substances and solid desensitized explosives
Class 4.2	Substances liable to spontaneous combustion
Class 4.3	Substances which, in contact with water, emit flammable gases
Class 5.1	Oxidizing substances
Class 5.2	Organic peroxides
Class 6.1	Toxic substances
Class 6.2	Infectious substances
Class 7	Radioactive material
Class 8	Corrosive substances
Class 9	Miscellaneous dangerous substances and articles

**Table 3. The classes of dangerous goods according to ADR 2009. (ADR, 2009 - Copiright® United Nations. All right reserved).**

In the U.S.A., also the Code of Federal Regulations, Title 49, Transportation, Parts 100-199, (CFR, 2010), in the “HAZARDOUS MATERIAL TRANSPORTATION GUIDES” (DG Guidelines, 2010), report and define more than 3300 goods considered hazardous (Zografos *et al.*, 2000). Approximately 1.5 billion tons of DG - of which 65% are carried by truck and rail - are being transported yearly in the United States. Worldwide generation of DG is estimated as 3–4 billion tons/year (Akgün *et al.*, 2007). [See, Attachment N.1]

The US Department of Transportation, for example, has estimated that there were 300 million dangerous goods shipments in 1998 and has forecasted a 2% annual growth in the amount of DG produced in the country (Berman *et al.*, 2007). Indeed, in the US,

approximately 300 million shipments per year are of DGT (Berman *et al.*, 2007); while, in Canada, about 27 million shipments of DG are transported (Kuncité *et al.*, 2003), of which, 48 million tons of DG freight was carried via rail, while 64 million tons was shipped via trucks in 2000 (Verma and Verter, 2007).

In European Union, the “Europa – RAMON, International statistical classifications and nomenclatures” classify what goods are transported, and also dangerous goods are reported (Europa-RAMON, 2010). In the UK, some 70 000 chemical substances are in use from industry to domestic life, of which some 2000 are considered potentially harmful. Overall, millions of tonnes are produced annually and more than 200 000 tonnes are freighted daily (Moles, 1999).

## **2.1 Hydrocarbons**

---

In this PhD work, I focus my attention on Crude oil, and Oil products. Oil products are composed of hydrocarbons. In organic chemistry, a hydrocarbon is an organic compound consisting entirely of hydrogen and carbon.

With relation to chemical terminology, aromatic hydrocarbons or arenes, alkanes, alkenes and alkyne-based compounds composed entirely of carbon and hydrogen are referred to as "pure" hydrocarbons, whereas other hydrocarbons with bonded compounds or impurities of sulfur or nitrogen, are referred to as "impure", and remain somewhat erroneously referred to as hydrocarbons.

Hydrocarbons are referred to as consisting of a "backbone" or "skeleton" composed entirely of carbon and hydrogen and other bonded compounds, and have a functional group that generally facilitates combustion.

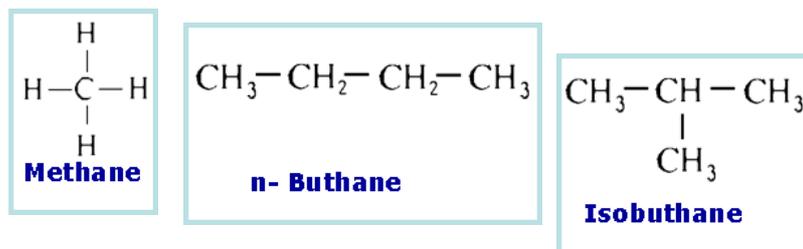
The majority of hydrocarbons found naturally occur in crude oil, where decomposed organic matter provides an abundance of carbon and hydrogen which, when bonded, can link together to form seemingly limitless chains.

To summarize some basic concepts:

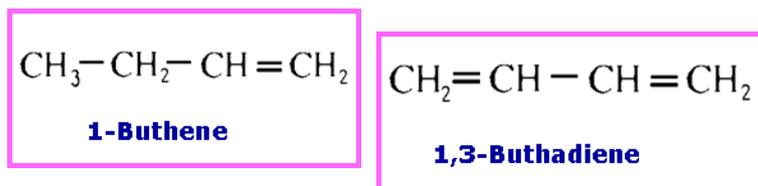
- Hydrocarbons are Carbon (C) and Hydrogen (H) compounds:

- Hydrocarbon's examples: methane, ethane, benzene, paraffin, bitumen, white wax oil, polyethylene, polypropylene, [...];
- Non Hydrocarbon's examples : ethylic alcohol, sugar, wood, olive oil, butter, margarine, PVC, PET, [...].
- Crude oil is a hydrocarbon mixture ranging from very light (gas) to heavy ones (bitumen).
- Oil products are mixtures of hydrocarbons produced by "cutting" crude oil by fractional distillation and often refined.

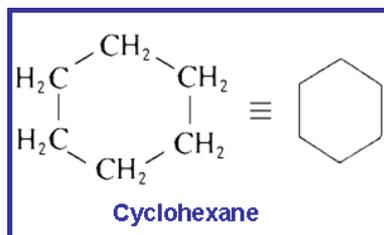
Paraffins:



Olefins:



Naphthenes:



Aromatics:

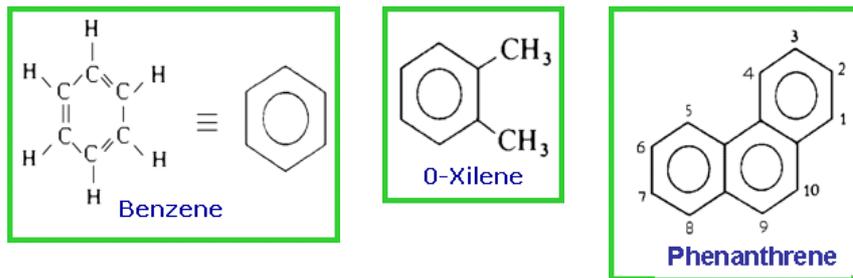


Figure 17. Structural formula of different hydrocarbons, divided in paraffins, olefins, naphthenes, and aromatics.

The principal hydrocarbons, that are transported on road are oil products, which are schematically reported hereinafter, considering their physico-chemical most important characteristics, while Crude oil is the only DG considered for the pipeline transport case study.

### 2.1.1 Crude Oil

- 
- Density: the density of Crude Oil can range from 800 kg/m<sup>3</sup> to 950 kg/m<sup>3</sup>
  - Viscosity: the viscosity can remarkably vary in function of its composition. Usually, it is not less than 2 cSt;
  - Flammability: the flash point for a crude oil is very low and usually it is less than 0°C.

### 2.1.2 Oil products

LPG (Liquefied Petroleum Gas):

- Density: the LPG density can range from 500 to 600 kg/m<sup>3</sup>;
- Vapour pressure: about 1500 kPa (38°C);
- Flammability: the flash point for a LPG is very low (< -40 °C).

GASOLINE OR PETROL:

- Density: gasoline density can range from 730 to 770 kg/m<sup>3</sup>;
- Evaporability: vapor pressure of petrol can range from 0.7 to 0.850 kg/cm<sup>2</sup> at 37 °C;
- Distillation: gasoline distillation (curve) ranges from 40 to about 200 °C;
- Flammability: the flash point for a gasoline is very low and usually is lower than 0°C.

PETROLEUM or KEROSENE:

- Density: the density can range from 780 to 830 kg/m<sup>3</sup>;

- Distillation: distillation ranges from 150 to about 250 °C;
- Flammability: the flash point for a petroleum is not less than 21.5 °C. Usually it is about 40 °C.

#### DIESEL OIL:

- Density: the diesel oil density can range from 820 to 860 kg/m<sup>3</sup>;
- Distillation: distillation ranges from 180 to about 350 °C;
- Viscosity: the viscosity (40°C) can range from 2 mm<sup>2</sup>/s (Centistokes) to 4.5 mm<sup>2</sup>/s;
- Flammability: the flash point for a diesel oil is about 55 °C.

#### FUEL OIL:

- Density: the fuel oil density can range from 920 ( for a half-fluid) to 970 (for a fluid) to 990 kg/m<sup>3</sup> (for a dense one);
- Viscosity: the fuel oil viscosity can range from 30 (very fluid) to 700 cSt (very dense);
- Flammability: the flash point for a fuel oil is not less than 65 °C.

#### LUBRICATING OIL:

- Density: the density can range from 870 to 950 kg/m<sup>3</sup>;
- Viscosity: the viscosity can range from 100 to 200 cSt;
- Flammability: the flash point is not less than 200 °C.

#### BITUMENS

- Density: the density can range from 990 to 1.100 kg/m<sup>3</sup>;
- Auto ignition temperature: not less than 300 °C;
- Flammability: the flash point is not less than 200 °C.

### 2.1.3 Oil products and their potential risks

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**Flammability.** Flammability is defined as how easily something will burn or ignite, causing fire or combustion.

**Anesthetic and asphyxiating properties.** For example, nitrous oxide, commonly known as laughing gas and nozz, is a chemical compound with the formula N<sub>2</sub>O. At room temperature, it is a colorless non-flammable gas, with a pleasant, slightly sweet odor and taste. It is used in surgery and dentistry for its anesthetic and analgesic effects.

It is known as "laughing gas" due to the euphoric effects of inhaling it, a property that has led to its recreational use as a dissociative drug.

**Blood disease.** Blood diseases affect the production of blood and its components, such as blood cells, hemoglobin, blood proteins, the mechanism of coagulation, etc. **Hematology**, also spelled **haematology** (from the Greek *αἷμα haima* "blood" and *-λογία*), is the branch of internal medicine, physiology, pathology, clinical laboratory work, and pediatrics that is concerned with the study of blood, the blood-forming organs, and blood diseases.

**Skin disease.** Clinically, the diagnosis of any particular skin condition is made by gathering pertinent information regarding the presenting skin lesion(s), including the location (such as arms, head, legs), symptoms (pruritus, pain), duration (acute or chronic), arrangement (solitary, generalized, annular, linear), morphology (macules, papules, vesicles), and color (red, blue, brown, black, white, yellow).

**Ingestion.** Ingestion is the consumption of a substance by an organism. Some pathogens are transmitted via ingestion, including viruses, bacteria, and parasites.

**Irritation.** Irritation or exacerbation, in biology and physiology, is a state of inflammation or painful reaction to allergy or cell-lining damage. A stimulus or agent which induces the state of irritation is an irritant. Irritants are typically thought of as chemical agents (for example phenol and capsaicin) but mechanical, thermal (heat) and radioactive activity (for example ultraviolet light or ionising radiations) can also cause it.

**Environment pollution.** Pollution is the introduction of contaminants into an environment that causes instability, disorder, harm or discomfort to the ecosystem. Pollutants, the elements of pollution, can be foreign substances or energies, or naturally occurring; when naturally occurring, they are considered contaminants when they exceed natural levels. Pollution is often classed as point source or nonpoint source pollution.

#### **2.1.4 Dangerous substances in oil products**

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A synthesis of dangerous substances in oil products are hereinafter reported:

- 1,3 - BUTADIENE (LPG);
- HEXANE (crude oil, petrol);
- HEPTANE (crude oil, petrol);
- BENZENE (crude oil, petrol, kero);
- TOLUENE (crude oil, petrol, kero);
- XYLENE (crude oil, petrol, kero);
- ETHYLBENZENE (crude oil, petrol, kero);
- ISO-OCTANE (petrol);
- PNA (crude oil, gasoline);
- LEAD ALKYL (petrol);
- SOME ADDITIVE (Es. MTBE).

### **2.1.5 Oil products hazard classification**

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A synthesis of oil products hazard classification is therefore proposed:

CRUDE OIL: extremely flammable, carcinogenic, dangerous for the environment.

LPG: extremely flammable, dangerous for the environment

PETROL: extremely flammable, carcinogenic, dangerous for the environment.

KEROSENE: flammable, irritant for the skin, dangerous for the environment.

DIESEL OIL: harmful, dangerous for the environment.

FUEL OIL: carcinogenic, dangerous for the environment.

### **2.1.6 Material Safety Data Sheet (MSDS)**

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A material safety data sheet (MSDS) is a form containing data regarding the properties of a particular substance, [See, Attachment N.2]:

1. Identification of producer/distributor;
2. Composition/Ingredient information;
3. Hazard Measure and Type;
4. Emergency Response;
5. Fire Exposure;
6. Spillage Disposal;
7. Packaging & Labeling and Storage;
8. Exposition Control/Individual Protection;

9. Physical and Chemical Properties;
10. Stability and reactivity;
11. Toxicological Information;
12. Environmental Information;
13. Waste Disposal;
14. Transport Information;
15. Laws and Regulations;
16. Others Information.

## 2.2 Transportation modalities

DGT is a worldwide problem of growing interest, mainly because of the increasing transported volumes of materials that can be classified as DG, and because of a globally challenge in the goods transportation performance (Table 4).

	EU-27		USA		Japane		China		Russia	
	[Billion tkm]	[%]								
Road	1888	46%	1890	30%	347	60%	975	11%	201	4%
Rail	435	10%	2705	43%	23	4%	2195	25%	1951	41%
Oil pipeline	135	3%	854	14%	-	0%	166	2%	2499	53%
Inland waterways	138	3%	486	8%	-	0%	1291	15%	58	1%
Sea (domestic/intra EU-27)	1545	37%	332	5%	208	36%	4258	48%	48	1%
Total, 5 modes	4140	100%	6266	100%	578	100%	8886	100%	4757	100%

**Table 4. Comparative goods transport performance. The data, concerning different Geographical entities, are qualitatively comparable – (“Panorama of Transport”, 2009).**

Actually, in European Union (EU) large quantities of DG are moved throughout the transport networks by different modality of transport – by air, by sea, by inland waterways, by road, by rail lines, and by pipelines, (Figure 18). It is estimated that, in 2007, about 4 billions tons of DG were transported yearly worldwide (Carotenuto *et al.*, 2007), and container, general cargo, RO cargo, refrigerant cargo, carriage in packages, bulks and tanks (Liquid Gas Tanker, Chemical Tanker, Oil Tanker, Rail tanker) might be used in DGT, using thousands of km of networks to move (Figure 18).

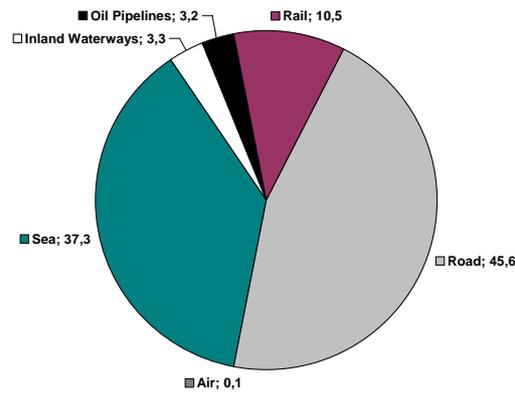


Figure 18. Goods transported in EU-27 - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

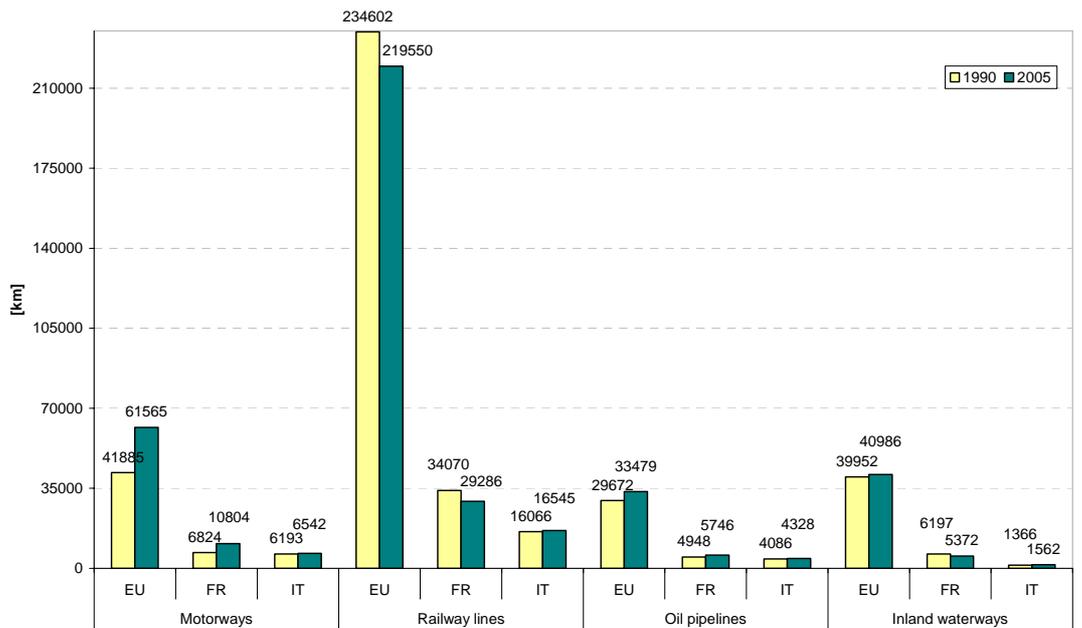


Figure 19. Length of main transport networks - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

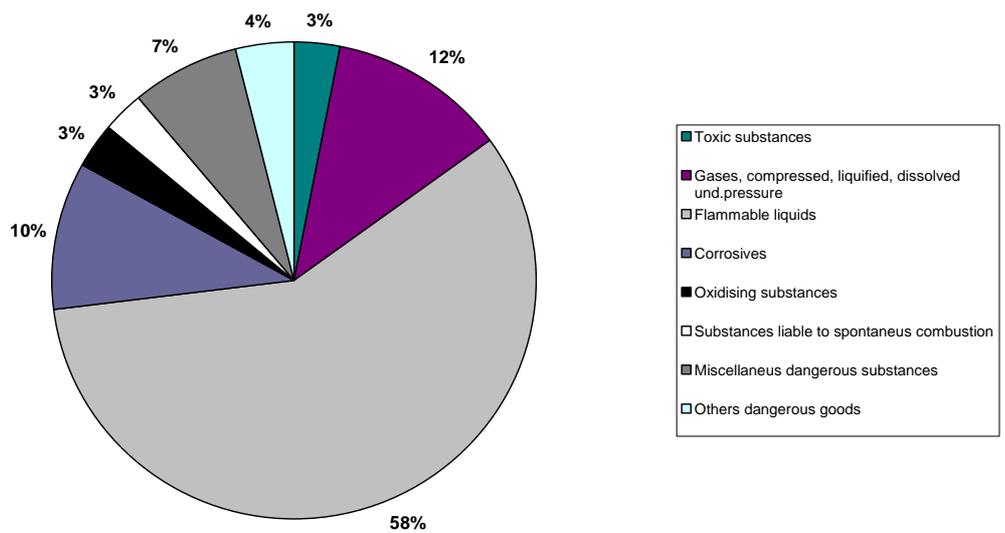
		10 <sup>6</sup> t 1996	10 <sup>6</sup> t 2001	evolution	10 <sup>8</sup> t.km 1996	10 <sup>8</sup> t.km 2001	evolution
road	Dangerous goods	76	82.6	+ 8.6 %	8	8.2	+ 2.2 %
	Total freight traffic	1 727	1 987	+ 15 %	159	189	+ 18.9 %
	% of dangerous goods	4.4 %	4.15 %	<del>X</del>	5 %	4.3 %	<del>X</del>
Railway line		17.9	18.1	+ 1.1 %	6.4	5.8	- 10.1 %
Pipeline		152	157	+ 3 %	23.4	22.5	- 4 %

Figure 20. Comparison between tons of DG and freight traffic transported by different transport modalities in France, (1996-2001 and evolution), (Analyse des risques TMD, DDE42/STI/TDP, Source: Cypres).

In this work, only two types of transport, pipeline and road, are taken into account, because of their relevance in France and in Italy, as well as in Europe. The aim of this agreement is developing research in the general field of DGT to reduce risk, and to increase security and safety in transport, using also Information and Communication Technologies - ICT. So, the next two sub-chapters the DGT on road and the DGT in pipeline will be described more in detail.

### 2.2.1 Dangerous goods transported on road

In the 90<sup>s</sup>, in the U.S., there were over 500,000 shipments of DG made every day. More than 90 percent of these shipments are transported by truck on the U.S.A. highways. At any given time, 5 to 15 percent of the trucks on the road are transporting DG regulated under the HMTA of 1975 (HMTA, 2010). Almost 50 percent of these materials are gasoline and other corrosive or flammable petroleum products, and 13 percent are chemicals. The remaining shipments represent any of the 2,700 chemicals considered hazardous. In this context, in the US, each year, many companies ship over 263 million ton-miles of DG, and over 60% of that is on trucks (Cutter and August, 1997). Whereas, in European Union the percentage of DGT on road is reported by Eurostat, (Figure 21), where more than 50 percent of shipments by trucks transported flammable liquids.



**Figure 21. Dangerous goods transported by road [% tkm] - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).**

In this context, considering that the number of vehicles per km transporting DG in EU is, in average, 4800 million *veh · km* , of which 14 percent are Italian vehicles, and 13 percent France one, (Figure 22). In this two Countries the DGT quantity is comparable in terms of [million *veh · km* ] (Figure 23), and in terms of flammable liquids and gases transportation, respectively, (Figure 24) and (Figure 25). In both countries flammable liquids represent more than 50 percent of DG transported on road, while gases represent approximately 25 percent of the total DGT, (Figure 24) and (Figure 25).

Million vehicles km of GDT in EU

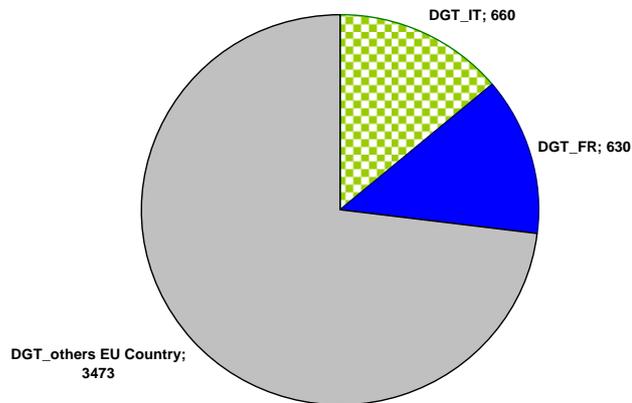


Figure 22. Dangerous goods transported on road [million *veh · km*] in European Union. Italian and France particular - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

Comparison between Italy and France

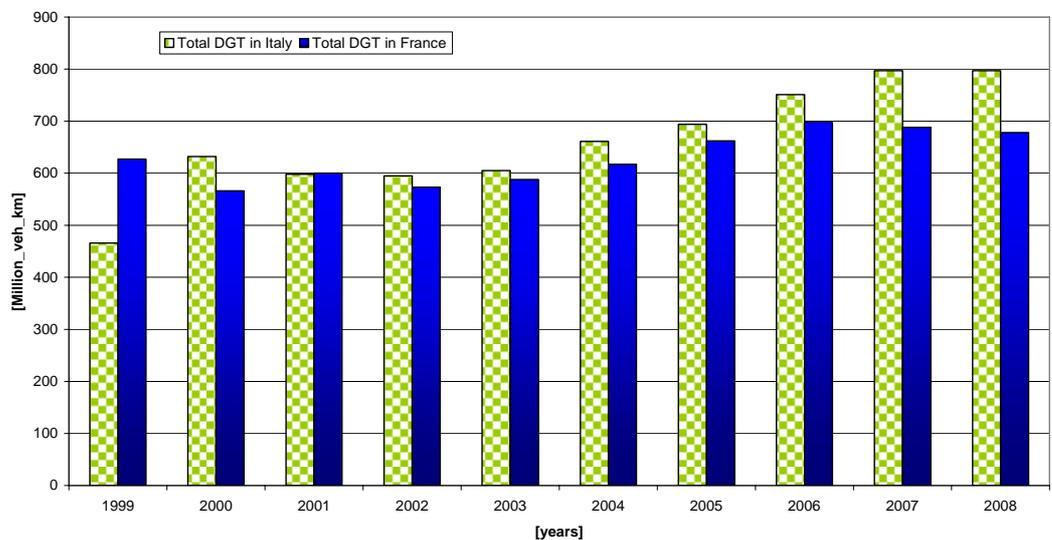


Figure 23. Dangerous goods transported on road [million *veh · km*]. Italian and France comparison in ten years data - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

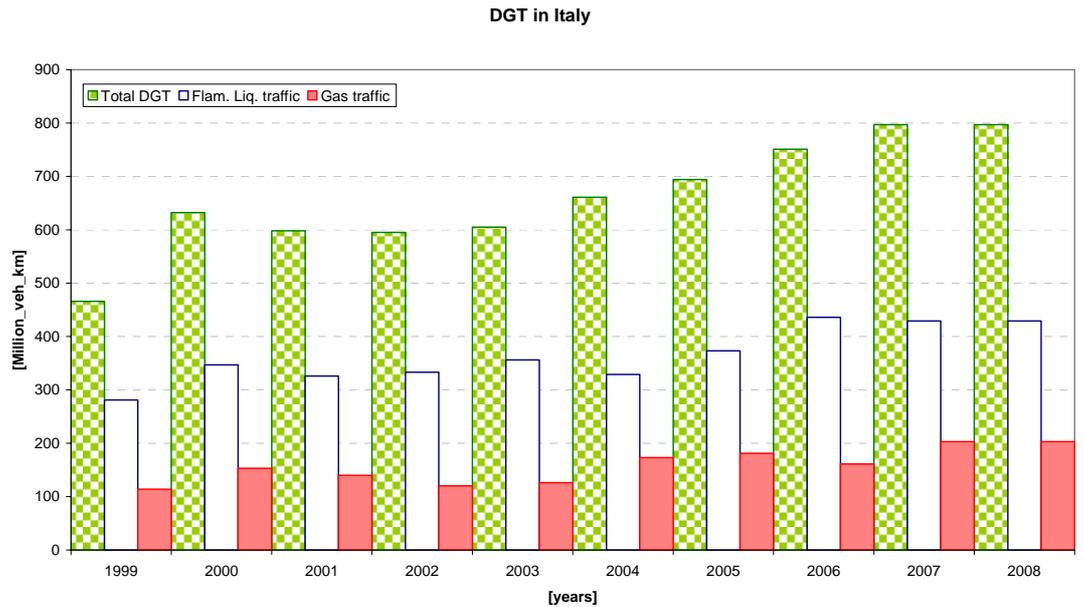


Figure 24. Comparison between the total amount of dangerous goods, flammable liquids, and gases – respectively -transported in Italy, expressed in [million *veh · km*] - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

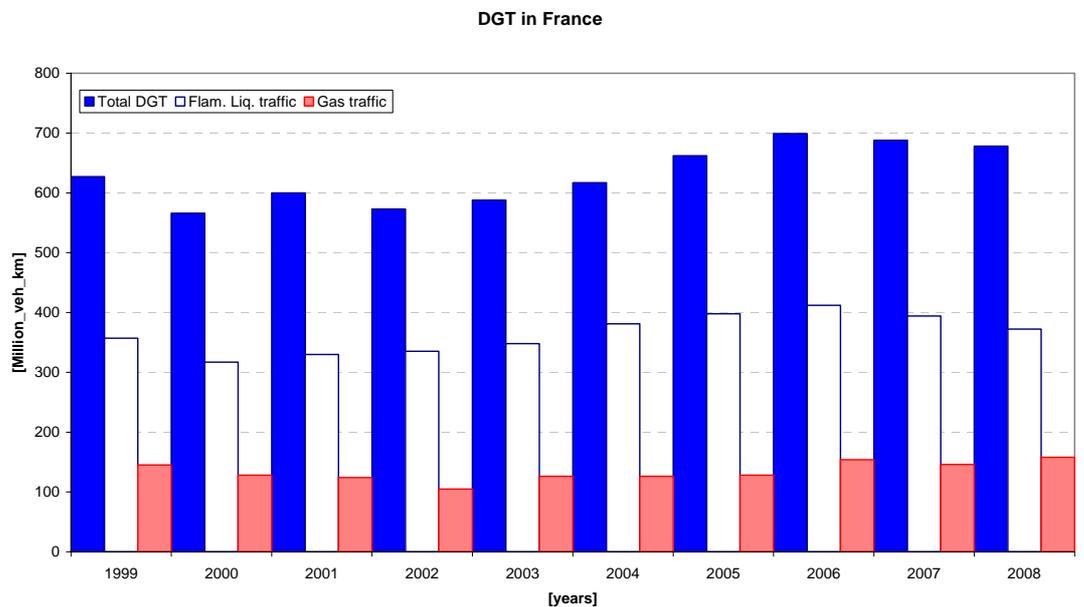


Figure 25. Comparison between the total amount of dangerous goods, flammable liquids, and gases – respectively -transported in France, expressed in [million *veh · km*] - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

In Europe, the overall trend of DGT seems to be increasing up to 30 percent in 2010 (White Paper, 2001). In Italy about 80 percent of goods is transported by this mean, with a 30 percent increase with reference to the 2010 forecast, and its 18 percent is currently represented by DGT (Fabiano *et al.*, 2005).

At present, in Italy, about 74 million tons of DG are transported annually on trucks (Carotenuto *et al.*, 2007). Indeed, more than 800 million trucks per km [*million veh.km*] travel each year on road (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity (Mio Tkm, Mio Veh-km, 1000 BTO)”, 2010), of which 200 million trucks per km representing vehicles transporting gas (Class 2 according to ADR 2009), and 450 million trucks per km representing vehicles transporting flammable liquids (Class 3 according to ADR 2009), (ADR, 2009).

Each truck transport, on average, 40 tons of product, so there are 240.000 tons per day and 90 million of tons per year of Oil product transported in Italy, and this quantity represent more than 80 percent of DGT.

The entire Italian road network has an overall length of more than 170.000 km, among which 6.500 km correspond to highways. In particular, Italian highways are very crowded with trucks, considering that 17% of the whole good traffic on road of European Union is transported on these highways (White Paper, 2001). In our Country, for example in 2005, were transported on road 78 million tons of DG, for a total of 12.000 million tons per km, where most of the goods are oil products (70 million tons, and about 9.000 million tons per km), (MIT, 2007).

The DGT by road represents two thirds of the transport of goods in France and Italy - (“Panorama of Transport”, 2009) and (“Annual road freight transport of dangerous goods, by type of dangerous goods and broken down by activity”, 2010).

DG are substances that due to their physical and chemical properties or the nature of the reactions they provoke, represent a grave danger to man, property or the environment.

According to the Ministry of the Infrastructure of French Transport (METL), more than 3000 substances circulate in the French territory. These goods are classified by the

ADR (European agreement regarding the international transport of dangerous goods by road, recently revised in 2007 and 2009) into 9 classes: goods are included in a class according to their physical-chemical characteristics, the principle type of risk they represent.

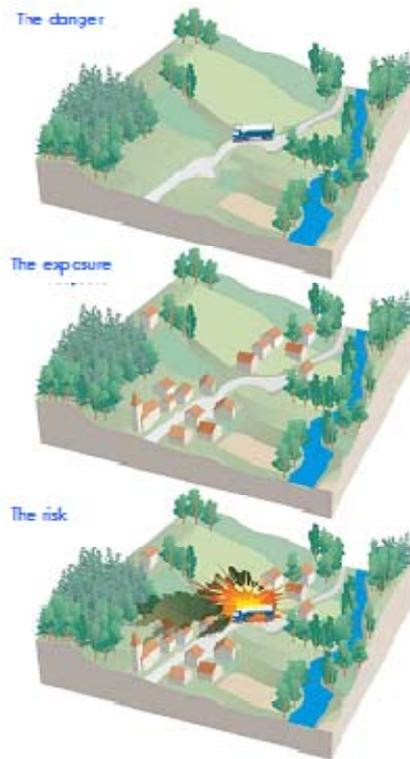
The transport of dangerous goods can be done in tankers, as unpacked goods, or packaged in cylinders or bags. There is also special packaging for radioactive and biological goods. The transport of packages, at times grouped with other types of goods, is carried out in accordance with regulation on quantity, type of package etc.

The risk attached to the transport of dangerous goods by road is a risk that is complex to understand as it is connected to all the road network and depends on multiple factors such as traffic density, weather conditions, the necessities of undesired events (road accidents, natural phenomenon etc.)

This risk is also strongly linked to the nature of the transported goods and to the presence of exposed humans and materials in proximity to the place of incident. For example, the transport of fuel such as petrol or GPL can provoke considerable fires or the explosion of the tankers in which it is transported, with heat, excess pressure and missile effects.

Other substances have toxic properties and can be the origin of toxic gas clouds in the case of leakage due to the accidental puncturing of the tanker.

On a national scale it is shown that DGT accidents on the roads make up no more than 0.1% of total accidents. But, even though this risk is minimal, the consequences are important when dangerous substances are involved. In France on the 8th September 1997, the collision between a vehicle transporting hydrocarbon and a lorry caused the deaths of 13 people and injured a further 43. In Italy on 9th February 1997 in a motorway accident a collision between a lorry transporting kerosene and a tanker caused a fire and a pile-up which resulted in 1 death and 40 injured.



**Figure 26. The risk of TDG (Source: Ministry of Ecology and Sustainable Development – France).**

Despite the high risks the public authorities and the management of the motorway and road infrastructure do not precisely know the nature, number and route of the dangerous goods transported on the territory.

The only statistics produced are the result of manual surveys carried out in various periods of the year, furthermore, carried out by different bodies such as motorway companies, territory institutions or some state services (for example the Ministry of Transport and Infrastructure). The results show that the transport of dangerous goods by road represents between 5 and 10% of the flow of goods transported by lorry.

The following table shows the statistics computed by the French motorway company ESCOTA regarding the numbers and categories of vehicle that cross the toll barrier at Ventimiglia (Italy). These figures show that around 5000 lorries pass the barrier each day and that this tendency has been on the increase for more than 20 years.

Authorised traffic between France and Italy: the Mediterranean coast (vehicles/day) [is par jour]

	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
Vintimille véhicules légers	7 221	10 236	12 350	12 349	13 132	14 325	15 231	15 569	15 549	16 993	17 781	18 261	17 831	Ventimiglia veicoli leggeri
Vintimille poids lourds	1 135	1 865	2 863	2 903	3 095	3 459	3 716	4 002	4 125	4 385	4 655	4 877	4 993	Ventimiglia veicoli pesanti

Source : Escota Fonte: Escota

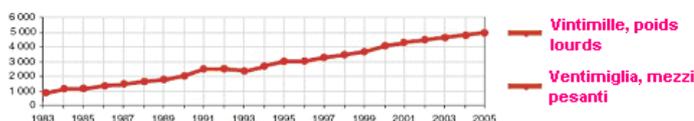


Figure 27. Calculation of the vehicles that pass the toll barrier of Ventimiglia (Italy). Data supplied by the company ESCOTA. Source: Union Routière de France.

Based on the approximation that 10% of those vehicles transport dangerous goods, the number of TDG vehicles that cross the toll barrier at Ventimiglia is around 500 vehicles per day (13,000 vehicles per month, 156,000 vehicles per year excluding the days when lorries are not allowed (Sundays)).

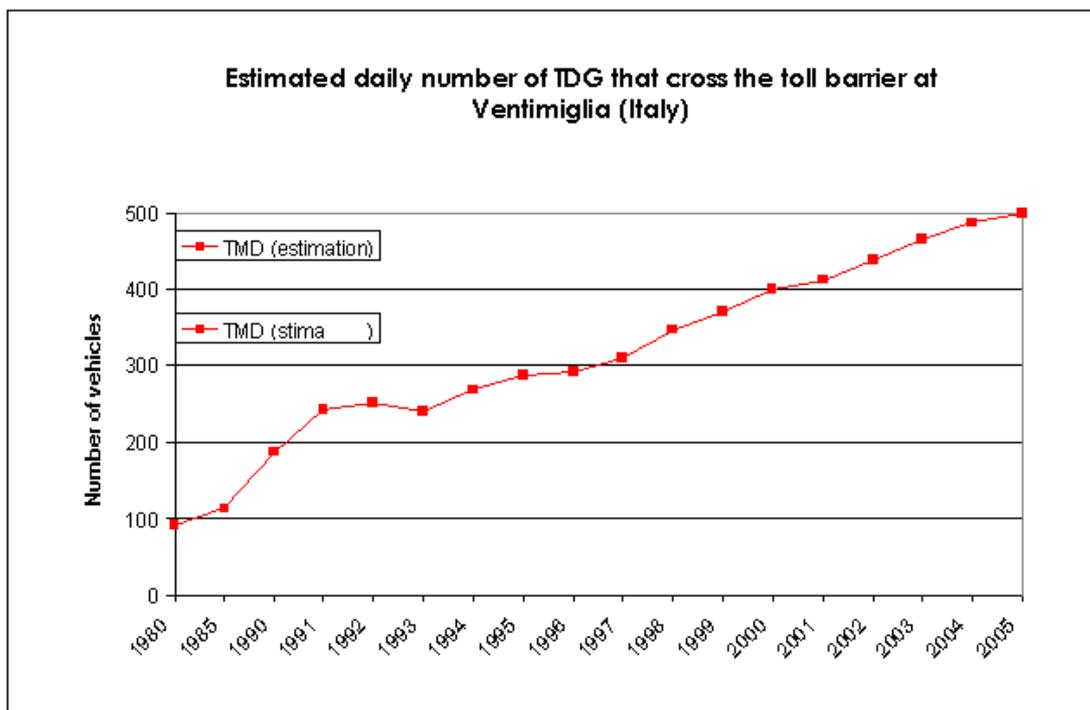


Figure 28. Number of vehicles that cross the toll barrier at Ventimiglia (Italy). Data supplied by the company ESCOTA. Source: Road Union of France.

Considering the figures for the flow of TDG vehicles in the cross-border area of Nice, Imperia and Savona, the public authorities have demonstrated their interest in the topic by supporting the TMDNIS project of which the objectives and development are to be found in this document.

	Bitumen	Petrol	Origin	Destination
	[tons]	[tons]	Sannazzaro (IT) Vado Ligure (IT)	Fos Sur Mer (FR) Imperia (IT)
Daily average	154	182		
Monthly average	886	5627		
Annual average	10626	66248		

Figure 29. Figures of the flow of the two types of dangerous goods. Indicating the origin and destination of the goods. Data supplied by the company Eni.

Class	Contents	1998		1999		2000	
		Thousands of tons	Thousands of tons per km	Thousands of tons	Thousands of tons per km	Thousands of tons	Thousands of tons per km
1	Explosive materials and objects	188	43 900	104	25 400	105	21 900
2	Petroleum gas	8 427	1 038 800	8 445	1 113 500	7 492	940 200
		7 346	875 400	7 210	917 000	6 638	771 200
3	Petroleum flammable liquids	65 465	5 932 500	72 087	6 321 700	63 889	5 613 400
		61 165	5 118 400	68 002	5 464 500	60 750	4 819 900
4.1, 4.2 et 4.3	Other flammable materials	781	141 800	433	85 400	438	71 600
5.1 et 5.2	Contents oxidizing or organic peroxides	950	121 900	825	102 900	742	130 600
6.1 et 6.2	Contents toxic or infectious	621	158 300	531	126 700	717	169 500
7	Mat. Radiative	108	5 500	5	100	51	4 800
8	Mat. corrosive	2 970	795 900	2 578	622 900	2 939	638 000
9	Dangerous contents and miscellaneous in petroleum	1 437	306 400	2 743	567 500	1 626	331 500
		890	144 900	1 652	269 100	816	193 000
ND	Unspecified class	688	62 400	211	58 700	89	20 000
TOTAL	Petroleum products	69 391	6 139 800	76 884	6 670 600	69 208	6 794 100
	Chemical products	10 252	2 200 300	8 784	2 031 600	7 787	1 893 400
	Others	2 051	269 500	2 313	322 700	2 115	274 200
	Whole DGT	81 694	8 607 400	87 961	9 025 000	79 089	7 941 600
	All road freight traffic	1 781 873	187 796 900	1 890 519	182 466 700	1 919 529	184 222 800
	% in one year (DGT/rft)	4,58%	5,13%	4,65%	4,94%	4,07%	4,31%

Figure 30. Different classes of dangerous goods transported on road and comparison with the road freight traffic in three years of data acquisition in France.

## 2.2.2 Dangerous goods transported by pipeline

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Natural gas, crude oil and petroleum products represent the main products transported by pipeline networks. The total length of European High Pressure networks for natural gas transport was approximately 200.000 km in 2003, compared to ~180.000 km in 1996 (Eurogas, 2005).

The combined traffic volume in the CONservation of Clear Air and Water in Europe (CONCAWE, the oil companies' European association for environment, health and safety in refining and distribution) system in 2001 was 130 billion cubic meters/km, of which ~70 percent was crude oil (16 percent higher than in 1994). A network of ~10.000 km pipelines convey more than 150 different DG such as: ethylene, propylene, chlorine, ammonia, hydrogen, oxygen, butadiene and styrene, (Papadakis, 1999).

In Europe, the quantity of oil transported by pipeline increased of 10 percent in 2006 compared to 2000 (Eurostat, 2008). In total, more than 500 million m<sup>3</sup> of crude oil and 300 million m<sup>3</sup> of refined products were transported by pipeline in Europe in 2006 (CONCAWE, 2008).

Based on available data, oil pipelines in the EU-27 extended to around 33.500 km in 2005, more than half the length of the motorway network for example. Compared to the estimated length in 1990, this represented an increase by about one eighth (12.8 %), ("Panorama of Transport", 2009).

However, the EU-27's density of oil pipelines of approximately 8 km per 1.000 km<sup>2</sup> is smaller when compared, for example, with that in the United States of around 26 km per 1.000 km<sup>2</sup>. The total length of the U.S.A. network was nearly eight times as long, ("Panorama of Transport", 2009).

France had the longest oil pipeline network of 5 746 km, contributing a 17 percent share of the EU-27 total. The other longest networks could be found in the United Kingdom, Italy, Spain and Romania, while pipeline length in Germany – only crude oil pipeline, Hungary and Poland also stood above 2.000 km. The length of oil pipelines in the EFTA country Norway was about 1.200 km in 2005, ("Panorama of Transport", 2009). In Italy, the overall length of pipelines for the transport of oil products is

estimated to 4179 km in 2006 (Eurostat, 2009). Finally, the world's longest oil pipeline – measuring around 4.000 km – reaches from Russia to the EU.

In France, after the accident occurred in Bondy (Seine-Saint Denis) the 30 of October 2007, the MEEDDM, taking charge of gas security policy, asks prefects for support DRIRE to make more aware the stakeholders in the prevention of such accidents and to conduct inspections of sites near the gas distribution networks, (DRIRE, Rhône-Alpes, “Sécurité des canalisations de distribution de gaz”, 3rd of July 2008). The total length of the French network of pipelines transporting DG is 50000 km distributed as follows:

- 73% for natural gas,
- 19% for petroleum products (crude oil and refined products),
- 8% for chemicals (ethylene, oxygen, nitrogen, hydrogen, ...)

Most of these pipes is buried, with the exception of the bodies necessary for their operation (pumping, compression, relaxation, sectioning, interconnection), (“Risques liés aux canalisations de transport”, MEEDDAT, 2009).

In 2007, CONCAWE reports that over 150 pipeline systems have a combined length of 34,721 km, the reported volume transported was 762 million m<sup>3</sup>, (533 million m<sup>3</sup>) of crude oil and (229 million m<sup>3</sup>) refined products, and the total volume was estimated at  $129 \cdot 10^9 \cdot m^3 \cdot km$  –  $91 \cdot 10^9 \cdot m^3 \cdot km$  for crude oil, and  $38 \cdot 10^9 \cdot m^3 \cdot km$  for products (CONCAWE, 2009).

In this study an oil pipeline, only dedicated to the transport of a very restricted group of goods (liquid oil products), is taken into account, because of the agreement between Eni and DIST. But, before going through the methodologies and methods used to evaluate risk in these two type of transport, an overview on DGT regulations, and then a risk definition framework will be introduced.

## **2.3 Regulations**

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### **2.3.1 Introduction**

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Laws and regulations on the use, loading, downloading, storing, transporting, and handling of DG may differ depending on the activity, status of the material, and modality of transport used (DGT, 2010). Most countries regulate some aspect of DG at UNECE level (UNECE, 2010), that is the most widely applied regulatory scheme. The UN Recommendations on the Transport of Dangerous Goods form the basis of several international agreements, such as UNECE regulations and many national laws (UN Recommendations on the TDG, 2002) and (UN Recommendations on the TDG, 2007).

The transport of dangerous goods is an activity which is increasingly international and multi method; the regulation involved can therefore not disregard connecting itself to international level to sustain a future integrated logistics system with multi method efficiency.

The ONU Recommendations for the transport of dangerous goods, published for the first time in 1957 and periodically updated, are the point of reference for all the laws specific to the different methods of transport (sea, air, road, railway, rivers/canals) at international, community and national level. For each method of transport the following international regulations are in place concerning dangerous goods.

ADR – for the transport of dangerous goods by road;

RID – for the international transport of dangerous goods by railway;

ADN - for the international transport of dangerous goods on internal rivers/canals;

ICAO and IATA – for transport by aeroplane;

IMDG Code – for maritime transport.

For instance, the International Civil Aviation Organization has developed regulations for air transport of DG that are based upon the UN Model but modified to accommodate unique aspects of air transport. Individual airline and governmental requirements are incorporated with this by the International Air Transport Association to produce the widely used IATA Dangerous Goods Regulations. Similarly, the International Maritime Organization has developed the International Maritime Dangerous Goods Code ("IMDG

Code", part of the International Convention for the Safety of Life at Sea) for transportation on the high seas, and the Intergovernmental Organization for International Carriage by Rail has developed the Regulations concerning the International Carriage of Dangerous Goods by Rail ("RID", part of the Convention concerning International Carriage by Rail). Many individual nations have also structured their DGT regulations to harmonize with the UN Model in organization as well as in specific requirements, (DGT, 2010).

Regulations on DGT, for instance in Canada and Australia, regard many aspects of transportation, and for this reasons are divided in tables of contents, where there are taken into account (Transportation of dangerous goods regulations, 2010) and (Best practice and internationally harmonized legislation for the land transport of dangerous goods in Australia, 2010):

- Coming into Force, Repeal, Interpretation, General Provisions and Special Cases;
- Classification;
- Documentation;
- Dangerous Goods Safety Marks;
- Means of Containment;
- Training;
- Emergency Response Assistance Plan;
- Accidental Release and Imminent Accidental Release Report Requirements;
- Road;
- Rail;
- Marine;
- Air;
- Protective Direction;
- Permit for Equivalent Level of Safety;
- Court Order;
- Inspectors.

The transport of dangerous goods by railway in Europe is subject to the RID (Regulation concerning the International transport by railway of Dangerous goods) which forms Attachment B of the COTIF convention (Convention of international transport by railway).

Due to the acknowledgement of the European Directive 96/49/CE and its updates, the RID is also applicable to the national transport of dangerous goods by railway.

The RID regulation, from the point of view of its contents, is substantially aligned to the ADR, for the way it classifies the goods, the method of transport, the package, the labelling, the recommendations etc.

Therefore it is greatly beneficial taking into consideration the growing demand of multi-method land transport with the aim of optimizing the transport both from the point of view of efficiency and safety.

The RID is divided into two main parts:

- The 1st part is dedicated to the “general limitations”;
- The 2nd part is dedicated to the “particular limitations for the various classes”.

The transport of dangerous goods by canal and river is regulated by the ADN, signed at Geneva in May 2000. This agreement, excluding the obvious differences due to the different characteristics of the method of transport, is, in terms of content, very similar to, and at times the same as, the text of the ADR and RID. For this reason there is direct reference to these regulations in particular to the parts concerning package and tankers.

The transport of dangerous goods by airplane is instead regulated by attachment 18 of the Chicago Convention concerning international civil aviation, managed by ICAO (International Civil Aviation Organization).

The regulation of reference for maritime transport is managed by IMO (International Maritime Organization) and is created from the IMDG Code (International Maritime Dangerous Goods). The IMDG Code contains the same classes of danger as the RID and ADR but contains some differences regarding the criteria of classification and the placement of goods inside a class. From the 1st August 2005, following the publication of DPR 134/2005, the IMDG code was also applied to Italian and French national transport from the 23rd November 1987.

The IMDG code is also separated into seven parts:

- Part 1: General arrangements, definitions and training of the figures involved in transport, in particular the training of coastal personnel for the risk connected to the transport of particular loads;
- Part 2: Classification of the goods;
- Part 3 and 4: Arrangements for the package and tankers;
- Part 5: Procedure of the delivery;
- Part 6: Construction and checking of the package, large containers for bulk transport, GIR, large packages, mobile tankers, containers for gas and multiple elements (CGEM) and road tanker vehicles.
- Part 7: Arrangements concerning the operation of the transport.

Currently, The EC Directive 2008/68, says that “*The ADR, RID and ADN lay down uniform rules for the safe international transport of dangerous goods. Such rules should also be extended to national transport in order to harmonise across the Community the conditions under which dangerous goods are transported and to ensure the proper functioning of the common transport market [...]. Art. 1 Scope: «1. This Directive shall apply to the transport of dangerous goods by road, by rail or by inland waterway within or between Member States, including the activities of loading and unloading, the transfer to or from another mode of transport and the stops necessitated by the circumstances of the transport. This directive establishes a common regime for all aspects of the inland transport of dangerous goods, by road, rail, and inland waterway»*, (Directive 2008/68/EC, 2010).”

This law is transposed into France execution measures, from:

- Arrêté du 29 mai 2009 relatif aux transports de marchandises dangereuses par voies terrestres (dit « arrêté TMD »);
- Arrêté du 9 décembre 2008 modifiant l’arrêté du 5 juin 2001 modifié relatif au transport des marchandises dangereuses par chemin de fer (dit « arrêté RID »);
- Arrêté du 9 décembre 2008 modifiant l’arrêté du 1er juin 2001 modifié relatif au transport de marchandises dangereuses par route (dit « arrêté ADR ») – (Source: National Execution Measures, 2010).

This law is transposed into Italian execution measures, from:

– Attuazione della direttiva 2008/68/CE, relativa al trasporto interno di merci pericolose;

– Attuazione della direttiva 2006/87/CE che fissa i requisiti tecnici per le navi della navigazione interna, come modificata dalle direttive 2006/137/CE, 2008/59/CE, 2008/68/CE e 2008/87/CE - (Source: National Execution Measures, 2010).

These execution measures are transposed into Italian law, with a National Legislative Decree, 27/01/10, No. 35, and it is applicable from 12/03/10.

### **2.3.2 Dangerous goods transported by pipeline**

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There is no international agreement about pipeline regulations, and many Countries in the world have no laws and regulations for the pipeline transportation.

In the US, pipelines are regulated by the Pipeline and Hazardous Materials Safety Administration (PHMSA). Offshore pipelines are regulated by the Minerals Management Service (MMS). In Canada, pipelines are regulated by either the provincial regulators or, if they cross provincial boundaries or the Canada/US border, by the National Energy Board (NEB) (Pipeline transportation, 2010).

The U.S.A. are the most well-advanced Country on the pipeline regulations. Indeed, the pipeline safety regulations are collected in the Code of Federal Regulations (CFR), Title 49 Parts 190 to 199, called “Transportation”; where, in Subtitle B, Chapter I, Subchapter D, are taken into account in a table of contents the following headings (CFR, 2010):

- pipeline safety programs and rulemaking procedures;
- transportation of natural and other gas by pipeline; annual reports, incident reports, and safety-related condition reports;
- transportation of natural and other gas by pipeline: minimum federal safety standards;
- liquefied natural gas facilities: federal safety standards;
- response plans for onshore oil pipelines;
- transportation of hazardous liquids by pipeline;
- regulations for grants to aid state pipeline safety programs;
- drug and alcohol testing.

In addition, first of all the “Pipeline inspection, protection, enforcement, and safety act of 2006” gives much more information about inspection, protection, enforcement, and safety in terms of technical and operational characteristics for pipelines (“Pipeline inspection, protection, enforcement, and safety act of 2006”, 2010). Secondly, the Federal Energy Regulatory Commission (FERC) includes (FERC – Regulation Oil Pipelines, 2010):

- regulation of rates and practices of oil pipeline companies engaged in interstate transportation;
- establishment of equal service conditions to provide shippers with equal access to pipeline transportation;
- establishment of reasonable rates for transporting petroleum and petroleum products by pipeline.

In Europe, Switzerland has a federal law for the gas and oil pipeline (CH federal law, LITC1, 2010), and an Executive Decree on the plants and pipeline carrying gaseous and liquid fuels (CH pipeline, 2010). In France, not only the European standards EN 1594 and EN 14161 are adopted for the safety of dangerous substances transported in pipelines; but also the “Arrêté du 4 août 2006” (INERIS, 2010). This decree regulates the safety of gas, liquid or liquefied hydrocarbons and chemicals fuels transportation in pipelines. This Order sets out minimum requirements for the design, construction, operation and shutdown, temporary or permanent pipelines transporting gas fuels, of liquid or liquefied hydrocarbons and chemicals to preserve the safety of persons and property and protect the environment. The main laws and regulations are divided by type of substance:

- Natural gas: «Décret n° 85-1108 du 15 octobre 1985 modifié et décret n° 70-492 du 11 juin 1970 modifié» ;
- Hydrocarbons: «Décret n° 59-998 du 14 août 1959 modifié, décret n°59-645 du 16 mai 1959 modifié, et décret n° 89-788 du 24 octobre 1989 modifié»;
- Chemical products: «Décret n° 65-881 du 18 octobre 1965 modifié».

Where the regulations collect a multiplicity of materials, liquid or gas, the texts are harmonised:

- Décret n° 91-1147 du 14 octobre 1991 modifié relatif à l'exécution de travaux à proximité de certains ouvrages souterrains, aériens ou subaquatiques de transport ou de distribution;
- Arrêté du 4 août 2006 portant règlement de la sécurité des canalisations de transport de gaz combustibles, d'hydrocarbures liquides ou liquéfiés et de produits chimiques;
- Circulaire du 4 août 2006 relative au porter à connaissance à fournir dans le cadre de l'établissement des documents d'urbanisme en matière de canalisations de transport de matières dangereuses.

### **2.3.3 Dangerous goods transported by road**

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The Hazardous Materials Transportation Act of 1975 (HMTA) is the major transportation-related statute regulating the transportation of DG. In 1990, Congress enacted the Hazardous Materials Transportation Uniform Safety Act (HMTUSA). Like the HMTA, the HMTUSA requires the Secretary of Transportation to promulgate regulations for the safe transport of hazardous material in intrastate and foreign commerce (Panwhar et al., 2000).

The Federal Hazardous Material Transportation Law (October 1994) states that “The secretary of transportation shall design material (including explosive material, radioactive material, etiologic agent, flammable or combustible liquid or solid, poison, oxidizing or corrosive material, and compressed gas) or a group or class of materials as hazardous when the secretary decides that transporting the material in commerce in a particular amount may pose an unreasonable risk to health and safety or property” (Frank et al., 2000).

The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) is the main regulation on DG transport on road. ADR has been written at Geneva on 30 September 1957 under the auspices of the United Nations Economic Commission for Europe, and it came into force on 29 January 1968. The Agreement itself was modified by the Protocol amending article 14 approved at New York on 21 August 1975, which entered into force on 19 April 1985 (ADR, 2009). The ADR was approved by law in Italy on 12th August 1962 n. 1839 and in France with act n. 60 – 794 on 22nd June 1960.

A set of new Amendments came into force on 1 January 2005, and consequently, a third consolidated "restructured" version was published as document ECE/TRANS/175, Vol. I and II (ADR 2005). Really, the ADR 2007 is almost ready effective. After gaining experience with the implementation of the early Seveso Directive (Council Directive of 24 June 1982), the Seveso II Directive (Directive 96/82/EC) was issued in 1996 (Council Directive of 9 December 1996) as a legislative framework in the European Union for the control of major accident hazards in fixed installations. Each member country, by adopting the Directive, establishes a national legislative and regulatory framework for risk management (Contini et al., 2000).

The Agreement itself is short and simple. The key article is the second, which says that apart from some excessively dangerous goods, other dangerous goods may be carried internationally in road vehicles subject to compliance with:

the conditions laid down in Annex A for the goods in question, in particular as regards their packaging and labelling; and

the conditions laid down in Annex B, in particular as regards the construction, equipment and operation of the vehicle carrying the goods in question.

In ADR appear the limitations applicable to the various operators of the logistics chain (buyers, transporters, manufacturers of packaging and tankers etc.) giving specific treatment to their field of interest, ordered in Parts 1 to 9 with attachment regulations A and B.

The regulation topics of law ADR are:

- The method of identification of dangerous goods,
- The lists of dangerous goods permitted transport on the roads,
- The modality regarding transport, type of packaging and the connected approval tests,
- The planning and construction of the tankers,
- The checks and the recognition of technical suitability of the vehicles used to transport the dangerous goods,
- The training and recognition of the vehicle drivers.

The ADR imposes that, except for some excessively dangerous goods, that the dangerous goods can be transported at an international scale on road vehicles that conform to:

- Conditions regarding package and labelling (attachment A);
- Conditions regarding the construction characteristics of the equipment and the installation of the vehicles (attachment B).

The ADR agreement is updated every two years and with Directive 2006/89/CE of 3rd November 2006 (GU of the European Union L305 of the 4/11/2006), the 2007 edition was acknowledged and became effective from 1st January 2007.

The attachments of ADR are separated into 9 parts:

#### ATTACHMENT A:

Part 1: general arrangement;

Part 2: classification;

Part 3: list of the dangerous goods, special placements, exemptions connected to the dangerous goods packed in limited quantities;

Part 4: arrangement connected to the use of the packaging and tankers;

Part 5: transport procedure;

Part 6: limitations connected to the construction of the packaging, large containers for bulk transport (GIR), large packaging and tankers and the tests which they must sustain;

Part 7: arrangement concerning the conditions of transport, the loading, the unloading and the movement.

#### ATTACHMENT B

Part 8: limitations connected to equipment, gear, the running of the vehicles and the documentation;

Part 9: limitations connected to the construction and approval of the vehicles.

An important change has been made with the modification of paragraph 1.10 in 2005. A paragraph has been added which cites the arrangements concerning safety which must be taken into account by every person involved in the transport of dangerous goods. In this chapter the transporters and all others involved in the transport of dangerous goods at high risk are required to adopt, carry out and follow a safety plan.

This must include:

- Specific roles of responsibility in the matter of safety;
- The recording of the dangerous goods in question and their typology;
- The monitoring of the vehicles;
- Definition of the measures to adopt to reduce the safety risks;
- Efficient procedures to identify and face threats, safety violations and incidents connected to safety;
- Procedure of evaluation and verification of the safety plans;
- Measures to assure the physical protection of information connected to the transport contained in the safety plan;
- Measures to assure that the distribution of information connected to the transport operation, contained in the safety plan, is limited according to necessity.

Furthermore, it is foreseen that vehicles that DGT must be installed with devices, equipment and other protection systems for protection from the theft of the vehicle or the load, and therefore guaranteeing both security and safety.

The use of a system of data transmission or other method of following the movement of the goods is proposed, if the device is installed and deemed useful. With the stipulation of ADR the **Kemler Code** was also introduced, representing a method of identification coding for dangerous substances transported by road and railway.

Through the reading and decoding of this code, in the case of an incident, it is possible to deduct the following information:

- Potential harm to the health of the people involved and/or first-aiders;
- The minimum equipment advised for the protection of the first-aiders;
- Precautions to take while waiting for the arrival of the Fire Brigade.

In accordance with this code two types of sign must be attached to the vehicles which transport dangerous goods:

A code of danger sign: of a rectangular shape (30 cm x 40 cm, readable also after a fire of no more than 15 minutes) containing in the upper part the code of danger, of two or three figures, and on the lower part the code of the substance transported (ONU number), of four figures, as shown in the following example:



**Figure 31. Example of a code of danger sign for dangerous goods, in accordance with the Kemler code.**

Ticket: of a square shape, displayed on a vertex, with different colours and with different pictographs indicating the type of danger based on the substances transported (minimum dimensions 25cm x 25cm). The following is an example for the transport of flammable liquid:



**Figure 32. Example of a ticket for dangerous goods in accordance with the Kemler code.**

In attachment A of the previous edition ADR 2007 particular relevance is given to the topic of training for the operators in the transport of dangerous goods, safety obligations and control and support measures for these figures and the confirmation of the need for a new professional role of “safety consultant”.

Annexes A and B have been regularly amended and updated since the entry into force of ADR. The last amendments entered into force on 1 January 2009, and consequently, a revised consolidated version was published as document ECE/TRANS/202, Vol.I and II ("ADR 2009").

Class	Type of dangerous goods	Hazard label
1	Explosive substances and articles	
2	Gases	
3	Flammable liquids	
4.1	Flammable solids, self-reactive substances and solid desensitized explosives	
4.2	Substances liable to spontaneous combustion	
4.3	Substances which, in contact with water, emit flammable gases	
5.1	Oxidizing substances	
5.2	Organic peroxides	
6.1	Toxic substances	
6.2	Infectious substances	
7	Radioactive material	
8	Corrosive substances	
9	Miscellaneous dangerous substances and articles	

Figure 33. DG classification on the bases of type of DG and hazard label (ADR, 2009).

In the transport of dangerous goods the problem is how to optimize transport and distribution, minimizing the risk of accident. So, not only ADR 2009, but also national regulation, such as Italian National Legislative Decree No. 286, and applications from the 21.11.2005, and the other Italian National Legislative Decree No. 214, and applications from 22.12.2008, and “Decreto interministeriale 30 giugno 2009 pubblicato sulla G.U. 153 del 30 giugno 2009 - Circolare esplicativa Ministero dell’Interno e Ministero dei trasporti del 19 luglio 2009” need to be implemented and modify to improve safety and security. Also the laws on road traffic control could be update in monitoring and control actions and administrative and penal sanctions (Directive 2004/112/CE).

Regulations are essential to prevent not only risk, but also to reduce hazard. After this explanation in locate each low in different countries and for different type of transport, what is important regard the control and the low application. Such technical regulations need a continuous fitting to satisfy the DGT requirements, but always taking into account safety and security. On the other hand, in risk definition, technical regulations are a fundamental part in the decisional level and management, and also in defining methodologies, the regulation represents constraints in model formalization.



### 3 Risk definition

“Risk is defined as a measure of frequency and severity of harm due to a hazard”. “The hazard in our context is the presence of DG having toxic, explosive, and/or flammable characteristics with the potential to cause harm to humans (and property or the environment if a broader context is considered). In the context of public safety, risk is commonly characterized by fatalities (and injury) to members of the public”, (Risk Assessment – Recommended Practices for Municipalities and Industry, 2010).

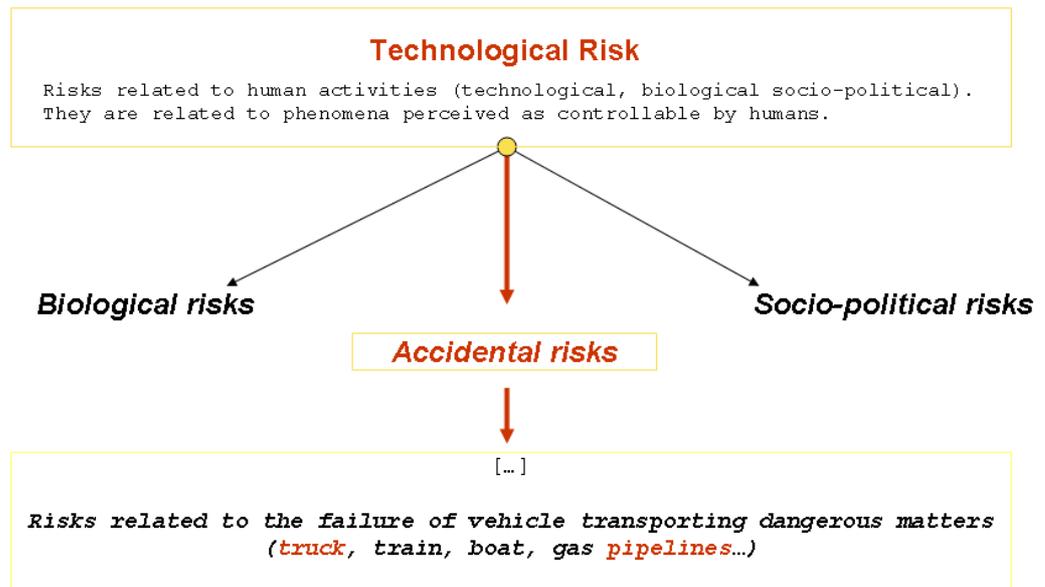


Figure 34. Risk definition and its classification.

Several factors contribute to making it difficult - to assess risk in transporting DG - including:

- the diversity of hazards: the substances transported are multiple and can be flammable, toxic, explosive, corrosive or radioactive materials;
- diversity of accident sites: highways, county roads, local roads, in or out of town (75% of road accidents take place in open country), facilities, pipelines, etc;
- Diversity of causes: failure mode of transport, containment, human error, etc., («Le transport de marchandises dangereuses», Prim.net, 2010).

Risk of DGT could be classified and identified into three types:

- **a close risk**: when the risk is near a facility subject to a specific response plan (this facility generates the bulk of the DGT flow);

- **a diffuse risk:** the risk is spread over the entire road network, rail and river;
- **a linear risk:** this risk is plainly and easily identifiable, and for example in France, it is listed in various documents, («Le transport de marchandises dangereuses», Prim.net, 2010).

### 3.1 Risk definition introduction

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When the transport network crosses heavily populated areas, a large number of persons could be affected by an accident such as a toxic spill or an explosion (Leonelli *et al.*, 1999). There is a substantial difference between incident and accident. “The accident begins with an incident” (Crowl *et al.*, 2007). An incident is defined as an event involving the transportation of DG that results in an unanticipated cost to the shipper, carrier or any other party. It is, also, defined as “the loss of containment or control of material or energy”; “most incidents are followed by a series of events that propagate the accident” (Crowl *et al.*, 2007).

An accident is an event that occurs and fires, explosions, and toxic releases could be included (Battelle, 2001). The accident in DGT can be related to high consequence and low frequency risks (Cozzani, 2007), and (Bell, 2006). Transportation risks are relevant to the occurring of sudden events, generally characterized by a low probability of occurrence, even though they can give rise to extreme impacts on population, goods, services, and environment (Beroggi and Wollace, 1998).

### 3.2 DGT risk by pipeline

Generally, pipeline transport risk is defined as the product of the probability of leakage or bursting and the related magnitude (Muhlbauer, 1996). Moreover, in this context, an accident is classified according to the probability that a loss (or release), a hole or a rupture can occur in a pipe (Cooke, 2002). So, in a quantitative risk analysis, safety and security must be evaluated by decision makers and planners both analytically and statistically, developing a quantitative estimation of risk in terms of mathematical techniques and engineering evaluation for estimating not only incident consequences, but also frequencies. Indeed, risk is also a “measure of human injury, environmental damage or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury” (Crowl *et al.*, 2007).

The risk along a pipeline is not a static component, but it changes continuously. Through the pipeline path, the boundary conditions are changeable, and the type of incident changes as much as the boundary conditions change. So, before assessing the risk it is better to find an answer to these three questions:

- What kind of incident might happen, and what are their causes? – Hazards detection;
- How probable an incident is? – causes of accident and frequency inspection;
- What are the consequences on humans and environment? – Intensity, damage distances, impact areas, exposed elements vulnerability, (Muhlbauer, 1996).

To assess the risk, then analyse and estimate the level of risk of accidents, in Dziubinski *et al.*, (2006), three different methods (Figure 35): qualitative, semi-quantitative and quantitative are defined. The semi-quantitative methods are applied to identify hazards and to select the so-called incidental events reasonably foreseeable ("credible failure events").

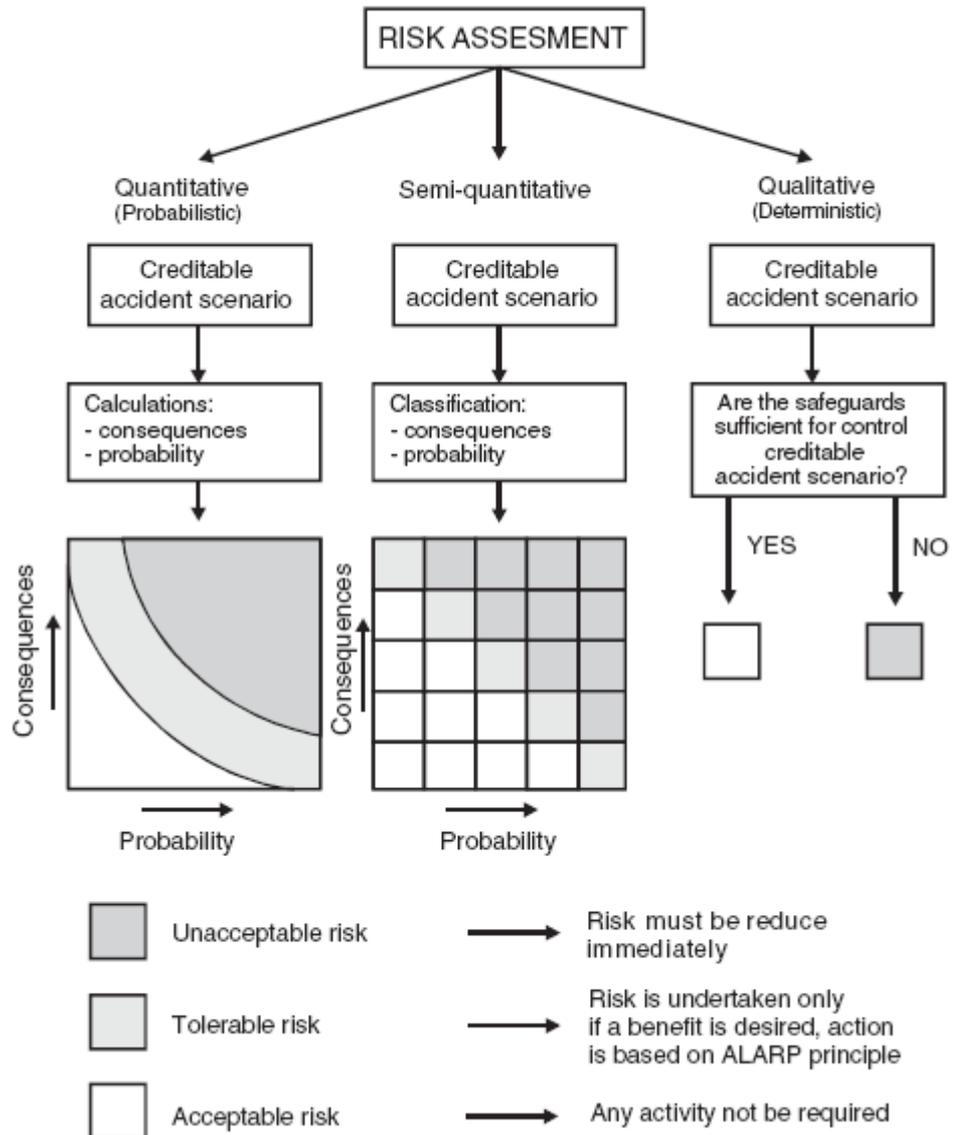


Figure 35. Methods of risk assessment.

Qualitative methods are used mainly in the validation of safety standards with regard to legal rules on the pipeline transport behaviour. These rules are usually considered as a minimum requirement that must be used to achieve certain levels of acceptable safety. However, for pipelines of great length, it is often necessary that the risk assessment is undertaken using a quantitative analysis, based on the concept of probabilistic risk. The quantitative assessment of risk is complex and involves a series of analysis and calculations, using many simulation models, particularly the physical analysis of the effects.

Another classification of methods for the definition of risk is proposed by Canadian Standards Association, (2001), as shown in Figure 36.

Method	Description
1. Risk Matrix	Qualitative estimates of frequency and consequence are expressed separately and combinations are presented in a two-dimensional risk matrix
2a. Semi-quantitative Risk Index	Factors that influence frequency and consequence are assigned values and mathematically combined, usually through summation
2b. Quantitative Risk Index	Factors that influence frequency and consequence are assigned values that, when combined through multiplication, give an estimate of failure probability and risk
3. Probabilistic Risk Analysis	Failure frequencies and consequences are estimated quantitatively and combined using probability theory

**Figure 36. Methods for estimating the risk – Canadian Standard Association, 2001.**

Some authors (Dziubinski *et al.*, 2006) suggest a methodology that includes a sequence of analysis and calculations to determine the main reasons of failure of a pipeline and the related possible consequences, taking into account the Individual and Societal Risk (Ale, 1991). A specific feature of this methodology is therefore the combination of qualitative techniques (analysis of historical data, compliance tests, and assigning a score on the risk of accidents) and the quantitative definition of the state of security for the transportation pipeline. A general outline of the proposed methodology is as follows (Figure 38)

This methodology takes into account the main factors for risk definition:

- Technical features of the pipeline;
- Sources of risk detection;
- Historical data analysis about incident and near-miss;
- Compliance tests;
- List of the possible accidental events;
- Definition of the layer of protection analysis (LOPA);
- Definition of the accidental events frequency;
- Consequences assessment (Figure 37).

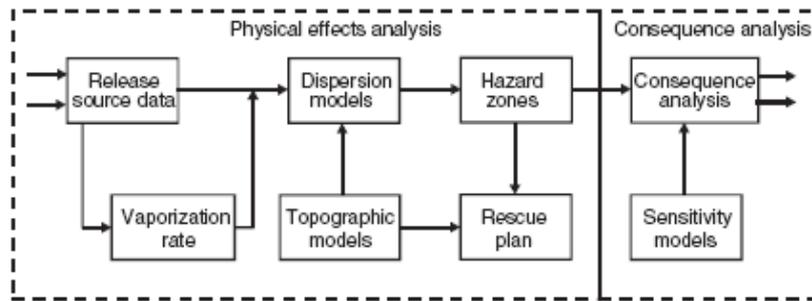


Figure 37. Model architecture for assessing and evaluating – computing - the potential consequences.

The type of event and the relative consequences depend on the different factors, such as the spill source location, the quantity of release, the state of the system, the process conditions, the release modalities, and finally the boundary conditions (Guidelines for Ecological Risk Assessment, 1998). The effects analysis is shown in Figure 37.

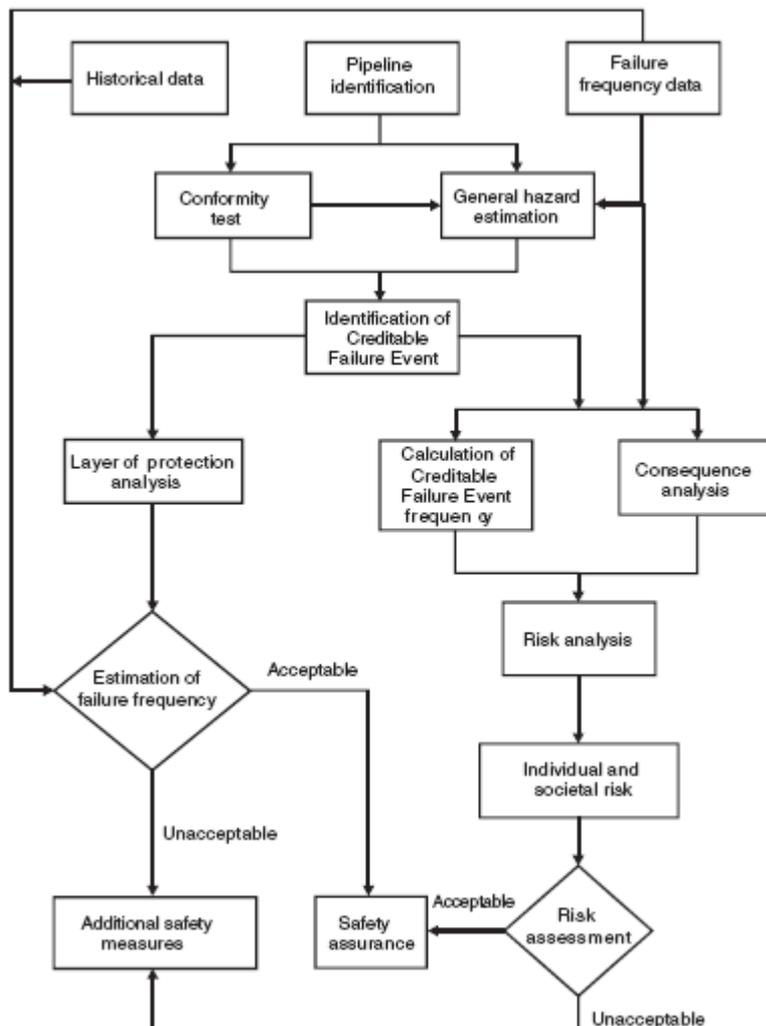
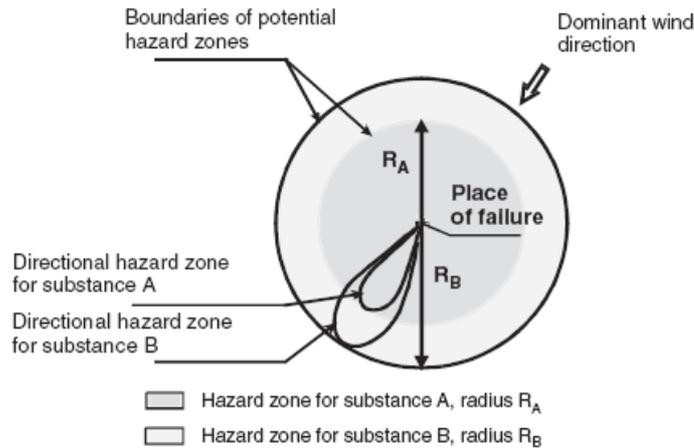


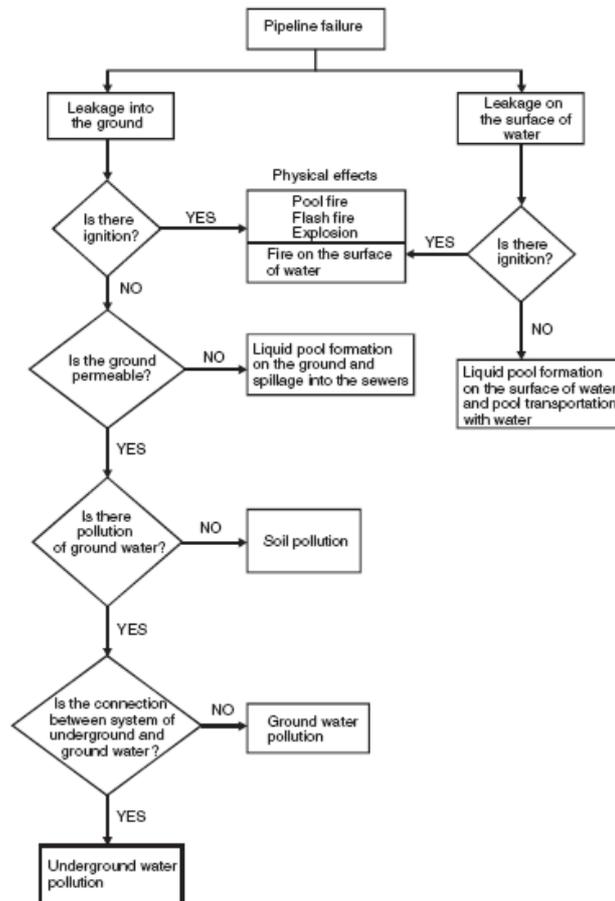
Figure 38. Methodologies for risk assessment in long pipelines.

For an event of blast or explosion - an overpressure – and for a thermal radiation – a fire – the overall standard is to define circular areas, with a distance radius equal to the value of the threat zone (critical range). In the case of toxic or flammable substances, without explosion, the threat zone area depends on the wind direction, as shown in Figure 39.



**Figure 39. Potential hazard zone, defined after an accidental release of a dangerous goods into the air.**

A diagram for the environmental risk definition is shown in Figure 40. The risk is caused by a dangerous good release in a specific point of the pipeline. The possible consequences depend on, not only the pipeline construction and characteristics, but also by the boundary conditions, such as type of soil, river crossing, elements in the vicinity of the pipeline, and so on. On the bases of historical data, (HSE, Contract Research Report 210, 1999), the explosion likelihood - when a crude oil release happens - is relatively low: the 96 percent of releases of petrol, or diesel oil, produce no one explosion.



**Figure 40. General diagram that formalize the environmental consequences caused by a pipeline failure or rupture.**

The article of Romano *et al.* (2008) shows the methodology used to conduct risk analysis on pipelines carrying flammable substances and involving several elements exposed along the territory. The pipeline is considered transporting liquid, but the proposed methodology is also applicable to pipelines carrying gaseous fluids. Risk analysis has been developed considering different types of statistical and historical ruptures, using the CONCAWE database for determining the frequency of occurrence of the incidental hypotheses. The accident scenarios considered have also determined the effectiveness of leakage detection, acting on the definition of response times and repairing time that the damage has caused as a result of spillage or release. The study has examined two configurations: the first consists of an analysis of risk without considering the action of the leak-detection system, while the second considers the presence and effectiveness of the detection system losses. The results show a reduction of the consequences of accident scenarios considered, given the reduction in the time of intervention and therefore the quantity of dangerous fluid released. The results of risk

analysis have determined a safe distance that should be respected in order to give the authorization by the local authorities for the construction of buildings, palaces, houses, commercial areas and other elements potentially exposed, (Romano *et al.*, 2008).

### **3.3 DGT risk by road**

Several methods can be found in literature to assess risk derived from dangerous goods transport (DGT). In particular, the risk associated to accidents involving DG shipments have attracted considerable attention by researchers and practitioners.

Risk derived from DG may derived from two type of sources:

- Industrial fixed installations
- Transport of dangerous goods, (Tixier, 2002).

Transportation risk can be considered at various levels. What is the probability of an accident on a road segment? What is the average DG trucks flow in the same road segment? Research is still going on in this direction to find answers to these questions. Several researchers have tried to provide sound quantitative definitions about transportation risk.

The accident is not only dependent on DG, as above explained, but also on the truck by which DG is transported. Each truck route has an origin and one, or more than one, destinations; thus, a transportation route can simply be viewed as a risk source on a segment constituted by a great number of (moving) point risk sources. Furthermore, in a corridor along the route, through the linear risk source, there are people living, in areas with different density population (Leonelli *et al.*, 1999). For this reason, the characterizations of the transportation network, of the vehicles carrying DG and of the potential impact areas are of fundamental importance for transportation risk assessment.

First of all, transportation risk falls within the area of technological risk. In fact, it refers to accidents that may arise in systems closely related to human activities. In general, an accident is an unplanned event or series of events which causes or has the potentiality to cause injury to people and/or damage to property and/or equipment. For the U.S. Department of transportation an accident is an accident involving a moving vehicle. It includes collisions with a vehicle, object, or person (except suicides) and derailment/left roadway, producing unintended injury, death or property damage. Accident refers to the event, not the result of the event (U.S. DOT, 2010).

Lassarre *et al.*, (2001), analysed the progress in road safety using a classic model based on a decreasing exponential form of the rate of fatalities per [ *vehicles · km* ], for ten different European Countries. He realized that the traffic each year is increasing maintaining the number of fatalities constant.

In this connection, equity in DG routing and designing safer networks for DG transport are viable approaches to reduce the DG transport risk. However, a fundamental requirement for route design is the assessment of the risk imposed by shipments traversing each link in a network (Zografos *et al.*, 2000). Shipments of DG, not only by road but also by rail, expose the population near the routes to the possibility of an accident resulting in a spill (Glickman *et al.*, 2007).

For instance, an analysis of the available UK data on road accidents involving tankers containing DG showed that releases could occur from two sources: firstly by puncture or rupture following collision or, secondly, from failure of the tanker equipment. For instance, 25 accidents were found over a four year period, for road transportation in UK. Analysis of these data yielded a spill frequency of  $1.4 \times 10^{-8}$  per loaded tanker km for large spills (>1500 kg) from collisions, and  $0.7 \times 10^{-8}$  per loaded tanker km for large spills (>1500 kg) arising out of equipment failure, (Purdy, 1993).

According to Suchman, (Suchman, 1961), an event can be classified as an accident if it is unexpected, unavoidable, and unintended. What's more, accidents involving DG can be broadly categorized into two major groups: fixed installation accidents and transportation accidents. The major hazards with which the DGT is concerned are DG releases (spills), or fires (thermo release), and explosions (pressure release). Spill is the most common, but explosion is more significant in terms of its damage potential, often leading to fatalities and damage to property (Khan and Abbasi (b), 1999).

In general, risk definitions include a term related to the probability of the hazard (UNESCO, 1972), and a term related to the strength of the effects on the elements that are in the geographic and temporal neighbourhood of the event. These two terms may be also adequate to the risk definition of DGT, taking into account that the probability of an

event and its magnitude are time/space varying, since they are subject to several external/internal time/space varying factors.

Particularly, Current and Ratick, (1995), assert that DG management system must consider the cost and risk associated with the transportation of DG as well as those associated with the facilities that generate, process, or dispose such materials, being the two aspects of the problem strictly correlated.

Leonelli *et al.*, (1999), indicate that risk assessment is typically structured as a process resulting from the interaction among (a) the transportation network, (b) the vehicles or travelling risk source and (c) the impact area. The same author, in a further paper, define the individual risk as corresponding to the yearly death frequency of an average person permanently staying, without protective devices, at a fixed point of the impact area. Then, they define a social risk, as corresponding to the cumulated frequency of having an accident with one or more fatalities, (Leonelli *et al.*, 2000).

Zhang *et al.*, (2000), consider risks that affect human populations by airborne contaminants, defining this risk as the product of the probability of an undesirable consequence (such as injury, illness, or death) and the population affected. The author structure the evaluation procedure into three stages: (a) determining the probability of an undesirable event, (b) estimating the level of potential exposure, given the nature of the event, and (c) estimating the magnitude of consequences (fatalities, injuries and property damages) given the level of exposure.

Frank *et al.*, (2000), discusses several strategies that may be followed in order to mitigate risk. First of all, a careful choice of the route can reduce the probability of an accident. Besides, choosing a route passing through less populated areas reduces the number of people exposed to high risk. Next, vehicle and container design could be modified, in order to reduce the severity of a release once an accident has occurred. Finally, accident probability could also be reduced by an improved driver training.

Serafini, (2006), highlights that the travelling of DG has raised the problem of determining vehicle routes minimizing not only the length (related to cost and/or time), but also the risk of damages caused by accidents. Indeed, two quantities are typically

involved in the assessment of the risk associated to a certain route. First, the probability of accident occurrence on a certain route link, and, second, the cost incurred in case of accident on that link.

In this connection, Akgün *et al.*, (2007) underline that weather conditions dynamically affect the accident probabilities, as well as the costs involved.

Despite such significant contributions, at the moment, in the literature, a well established definition of DGT risk can not be found. On the other hand, the literature in this field is growing and deepening the various issues related to transportation risk. Thus, it is realistic to assume that, in a very short time, a common framework could be set as regards DGT risk assessment, as regards its evaluation and quantification, as well as the development of strategies allowing this risk and/or the mitigation of its impacts.

On the other hand, the analysis and management of risk of major accidents in transport activities involving DG is a subject not completely clear, since there are not universally accepted definition and classifications. As a matter of fact, the research on DG transport risk has still many open issues, and is still in a rapid evolution phase.

In Italy,  $168 \times 10^3$  accidents per year occur on the roads, where  $18 \times 10^3$  are related to trucks in general reference. The truck accident frequency is  $1.8 \times 10^{-7}$  [accident/year\* km], (Fabiano *et al.*, 2002). However, such information refers to heavy traffic accidents and not specifically to DG tracks. What we know about DG accident frequency in Italy is not enough in comparison with other countries. We know that spill probability during DG pick up and delivery is  $1.4 \times 10^{-4}$ . Moreover, the probability that a spill causes a pool fire is  $1.4 \times 10^{-5}$  with a radius of impact equal to 20÷35 m (depending on the quantity of spill) and a thermo release of 12.5 kw/m<sup>2</sup>. In addition, the probability that a spill causes a UVCE (Unconfined Vapor Cloud Explosion) is  $1.4 \times 10^{-7}$  with a radius of impact equal to 20÷91 m (depending on the quantity of spill) and a pressure release of 0.3 bar (Khan and Abbasi (b), 1999), (Khan and Abbasi (a), 1999), and (Khan and Abbasi, 2000).

So, in which way the risk assessment has been analyzed? One of the first approaches related to risk assessment regards the article of Abkowitz and Cheng, (1988), in which a Risk/Cost Framework for routing truck movements of DG had been developed.

The main idea of this study was firstly, representing accurately the risk in transport, secondly, defining a framework for this type of system, then designing a permanent set the shipping routes based on optimizing across risk and cost, and finally estimating risk and uncertainty.

In this approach the movement of DG differs from fixed facility risks because of its dynamic nature of exposure to the population and environment along routes of travel. Moreover, risk assessment involves not only determining the frequencies and consequences of undesirable events, but also evaluating the associated risk in quantitative terms, (Glickman, 1991). In any case, risk assessment is typically structured as a sequential process:

- beginning with understanding the level of involvement;
- the frequency and type of incident occurrence;
- finally, the consequence for a given incident.

In this sub sequential approach no systematic procedure has emerged, because the risk assessment is characterized as a quantitative one, and it is based on historical data or data available. So, if there is a lack of data the risk assessment is compromised, if there is a great amount of historical data the risk assessment is particularly accurate. On the other hand, the purpose of the risk assessment and the preferences of the analyst could also vary the quantification of risk.

There are many methods to estimate risk. Expressing risk as a single measure is the simplest way to do that, but it does not provide as much information as a risk profile. A risk profile is a probability distribution of incident likelihood and severity. The shape of the risk profile particularly helps in distinguishing between high-probability/low-consequences events and low-probability/high-consequence events.

The estimated consequences of an incident involving a shipment of DG depend on a variety of factors, such as:

- the amount released;
- toxicity of the chemical;
- health effects;
- population and environment exposed;
- Weather conditions at the time of the incident.

Estimated the consequences of an incident, in general, there are two types of damages, as the result from the consequent impact of material spill:

- Direct damages;
- Indirect damages.

Direct damages are damages to individuals, who are directly involved in an incident or properties damaged during the incident, while, damages to individuals residing in the vicinity of the incident site, or for example ecological effects, are indirect damages. To estimate the indirect damages it is useful determine the area of exposure. The length of this area, in others words the impact radius, depends on:

- the material;
- severity of spill;
- Weather conditions present at the time of incident.

But, in general the determination of indirect damages is the most difficult task to reach, as a matter of fact, environmental effects include:

- release into air;
- surface water;
- Groundwater.

Erkut and Verter, (1995) considered the approach proposed by Abkowitz and Cheng, (1988) to talk about how to estimate the probability of an incident. Generally speaking, traffic accidents are the main cause of unintentional DG releases during transport. In the context of DGT, risk refers to the likelihood of incurring the undesirable consequences of a possible release event. The probability considered by Erkut and Verter, (1995), is an incident probability, reasonably assumed as a constant value over segments, since road characteristics are uniform within each segment. This probability takes into account three types of probability definitions:

- Probability of an accident [per unit distance movement].
- Probability of an incident given an accident on road segment  $s$  during transport of material. In others words it is the product of the probability of the release of material  $m$ , given an accident at road segment  $s$ , and the probability of an incident, given the release of material  $m$ .

But how estimate this kind of probability?

If historical data is available, it is possible to use the statistical inference to infer future expectations. Actually, the existing data and observed data are usually insufficient,

so it is impossible to estimate directly the condition of a release and the incident probability. In order to overwhelm this gap logical diagrams, like fault trees and event trees can be used.

In any case, these techniques need basic events, in others words, sufficient historical data or expert judgments, to be able to estimate the probability of an event on the basis of the probability of a set of basic events.

Then, another aspect of the probability evaluation is to estimate the probability of the consequences of interest occurring after an accident. This is a task usually difficult to reach.

Also in the approach of Zhang *et al.*, (2000), the target to reach is to assess the potential risk imposed by shipments traversing each link in a network. All the subjects involved in DG transport, such as shippers, DG producers, governments and communities are held to reduce the potential negative impact of this kind of transport. The principal reason is that all the dangerous goods could be, by definition, extremely harmful to environment and to human health. It is follows that transporting dangerous materials is also inevitable not only in populated areas but also through environmentally sensible areas. So, Zhang *et al.*, (2000), assessed the risk of DG, using a traditional method, which was imposed on human population by such airborne contaminants, considering the area impacted and the number of persons involved.

In the literature there are many others approaches to assess risk. Some authors consider possible to apply a Quantitative Risk Assessment to the DGT.

Scenna, and Santa Cruz, (2007), said that the five components of a Quantitative Risk Analysis for transport of DG are:

- involvement of a dangerous vehicle in an accident;
- breakage occurrence and characteristics (type, size, etc);
- release occurrence;
- calculation of Individual Risk and Societal Risk for each segment of the road;
- calculation of the risk distribution over a given area for each scenario.

In this study a road risk analysis has been applied due to the transport of chlorine in Rosario city. The case study shows what are the potential consequences and the catastrophic accidents involving dangerous goods along a road; where the most important indicator for consequence calculation is the population density and the most

probable hazardous event is the toxic gas cloud diffusion. This study was encouraged by the municipal government agency.

Ronza *et al.*, (2007), used transport accident data bases to investigate ignition and explosion probability of flammable spills. They defined a Quantitative Risk Analysis to determine Individual and Societal Risk in or around an area characterized by certain activities to which accident scenarios can be associated. They based their analysis on event trees method to assess the risk of DG spill and blast scenario. They calculated the probability of occurrence for events, such as, spill ignition and blast formation.

Brown, and Dunn, (2007), applied a Quantitative Risk Assessment Method to define emergency response planning. Firstly, they collected data from past accidents, which were characterized by statistical analysis of historical DG accident data. Secondly, they described how to apply QRA to societal risk estimation (societal impact analysis), routing optimization and container safety optimization. Finally, they developed a risk assessment method for evaluating consequence distributions associated with DGT, where the range of consequences depends on:

- local weather conditions;
- population density;

Specific attributes of the spill itself. They used a physical model for describe DG releases.

The variables take into account in this work are:

- variability in container type;
- incident type;
- accident severity (release amount);
- location;
- time of day;
- time of year;
- meteorology.

Also in this approach total risk for many of these materials is greatly influenced by low-probability/high-consequence events.

For the definition of risk, strictly links to risk perception and acceptability, as introduced in Chapter number one, the distinction of the following two indicators is fundamental: the individual risk and the social risk.

The individual risk is defined as the probability in a year that an exposed person, positioned at a precise distance to the source of risk, is hit by the undesired effects of the event (Ale, 1991). This is formally defined by the following expression:

$$IR = P_f \cdot P_{d|f} \quad (3.1)$$

where:

$P_f$  is the probability of accident happening;

$P_{d|f}$  is the probability of death of the individual if the accident happened.

The individual risk is graphically represented by a curve at the same risk, (isorisk curve), which links points with identical values of individual risk.

The social risk is instead defined, (Ale, 1991), as the relationship that exists between the number of people affected (killed) following a single accident (N) and the probability (F) that the number of people affected is exceeded.

The most convenient representation of the social risk is the F-N curve; this curve, expressed in log scale and characterised by the monotonous upwards trend, represents the frequency (F) of accidents and the number (N) of victims with N varying from 1 to the maximum possible number.

There are two general methods for the construction of the F-N curve: the first is to calculate the F-N curve directly from the empirical frequency of the data of passed accidents; the second is to develop and use a probabilistic model to estimate the frequency (F).

The indicators of individual and social risk, initially defined by fixed installation and then for precise source of risk, can extend to the road arches and then the linear sources, even if with notable computational effort (Leonelli *et al*, 2000).

To calculate the F-N curve associated with each arch it is in fact necessary to know information such as: the number of journeys per year, the frequency of accidents (F). the probability that a particular accident happens, the dimensions of the area potentially involved in the accident and the population density in the area under examination.

The approach proposed by Pastorino *et al.*,(2002) is therefore innovative as the frequency of an accident on the i-esimo stretch can be expressed by the following equations:

$$f_i = \gamma_i L_i n_i \quad (3.2)$$

$$\gamma_i = \gamma_0 \prod_{j=1}^6 h_j \quad (3.3)$$

where:

$\gamma_i$  = frequency expected on the i-esimo stretch of road [accidents km-1 per vehicle]

$L_i$  = road length [km]

$n_i$  = number of vehicles [vehicles]

$\gamma_0$  = basic frequency [accidents km-1 per vehicle]

$h_i$  = parameters of amplification / local mitigation

In their study the authors proposed gauging the parameters of the amplification and mitigation, for a stretch of the A7 motorway near Genoa. They were subdivided into 6 categories; in particular h1 and h2 refer to geometric characteristics of the road, h3 to the type of roadway, h4 to the weather conditions, h5 to the type and intensity of traffic, h6 to the presence or not of tunnels and bridges.

Intrinsic characteristics	h1	h2	h3	h6
Direct road	1			
Curve of the road (distance > 200m)	1,3			
Curve of the road (distance < 200m)	2,2			
Level road		1		
Ascending road (gradient < 5%)		1,1		
Steeply ascending road (gradient > 5%)		1,2		
Descending road (gradient < 5%)		1,3		
Steeply descending road (gradient > 5%)		1,5		
Two lanes for every roadway			1,8	
Two lanes plus the emergency lane for every roadway			1,2	
Three lanes plus the emergency lane for every roadway			0,8	
Tunnel				0,8
Bridge				1,2

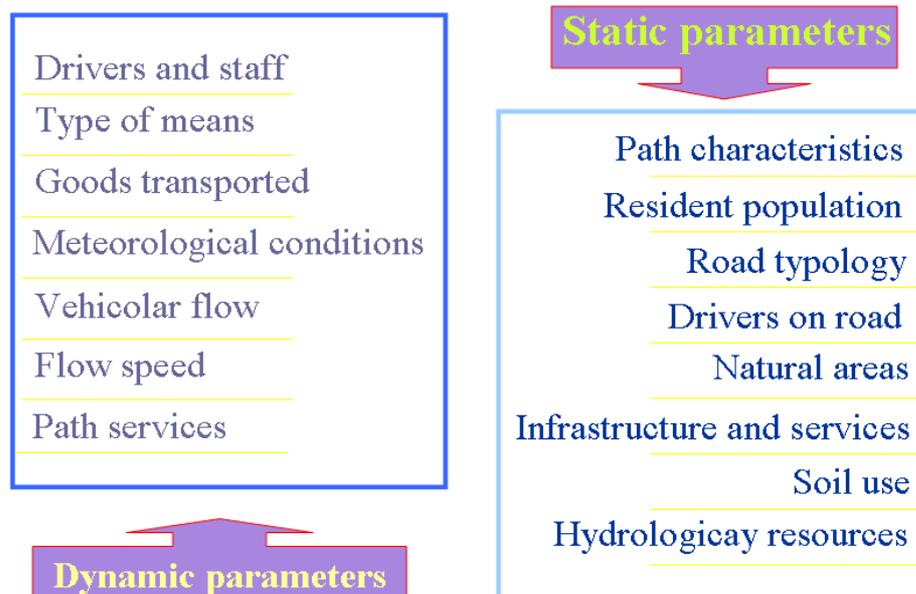
**Table 5. Factors interrelated to the intrinsic characteristics of the road.**

Weather Conditions	h4
Fine weather	1
Rain/fog	1,5
Snow/ice	2,5

**Table 6. Factors interrelated to the weather conditions.**

Traffic Characteristics	h5
Low intensity < 500 vehicles/hours	0,8
Medium intensity < 1250 vehicles/hour with heavy traffic < 125 lorries per day	1
High intensity > 1250 vehicles/hour	1,4
High intensity < 1250 vehicles/hour with heavy traffic > 250 lorries per day	2,4

**Table 7. Factors interrelated to the characteristics of traffic on the A7 motorway.**



**Figure 41. Dynamic and static parameters involved in risk definition.**

Another approach, based on the calculation of the population, is that of Carotenuto *et al.*, (2007). The authors, in this work, consider unitary segments of risk, or rather each road arch is subdivided in segments of unitary length. Assuming furthermore that the risk is connected to a segment of unitary length  $x$ , belonging to a generic arch, and to the population, that resides in the proximity of the segment next to the unitary length  $y$ . The risk is defined as the product between the probability, per unitary length, that is verified as an accident in segment  $x$  and the consequences of that accident for the population that lives in the proximity of segment  $y$ :

$$\sigma_x^y = P_x \cdot pop_y \cdot e^{-\alpha[d(x,y)]^2} \quad (3.4)$$

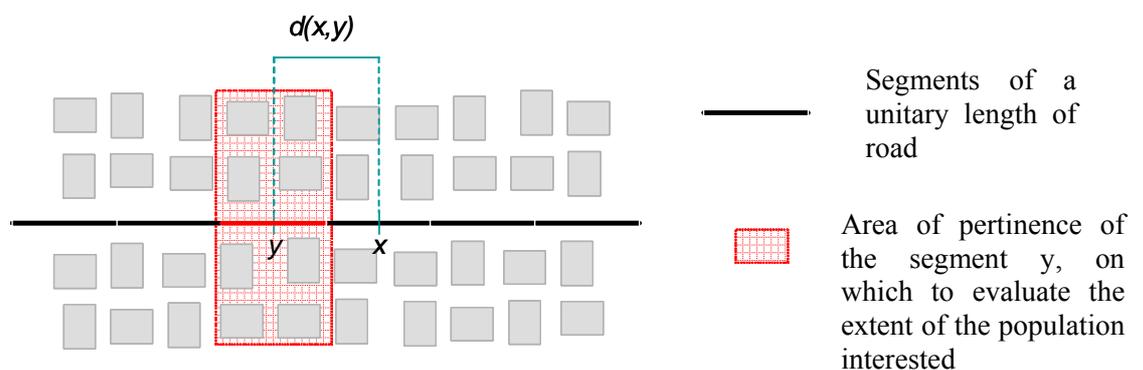
where:

$P_x$  = probability that an accident happens in the stretch of unitary length  $x$

$pop_y$  = population in the proximity of the segment of unitary length  $y$

$d(x, y)$  = euclidean distance between the centre of the 2 segments  $x$  and  $y$  of unitary length

$\alpha$  = factor of impact, dependent on the particular dangerous goods considered.



**Figure 42. Representation of the area of pertinence of a segment and the distance between the centres of the two different segments.**

The risk  $\sigma_x$  associated to segment  $x$  for the population that lives in proximity to the arch considered can be evaluated by the comparison:

$$\sigma_x = P_x \sum_{y \in S} pop_y \cdot e^{-\alpha[d(x,y)]^2} \quad (3.5)$$

where S is the combination of the segments of unitary length that make up the entire network under consideration. At this point the risk associated to the arch can be calculated as the sum of the risk associated to each segment of unitary length that makes up the same arch, and therefore:

$$r_h = \sum_{x=1}^{q_h} \sigma_x \quad (3.6)$$

Therefore combining the definition of the frequency of accidents, calculated using the approach of Pastorino, with that of the population involved proposed by Carotenuto, a complete definition of risk associated with a road arch is obtained. This solution is displayed in the following figure:

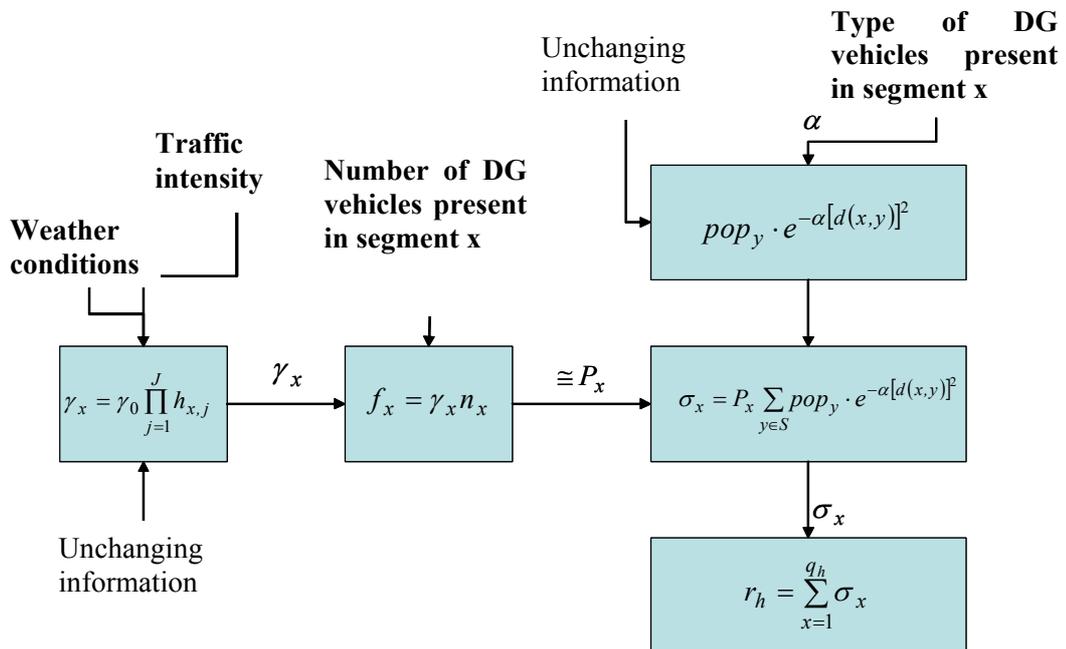


Figure 43. Summary diagram regarding the definition of risk in the transport of dangerous goods relative to a h arch.

This last risk definition – shown in the previous scheme (Figure 43) - is one of the results of project n. 176 titled “Definition, planning and prototype creation of an information distribution system, the monitoring and the management of the transport of

dangerous goods by road aimed at the strengthening of the security measures of the transport infrastructure cross-border area of Nice – Imperia – Savona” of the programme InterregIIIA - Alcotra ([www.interreg-alcotra.org](http://www.interreg-alcotra.org)).

### **3.4 Monitoring a DGT vehicle – state of the art**

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The first applications in Italy in the telly-control of vehicles that transport dangerous goods, an activity foreseen in the recent modifications of the ADR, were carried out in the ReLaMP and SIMAGE projects.

The first, supported by Regione Liguria and set up by Filse (Finanziaria Ligure per lo Sviluppo Economico) in partnership with Elsig and Set Italia, was developed with the help of the Ministry of the Environment and is based on a system that plans the itinerary for the vehicles’ journeys thanks to a combination of territory data and data from the telly-control of the vehicles during the transport. The aim of the project was to supply an efficient product to support the Fire Brigade, Traffic Police and other authorities in case of emergency, supplying useful data for giving aid.

SIMAGE instead, is a programme between the Italian Ministry of the Environment and the Joint Research Centre of the European Community (JRC), that consists in putting into practice a pilot system for the monitoring and management, in case of accident, of the transport of dangerous goods throughout the Italian territory and in particular the provinces of Taranto, Brindisi and Porto Marghera. The main objectives of the system are:

- (a) to construct and install an information system for the monitoring in real time of the vehicles that transport dangerous goods;
- (b) to supply alarm signals to the authorized authorities in case of emergency;
- (c) to supply functionality in risk management;
- (d) to supply an estimate in real time of the vulnerability in the territory;
- (e) to validate the system through the installation of a significant number of data transmission sensors operating simultaneously.

The definition of the typology characteristics and the vulnerability of the infrastructure network and the relative flows of traffic assume great importance in the analysis of risk in the transport of dangerous goods.

On this subject the work finished in 2006, by Maja, Studer, Rainoldi *et al.* of the Politecnico di Milano in collaboration with the Ministry of Infrastructure and Transport, is interesting. It regards the definition of the origin – destination itineraries, of great interest for the analysis of risk applied to the region of Lombardia. The objective of the study was to individuate, among all available itineraries, that with the most interesting telly-control of the vehicles used for the transport of refinery products, aimed at minimizing the risk connected to that transport. After the first phase of geographic aggregation of data, carried out for the analysed origins (Rho-Pero and Sannazzaro de Burgundi) and for each goods category transported (petrol/oil and GPL), the social risk for each route was calculated, defined as the relationship between the frequency of an accidental event and the number of deaths which followed, represented graphically with curve F-N (Ale, 2002). Comparing the results obtained with the established threshold, three classes of risk are defined:

- Not interesting: the social risk curve does not exceed the threshold;
- Interesting: the social risk curve slightly exceeds the threshold;
- Very interesting: the social risk curve greatly exceeds the threshold.

This allowed to obtain the thematic maps in which the arches are differently coloured according to the level of risk which it characterises.

Another objective of the work was to define four operational levels of alarm of the anomaly detected by the telly-control and, for each of them, an operative protocol to apply in case of a detected emergency.

In France, different studies based on the integration of information supplied by the transport companies and public authorities have been carried out on a national, regional, departmental and local scale. In particular two of these have caught our attention, connected to the types of transport of dangerous materials:

1. Data collection relative to the definition of the TDG flow in Provence-Alpes-Côte d'Azur (PACA) carried out by DRIRE PACA (Direction Régionale de l'Industrie, de la recherche et de l'Environnement), CYPRES (Centre d'information du Public pour la

Prévention des Risques industriels et la Protection de l'environnement), DRE PACA (Direction Régionale de l'Équipement) and the Prefecture PACA. This activity set out to collect information on dangerous goods transported, the quantity, destinations and itineraries etc. in order to prevent the risk of TDG accidents and for preparation of crisis management. The information is collected starting from the interested companies and in the administration. A large part of this data is available on the website CYPRES, from the GIS interface.

2. The GLOBAL project regards the global evaluation of the technological risks connected to the transport and storage of dangerous goods. This project, carried out by CIRANO of Ecole Polytechnique de Montréal and INERIS (Institut National de l'Environnement Industriel et des Risques), tries to define and propose a method of evaluation of risk in all the logistics chain integrating Quantitative Risk Assessment and the aspects connected to costs, professional risk, impact on the environment etc.

### ***3.5 DGT risk definition comments and comparison***

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At the end of Chapter 3 about risk definition, one thing is clear, that there is not only one way to define risk in DGT.

The general assumption that DGT risk is define as the product between probability of accident occurrence and magnitude of its consequences is generally accepted by all the Authors mentioned in this chapter. Then, both road and pipeline transportation are characterised as accidental risks, strictly related to technological risk definition.

Both risks are dynamic, because of their dependency from dynamic parameters and variables, and they can be define as linear risk, because of the shape of infrastructure used to transport. The causes of accident can be different, but the possible outcomes to an accident are the same: explosion, fire, release of substance. Therefore, the models and methods used to quantify the threat zone area are the same, in term of boundary conditions, (wind direction, atmospheric condition, chemical and physical parameter considered, etc.), and in term of levels of concern.

There are also some differences. Each risk evaluation model is an ad hoc risk description. This depends not only on the targets that the decision makers want to reach, but also on the type and quantity of substances involved (different case by case), the amount of elements exposed (different area by area considered), and the boundary conditions considered.

In this two type of transport we can apply various approaches - a qualitative one, or a semi-quantitative one, or a quantitative one - to define risk, using all the techniques described in Chapter 1 to assess DGT risk. So, a continuous approach or a discrete approach could be investigated to define quantitatively or qualitatively the risk.

In this PhD work, considering and taking my stand on all the literature on risk definition reported before, I have developed, and tested the risk definition reported in project n. 176, that represent a new, but reasonable approach to define risk in a quantitative way, consider not only static parameter, but also dynamic variables. Data considered in the risk formulation represent a realistic description of the DGT system studied.

The risk algorithm can be implemented in real time, using real time data deriving from meteorological information, motorway traffic condition, and also other static parameters, such as infrastructure geometry, population density, and many others. The value of risk resulted by the computational analysis can be compare with the limit of acceptability defined in the Netherlands, reported in Chapter one, so each segment of road can be identified by a color. Three are the colors considered:

- Red if the risk is unacceptable;
- Yellow if the risk is acceptable, adopting measure for its reduction;
- Green if risk is acceptable.

Regarding different aspects of risk definition the publications that follows are related to my work in this field, during my PhD studies:

- E. Garbolino, A. M. Tomasoni, E. Trasforini (2007). “Chapitre 3 / Capitolo 3 – Aspects méthodologiques du risque de transport de marchandises dangereuses sur route / Aspetti metodologici del rischio legato al trasporto di merci pericolose su strada” in “LIVRE BLANC/LIBRO BIANCO, Modèle technologique et

méthodologique de référence pour le contrôle et le suivi du trafic de matières dangereuses sur route sur l'axe Nice-Imperia-Savona/Modello tecnologico e metodologico di riferimento per il controllo ed il monitoraggio del traffico di merci pericolose su strada sull'asse Nizza-Imperia-Savona”, Eds C.Bersani, E. Garbolino, R. Sacile, DIST – UNIGE Septembre/Settembre 2007 – ISBN – 978-88-901 344-4-9.

- E., Garbolino, A. M. Tomasoni, E. Trasforini (2008). “Assessment of Risk and Accident Impacts related to dangerous Goods Transport in a Dense Urbanized Area” in “Advanced Technologies and Methodologies for Risk Management in the Global Transport of Dangerous Goods”, Eds C.Bersani, A. Boulmakoul, E. Garbolino, R. Sacile, NATO Science for Peace and Security Series - E: Human and Societal Dynamics (ISSN 1874-6276) Volume 45 ISBN 978-1-58603-899-1. Amsterdam: IOS Press, 2008.
- C. Bersani, R. Minciardi, R. Sacile, A. M. Tomasoni, E. Trasforini (2008). “An Integrated System for the Hazardous Material Transport in a Sub-Regional Scale Area” in “Advanced Technologies and Methodologies for Risk Management in the Global Transport of Dangerous Goods”, Eds C.Bersani, A. Boulmakoul, E. Garbolino, R. Sacile, NATO Science for Peace and Security Series - E: Human and Societal Dynamics (ISSN 1874-6276) Volume 45 ISBN 978-1-58603-899-1. Amsterdam: IOS Press, 2008.
- Davide Giglio, Roberto Sacile, Riccardo Minciardi, Roberto Rudari, Angela Tomasoni, Domenico Pizzorni, Eva Trasforini. Towards A Decision Support System for Real Time Risk Assessment of Hazardous Material Transport on Road, in: Pahi-Wosti, C., Schmidt, S., Rizzoli, A. E., Rizzoli, Jakeman, A. J. (eds). Proceedings of the iEMSS Second Biennial Meeting: "Complexity and Integrated Resources Management ". International Environmental Modelling and Software Society, Osnabrück, Germany, June 2004. CD ROM. Internet: <http://www.iemss.org/iemss2004/sessions/all.html#S11>, ISBN 88-900787-1-5.



## 4 Accident occurrence evaluation in the pipeline transport of dangerous goods

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A pipeline is a complex system, geographically spread on a wide territory, requiring technologies and methodologies to support the identification of pipeline segments that are highly potentially at risk of failure. This Chapter 4 tackles a dual problem: to describe the most significant causes that may lead to a pipeline segment failure; to evaluate the occurrence of these causes leading to a failure, according to technical characteristics of the pipeline, infrastructures, territorial elements, and land use activities in the pipeline neighbourhood. This analysis constitutes the methodological basis to implement a Geographic Information System to support decisions as regards risk analysis and land planning criteria.

### 4.1 Introduction

Natural gas, crude oil and petroleum products represent the main products transported by pipeline networks. The total length of European High Pressure networks for natural gas transport was approximately 200,000 km in 2003, compared to ~180,000 km in 1996 (Eurogas, 2005). The combined traffic volume in the CONservatio of Clear Air and Water in Europe (CONCAWE, the oil companies' European association for environment, health and safety in refining and distribution) system in 2001 was 131 billion cubic meters/km, of which ~70 % was crude oil (16 % higher than in 1994). A network of ~10, 000 km pipelines convey more than 150 different DG such as: ethylene, propylene, chlorine, ammonia, hydrogen, oxygen, butadiene and styrene, (Papadakis, 1999).

In Europe, the quantity of oil transported by pipeline increased of 10% in 2006 compared to 2000 (Eurostat, 2008). In total, 526 Mm<sup>3</sup> of crude oil and 279 Mm<sup>3</sup> of refined products were transported by pipeline in Europe in 2006 (CONCAWE, 2008). In Italy, the overall length of pipelines for the transport of oil products is estimated to 4179 km in 2006 (Eurostat, 2009).

Generally, pipeline transport risk is defined as the product of the probability of leakage or bursting and the related magnitude (Muhlbauer, 1996). Moreover, in this context, an accident is classified according to the probability that a loss (or release), a

hole or a rupture can occur in a pipe (Cooke *et al.*, 2002). So, in a quantitative risk analysis, safety and security must be evaluated by decision makers and planners both analytically and statistically.

In this chapter, the problem is to evaluate the occurrence of a failure in a pipeline. From a statistical point of view, the main issue is represented by the collection and analysis of data about accidental events occurred in similar pipeline over the years taking into account information relevant to construction and operation elements, and various technological, operative and environmental features of the selected pipes. This statistical analysis is a hard task due to the fact that, auspiciously, pipeline failures are extremely rare events.

Hereinafter, the main types of accidents in a pipeline are described, as well as the main factors that directly or indirectly may lead to them. Then, a methodological approach based on Artificial Neural Networks and preliminary results are shown for the case of accidents due to third parties activities.

## **4.2**     *Types of accident*

Several types of accidents have been identified by the gas and oil pipeline industry in the past according to US Department of Transportation (DOT) Office of Pipeline Safety, 1991 and CONCAWE 1996 (Papadakis, 1999).

They are most frequently classified in five cause categories:

- **Third parties activities**, that represent a damage caused by operations carried out by others in the pipeline vicinity and not related to its management;
- **Corrosion**, when pipeline is subject to two types of corrosion, the first one is an inside corrosion, derived from water or other substances transported with hydrocarbons (viscosity and temperature are crucial information for the accident analysis), the second one is an outside corrosion related to the pipe coating and cathodic protection;
- **Mechanical failure**, that are fractures or cracks that occur when efforts go beyond the efforts of the system permits;
- **Operational error**, which are caused by excessive pressure or system malfunction;

– **Natural events** such as landslides, floods, erosion in general, subsidence, earthquakes, frost or lightning.

On the bases of CONCAWE (CONCAWE, 2008), and DOT statistics (U.S. DOT, 2009), in a time period of twenty five years data (1971-1996) the cause of accident can be classified as follows (Table 8):

	CONCAWE[%]	DOT[%]
Third Parties	33	34
Corrosion	30	33
Mechanical	25	18
Operational Errors	7	2.5
Natural Events	4	4.5
Others	1	8

**Table 8. Relevant causes leading to an accident or failure and their percentage.**

In this work, three causes of accident (corrosion, mechanical, third parties) have been taken into account, first of all, since the percentages from CONCAWE and DOT are comparable and because the sum of their percentage value (88% for CONCAWE and 85% for DOT) has a statistical significance.

### **4.3 Factors leading to an accident**

Several works present in the literature (among others Cooke *et al.*, 2002, Mazzucchelli *et al.*, 1999 and Muhlbauer, 1996) have analyzed the factors that may lead, either directly or indirectly, to a pipeline failure and to a related accident. These factors can be grouped into three main subsets: hydrological, anthropogenic, and technical factors. The first table, (Table 8) reported above describes what factors are leading to hydro geological, anthropogenic or technical factors, the second table, (Table 9), shows the factors which are mainly related to a pipeline failure respectively for corrosion, mechanical, third parties causes (Mazzucchelli at al., 1999).

Hydrogeological factors	Anthropogenic factors	Technical factors
1. Crossing of rivers	1.Land use (six classes):	1. Operating pressure (bar)

2. Groundwater depth	- Farmland: grass, crops	2. Diameter (inch)
3. Zone of landslide	- Farmland: trees	3. Wall thickness (mm)
4. Lithology divided in four classes:	- Woodland	4. Burial depth (meter)
-Bedrock;	- Quarries & bare ground	5. (MAOP)Maximum available operating pressure (bar)
-Weathered rock;	- Urban areas	6. Specified Minimum Yield Strength (SMYS) (bar)
-Alluvial coarse deposits;	2.Population density (habitants/km <sup>2</sup> )	7. Year of construction
-Alluvial fine deposits;	3. Street crossing	8. Kind o f metal jointPIG data
5. Soil permeability divided in four classes:	4. Railways crossing	9. (FRS)Index to identify imperfection severity.
-A: Deep sands and rapidly permeable gravel, with very little silt and clay;	5.Sewage systems crossing	Imperfections significant for FRS> 0,9
-B: Mostly sandy soils less deep and aggregated than A;	6. Aqueduct crossing	10. Number of internal and external imperfections of the Tube.
-C: Shallow soils and soil containing considerable clay and colloids;	7.Electrical system crossing	11. Absence of metal in the imperfections of the tube.
-D: Mostly clays of high swelling percentage and/or with nearly impermeable sub-horizons near the surface.	8.Other utilities crossing.	

**Table 9. Main factors leading to a cause of accident.**

Causes	Hydro geological factors	Anthropogenic factors	Technical factors
Corrosion	1. – 4. (Bedrock) – 5.	None	5. – 9.
Mechanical	1. – 2. – 3. – 4. – 5.	None	1. – 2.
Third parties	1.	1. – 2. – 3. – 4.	2.

**Table 10. Main factors leading to failure due to corrosion, a mechanical cause, and third parties causes.**

#### **4.4 Data sources**

Three databases have been implemented to collect data, one for each of the main causes of accidents: corrosion, third parties, mechanical failure. The databases includes records describing either accidents or non-accidents. As regards corrosion, data from a specific crude oil pipeline in Italy (MonteAlpi Taranto, Italy) have been taken into

account. For the other two causes, data from the US Department Of Transport (DOT) have been used, (U.S. DOT, 2010). These databases are used as the training and testing sets to identify a relationship between “factors” and “failures”.

#### 4.5 Evaluation of failure occurrence

The main goal of risk assessment is to encourage the implementation of preventive measures by eliminating risk evaluation’s subjectivity. The idea of this approach to assess failure occurrence is to find a relationship between boundary conditions of an existing pipeline and the boundary conditions recorded in sites where a previous failure took place.

Since the relationship between “factors” and “failures”, when existing, is very complex to be modelled, a “black-box” approach has been adopted. Specifically, in this work an Artificial Neural Network (ANN) approach has been used. A three-layered ANN, with factors as input unit, the fact that a failure happened or not as output unit, and choosing an adequate number of hidden units (equal to the number of input units) have been implemented for each of the three causes of failure, as shown in Figure 44 and 45.

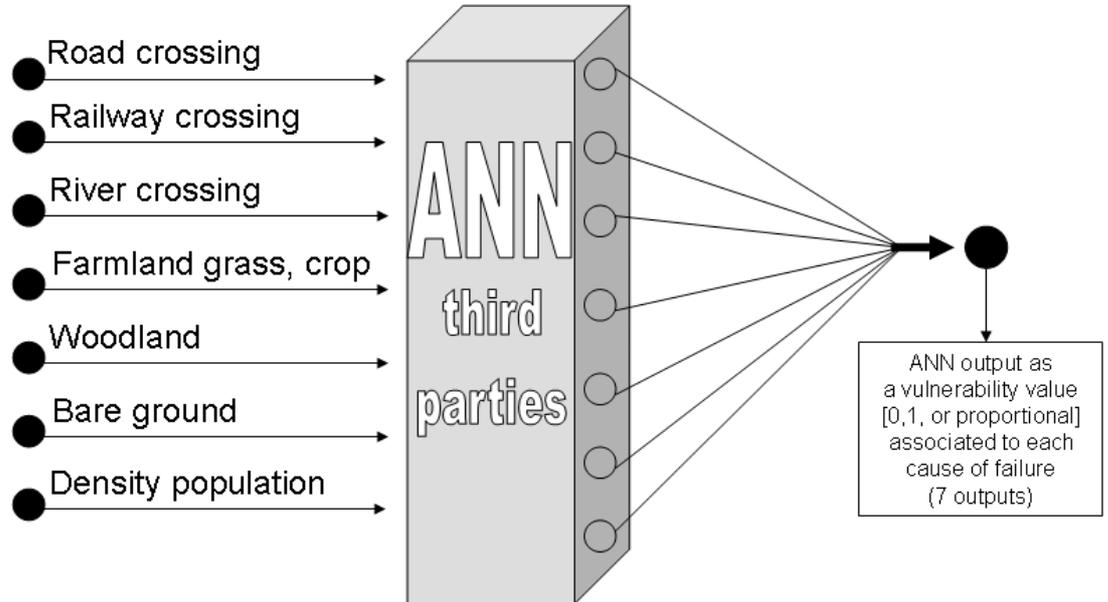


Figure 44. Artificial Neural Network architecture implemented for third party activity cause of failure.

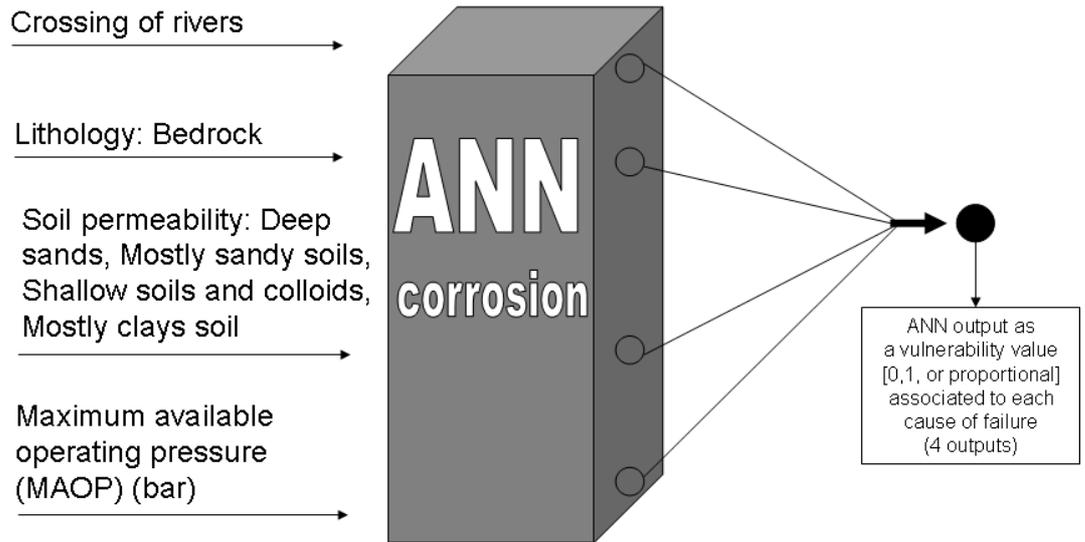


Figure 45. Artificial Neural Network architecture implemented for corrosion cause of failure.

#### 4.6 Third party activity results

A study has been performed on the third party activity factors causing an accident. In this case, 128 significant accidents has been extracted from the DOT database and characterised by the factors described in Table 9. These accidents often occurred in pipeline with very short diameters (90% of them were less than 12’). So, this factor, that is the pipeline diameter, was not taken into account in this study since it strongly affects the results.

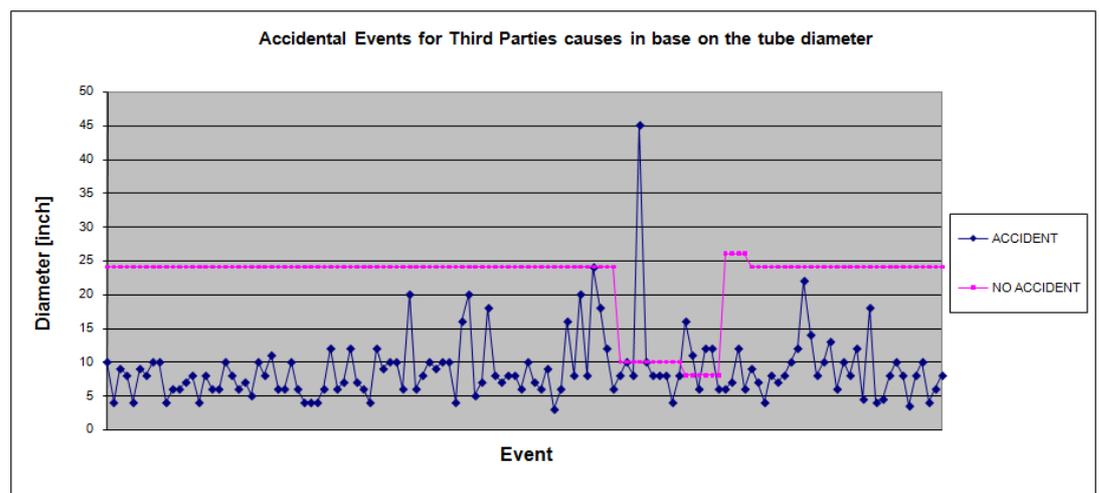


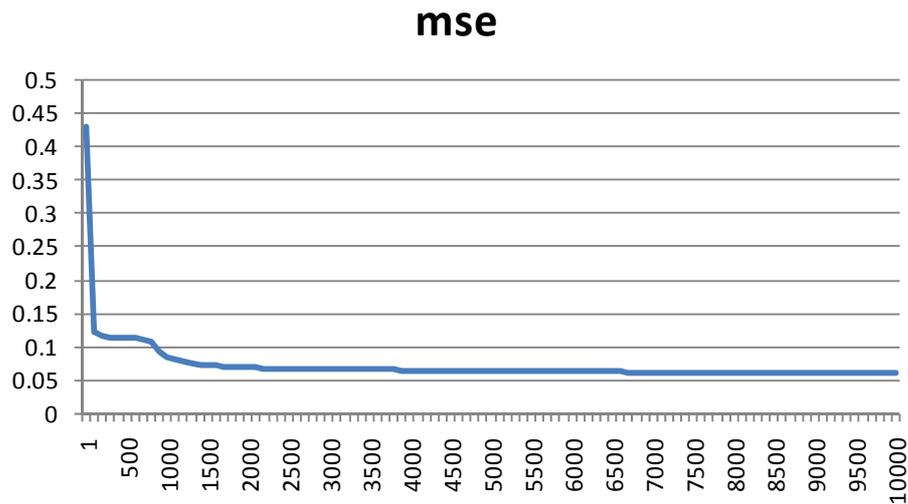
Figure 46. Tube diameter influence in accidental events caused by third party activity.

Specifically the following factors have been taken into account:

- Average population density in an area surface of 1km<sup>2</sup>, in the neighbourhood of the pipeline, coded as follows:
  - 0 low (less than 50inh/km<sup>2</sup>),
  - 0.144 when population density equal to 72inh/km<sup>2</sup>,
  - 0.286 when population density equal to 144inh/km<sup>2</sup>,
  - 0.32 when population density equal to 160inh/km<sup>2</sup>,
  - 1 high (population density more than 500inh/km<sup>2</sup>).
- Land use, classified in three classes as:
  - Other (000),
  - farmland grass, crops, (100),
  - woodland, (010),
  - bare ground, (001), orthogonally coded.
- Crossing of roads, coded with 0 no crossing, 1 crossing.
- Crossing of rivers, coded with 0 no crossing, 1 crossing.
- Crossing of railways, coded with 0 no crossing, 1 crossing.

The ANN training also requires a set of negative patterns, in this case pipeline locations where an accident did not happen. Since, as it is widely reckoned, the pipeline accident is an extremely rare event, this set was generated taking into account all the possible permutations, that is defining the five factors quoted above (coded according to seven numbers), with the average population density assuming the values of 0, 0.144, 0.286, 0.32, 1, resulting in 128 different patterns. It is important to underline that for the 128 positive cases, just 35 of them were unique, while the others are duplicated patterns.

An ANN with 7 input units, 1 output unit, and 7 hidden units has been so trained. The figure below shows the trend of the square mean error of the output unit per number of learning iteration. The learning process was stopped after 10000 back propagation learning iterations (mean square error, mse, less than 6%). The trend in the figure shows the mse as a function of the learning step (Figure 47).



**Figure 47. Mean square error as a function of the learning step during the ANN training on the set of 256 patterns (128 accidents, 128 no accidents).**

The ANN was then tested, in this approach on all the possible 128 permutations, so that to put in evidence the patterns that are more sensible to the occurrence of an accident. Table 11 shows the 6 patterns that have shown a significant (greater than 0.85) prediction of accident occurrence. From this table some preliminary considerations or rules may be inferred. For example that higher population density seems to be a safer factor for third parties accidents, that roads crossings seems to be highly related to these types of accidents.

Population density	Farmland grass, crop	Woodland	Bare ground	Roads crossing	River crossing	Railway crossing	Prediction (1 acc., 0 no acc.)
0	0	0	0	0	0	0	0,873897
0	0	0	0	1	0	0	0,897517
0	1	1	0	1	0	0	0,982055
0,144	1	0	0	0	0	0	0,983035
0	1	0	0	1	0	0	0,990304
0	1	1	0	0	1	0	0,992286
0	0	1	0	0	0	0	0,993392
0	1	0	0	0	0	0	0,999331
0	1	1	0	0	0	0	0,999651

**Table 11. Significant (greater than 0.85) predictions of third parties accident occurrence by the ANN.**

## **4.7 Preliminary results**

A preliminary study has been performed on the third parties factors causing an accident. In this case, 128 significant accidents has been extracted from the DOT database and characterised by the factors described in Table 9. These accidents often occurred in pipeline with very short diameters (90% of them were less than 12'). So, this factor, that is the pipeline diameter, was not taken into account in this preliminary study since it strongly affects the results.

The ANN training also requires a set of negative patterns, in this case pipeline locations where an accident did not happen. Since, as it is widely reckoned, the pipeline accident is an extremely rare event, this set was generated taking into account all the possible permutations, that is defining the five factors quoted above (coded according to seven numbers), with the average population density assuming the values of 0, 0.144, 0.286, 0.32, 1, resulting in 128 different patterns. It is important to underline that for the 128 positive cases, just 35 of them were unique, while the others are duplicated patterns.

## **4.8 Future Developments**

In this preliminary results, the fundamental of the work to predict the occurrence of a pipeline accident has been exemplified. However, it is quite obvious that similar results could have been obtained using more classical statistical approaches. However, the aim here is to use a methodology that can be easily adapted to peculiarities of a pipeline, adding for example historical data on accidents of a specific pipeline or of a set of National / regional pipelines. The ANN approach allows easily to customize the predictions of accident occurrence by properly modifying the training set.

In the next future research, the proposed statistical model and analysis will be applied to a specific case study located in the Monte Alpi -Taranto pipeline, in the south of Italy, adding also specific data of historical failures or accidents of that pipeline. This pipeline transports oil production from the Viggiano Oil Center to the Taranto refinery and it is 136 km long with a transportation capacity of more than 150,000 bopd (barrels of oil per day). Each sector of the pipeline network will be divided in segments of 50 meters of length, and for each of these segments the boundary variables related to territorial, technical and environmental conditions and other externalities will be retrieved through a complete geological study and several other sources of information.

In Attachment N.3 some preliminary results of a risk characterisation on the bases of factor of accident are reported. These figures are the results of a GIS application. Indeed, an ArcGis platform has been used to identify and positioning territorial elements leading to a cause of accident relating to the study pipeline.

On the bases of this work a publication is available:

- Chiara BERSANI, Lucia CITRO, Roberta V. GAGLIARDI, Roberto SACILE, Angela M. TOMASONI. “Accident occurrence evaluation in the pipeline transport of dangerous goods”. Chemical Engineering Transactions, proceedings of "CISAP4" 4th International Conference on Safety & Environment in Process Industry - Florence. Italy, 14-17 March 2010. Vol.19, 2010, Simberto Senni Buratti (Ed.), ISSN 1974-9791.



## 5 Risk evaluation of real-time accident scenarios in the transport of dangerous goods on road

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To transport DG from the depot, to the final destination, a truck may transit through urbanised areas, using overcrowded infrastructures, in the neighbourhoods of dense populated areas, industrial facilities, and every kind of environmental and territorial vulnerable elements.

This Chapter tackles the complex problem of integrating real-time data information about the tracking of a DG vehicle with classical risk evaluation methodologies in order to describe possible accident scenarios. The application described as case study deals with the transport of a hydrocarbon dangerous goods, where the accident consequences may involve the population exposed along the infrastructure used for transportation.

Three different approaches are taken into account:

- the acquisition of real-time data about the travel and the carried DG at transportation level, using the Transport Integrated Platform (TIP);
- the evaluation of the risk area using the Areal Location Of Hazardous Atmospheres (ALOHA) tool have been made;
- a Geographic Information System (GIS) interface to visualize, analyse and evaluate the scenario results, as regards infrastructures, territorial elements, and land use activities in the point of accident neighbourhood.

The results of this analysis constitute the methodological basis to implement a decision support system (DSS) as regards risk analysis, also in real time, with import evaluations for planning criteria. The goal of this study is to use a technology, based on the integration of existing methodologies and tools, which can not only predict the toxic or flammable, or overpressure effects of a DGT accident, but also to enhance the safety of a territory by an efficient and effective use of technology.

The accident scenario representation is based on distances of impact that are defined according to the use of a software tool. So the research limitations are related to the software limitations, in terms of data quality in input, mathematical model accuracy used and computational complexity. However, the information displayed by the GIS interface

is easy to use, the software output is quick on the draw and give to the final users few clear information about the accident consequences in term of area of impact in the time and space scale requested.

In terms of the total impact from the DGT system to the whole environment (humans, goods, infrastructures, services and natural elements), the paper focuses on the importance of creating a historical real-time database implemented from a real time information (by TIP), that represents a standard set of information necessary to define a accident scenarios, for DG transport.

## **5.1 Introduction**

There are several ways to transport DG all over the world, using terrestrial, water, or air ways (Michel Nicolet-Monnier *et al.*, 1996). Some ways are more ecologically sustainable (ferry, rail) than others (terrestrial vehicles) for example because of emission reduction but also as regards the related risk on the territory.

In this Chapter, a decision support system (DSS) integrating different methodologies and technologies is proposed for the evaluation of DG transport risk on road, with the aim to enhance its sustainability. In fact, sustainability entails structuring the future with responsibility, and, with respect to DG transport, sustainability would regard the need to safeguard and to multiply the opportunities of future generations while making this transport possible when it is really needed. Nowadays, this is the case for example of the transportation of fuel to service stations.

In Italy, more than  $797.10^6$  [*veh·km*] DG vehicles travel each years on road (Eurostat, 2009),  $203.10^6$  [*veh·km*] representing vehicles transporting flammable liquid (Class 2 according to ADR 2009), and  $429.10^6$  [*veh·km*] representing vehicles transporting gas (Class 3 according to ADR 2009), (ADR, 2009). This implies that a great amount of DG pass through urbanised areas, representing a potential risk, first of all, for people living in, or passing through, the infrastructure neighbourhoods.

In this context many authors tries to quantify risk derived from DG transport (Carotenuto *et al.*, 2007, Erkut *et al.*, 2007 and Fabiano *et al.*, 2002) and in a traditional method of DG transport risk assessment the DG vehicle represent a potential hazard, that

associated to its possible consequential accident effects, involving elements exposed, defines a risk (Garbolino *et al.*, 2008 and Zhang *et al.*, 2000).

In this study, different methodologies and tools are integrated to estimate the numbers of inhabitants involved in the consequential effect of a release due to a DG transport accident. In this respect, the approach can be taken into account as a consequence-based approach, such as the approach reported in Cozzani *et al.*, 2006. The aim is to define a quantitative area risk assessment (QARA) at a planning level, along a piece of infrastructure, for a specific kind of vehicles, that transports a well known DG.

In Zhang *et al.*, 2000, the risk is quantified in a two step process: firstly, it consists of estimating the area impacted by an DG accident, secondly, counting the number of persons within the impact area. Also in Zografos *et al.*, 2000, methods and techniques are implemented for the consequence minimization in case of an accidental release.

In Cozzani *et al.*, 2007, different scenarios, caused by fires, or overpressure, or fragments are taken into account to calculate the various consequence distances, and in Reniers and Dullaert, 2007, it is also possible to know that for each type of installation with possible scenarios, each scenario has a quantify frequency. Moreover, the Guidelines for Quantitative Risk Assessment (Purple Book, 1999), give us the methods and principles used to calculate the various effect distances, using an expected consequence approach.

This kind of approach is used in Godoy *et al.*, 2007, where improving available tools and developing new ones to compute risk indexes, it is possible to estimate safe distances, useful for emergency and contingency planning. Finally in Giglio *et al.*, 2004, as in this work, the use of on-board sensors are taken into account to have a measure of potential hazard, that added to the potential elements exposed, give us a measure of risk.

## **5.2 Accident scenario**

As previously seen to calculate the number of people involved in an accident caused by the transport of dangerous goods it is necessary to know, or at least estimate, the dimensions of the area affected by the accident.

The accidents that can occur during the transport of dangerous goods can be substantially classified into three categories:

- Release of substances which are toxic to health and the environment;
- Release of thermal Energy;
- Release of pressure.

The consequences that derive depend on the type of transport, the characteristics of the vehicle, the substances transported and how the event happened.

Furthermore, above all for the degree to which it concerns the transport of rubber accident scenario, the domino effect cannot be ignored, made more probable by energy releases in conditions of traffic congestion and the proximity of storage, production and distribution systems to the substances of risk.

During this research and development work the impacts connected to the release of energy will be evaluated, in particular the two types of phenomenon BLEVE and UVCE.

BLEVE (Boiling Liquid Expanding Vapour Explosion) is a scenario similar to the explosion generated from the rapid expansion of inflammable vapours produced by gas substances kept under pressure in a liquid state; from this event can derive both effects of excess pressure and fire balls dangerous for people and structures. This type of event entails three main dangers: the wave from the explosion, the thermal flow and projectiles.

The wave from the explosion is due to the abrupt pressure variation and consists of two phases: the wave of excess pressure and the wave of depression. The thermal flow expressed in kW/m<sup>2</sup>, is often caused by the fire ball; for hydrocarbon the diameter of this is calculated by the formula:

$$D=6,48 M^{0,325} \tag{5.1}$$

where M represents the mass of hydrocarbon measured in kg

The thermal flow radiated from the ball of fire depends on the distance and is expressed by:

$$F = F_0(R/X)^2 \quad (5.2)$$

With :

- $F_0$  = flow on the surface of the ball of fire;
- $R$  = beam from the ball of fire in metres;
- $X$  = distance in respect to the centre of the ball in metres.

To evaluate the effects of the thermal flow it is necessary to also know the exposure times. Through the following formula it is therefore possible to calculate the time of combustion of the hydrocarbon ball of fire:

$$t = 0,852.M^{0,26} \quad (5.3)$$

With:

- $M$  = mass of the ball of fire in kg;
- $t$  = duration of the ball of fire in seconds.

Finally, you can calculate the area in which there is a strong possibility of lethal burns:

$$DG = 1,26 DBF \quad (5.4)$$

Where :

- $DG$  = area of strong possibility of lethal burns;
- $DBF$  = diameter of the ball of fire in m.

The projectiles are the fragments generated by the tanker explosion; studies carried out on the types of tanker have demonstrated that:

- 80% of the fragments are thrown to around 250 m;
- 10% of the fragments are thrown to around 400m;
- the maximum distance of projection has been recorded as around 1200 m.

UVCE (Unconfined Vapour Cloud Explosion) is an accident scenario determined by the release and dispersion in an open area of inflammable substances in a gas or vapour state, from which can derive, if triggered, variable thermal effects and excess pressure, often dangerous for man and the environment.

This explosion has both thermal effects and excess pressure effects that strongly depend on local conditions and, in particular, mixes of gases and weather conditions.

The thermal effects are mainly due to the passage of the front of the blaze; as regards man, therefore, all people along the route of the blaze are at risk of lethal harm while the effect on structures is generally limited to superficial damage, even if at times metal structures can suffer small cracks.

The effects of excess pressure are, due to the size of the wave of pressure generated, directly proportional to the speed at which the front of the blaze spreads.

The pressure threshold values, both for man and for structures, are included in the next chapter, in which an accident is simulated.

The model used for the UVCE simulation is, instead, that of a TNT equivalent, based on the correlation between the consequences of an explosion of a mass of a certain product, a mass of TNT would produce the same consequences at the same distances.

This relationship is defined through the combustion energy of the mass of TNT and the potential combustion energy of the mass of product released during the explosion.

$$a = \frac{M_{\text{TNTequi}} \times Q_{\text{TNT}}}{M_{\text{prodotto}} \times Q_{\text{prodotto}}} \quad (5.5)$$

With :

- a = the TNT equivalent based on the energy (adimensional);
- $M_{\text{TNTequi}}$  = mass of TNT equivalent (kg);
- $M_{\text{prodotto}}$  = mass of equivalent product (kg);
- $Q_{\text{TNT}}$  = combustion energy of TNT per unit of mass (kJ/kg);
- $Q_{\text{prodotto}}$  = combustion energy of the product per unit of mass (kJ/kg).

It is noted that, in both models, information regarding the morphology of the terrain is not considered; this, which is due to the bi-dimensional nature of the models, is a limit for the simulation and the consequent evaluation of risk.

### 5.3 Problem framework

In the context of providing a decisional support tool to final users, working in the emergency response planning activities, a prototype system is hereinafter proposed. The system is composed by three basic tools, as shown in Figure 48:

- The Transport Integration Platform (TIP);
- The Areal Location of Hazardous Atmospheres (ALOHA);
- a GIS (or WEB GIS) platform to visualize all data collected and show the concerning results.

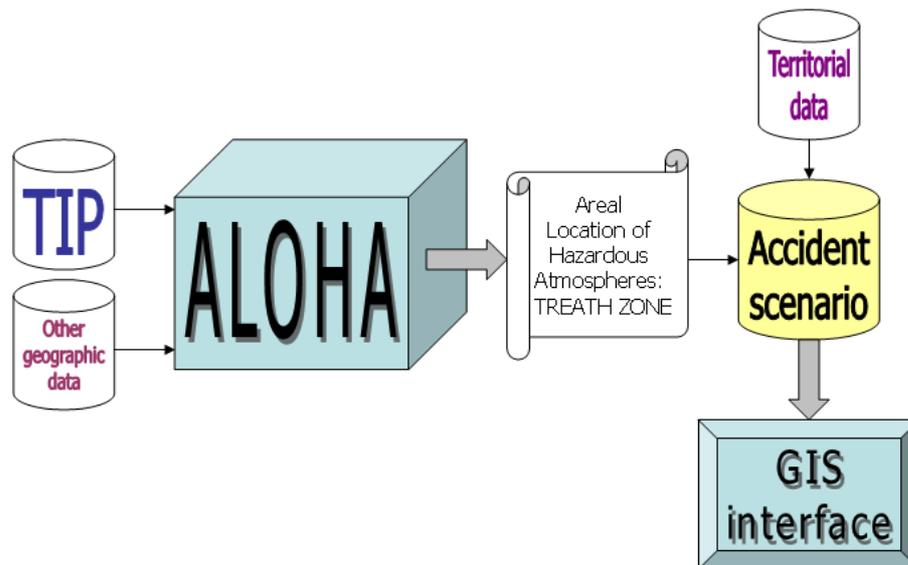


Figure 48. Illustration of a simplified scheme of data model architecture, from TIP to ALOHA, until GIS visualization.

#### 5.3.1 Transport Integrated Platform (TIP)

TIP is a complex system designed and implemented at the University of Genova, providing many functionalities to support the DGT on road in Eni Group. One of the TIP functionality is to collect data in real time, using on board sensors related not only to trucks (GPS position, type of vehicle), but also to the transported DG, (type of good, quantity, physical state, temperature, pressure, etc.).

TIP can be also taken into account as a web integrated platform, that can collect, analyze and report data deriving from trucks and trailers sensors. These sensors can collect a great variety of parameters as shown in the Table 12.

AVAILABLE PARAMETERS	Volumetric Tanker	Kilolitic Tanker	LPG	LPG Heat	F.O. Bunker	Jet Fuel	Wholesale
<b>TRUCK</b>							
Odometer	x	x	x	x			
CAN Bus	x	x	x	x			
ON OFF	x	x	x	x			
Alarm Button	x	x	x	x			
Manual Input (data from HMI)	x	x	x	x			
Odometer	x	x	x	x			
-	-	-	-	-	-	-	-
<b>TRAILER</b>							
Electronic Oil Meter	x		x				
Air Suspension pressure sensor	x	x	x	x	x	x	x
Product Temperature			x	x			
Product Pressure			x	x			
Alarm Button	x	x	x	x	x	x	x
Opening/Closing Loading Station	x						
Opening/Closing Manholes	x	x			x	x	x
On/Off Vapor Recovery	x	x			x	x	x
Opening/Closing Bottom valves	x	x	x	x	x	x	x
Opening/Closing Pneumatic EV	x						

**Tabella 12. The monitoring parameters using TIP.**

In this work, TIP information has been used, to input data as a specific DG travel.

In real time for monitoring and controlling the overall truck system it is possible to know not only the truck position, but also the DG status, as shown in the table 12.

In this context, as shown in section 5.5 of this chapter, only a sub set of TIP data are been chosen and collected as input data for ALOHA tool calculation.

### 5.3.2 Areal Location of Hazardous Atmospheres (ALOHA)

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ALOHA is a software tool used to describe chemical releases. It is generally used for emergency planning, and for public and private technicians training. As mentioned in the ALOHA Manual, “ALOHA is an air dispersion model used for evaluating releases of hazardous chemical vapors.

ALOHA allows the user to estimate the downwind dispersion of a chemical cloud based on the toxicological/physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release. ALOHA can estimate threat zones associated with several types of hazardous chemical releases, including toxic gas clouds, fires, and explosions. A threat zone is an area where a hazard (such as toxicity, flammability, thermal radiation, or damaging overpressure) has exceeded a user-specified Level of Concern (LOC).”

The ALOHA dispersion model is a Gaussian plume model (ALOHA Manual, 2009). ALOHA is a module of CAMEO (Computer-Aided Management of Emergency Operations ) software and all these tools are developed by EPA’s Office of Emergency Management (OEM) and the National Oceanic and Atmospheric Administration Office of Response and Restoration (NOAA), to assist front-line chemical emergency planners and responders (CAMEO, 2009). ALOHA has been also widely used in Europe, as reported in Garbolino *et al.*, 2007, Martin *et al.*, 2004, Mundy, 2004, Lacombe *et al.*, 2006 and Tixier *et al.*, 2002.

#### **Level of Concern**

In ALOHA, some important outputs are the Levels of Concern (LOCs), that are threshold values of a hazard (toxicity, flammability, thermal radiation, or overpressure). The LOC is defined as the value above which a specific threat to people or property may exist. For each LOC chosen, ALOHA estimates a threat zone where the hazard is predicted to exceed that LOC in a defined period after a release begins, (ALOHA Manual, 2009). Specifically, ALOHA includes the following LOCs to model different hazards:

- Toxic LOCs
- Thermal LOCs (thermal radiation and flammable)
- Overpressure LOCs.

### **Threat Zone Window and Other Output**

The threat zone window allows to display up to three threat zones overlaid on a single plot. A threat zone represents the area within which the hazard level (toxicity, flammability, thermal radiation, or overpressure) is predicted to exceed a user defined LOC at some time after a release begins. If three LOCs are chosen, ALOHA will display the threat zones in red, orange, and yellow. By default, the red zone represents the worst hazard. For dispersion scenarios, dashed lines along both sides of the threat zone may be adopted, representing uncertainty in the wind direction (NOAA, 2009).

### **5.3.3 GIS Interface**

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A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. In this context, GIS software has been used to acquire data, for example on the location of the accident, and to display the resulting threat zone plots. A variety of mapping programs, including MARPLOT, ArcGIS, Google Maps, and Google Earth (NOAA, 2009) may be adopted. In this work an ArcGIS mapping program has been used.

## **5.4 Case study**

In this section, the functionalities of the overall DSS are shown on a real daily planned DG transport and an effect study, using ALOHA, has been carried out for a low probability, but realistic, accident scenario. Figure 30 shows the TIP graphical representation of the case study area, where the starting point is Marghera depot (near Venice, Italy) and the delivery points are three petrol station along the A4 Highway: Arino di Dolo Est, Arino di Dolo West, and Bazzera petrol station.

In this example, there is not a pre-software risk analysis, the risk evaluation can be taken into account as a consequence based approach, and no inference on the probability of such an accident is given.



Figure 49. The Case study area – A4 Highway near Padua, Nord-East of Italy: a truck tracing, in a specific LPG transport planning day.

### 5.5 Consequence-based approach methodology

To assess scenario effect in the accident area, (Arino di Dolo Est petrol station) a six step methodology has been developed, as shown in Figure 31.

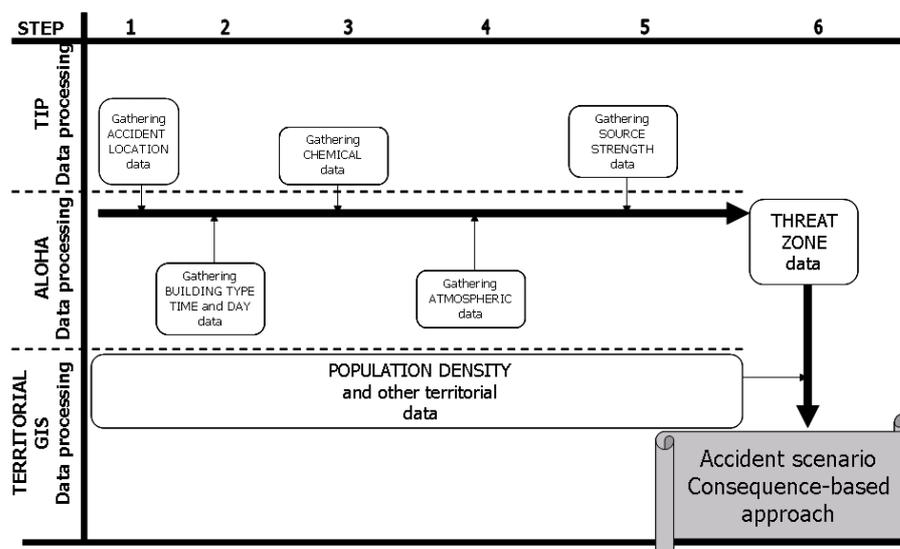


Figure 50. Methodology construction, as a flow of information representation, in order to obtain accident consequence evaluation.

Data gathering for each step can be static and dynamic parameters reported below:

**Accident location data (from TIP).** **Date** (dd/mm/yy), **Time** (h.min.sec.), **Address** and geographical **Location** (longitude [deg., min.], latitude [deg., min.], elevation [m]) of the accident source point, to determine the sun angle, to estimate the incoming solar radiation (NOAA, 2009) and atmospheric pressure to compute the ground-air energy budget for the atmospheric stability (Arya, 1999).

**Building type**, (not only most common, single-storied, double-storied, enclosed office building, but also unsheltered rather than sheltered buildings) for toxic gas dispersion scenarios, ALOHA can estimate the pollutant gas concentration within buildings downwind of a chemical release. To estimate indoor pollutant concentration, ALOHA first estimate the building's air exchange rate, and to estimate infiltration rate into a building, ALOHA assumes that all doors and windows are closed, (ALOHA Manual, 2009).

**Chemical data (from TIP).** **Chemical name** and **Molecular Weight** [g/mol] are the first two information requested from ALOHA to characterize a chemical. Another physical property item requested is the Ambient Saturation Concentration [ppm] or [%], because it could be useful to compare it with a threshold concentration of concern, such as a Lower Explosive Limit. It is also includes values for AEGLs (Acute Exposure Guideline Levels, 2009), ERPGs (Emergency Response Planning Guideline, 2009), TEELs (Temporary Emergency Exposure Limit, 2009), IDLH (Immediately Dangerous to Life and Health limit, 2009), UEL and LEL (Flammability limits, 2009).

**Atmospheric data.** In this section, the hypothesis that weather conditions remain constant throughout the incident area are supposed. If in this area weather conditions change, it is possible to update this information and run ALOHA again. Wind speed and direction are determine in terms of [Knots] and [Degrees] respectively. In addition, the roughness of the territory where the accident is supposed to happen (for example urban, Forest, or Open Country) is required.

<b>CLASS OF DATA:</b>	<b>TYPE OF DATA:</b>	<b>VALUES:</b>
SITE DATA	Location:	VIA DEI PETROLI, ITALY (VE), ITALY
	Building Air Exchanges Per Hour:	0.50 (enclosed office)
	Time:	October 5, 2009 1019 hours ST (user specified)
CHEMICAL DATA	Chemical Name:	PROPANE
	Molecular Weight:	44.10 g/mol
	TEEL-1	5500 ppm
	TEEL-2	17000 ppm
	TEEL-3	33000 ppm
	IDLH	2100 ppm
	LEL	20000 ppm
	UEL	95000
	Ambient Boiling Point:	-42.7° C
	Vapor Pressure at Ambient Temperature:	greater than 1 atm
	Ambient Saturation Concentration:	1,000,000 ppm or 100.0%
	ATMOSPHERIC DATA (Manual Input of Data)	Wind:
Ground Roughness:		urban or forest
Cloud Cover:		7 tenths
Air Temperature:		24° C
Stability Class:		B
Inversion Height:		No
Relative Humidity:		75%
SOURCE STRENGTH		Description:
	Tank Diameter:	2.8 meters
	Tank Length:	8 meters
	Tank Volume:	49.3 cubic meters
	Internal Temperature:	30° C
	Chemical Mass in Tank:	21,067 kilograms
	Circular Opening Diameter:	10 centimeters
	Opening is:	0.50 meters from tank bottom
	Release Duration:	5 minutes
	Max Average Sustained Release Rate:	8,720 kilograms/min (averaged over a minute or more)
	Total Amount Released:	20,927 kilograms
	Note:	The chemical escaped as a mixture of gas and aerosol (two phase flow)

Table 13. Data summary required by ALOHA for the case study.

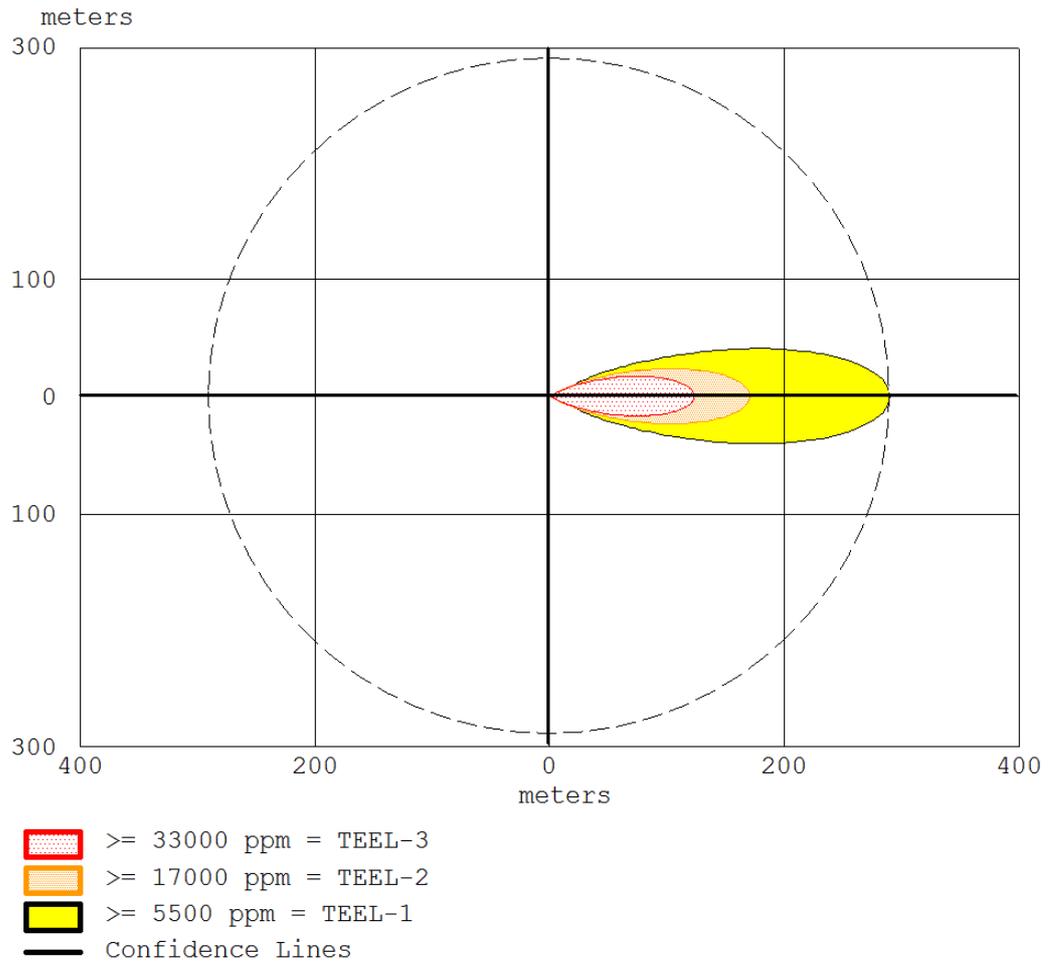
**Source strength data (from TIP).** Others geometrical, geographical, chemical, and territorial information are requested. In the case study, a tank as type source, storing a liquefied gas has been taken into account. The supposed accident scenario is due to a mechanical rupture causing a sudden pressure loss in a tank of propane. The liquid boils violently, the tank contents foam up, and the tank fills with a mixture of gas and fine liquid droplets (called aerosol). When such a two-phase mixture escape from the tank the release rate can be significantly greater than that for a purely gaseous release (ALOHA Manual, 2009). The hazard levels for toxicity, flammability, thermal radiation, or overpressure) have been evaluated.

**Threat zone data.** Threat zone has been define on the bases of previous data, where some of them, such as location, data and time, chemical and physical substance characteristics, source strength, and quantity and geometry of the release are collected by TIP and then implemented in ALOHA. The three zones of threat (red, orange, and yellow one) are defined for each type of dangerous event: toxic, flammable and blast threshold values of associated hazard. In the case study, more emphasis is done on flammability and overpressure hazard, due to the DG considered: propane.

## ***5.6 Solution method and computational results: accident scenarios***

Propane, in its liquid phase, stored in a tank at a temperature above its boiling point has been taken into account, so the pressure within the tank will be greater than atmospheric pressure. When such a tank is punctured, (10 cm of leak), the liquefied gas contents may escape as a two-phase mixture of gas and aerosol.

If a flammable chemical escapes from a tank and does not immediately burn, either the chemical will go directly into the air, and a flammable vapour cloud will form (ALOHA Manual, 2009). This is the first studied accident scenario, but it is not the worst, and the resulting threat zone is displayed in Figure 51.



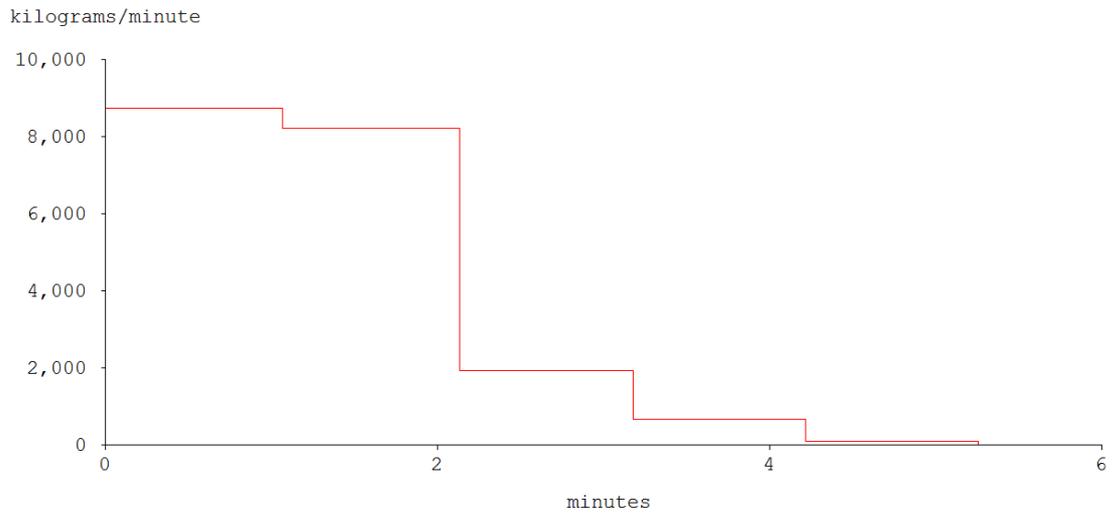
**Figure 51. ALOHA Toxic Threat Zone Plot for this scenario.**

The white zone, in Figure 51, with small red points, the smallest one, of the toxic area of vapour cloud represents the airborne concentration [ppm] of propane above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death (TEEL-3).

The orange zone with yellow dots, the medium one, is the airborne concentration of propane above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting, adverse health effects or an impaired ability to escape (TEEL-2).

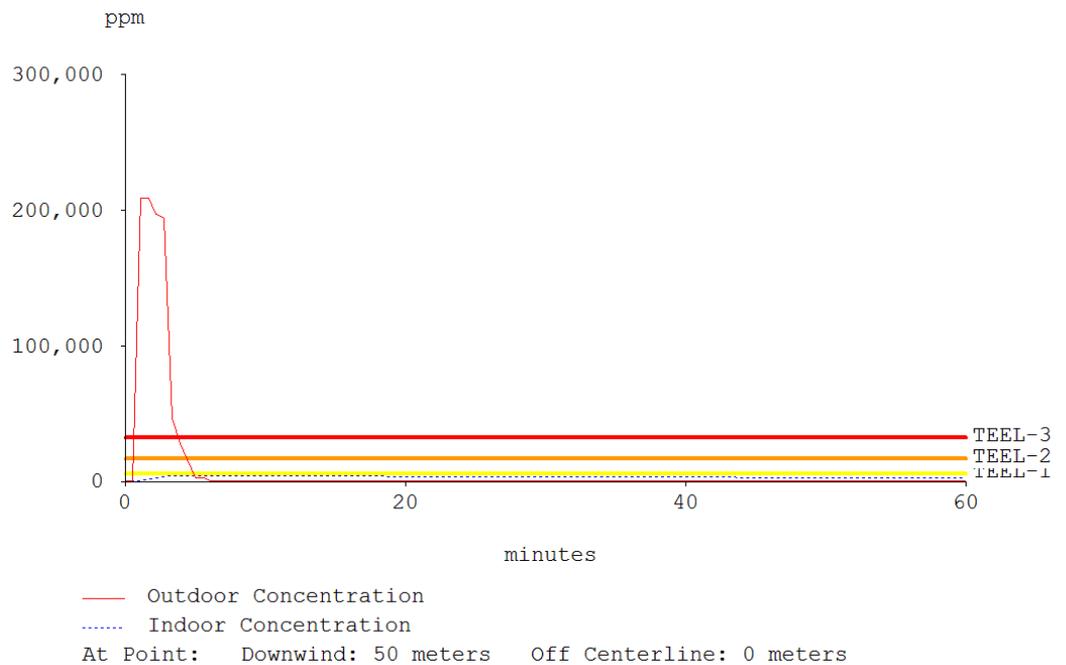
The yellow zone, the larger one, is the airborne concentration of propane above which it is predicted that the general population, including susceptible individuals, could experience discomfort, irritation, or certain asymptomatic, non sensory effects. However,

these effects are not disabling and are transient and reversible upon cessation of exposure (TEEL-1).



**Figure 52. ALOHA Source Strength graph for Propane accident scenario.**

ALOHA estimates the toxic area of vapor cloud for one minute release, and the release rate give us a measure of flux of mass simulation [kg/min] (vertical axis) from the source point in the time scale of the considered scenario. The source effects comes decreasing in about 5 minutes (horizontal axis), as shown in Figure 52. This source is the same for the three different threat zone displayed.



**Figure 53. ALOHA Concentration at Point.**

ALOHA displays a graph of predicted propane concentrations at a specific point far from the source point, during the hour after the release begins. In Figure 53, the horizontal axis represent time from 0 to 60 minutes after the release starts, and the vertical axis represents concentration at the location expressed in parts per million [ppm]. Solid lines represent the predicted outdoor, ground-level concentration (LOCs). The dashed line represents predicted concentration inside a building of the type selected.

The concentration distribution go decreasing according to the time line, and a measure of concentration space variation is given by Table 14. The space scale decreasing effect has been described also for the flammable, and overpressure levels of hazard. Indeed, we consider that a fire starts, after the toxic release. In Figure 54 we can see the graphical result, where this scenario is more hazard then the previous one.

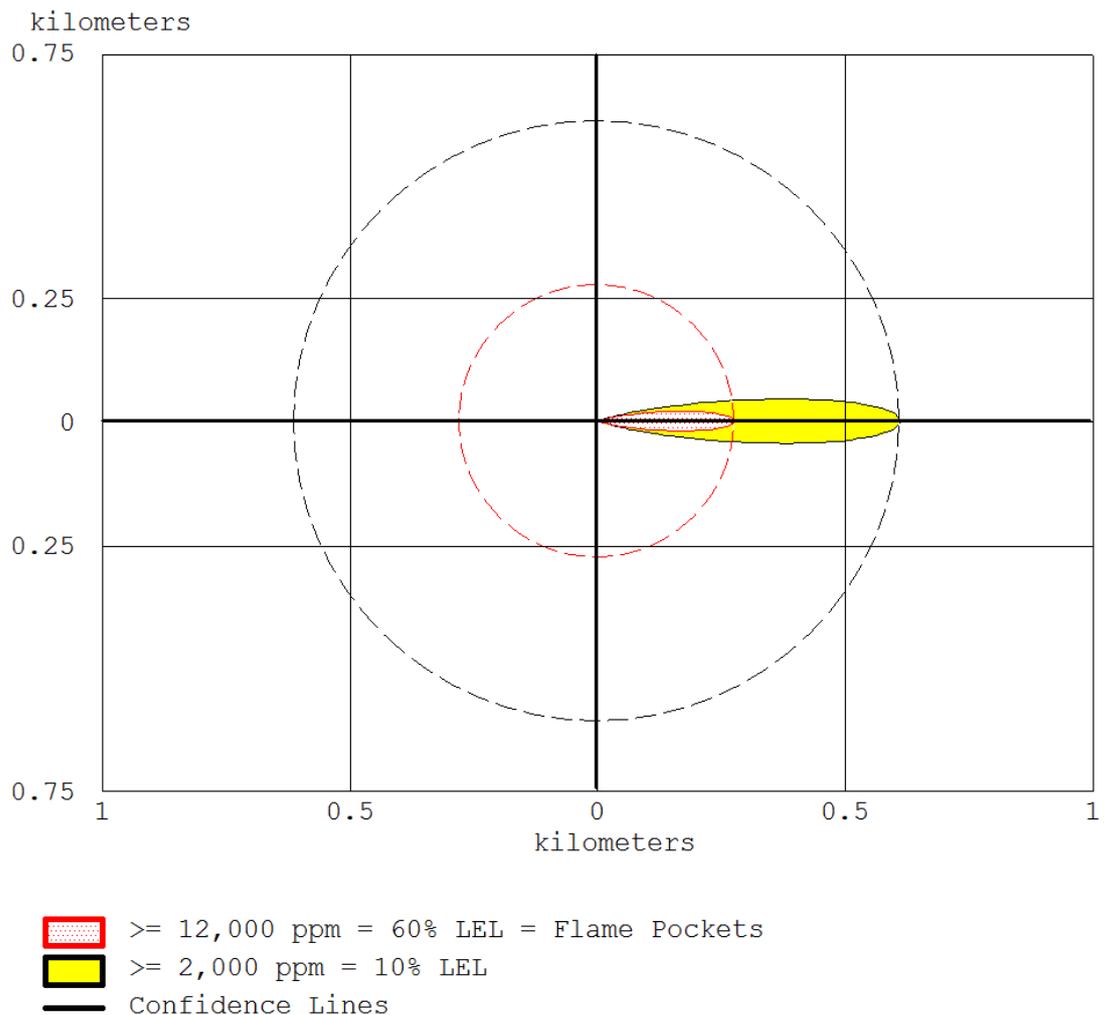
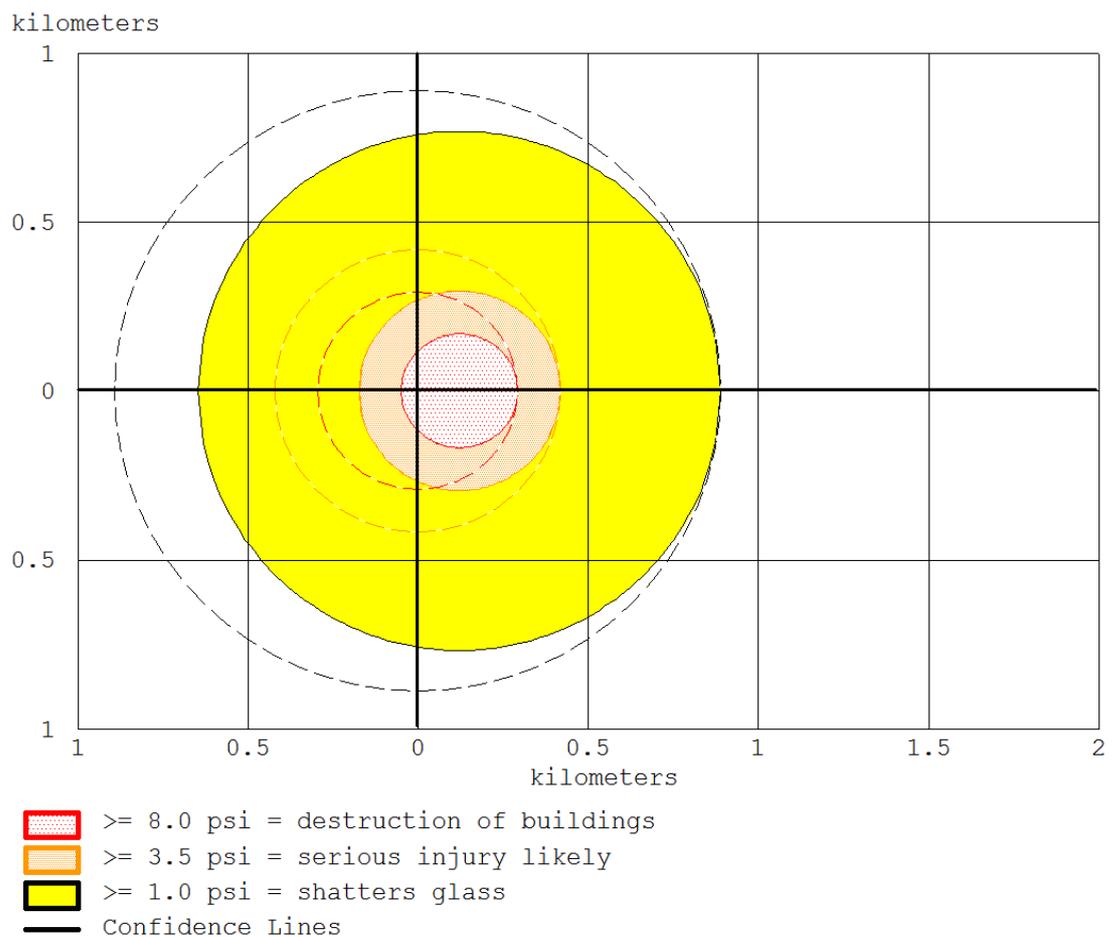


Figure 54. ALOHA Flammable Threat Zone Plot for this scenario.

We considered that propane burns by detonation at an unknown instant of time from the start of release. The red zone, in Figure 54, with small red points, the smallest one zone, of the flammable area of vapour cloud describes the 60% of leanest mixture that is still flammable, (60% LFL - lower explosive limit). The yellow zone, the biggest one, of the flammable area of vapor cloud describes the 10% of leanest mixture that is still flammable, (10% LFL).

After the fire, an explosion takes place. This is the worst case scenario. We do not know when, but we know the cause of blast: a detonation, as shown in Figure 55. The toxic results and the blast one are visualised in a GIS interface, ArcGIS 9.1, as shown in Figure 56 and 57. In this way the hazard information is linked to population density information to have a measure of potential people involved in the accident scenario effects.



**Figure 55. ALOHA Blast Threat Zone Plot for this scenario. The shift between the centre of the coordinate system and the centre of the blast source depends on the time spent between the release and the successive explosion, but also on the wind direction and speed.**

The blast area of vapour cloud explosion represent the overpressure or a blast waves after an explosion. The overpressure values (in pounds per square inch, psi) are based on a review of several widely accepted sources on overpressure and explosions respectively grater or equal to 8.0 psi (the white zone, in Figure 57, with small black points, the smallest one), grater or equal to 3.5 psi (the white medium zone with grey dots), grater or equal to 1.0 psi (the light gray zone, the biggest one).

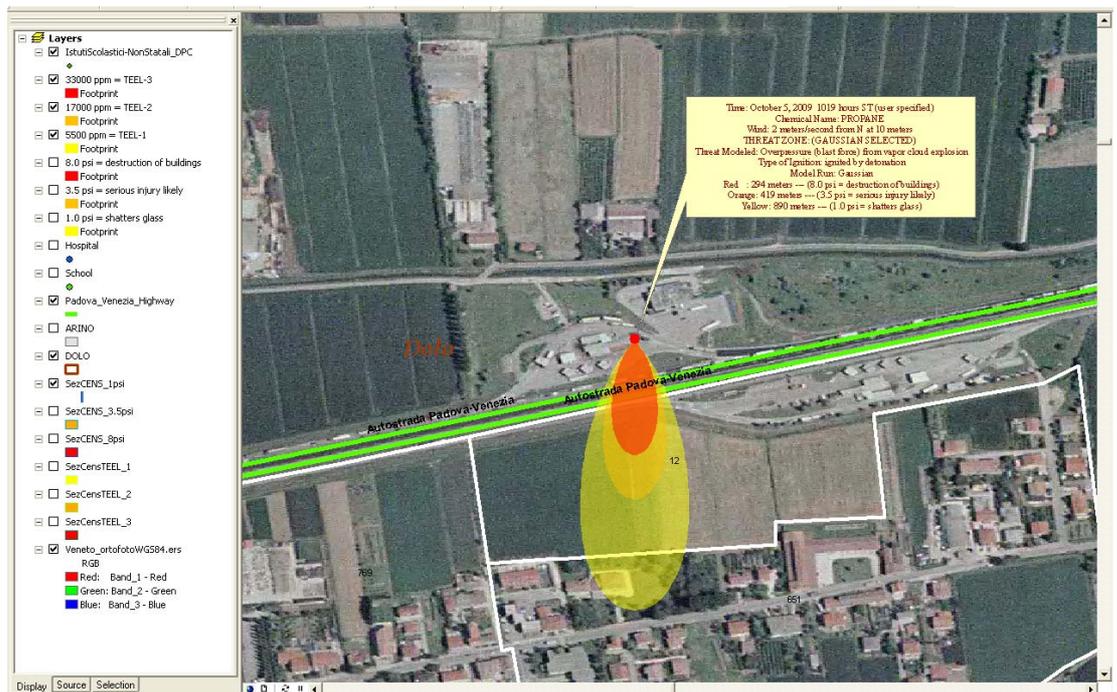


Figure 56. ALOHA Toxic vapour cloud applied to the release point in Arino di Dolo Est Petrol Station, characterized by longitude and latitude - ArcGIS representation.

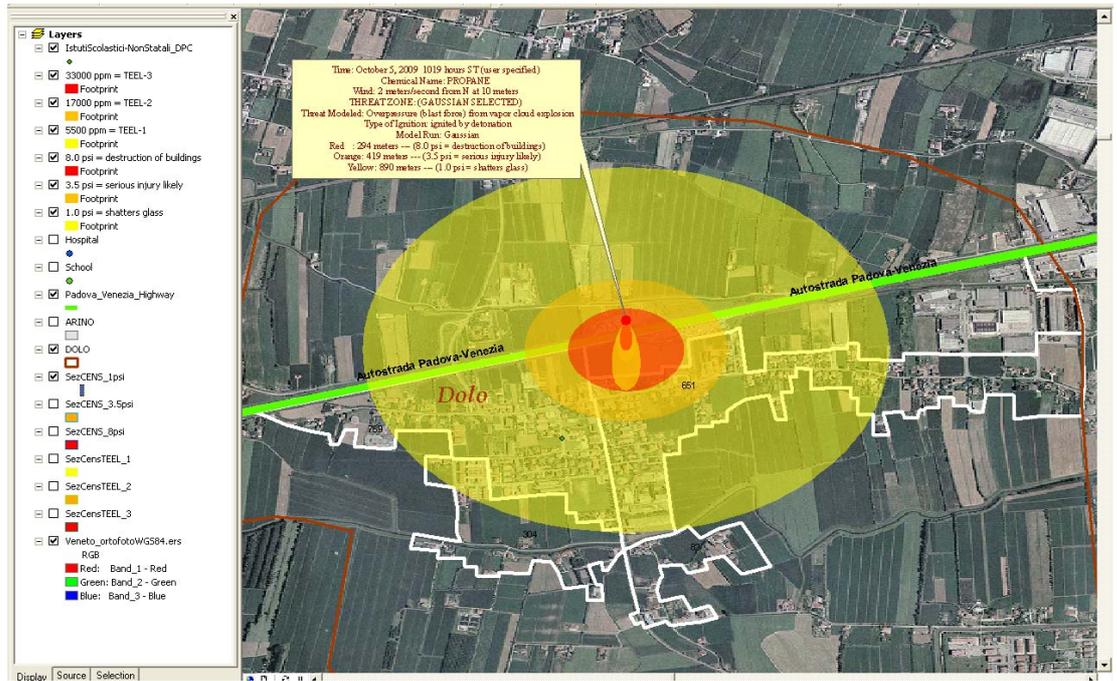


Figure 57. ALOHA Overpressure (blast force) from vapour cloud explosion – ArcGIS representation and number of people potentially exposed.

TOXIC THREAT ZONE:	Model Run:	Gaussian		
	Threat Modeled:	Toxic vapour cloud		
	Red :	124 meters --- (33000 ppm = TEEL-3)		
	Orange:	171 meters --- (17000 ppm = TEEL-2)		
	Yellow:	290 meters --- (5500 ppm = TEEL-1)		
	THREAT AT POINT for a TOXIC HAZARD:			
	Concentration Estimates at the point	Downwind - <b>50</b> meters	Off Centerline - 1 meters	
	Max Concentration:	Outdoor - 205,000 ppm	Indoor - 4,000 ppm	
FLAMMABLE THREAT ZONE:	Concentration Estimates at the point	Downwind - <b>100</b> meters	Off Centerline - 1 meters	
	Max Concentration:	Outdoor - 50,800 ppm	Indoor - 1,050 ppm	
	Concentration Estimates at the point	Downwind - <b>300</b> meters	Off Centerline - 1 meters	
	Max Concentration:	Outdoor - 5,140 ppm	Indoor - 103 ppm	

	Red :	294 meters --- (8.0 psi = destruction of buildings)	
	Orange:	419 meters --- (3.5 psi = serious injury likely)	
	Yellow:	890 meters --- (1.0 psi = shatters glass)	
	THREAT AT POINT for a FLAMMABLE HAZARD:		
	Concentration Estimates at the point:	Downwind - <b>50</b> meters Off Centerline - meters	
	Max Concentration:	Outdoor - 192,000 ppm Indoor - 3,740 ppm	
	Concentration Estimate at the point:	Downwind - <b>100</b> meters Off Centerline - meters	
	Max Concentration:	Outdoor - 83,200 ppm Indoor - 1,720 ppm	
	Concentration Estimate at the point:	Downwind - <b>300</b> meters Off Centerline - meters	
	Max Concentration:	Outdoor - 9,930 ppm Indoor - 200 ppm	
	Concentration Estimate at the point:	Downwind - <b>550</b> meters Off Centerline - meters	
	Max Concentration:	Outdoor - 2,440 ppm Indoor - 55 ppm	
BLAST THREAT ZONE:	Model Run:	Gaussian	
	Threat Modeled:	Overpressure (blast force) from vapor cloud explosion	
	Type of Ignition:	ignited by detonation	
	Red:	294 meters --- (8.0 psi = destruction of buildings)	
	Orange:	419 meters --- (3.5 psi = serious injury likely)	
	Yellow:	890 meters --- (1.0 psi = shatters glass)	
	THREAT AT POINT a OVERPRESSURE HAZARD:		
	Overpressure Estimate at the point:	Downwind - <b>50</b> meters Off Centerline - meters	
		Overpressure:	285 psi
	Overpressure Estimate at the point:	Downwind - <b>200</b> meters Off Centerline - meters	
		Overpressure:	43.9 psi
	Overpressure Estimate at the point:	Downwind - <b>500</b> meters Off Centerline - meters	
		Overpressure:	2.5 psi
Overpressure	Downwind - <b>2000</b> meters Off Centerline -		

	Estimate at the point:		meters
		Overpressure:	0.336 psi
	Overpressure Estimate at the point:	Downwind - <b>5000</b> meters	Off Centerline - meters
		Overpressure:	0.109 psi

**Table 14. Comparison between the three different threat zone effect at the same and different distance from the point source of release.**

Threat Zone	Estimated Area [km <sup>2</sup> ]	[ab/km <sup>2</sup> ] in the Threat Zone
TEEL_1	0,469	11
TEEL_2	0,427	10
TEEL_3	0,181	4
8.0 psi	0,080	2
3.5 psi	0,283	7
1.0 psi	1,862	43

**Table 15. Comparison between the three different threat zone effect at the population exposed in term of Population density [ab/km<sup>2</sup>].**

## **5.7 Concluding remarks**

A consequence based approach methodology has been developed. This methodology has been based on the integration of three well assessed methodologies and related tools: a methodology for telecontrolling DG transport (using TIP (Transport Integrated Platform)) to collect territorial, DG, truck and trail data; a Gaussian dispersion model (using ALOHA) to determine the levels of concerned and verified the value of population density exposed to these levels; and a geographic representation models (using ARCGIS software).

The levels of concern and the corresponding threat zones have been define also setting atmospheric parameters and type of release source. The accident scenario has been define for a source strength characterized by a leak, from a 10 cm hole, in a horizontal cylindrical tank in which three successive events happened: a toxic release, as a mixture of gas and aerosol, than a fire that develops a flammable area of vapour cloud, and finally an explosion that determine a blast area, that is the worst case scenario

studied. In this study, the population density is been estimated as element exposed to the atmospheric release of propane in three different possible scenarios, from the less to the worst case (toxic, flammable, and blast) scenario, (See Table 15).

Using TIP, the data collection is in near real time and the scenario construction and visualization is a user friendly operation. The computational time is modest, but the overall DSS is not user-friendly. In the authors' opinion, the methodology output is effective, efficient for a emergency response use, or also for operator and technicians training, and may represent an important step to evaluate risk in DGT, contributing to the enhancement of the overall sustainability of DGT.

On the bases of this work a publication on an international journal is available:

- E. Garbolino, M. Rovatti, R. Sacile, A. M. Tomasoni, (2010). "Risk evaluation of real-time accident scenarios in the transport of hazardous material on road". Accepted article to Management of Environmental Quality.



## 6 Risk adverse routing of dangerous goods with scheduled delays

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The term “risk-adverse” in the routing of DG, is used for problems whose aim is to find the best and safest routes to connect various origin-destination (OD) pairs, taking into account the objective of minimizing either the maximum risk or the maximum exposure.

In literature there are, in fact, different approaches connected to the best routing for the DGT, based on the formalisation of bi-objective problems in which there is normally the need to minimise both the cost of transport and the risk associated to the DGT (Zografos and Androutsopoulos, 2004).

Recently however the problems of routing have been faced through the use of decisional models based on the rules of the game.

Among the most interesting approaches is that of Bell (2006) which asserts that the best strategy for the decision maker, also irrespective of a principle of exposure equity in the territory, is to use more routes for the vehicles that transport dangerous goods.

In fact, given a road network upon which vehicles having the same origin and destination can move, and assuming that the probability of accidents associated to each arch is not known, it is demonstrated that, under these conditions, the best strategy, from the point of view of risk minimisation for the population, is that of dividing the vehicles upon the various possible routes rather than concentrating them on just one minimum risk route.

The problem can therefore be interpreted as a game between the users of the network with the objective of minimising, along all the route, the number of people involved in a hypothetical accident, with a body defined as ‘demon’ having the aim of maximising exposure.

In recent works, it has been demonstrated that - for repeated shipments where the accident probabilities over the various links in the network are unknown - the safest strategy is generally based on the multiplicity of routes for each O/D pair. In this work, it is demonstrated that further improvements can be obtained scheduling the deliveries with different delays, that is spreading the risk both in space and in time. The improvement is particularly relevant when the vulnerability of the network is also time dependent.

## **6.1 Introduction**

The increasing need for sustainable freight transportation due to economic, environmental, and risk aspects, implies the definition of models which enhance the overall transport planning process. As DGT is concerned, current decision making tools do not sensibly differ from traditional planning tools for general freights, that is they support decision makers in the computation of the best route based on the economical factors related to covered distances and transport operational costs.

However, from a sustainable transport viewpoint, the best route choice selection may also depend on the risk and safety interests which are often in conflict with the economic optimality of the transport processes. On the other hand, the DGT risk does not have a worldwide accepted definition, as scientific papers are currently present in the literature (Akgün *et al.*, 2007; Brown *et al.*, 2007; Carotenuto *et al.*, 2007; Fabiano *et al.*, 2005; Verma *et al.*, 2007), and still some work seems to be necessary. In addition high consequences scenarios have very low probabilities, despite their high consequences, making the DG transport risk definition very hard to be defined from a statistical viewpoint.

In this context, the risk adverse routing planning for DG vehicles represents an important research approach taking into account the status of transportation infrastructures, threat of security and safety concerns, and occurrence of DG and traffic incidents. Specifically, the term “risk-adverse” in the routing of DG is used for problems whose aim is to find the best and safest routes to connect various origin-destination (OD) pairs of a transport network, taking into account the objective of minimizing either the maximum risk on a link, or - in case of information lack on risk – the maximum link exposure, that is the loss in the event of an incident on the link times the probability of link use (Bell, 2006).

From a practical viewpoint, distribution companies and common transport network users will be more and more required to make a trade-off between the travel cost (including distances, travel time, delay penalty, etc. ) and the risk to use a specific path. In case of DGT, the high consequences for an accident event have been a focus for a growing literature which models the DG routing planning considering accidents, explosion, releases, incidents probability and/or population and environmental vulnerability in the risk assessment.

Those research studies are carried by Bonvicini *et al.*, (1998), Frank *et al.*, (2000), Leonelli *et al.*, (2000), Fabiano *et al.*, (2002), Erkut *et al.*, (2007) and Zografos and Androutsopoulos (2004) just to name a few. In Zografos and Androutsopoulos (2004), the authors developed a model that aims at achieving the lowest level of operational costs and the highest level of safety during DG transport.

To obtain this goal, the optimization problem is formalised as a bi-objective routing and scheduling problem: the minimization of operational costs and the minimization of the risk for the population. To solve the bi-objective mathematical problem a new heuristic algorithm to calculate the optimal route was proposed. For a complete survey the reader is referred to Erkut *et al.*, (2007) and Centrone *et al.*, (2008).

Several studies have deepened the risk-adverse behaviour of route choices. One approach is the game theoretic approach (e.g., Bell, 2000, and Bell and Cassir, 2002), whose fundamental hypothesis is that network users are pessimistic about the state of the road network, and they are behaving with the certainty that one accident will surely happen. This model of route choice behaviour deals with events which threaten transport network reliability, and where expected cost is minimized with respect to link use frequencies and maximized with respect to failure probabilities.

In particular, Bell and Cassir (2002) model user equilibrium traffic assignment, known as risk-adverse user equilibrium traffic assignment, but they assume that the number of users is fixed. Erkut and Ingolfsson (2000) present three ways of introducing risk aversion: minimising the maximum consequence along a route; incorporating the variance of the losses along a route into route selection; and minimising the expected

disutility of the losses when a convex utility function is used. It is shown that all these three approaches can be solved as shortest path problems by appropriately defining arc length.

Bell (2006) has demonstrated that - for repeated shipments where the accident probabilities over the various links in the network are unknown, - the safest strategy is generally based on the multiplicity of routes for each O/D pair. Bell also has observed that when there are multiple OD pairs, they may be considered separately, since there is no reason for drivers relevant to different OD pairs to share expectations (or fears) of link costs.

Other models have tackled the DG routing problem defining paths at minimum risk but guaranteeing the equalization of the risk spreading it on the transport network: see, for example, the models in Gopalan *et al.*, 1990; Current and Ratick, 1995, Akgün *et al.*, 2000, Bersani *et al.*, 2008. Specifically, in this latter case, it has been supposed to know data about the flows of general vehicles and of DG vehicles on each road of the network and the problem is to plan the routing through an equity risk based model.

The objective is so to spread the risk, minimizing it, on the different links of a transport network. The decisional variables are the percentage of DG flow to be routed from each node towards the output links, taking into account the O/D needs of the trucks and the risk on the links.

Other approaches aim to find the risk equity determining a set of minimum and equitable risk alternative routes from origin to destination points (Carotenuto *et al.*, and 2007, Bianco *et al.*, 2008). In Carotenuto *et al.*, (2007), the model assigns a route to each DG delivery and schedule them on the assigned routes in order to minimize the total shipment delay, while equitably spreading the risk spatially and preventing the risk induced by vehicles travelling too close to each other.

This DG shipment scheduling problem is modelled as a job-shop scheduling problem with alternative routes. In Bianco *et al.*, (2008) a DG network design problem has been implemented with a linear bi-level model, where, at the higher level, the leader aims to minimize the maximum link risk over populated links of the whole network, that is, risk

equity, and at the lower level, the follower aims to minimize the total risk over the network.

In the proposed approach, the case study of a decision maker (DM) planning each day several deliveries of DG from more depots (e.g. petrol refineries) to several other depots (e.g. petrol service stations) is taken into account. It is supposed that the DM wishes to follow a risk-adverse routing in the deliveries and that he/she takes into account the combined risk arising from the simultaneous presence of two or more vehicles on the same link at the same time.

In addition, as it normally happens in planning practise, the DM has a-priori defined a small number of alternative paths for each OD pair. The DM can play on two classes of decision variables: the path probability for each OD pair and the time schedule with which leaving the depots. More in details, the main contribution of this paper lies in the proof that spreading over time the deliveries generally provides an additional improvement as regards the minimisation of the overall maximum exposure. The improvement is particularly relevant when the vulnerability of the network is also time dependent.

## **6.2**     *The problem*

Each day, a single DM must plan the deliveries of a fleet of DG vehicles according to customer orders, that must be satisfied within that day but without any other specific temporal constraint. These DG vehicles leave from a given depot (origin, for example a tank of a refinery) towards another depot (destination, for example a petrol service station), according to a full drop (FD) delivery strategy.

This FD delivery strategy means that, after one stop, the vehicle is completely empty and thus it does not induce any danger for the territory and its population. The FD delivery is quite frequent in the DG delivery, such as petrol products, as well as in the general freight transportation, since it has been demonstrated that it is a simple way to optimise the overall distribution process.

In this case study, the DM deals with several OD. For each OD pair, it is assumed that the DM has already a-priori selected a limited number of eligible paths, having

minimum (or near-minimum) cost, by means of a “k shortest paths” algorithm minimising for example the OD distance. The DM has also a detailed knowledge of the flows for example per day, of DG vehicles, for each OD pair, and he/she knows that this flow is relevant, so that it makes sense to deal with percentages of the flow for each OD pair to be assigned to each possible path.

The DM wishes to follow a risk-adverse routing. In particular, he/she wishes to minimise the maximum exposure on a set of clearly identified critical infrastructures (for example tunnels) that are present on the different paths. Moreover, it is assumed that in case of an accident on a critical infrastructure, the presence at the same time of more than one DG vehicle can sensibly amplify the number of persons injured, due to the nature of the accident or to other causes such as domino effects.

So, the risk-adverse routing of the DM also corresponds to the wish of avoiding the presence of more DG vehicles on critical infrastructures at the same time. Thus, the DM wants to determine and use a control law, defining for each delivery the path and the scheduled delay with respect to the beginning of the work time, so that he/she can obtain daily delivery plans according to a risk adverse criterion.

## **6.3      *The model***

### **6.3.1    Network model**

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The road network road is supposed to be represented by a graph  $G(N,L)$ , where each link  $l \in L$  represents a critical infrastructure, where the criticality per unit area is characterised by a given exposure  $e(l,t)$  which can vary in time. Thus, in the adopted model, it is supposed that the road network is entirely made by critical infrastructures.

In addition, each link is supposed to be characterized by a unitary travel time - this modelling assumption should not represent a limitation, since if a longer time is required to traverse a critical infrastructure, then it may be modelled by several links.

It is assumed that there is no availability of a significant historical data base of accidents on the road network, so that it is not possible, for any link, to define an objective value of an accident occurrence probability. It is supposed that an accident of

one vehicle involves a single unitary area (of predefined extension) – that is an accident of one vehicle on link  $l$  at instant  $t$  causes a loss of  $e(l, t)$ .

It is assumed to take into account direct FD deliveries only (FD deliveries, in which no vehicle serving multiple destinations within the same tour).

If two or more vehicles, either related to the same or to different OD pairs, in the same interval, travel on the same link, the expected exposure is additive. In particular, it is assumed that if an accident occurs on a link, all the DG vehicles present at that time on that link are involved.

Links are assumed to be isolated systems, such as an accident on one link does not induce any effect over other links, such as, for example, the adjacent ones.

### **6.3.2 Decision making behavior**

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It is supposed that some demon wishes to cause one accident during the day, with the intent to cause the maximum possible loss. Moreover, it is also assumed that such a malicious agent has the possibility to spread the probability of such a loss over the links of the network and over the possible time intervals within the considered time horizon.

The DM wishes to follow a risk aversion behaviour. The DM knows that an accident will surely happen in the day, on one link, at a specific time interval. Thus, two possible risk aversion behaviours may be considered:

- minimising the maximum link loss over the whole time horizon - this may be viewed as a true risk adverse behaviour;
- minimising the sum of the maximum link losses which may be caused at the various time intervals.

The choice of this latter behaviour is equivalent to the choice of minimising the average maximum risk over the time horizon.

It is worthwhile to underline that the definition of risk used in this work is not the classic one, where the probability of accident is a-priori known. In the present model, such a probability is unknown. Instead, in the present case, the risk is evaluated as the product of the exposure, in terms of the magnitude of the loss (for instance, in the considered case study, the number of persons involved in the accident), times the percentage of DG vehicles passing on that link, as it will be clarified in the following.

### 6.3.3 Set definitions

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$l = 1, \dots, L$  : the set of network links ;

$t = 0..T-1$  : the number of temporal working units of the day (for example hours);

$od = 1 \dots OD$ : only a limited number of OD pairs are considered;

$p = 1 \dots Pod$ : the DM provides a limited set Pod of predefined paths for each OD pair.

### 6.3.4 Modeling assumptions and parameters

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$f(od, t), t = 0, \dots, T-1, od = 1, \dots, OD$ , is the flow of DG vehicles entering the network for each OD pair and at each instant; such value is normalised with respect to the value  $\max_{t, od} f(od, t)$ , so that  $f(od, t) \in [0, 1]$ ; such values are all known a-priori.

It is supposed that, at each time instant  $t$ , and for each origin/destination pair, the DM has to assign to each vehicle relevant to the flow  $f(od, t)$  a path  $p \in Pod$  and an (integer) delay  $\tau \geq 0$  corresponding to a number of time intervals that the vehicle has to wait for, before starting its route.

It is supposed that the travel time for a DG vehicle on each link is equal to one time unit; on this basis, and on the basis of the knowledge of the selected (by the DM) path  $p$  and delay  $\tau$ , it is possible to determine the position (i.e. the link over which it travels) in any time interval  $(t, t+1), t \geq t + \tau$ , of any DG vehicle arrived in time interval  $(\bar{t}, \bar{t} + 1), \bar{t} \geq 0$ ;

then, it is possible to determine the value of the binary variable  $tr(l, p, od, \bar{t}, t, \tau)$ , which is equal to 1 if a vehicle assigned to path  $p \in Pod$ , with a delay  $\tau$  in time interval  $(\bar{t}, \bar{t} + 1)$ , lies on link  $l$  (belonging to that path) in time interval  $(t, t+1)$ , and 0 otherwise;

$e(l, t)$  is the exposure, representing the possible loss, per square area unit, when an accident take place on link  $l$  in time interval  $(t, t+1)$ .

### 6.3.5 Decisional variables

---

$h(p, od, \bar{t}, \tau)$ , that is the fraction of  $f(od, \bar{t})$  that is routed (in time interval  $(\bar{t} + \tau, \bar{t} + \tau + 1)$ ) through path  $p \in Pod$ .

### 6.3.6 Other variables

$C$  which is the maximum risk on a link, for any choice of the link and of the time instant;

$c(t)$  which is the maximum risk on a link, for any choice of the link for a given instant  $t$ .

### 6.3.7 Model formulation

Then, two possible decision models can be considered.

Decision model 1: minimising the maximum link loss over time

$$\min_{h(p,od,\bar{t},\tau)} Z_1 = C \quad (6.1)$$

$$\sum_{\bar{t}=0}^{T-1} \sum_{od=1}^{OD} \sum_{p=1}^{p_{od}} \sum_{\tau} f(od,\bar{t})h(p,od,\bar{t},\tau)tr(l,p,od,\bar{t},t,\tau)e(l,t) \leq C$$

$$l = 1, \dots, L$$

$$t = 0, \dots, T-1 \quad (6.2)$$

s.t.

$$\sum_{p=1}^{p_{od}} \sum_{\tau} h(p,od,\bar{t},\tau) = 1 \quad \begin{array}{l} od = 1, \dots, OD \\ \bar{t} = 0, \dots, T-1 \end{array} \quad (6.3)$$

Decision model 2: minimising the sum of the maximum link losses at each instant

$$\min_{h(p,od,\bar{t},\tau)} Z_2 = \sum_{t=0}^{T-1} c(t) \quad (6.1')$$

$$\sum_{\bar{t}=0}^{T-1} \sum_{od=1}^{OD} \sum_{p=1}^{p_{od}} \sum_{\tau} f(od,\bar{t})h(p,od,\bar{t},\tau)tr(l,p,od,\bar{t},t,\tau)e(l,t) \leq c(t)$$

$$l = 1, \dots, L$$

$$t = 0, \dots, T-1 \quad (6.2')$$

s.t.

$$\sum_{p=1}^{p_{od}} \sum_{\tau} h(p,od,\bar{t},\tau) = 1 \quad \begin{array}{l} od = 1, \dots, OD \\ \bar{t} = 0, \dots, T-1 \end{array} \quad (6.3')$$

Decision model 3: integrating decisional models 1 and 2.

It might be supposed that a risk adverse DM can follow an approach which is a mix of the two previous ones. This may be accomplished by introducing a weighting parameter  $\alpha$ , where  $\alpha = 0$  the model tends to model 2, while for  $\alpha \rightarrow \infty$  corresponds to model 1.

$$\min_{h(p,od,\bar{t},\tau)} Z_3 = \sum_{t=0}^{T-1} c(t) + \alpha C \quad (6.1'')$$

s.t.

$$\sum_{\bar{t}=0}^{T-1} \sum_{od=1}^{OD} \sum_{p=1}^{p_{od}} \sum_{\tau} f(od, \bar{t}) h(p, od, \bar{t}, \tau) tr(l, p, od, \bar{t}, t, \tau) e(l, t) \leq C$$

$$l = 1, \dots, L$$

$$t = 0, \dots, T-1 \quad (6.4)$$

$$\sum_{\bar{t}=0}^{T-1} \sum_{od=1}^{OD} \sum_{p=1}^{p_{od}} \sum_{\tau} f(od, \bar{t}) h(p, od, \bar{t}, \tau) tr(l, p, od, \bar{t}, t, \tau) e(l, t) \leq c(t)$$

$$l = 1, \dots, L$$

$$t = 0, \dots, T-1 \quad (6.2')$$

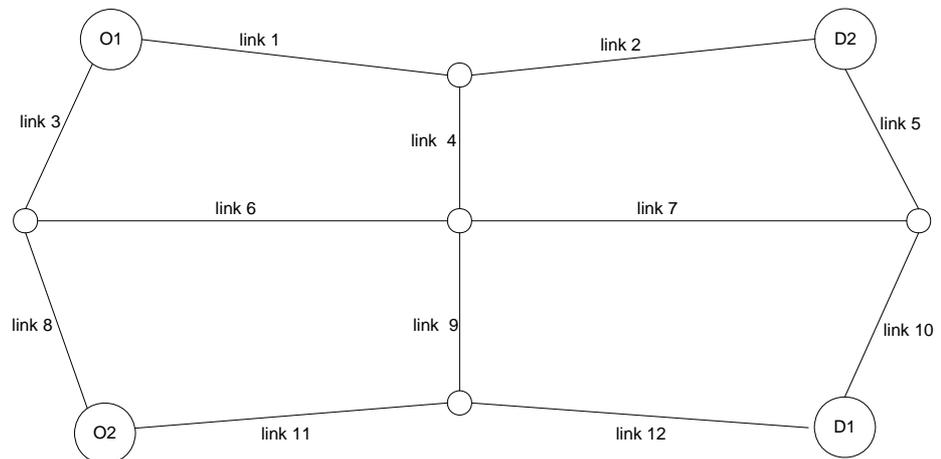
$$\sum_{p=1}^{p_{od}} \sum_{\tau} h(p, od, \bar{t}, \tau) = 1$$

$$od = 1, \dots, OD$$

$$\bar{t} = 0, \dots, T-1 \quad (6.5)$$

## 6.4 Case study

Consider the transport network (L=12) shown in figure 58.



**Figure 58. Transportation network used in this work (adapted from Bell 2006)**

In the network, there are two OD pairs (i.e. OD=2), where (figure 1) O1 and O2 represent the origins and D1 and D2 represent the destinations, respectively for od=1 and od=2.

It is supposed that the overall flow is equally balanced on the two OD pairs and that it is different from 0 just in the first instant, i.e.:

$$f(od,0) = 1 \quad od = 1, \dots, OD$$

$$f(od,t) = 0 \quad \forall t \neq 0 \quad od = 1, \dots, OD$$

As a consequence, hereinafter,  $\bar{t}$  will be omitted (e.g.  $h(p,od,\bar{t},\tau)$  will be referred to as  $h(p,od,\tau)$  and  $f(od,t)$  will also be omitted).

This scenario corresponds to a fleet of vehicles that should leave at the beginning of the day from each origin.

Time is discretised in hours, and each day is supposed to be made of eight working hours, i.e.  $t = 0..7$  and  $T=8$ . A DG vehicle spends one hour to traverse each link.

There are two paths for each OD pair. The links for each path are:

od=1; p=1: links: 1, 4, 7, 10

od=1; p=2: links: 3, 6, 9, 12

od=2; p=1: links: 2, 4, 9, 11

od=2; p=2: links: 5, 6, 7, 8

The possible delays that are both feasible and allowed by the DM are the same for all the  $od$  and  $p$ , specifically  $\tau = 0.3$ .

As regards exposures, it is supposed that they can be observed by statistical methods, reproducing a profile that varies during the day but that is constant within each hour. For the case study, the following table reports the exposure values.

<b>Link\ Hour</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
<b>1</b>	1000	8000	<b>11000</b>	8000	5000	3000	10000	8000
<b>2</b>	5000	<b>6000</b>	5000	4000	3000	2000	1000	500
<b>3</b>	2000	1000	<b>2000</b>	2000	1500	1000	200	1000
<b>4</b>	10000	11000	<b>15000</b>	14000	13000	9000	4000	3000
<b>5</b>	20000	30000	25000	28000	<b>31000</b>	28000	15000	10000
<b>6</b>	1000	800	<b>1000</b>	800	200	200	1000	500
<b>7</b>	12000	18000	25000	<b>32000</b>	25000	18000	17000	15000
<b>8</b>	6000	<b>7000</b>	6000	5000	4000	1000	1000	1000
<b>9</b>	28000	20000	15000	14000	15000	20000	<b>28000</b>	10000
<b>10</b>	10000	9000	10000	10000	9000	15000	<b>17000</b>	12000

<b>11</b>	20000	18000	10000	18000	<b>22000</b>	18000	10000	8000
<b>12</b>	5000	6000	8000	10000	<b>14000</b>	12000	5000	1000

**Table 16. Exposures (for square unit) on each of the 12 links at each of 8 instants. In bold, the maximum values for each link.**

Under a worst case view, the previous exposures on each link may be supposed to be constant, and for each link, equal to the maximum values expected during the whole day as reported in bold in the Table 16.

## **6.5 Results**

In order to validate the performances the proposed model has been compared with the mixed route strategy for risk adverse shipment of hazardous material developed by Bell (2006), according to a worst case (that is taking into account the worst hourly loss for each link) and to an average loss (according to a loss that for each link has been averaged on all time instant).

Link	Worst	Average
1	11000	6750
2	6000	3312.5
3	2000	1337.5
4	15000	9875
5	31000	23375
6	1000	687.5
7	32000	20250
8	7000	3875
9	28000	18750
10	17000	11500
11	22000	15500
12	14000	7625

**Table 17. Worst and average exposures for each link used to compare the proposed model with the Bell's approach (2006).**

The path probabilities that have been obtained according to Bell's approach are reported in Table 18.

od	p	h (worst)	h (average)
1	1	0,466667	0,480769
1	2	0,533333	0,519231
2	1	0,533333	0,554896
2	2	0,466667	0,445104

**Table 18. Path probabilities obtained according to the Bell's approach (2006), computed on the link costs of Table 17.**

Since Bell's approach (2006) does not take into account delays, the path probabilities that have been obtained have been shared in all the eligible time instants as shown in Table 19. This strategy should be quite reasonable for a DM following a risk adverse behaviour. The  $h(p,od,\tau)$  values for  $\tau = 0,1,\dots,3$ , which have been obtained, are reported in Table 19 (worst) and 20 (average).

OD	Path	$h(p,od,0)$	$h(p,od,1)$	$h(p,od,2)$	$h(p,od,3)$
1	1	0,116667	0,116667	0,116667	0,116667
1	2	0,133333	0,133333	0,133333	0,133333
2	1	0,133333	0,133333	0,133333	0,133333
2	2	0,116667	0,116667	0,116667	0,116667

**Table 19. Path probabilities obtained according to the Bell's approach (2006) on worst link exposures, spread in time.**

OD	Path	$h(p,od,0)$	$h(p,od,1)$	$h(p,od,2)$	$h(p,od,3)$
1	1	0,120192	0,120192	0,120192	0,120192
1	2	0,129808	0,129808	0,129808	0,129808
2	1	0,138724	0,138724	0,138724	0,138724
2	2	0,111276	0,111276	0,111276	0,111276

**Table 20. Path probabilities obtained according to the Bell's approach (2006) on average link exposures, spread in time.**

Forcing the  $h(p,od,\tau)$  values reported in Table 19 and 20 in (6.1), (6.2), (6.1') and (6.2'), the  $Z1^*$  and  $Z2^*$  objectives have been computed and then compared with the optimal  $Z1$  and  $Z2$  values obtained solving the problems described in section 6.3.

The Figure 59 report the solution of the problem for the case study according to the decisional models 1, 2, and, in general, 3. The solution is reported in the space  $Z1$ ,  $Z2$ . The exposures that have been used in equations (6.2) and (6.2') are the ones reported in table I for the case with variable losses (continuous line), and in the “worst” column of table II for the case with constant losses.

According to the risk adverse approach, the graph shown in Figure 59, showing the objectives values in the  $Z1$   $Z2$  space, underlines that, both in case of constant and variable values of arc exposures during the time horizon, the possibility to shift the beginning of the work time for some deliveries, produces a significant improvement of the performance for the proposed model in respect with the Bell’s model with deliveries spread uniformly in time. In particular, the possibility to consider the varying exposure during the time horizon on each arc will have the favourable result of reducing the deliveries on the critical arc during the high level of exposure.

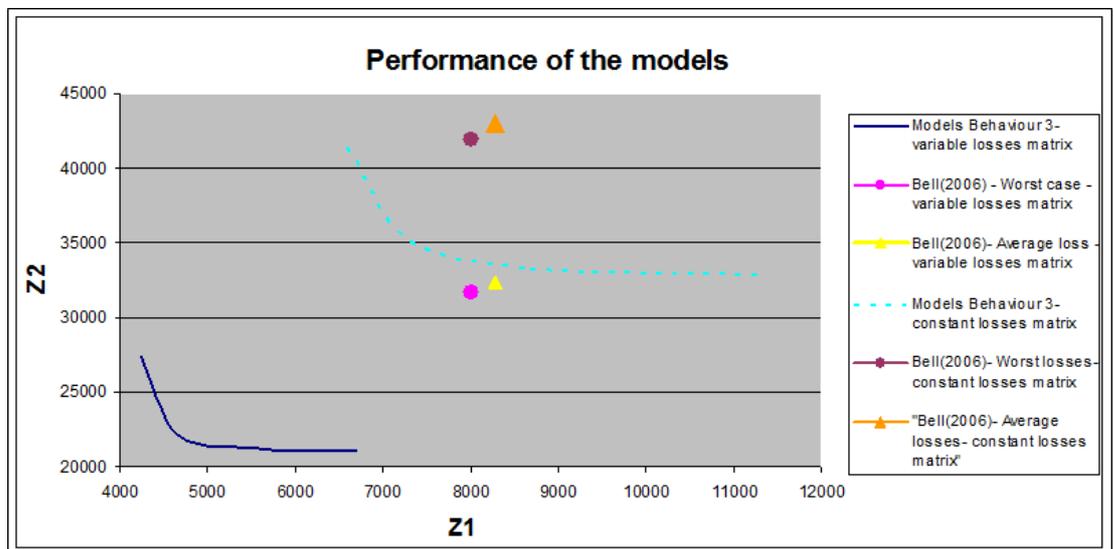


Figure 59. Results obtained for the proposed model (Behaviour 3 varying the parameter  $\alpha$ ).

Another evaluation was performed with an optimal scheduling of a limited number of vehicles, modifying the problem 3 defined in section 6.3 in an integer programming problem, reported hereinafter with the simplifications related to the case study.

$$\min_{h(p,od,\bar{l},\tau)} Z_3 = Z_1 + \alpha Z_2 \quad (6.1^*)$$

$$Z_1 = \frac{\sum_{t=0}^{T-1} c(t)}{nveh}$$

$$Z_2 = \frac{C}{nveh}$$

s.t.

$$\sum_{od=1}^{OD} \sum_{p=1}^{P_{od}} \sum_{\tau} h(p, od, \tau) tr(l, p, od, t, \tau) e(l, t) \leq C \quad \begin{matrix} l = 1, \dots, L \\ t = 0, \dots, T-1 \end{matrix} \quad (6.2^*)$$

$$\sum_{od=1}^{OD} \sum_{p=1}^{P_{od}} \sum_{\tau} h(p, od, \tau) tr(l, p, od, t, \tau) e(l, t) \leq c(t) \quad \begin{matrix} l = 1, \dots, L \\ t = 0, \dots, T-1 \end{matrix} \quad (6.2^{**})$$

$$\sum_{p=1}^{P_{od}} \sum_{\tau} h(p, od, \tau) = nveh \quad \begin{matrix} od = 1, \dots, OD \\ h(p, od, \tau) \in Z^{0,+} \end{matrix} \quad (6.3^*)$$

Taking into account variable exposures, the model has been tested considering different number of available vehicles ( $nveh$ ) for the scheduled deliveries. Figure 60 shows that increasing the number of vehicles implies respectively the improvements of the model performances and that the models proposed in section 6.3 can be also taken into account As a representation of the integer problem described above for an infinite number of DG vehicles.

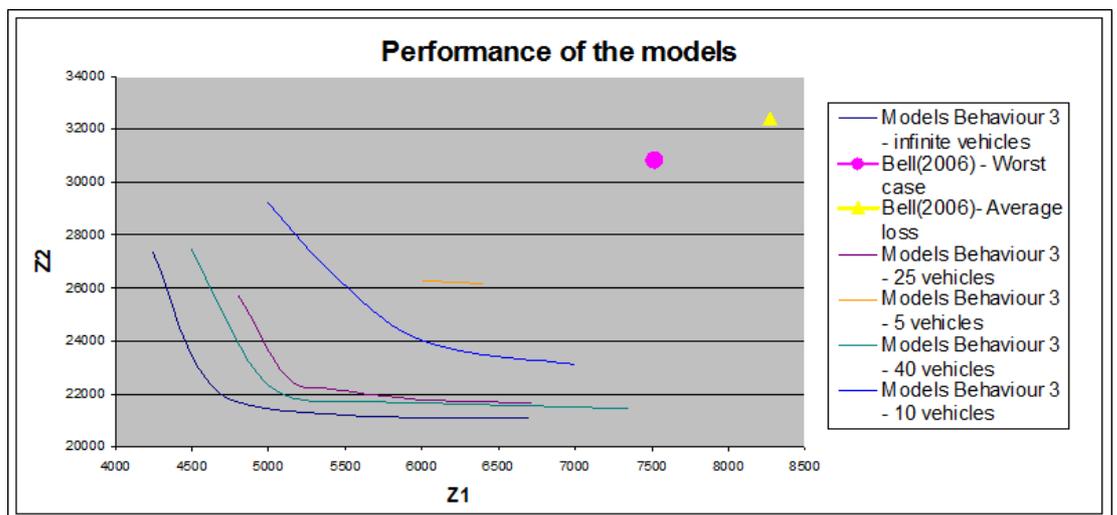


Figure 60. Results obtained for a varying number of DG vehicles.

## 6.6 Discussion

In this work, a risk adverse decisional model for DG transport planning on road has been proposed, with the intent to show that spreading not only in space (i.e. on multiple paths) but also in time (i.e. adding delays in the departure of the deliveries) can decrease the overall maximum exposure.

The proposed model is formulated at planning level with one DM wishing to plan a relevant number of DG FD deliveries on several OD pairs. The DM can decide the routing path on a set of predefined path for each OD pair and whether to make a vehicle start immediately or to make it wait a certain delay. Results shown on a simplified network demonstrate that there is an enhancement with respect to previous results which did not take into account the possibility to delay deliveries. The enhancement is more evident taking into account exposures time varying

Future developments regards the possibility to avoid to adopt predefined paths for each OD pair for example adapting the method of successive averages (Bell, 2006) to the current formulation, to verify whether optimality conditions similar to the ones quoted in Bell 2006 can be defined for the proposed formulation, and to verify whether the solution of the problem introduced in the current work can give additional insights on the integer programming problem quoted in the result sub chapter.

Two scientific works have been discussed on this topic:

- C. Bersani, R. Minciardi, R. Sacile, A. M. Tomasoni, (2009). “Risk averse routing of hazardous materials with scheduled delays”. Published by , NATO Science for peace Series 2009, Eds. GH M. Bell et al.
- C. Bersani, R. Minciardi, R. Sacile, A. M. Tomasoni. “Risk averse routing of hazardous materials with scheduled delays”. Conference Proceedings of the NATO Advanced Research Workshop “Security and Environmental Sustainability of Multimodal Transport” – International Workshop at the Imperial College of London. London, Great Britain, 8th – 9th January 2009.



## 7 Optimal control of dangerous goods traffic flow - The case of transport through a critical infrastructure

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In this work, a preliminary study as regards the possibility to define optimal control strategies for the DG traffic flowing towards one critical road infrastructure (e.g. as in the case study a tunnel) at the macroscopic level is introduced. Specifically, the simplified model that is studied is related to part of a highway, on which the DG traffic can flow from one entrance. The control variables are represented by the number of vehicles that are allowed to enter the highway during a specific time interval, while the state variables are the queue of vehicles before the entrance, the number of vehicles in the various tracts of the highway, and the number of vehicles that enter the tunnel. The objective function to be minimized is characterized by three main terms: the queue, the hazard over the road, and the hazard related to the tunnel

### 7.1 Introduction

DG cover a wide range of products (explosives, gases, flammable liquids and solids, radioactive materials, hazardous wastes, etc. (Verter and Kara, 2008)). Transportation of these materials (that is, in general, multi-modal: road, pipelines, railway, ship) is a relevant problem to be considered because of the significant amount of material that flows among roads, territory and infrastructures (Bersani *et al.*, 2008). Defining strategies for DGT management is a complex task because it is necessary to take into account different objectives (minimize risks, satisfy goods demand transportation), different decision makers (fleet managers, local authorities, infrastructures managers), and different approaches (mainly based on the different spatial-temporal scales to be considered: strategic planning, tactical planning, operational management).

In the literature of DGT on road, there are few, thought important and relevant, works on this subject (for example: Berman *et al.*, 2007; Verter and Kara, 2007; Kara and Verter, 2004; Sadjadi, 2007; Bell, 2009; Bell and Cassir, 2002, Bersani *et al.*, 2008a; Serafini, 2006; Beroggi and Wallace, 1994). The majority of these works is based on optimization models for planning and design purposes. The preliminary approach

presented in this work is instead based on real time operational management (like the work presented by Bersani et al., 2008b) with specific reference to the case of critical infrastructures.

The DGT on road has important consequences in the overall traffic management (Minciardi *et al.*, 2008). This fact is more evident when a vehicle requires to move towards a critical road infrastructure, such as a tunnel or a bridge. The control of traffic networks has been the subject of a great amount of literature from different viewpoints. The main articles related to the case of a tunnel are reported in (Minciardi *et al.*, 2008). The aim of this preliminary study regards the possibility to define optimal control strategies for the DG traffic flowing towards one critical road infrastructure (e.g. as in the case study a tunnel).

A given number of DGT vehicles has to use a highway and to reach one critical infrastructure (e.g. a tunnel). They can stop in a park before the highway entrance and start their travel according to the exigencies of a decision maker that can be identified as the tunnel manager. The park may be taken into account as an inventory in which the state of the system is represented by the vehicles that are present at a specific time instant.

The flow dynamics of DG vehicles on the highway has also to be modelled. In particular, the problem is defined at a macroscopic level, in which the state and the control variables correspond to the number of vehicles, for which the integrity condition may be relaxed, in order to obtain a continuous-variable decision problem.

The control variables are represented by the number of vehicles that are allowed to enter the highway during a specific time interval, while the state variables are the queue of vehicles before the entrance, the number of vehicles in the various tracts of the highway, and the number of vehicles that enters the tunnel. The objective function to be minimized is characterized by three main terms: the queue, the hazard over the road, and the hazard related to the tunnel.

The resulting optimal control problem is linear quadratic with non-negativity constraints over the state and control variables. A receding horizon control scheme is

used to derive the solution and to allow the model to be suitable in real time decision frameworks. An optimization package (Lingo 9.0, [www.lindosystems.com](http://www.lindosystems.com)) is used to solve the problem at each step.

In fact, the explicit form of the optimal control law of a given linear, discrete-time, time-invariant process subject to a quadratic cost criterion is well known in the unconstrained case, while, even for simple constraints, solution is hard to achieve. In (Castelein and Johnson, 1989), the authors use the controllable block companion transformation and derive sufficient conditions on the weighting matrices of the cost criterion to ensure that the closed-loop response of the original process with the standard, unconstrained optimal feedback law will be nonnegative.

Bertsimas and Brown (2007) assess that the celebrated success of dynamic programming for optimizing quadratic cost functions over linear systems is limited by its inability to tractably deal with even simple constraints, and present an alternative approach based on results from robust optimization to solve the stochastic linear-quadratic control (SLQC) problem.

For this reason, interesting developments of this work will be devoted to the definition of methodologies to find efficient solutions for the optimal control strategies.

In the next subsections, the system model is described in detail. Then, the decision problem is formalized. Finally, results and conclusion are drawn.

## 7.2 *The system model*

The Figure 61 shows the schematic representation of the decision framework: the highway directed towards one critical infrastructure is modelled as a line divided in highway tracts. As a simplification, two highway tracts have been considered.

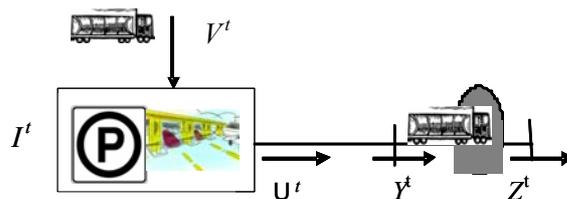


Figure 61. The considered system.

The physical inputs of the whole system are the quantities  $V^t$ , i.e., the (known) number of vehicles entering the park near the highway entrance in time interval  $(t, t+1)$ ,  $t = 0, \dots, T-1$ . The control variables correspond to the number of vehicles that enter the highway  $U^t$  in a specific time interval  $(t, t+1)$ , while the state variables correspond to the number of vehicles in the inventory/queue,  $I^t$ , the number of vehicles per tract of the highway  $(N_1^t, N_2^t)$ , and the number of vehicles entering the tunnel, and number of vehicles going out from the tunnel  $(Y^t, Z^t)$ .

Two different kinds of state equations have to be introduced, regarding, respectively, the queue in the park at the highway entrance, and the highway tracts. Moreover, the hazard has been formalized as a function of the state and control variables.

### 7.2.1 The queue state equation

---

The state equation is:

$$I^{t+1} = (I^t + V^t - U^t) \quad t=0, \dots, T-1 \quad (7.1)$$

where:

- $I^t$  is the number of vehicles stored, at time instant  $t$ , in the park near the entrance, i.e., the inventory of the entrance park area, in time interval  $(t, t+1)$ ;
- $U^t$  is the number of vehicles that enter the highway in time interval  $(t, t+1)$ , from the entrance park area;
- $V^t$  is the (known) number of vehicles that enters the entrance park in time interval  $(t, t+1)$ .

### 7.2.2 The highway tract state equations

---

These state equations describe the evolution over time of a state variable that represents the number of DG vehicles (per unit length) present in a specific tract of the highway. The speed of these vehicles is related to the overall vehicle density over the considered tract. It is assumed that the vehicle flow can be represented through an average speed, which is common to DG and non-DG vehicles. In agreement with the literature dealing with traffic models, it is assumed that the (average) vehicle speed is never so high to allow the complete covering of a highway tract within a single time

interval (of course, this may be also seen as a constraint over the space discretization of the highway). The equations are given by

$$N_1^{t+1} = N_1^t + \frac{U^t}{L_1} - \frac{Y^t}{L_1} \quad t=0, \dots, T-1 \quad (7.2)$$

$$N_2^{t+1} = N_2^t - \frac{Z^t}{L_2} + \frac{Y^t}{L_2} \quad t=0, \dots, T-1 \quad (7.3)$$

with

$$Y^t = N_1^t vel_1^t \Delta t \quad t=0, \dots, T-1 \quad (7.4)$$

$$Z^t = N_2^t vel_2^t \Delta t \quad t=0, \dots, T-1 \quad (7.5)$$

where:

$N_1^t, N_2^t$  are the number of (DG) vehicles per unit length that is present in the highway road in tract 1 and in the tunnel, in time instant  $t$ ;

$L_1, L_2$  are the tract and tunnel lengths respectively;

$\Delta t$  is the time interval length;

$vel_1^t, vel_2^t$  are the (average) velocities in the tract 1 and tunnel in time interval  $(t, t+1)$ , which is assumed to be imposed by the ordinary traffic (i.e., non DG), assuming that the DG vehicle flow is only a negligible part of the overall traffic flow;

$Y^t$  is the number of vehicles that passes from tract 1 to the tunnel in time interval  $(t, t+1)$ ;

$Z^t$  is the number of vehicles that going out from the tunnel in time interval  $(t, t+1)$ .

### 7.2.3 Hazard assessment

The hazard of accidents depends on different structural and environmental parameters that may vary for each time interval and for each highway tract, and on the number of vehicles (Fabiano et al., 2002; Fabiano et al., 2005). In this work, the hazard  $HAZ^t$  is simply represented as a time-varying a-dimensional parameter  $\eta_{HAZ}^t$  multiplied by the density of vehicles in the specific tract. That is,

$$HAZ^t = \eta_{HAZ_1}^t N_1^t + \eta_{HAZ_2}^t N_2^t \quad t=0, \dots, T-1 \quad (7.6)$$

### 7.2.4 The decision problem

---

The objective function has to take into account the number of vehicles in the park entrance, the number of vehicles per unit length in tract 1 of the highway, and the number of vehicles that enter the tunnel. In particular the following terms have to be minimized:

the number of vehicles waiting in the park entrance;

the number of vehicles per unit length for tract 1,  $N_1^t$ ;

the number of vehicles per unit length that enter the tunnel,  $N_2^t$ ;

Thus, the objective function can be expressed as

$$\min \sum_{t=0}^{T-1} (I^t)^2 + \alpha (N_1^t)^2 + \beta (N_2^t)^2 \quad (7.7)$$

where:

$N_1^t, N_2^t$  are the number of DG vehicles per unit length that is present in the highway road in tracts 1 and in the tunnel, in time instant  $t$ ;

$I^t$  is the number of vehicles stored, at time instant  $t$ , in the park near the entrance, i.e., the inventory of the entrance park area, in time interval  $(t, t+1)$ ;

$\alpha, \beta$  are specific weighting factors.

### 7.2.5 The statement of the optimal control problem

---

The optimal control problem reported in equations (1)-(7) can be expressed in the following form

$$\min_{u_t} \sum_{t=0}^{T-1} \underline{x}_t^T Q_t \underline{x}_t \quad (7.8)$$

where  $\underline{x}_t$  is the space vector and  $Q_t$  a matrix of time dependent parameters. Specifically,

$$\underline{x}_t = \begin{bmatrix} I^t \\ N_1^t \\ N_2^t \end{bmatrix} \quad t=0, \dots, T-1 \quad (7.9)$$

$$Q_t = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \alpha & 0 \\ 0 & 0 & \beta \end{bmatrix} \quad t=0, \dots, T-1 \quad (7.10)$$

s.t.

$$\underline{x}_{t+1} = A_t \underline{x}_t + \underline{b}u_t + \underline{d}_t \quad t=0, \dots, T-1 \quad (7.11)$$

$$u_t \geq 0 \quad t=0, \dots, T-1 \quad (7.12)$$

$$\underline{x}_t \geq 0 \quad t=0, \dots, T-1 \quad (7.13)$$

Where:

$u_t = U_t$  are the control variables,  $A_t$  is a matrix of time dependent parameters,  $\underline{b}$  a vector of parameters, and  $\underline{d}_t$  a vector of time dependent parameters.

$$A_t = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 - \frac{vel_1^t \Delta t}{L_1} & 0 \\ 0 & \frac{vel_1^t \Delta t}{L_2} & 1 - \frac{vel_2^t \Delta t}{L_2} \end{bmatrix} \quad t=0, \dots, T-1 \quad (7.14)$$

$$\underline{b}_t = \begin{bmatrix} -1 \\ \frac{1}{L_1} \\ 0 \end{bmatrix} \quad t=0, \dots, T-1 \quad (7.15)$$

$$\underline{d}_t = \begin{bmatrix} V^t \\ 0 \\ 0 \end{bmatrix} \quad t=0, \dots, T-1 \quad (7.16)$$

The optimal control problem expressed by equations (7.8)-(7.16) is a linear-quadratic one, with non negativity constraints over the state and control variables.

### 7.3 Results

The space-time discretization of equations (7.2)-(7.3) has been chosen in order to avoid instability of the traffic flow (i.e., in the time interval, the vehicles are not allowed to pass the tract length), and in order to have a meaningful time interval for traffic flow simulation (Kotsialos and Papageorgiou, 2004). That is,

$$\begin{aligned} T &= 15 \\ \Delta t &= 10 \text{ [s]} \\ L_1 &= 800 \text{ [m]} \\ L_2 &= 800 \text{ [m]} \\ vel_1^t &= 16.6 \text{ [m/s]} \\ vel_2^t &= 16.6 \text{ [m/s]} \end{aligned}$$

Firstly, the optimization problem (7.1)-(7.7) has been solved, with the following inputs:  $\underline{V} = [10, 3, 2, 0, 0, 0, 0, 0, 0, 2, 3, 0, 0, 0, 0]$ , and the following weights in the objective function:  $\alpha = 2 \cdot 10^4$ ,  $\beta = 2 \cdot 10^4$ .

A receding-horizon control scheme has been applied and, in the two table below, (Table 21, and 22) the optimization results are reported.

Time	$U^t$	$Z^t$	$I^t$
0	8.38	0	0
1	0.56	0	1.62
2	0.6	$0.26 \cdot 10^{-4}$	4.06
3	0.66	$0.26 \cdot 10^{-4}$	5.46
4	0.74	$0.25 \cdot 10^{-4}$	4.8
5	0.86	$0.24 \cdot 10^{-4}$	4.06
6	1	$0.23 \cdot 10^{-4}$	3.2

7	1.19	$0.21 \cdot 10^{-4}$	2.2
8	1	$0.19 \cdot 10^{-4}$	1
9	2	$0.17 \cdot 10^{-4}$	0
10	2.23	$0.14 \cdot 10^{-4}$	0
11	0.77	$0.12 \cdot 10^{-4}$	0.76
12	0	$0.83 \cdot 10^{-5}$	0
13	0	$0.44 \cdot 10^{-5}$	0
14	0	0	0

**Table 21. Results of the optimization problem:  $U^t, Z^t, I^t$ .**

Time	$N_1^t$	$N_2^t$	$Y^t$
0	0	0	0
1	$0.1 \cdot 10^{-1}$	0	1.74
2	$0.9 \cdot 10^{-2}$	$0.22 \cdot 10^{-2}$	1.49
3	$0.79 \cdot 10^{-2}$	$0.4 \cdot 10^{-2}$	1.3
4	$0.71 \cdot 10^{-2}$	$0.57 \cdot 10^{-2}$	1.17
5	$0.65 \cdot 10^{-2}$	$0.71 \cdot 10^{-2}$	1.08
6	$0.63 \cdot 10^{-2}$	$0.85 \cdot 10^{-2}$	0.04
7	$0.62 \cdot 10^{-2}$	$0.98 \cdot 10^{-2}$	1.03
8	$0.64 \cdot 10^{-2}$	$0.11 \cdot 10^{-1}$	1.06
9	$0.63 \cdot 10^{-2}$	$0.12 \cdot 10^{-1}$	1.05
10	$0.75 \cdot 10^{-2}$	$0.14 \cdot 10^{-1}$	1.25
11	$0.87 \cdot 10^{-2}$	$0.15 \cdot 10^{-1}$	1.45
12	$0.79 \cdot 10^{-2}$	$0.17 \cdot 10^{-1}$	1.31
13	$0.63 \cdot 10^{-2}$	$0.19 \cdot 10^{-1}$	1.04
14	$0.49 \cdot 10^{-2}$	$0.2 \cdot 10^{-1}$	0.82

**Table 22. Results of the optimization problem:  $N_1^t, N_2^t, Y^t$ .**

The overall hazard is (summation over time of equation (7.6)) equal to 1978, with

$$\eta_{HAZ1}^t = \eta_{HAZ2}^t = \eta_{HAZ3}^t = 10.$$

Then, the non-negativity constraints have been removed. The optimal values are the same like in the constrained case.

Similar results, in the unconstrained case, can be found through the use of the Riccati equation. Instead, for the constrained case an efficient method of solution has to be found. A possible approach can be the one reported in (Bertsimas and Brown, 2007). Otherwise, one can try to use dynamic programming and reduce the explosion of computation that arises.

## **7.4 Conclusions**

A preliminary approach for the optimal control of DG traffic flow has been presented. The novelties of the presented approach in the literature of DG T have been highlighted, as well as the methodological approaches that might characterize the solution of the optimal control problem.

Future research related to the present work will regard the development of methods to derive the optimal control law to the considered problem in a closed form. After that, the decision problem could be extended to the optimal control of two fleets of hazardous material that have to flow through a tunnel in both competitive and collaborative cases.

Moreover, a hierarchical control can be formalized in which a decision maker related to the tunnel has to decide the price to assign to the two fleets on the basis of the costs, the goods demand, and the risk to be minimized in the overall system, while the fleets aim at minimizing their own benefits and hazards.

This work has been presented at an international conference:

- Chiara Bersani, Riccardo Minciardi, Michela Robba, Roberto Sacile, Angela M. Tomasoni. Optimal control of hazardous materials traffic flow - the case of transport through a critical infrastructure. Conference Proceedings of the ICINCO Advanced Research Workshop “Security and Environmental Sustainability of Multimodal Transport” – International Workshop. Milan, Italy, 2th – 5th July 2009.



## 8 General conclusion and future developments

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The work presented in this PhD thesis on DGT has expressed the need to describe the DGT system quantitatively to find solutions or answers in order to minimize the risks arising from transport or maximize the level of security in freight traffic. The system of DGT logistics has tackled by splitting a complex system – the DGT system - into its subsystems, studying specific aspects as well as proposing new methodologies. The thesis work has developed in finding resolutions or optimal solutions of models - applied to each subsystem - with assumptions, methodologies and targets ad hoc for each analyzed case study.

In my PhD work, two transport modalities, pipeline and road, have been taken into account, since they represent the most common modalities of transport in Europe, as well as in France and Italy.

All the models that I have described and defined have been based on the classical definition of technological risk – related to humans activity – categorized as accidental risk, where the risk has been related to the failure – or accident – of a vehicle, or a pipeline, transporting dangerous goods matters. This risk definition has been the same for the pipeline and road, but I used different methodological approaches to evaluate transport risk.

The different methodologies that have been used throughout my PhD work are strongly oriented to an engineering vision of the hazard and of the related risk, where a numerical quantitative evaluation is required. To support this view, I have deepened and used methodologies and technologies oriented to Innovative Statistic Approaches based on Artificial Neural network in Chapter 4, Geographic Information Systems in Chapter 5, Mathematical Programming and in part, Game Theory in Chapter 6, and finally Optimal Control in Chapter 7.

At the end of this work I can say that it was not so easy to define all the proposed approach precisely as a quantitative method, because several techniques are embedded or overlap in other ones. What is extraordinary is that some of them are subjective risk approach because of the impossibility to quantify all the variables that are involved in an

accident. All these variables are subjected to change, so the overall system change, but sometime do not change the risk perception or evaluation.

So, the first proposal for a future argument of research is a methodology or a method to evaluate statistically the weight of each variable in the accident evaluation, and in which way the overall system change at every single change of a variable, to understand if there are variables much more related or correlated to risk than others. In this way, it is possible to define what variables are related to probability, and what variables are linked to consequences, in the technological risk definition. Indeed, it is possible to reduce risk or in prevention - when the variables are associated to consequences - or in protection, when the variables are associated to probability.

This research can be developed both in pipeline and road transport, because of a bi-level transport of hydrocarbons from the petrol inland extraction platform to this two modality of transport through an urbanised territory, and the comparison between risk derived from this two type of transport is an interesting and challenging objective for my future research.

Another theme of research, that could be developed as a continuation of this work, could be the development of a transnational traffic control centre on road – but also using other type of transport – that, on the bases of data collection deriving from Italy and France, collect, control and monitoring freight traffic to define firstly, systemic vulnerability through the boundary territory; to identify secondly, critical infrastructure and possible accident scenario; and thirdly to define new routing and alternative paths in case of an infrastructure inefficiency.

Then, using suitable communication and information technology it could be possible define protocols and standards of communication and levels of shearing information to prevent accidents, in case of emergency, and also in real time to control how many and when freight traffic, and specially dangerous goods transport pass through the EU territory.



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# ATTACHMENTS

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**Attachment N.1 - The classes of dangerous goods according to HAZARDOUS MATERIAL TRANSPORTATION GUIDES. (DG Guidelines, 2010).**

DOT HAZARD CLASS	UN CLASS DEFINITION	DESCRIPTION
EXPLOSIVES		An Explosive is any chemical compound, mixture, or device which is designed to function by explosion, that is substantially instantaneous with the release of gas and heat. Exception — such compound, mixture, or device which is otherwise specifically classified in Parts 171-180. (See 49 CFR 173.50)
	CLASS A - 1	Detonating. Maximum Hazard. The nine types of Class A explosives are defined in 49 CFR 173.53.
	CLASS B - 1	Flammable Hazard. In general, functions by rapid combustion rather than detonation. Included are explosive devices such as special fireworks, flash powders, etc. (49 CFR 173.88)
	CLASS C - 1	Minimum hazard. Small arms ammunition, certain types of fireworks and various types of manufactured articles containing restricted quantities of Class A and/or Class 11 explosives as components. Included are common fireworks and various types of small arms ammunition manufactured articles which contain restricted quantities of Class A or Class B explosives. (49 CFR 173.100)
	BLASTING AGENT - 1	Blasting Agent. A

		material designed for blasting which has been tested in accordance with 49 CFR 173.114(a)(b). It must be so insensitive that there is very little probability of: (1) accidental explosion or (2) going from burning to detonation. (49 CFR 173.114a(a))
GASES	2 - Compressed Gas	Any material or mixture having in-the-container an absolute pressure exceeding NON-FLAMMABLE GAS 40 psi at 70' F, OR a pressure exceeding 104 psi at 130'F; or any liquid flammable material having a vapor pressure exceeding 40 psi at 100'F. (49 CFR 173.300(a))
	2 - non-liquified Compressed Gas	A gas (other than gas in solution) which, under the charged pressure, is entirely gaseous at a temperature of 70'F. (49 CFR 173.300(c))
	2 - Liquefied Compressed Gas	A gas which, under the charged pressure, is partially liquid at a temperature of 70-F. (49 CFR 173.300(d))
	2 - Compressed Gas in solution	A non-liquefied compressed gas which is dissolved in a solvent. (49 CFR 173.300(e))
	2 - Flammable Compressed Gas	Any compressed gas meeting criteria as specified in 49 CFR 173.300(a) and (1)). This includes: lower flammability limit, flammability limit range, flame projection, or flame propagation.
	2 - Non-flammable Gas	Any compressed gas other than a flammable compressed gas.
FLAMMABLE LIQUID	3 - Flammable liquid	Any liquid having a flash point below 100'F. Authorized methods to determine flashpoints are listed in 49 CFR 173.115(d). For exceptions, see 49 CFR 173.115(a).

	3 - Pyrophoric Liquid	Any liquid that ignites spontaneously in dry or moist air at or below 130°F. (49 CFR 173.115(c)).
COMBUSTIBLE LIQUID	3 - Combustible liquid	Any liquid that does not meet any other hazard class, other than ORM-E, having a flash point at or above 100°F. and below 200°F. For exceptions, see 49 CFR 173.115(b). Authorized methods to determine flashpoints are listed in 49 CFR 173.115(d). Exceptions are found in 49 CFR 173.118(a).
FLAMMABLE SOLID	4 - Flammable Solid	Any solid material (other than an explosive) which under normal transportation conditions is liable to cause fires through friction or retained heat from manufacturing or processing. It can, be ignited readily and burns so vigorously and persistently, as to create a serious transportation hazard. Included in this class are spontaneously combustible and water reactive material. (49 CFR 173.150).
	4 - Spontaneously Combustible Material (solid)	A solid substance (including sludges and pastes) which may undergo spontaneous Treating or self-ignition under normal transportation conditions. These materials may increase in temperature and ignite when exposed to air. (49 CFR 171.8).
	4 - Water Reactive Material (solid)	Any solid substance (including sludges and pastes) which react with water by igniting or giving off dangerous quantities of flammable or toxic gases. (49 CFR 171.8).
ORGANIC PEROXIDE	5 - Organic Peroxide	Any organic compound containing the bivalent -O-O- structure. It may be

		considered a derivative of hydrogen peroxide where one or more of the hydrogen atoms have been replaced by organic radicals. It must be classed as an organic peroxide unless it meets certain criteria listed in 49 CFR 173.151(a).
OXIDIZER	5 - An Oxidizer	A substance such as chlorate, permanganate, inorganic peroxide, or a nitrate, that yields oxygen readily to stimulate the combustion of organic matter. (49 CFR 173.151).
POISON A	2 - Extremely Dangerous Poisons	Poisonous gases or liquids--a very small amount of the gas, or vapor of the liquid, mixed with air is dangerous to life. (49 CFR 173.326).
POISON B	6 - Less Dangerous Poisons	Substances, liquid or solid (including pastes and semi-solids), other than Class A Poisons or Irritating Materials--so toxic (or presumed to be toxic) to man that they are a hazard to health during transportation. (49 CFR 173.343(a)).
IRRITATING MATERIAL	6 - An Irritating Material	A liquid or solid substance which, upon contact with fire or air, gives off dangerous or intensely irritating fumes. It does not include any poisonous material, Class A.(49 CFR 173.381).
ETIOLOGIC AGENT	6 - An Etiologic agent	A living micro-organism (or its toxin) which causes (or may cause) human disease, and includes those agents listed in 49 CFR 72.3.(49 CFR 173.386).
RADIOACTIVE MATERIAL	7 - Radioactive Material	Any material, or combination of materials, that spontaneously gives off ionizing radiation. It has a specific activity greater than 0.002 microcuries per gram. (49 CFR 173.403)(See 49 CFR 173.403(a) through (z)

		for details.)
CORROSIVE MATERIAL	8 - Corrosive Material	A liquid or solid that causes visible destruction or irreversible damage to human skin tissue on contact. Also, it may be a liquid that has a severe corrosion rate on steel. (See 49 CFR 173.240 (a) and (b) for details.)
ORM- OTHER REGULATED MATERIALS	9 – Other regulated materials	(1) Any material that may pose an unreasonable risk to health, safety, and property when transported in commerce; and (2) does not meet any of the definitions of the other hazard classes specified in this subchapter, or (3) has been re-classed an ORM (specifically or permissively) according to this subchapter. (49 CFR 173.500(a)).
	9 - ORM-A	An ORM-A is material which has an anaesthetic, irritating, noxious, toxic, or other similar property. If the material leaks during transportation, passengers and crew would experience extreme annoyance and discomfort. (49 CFR 173.500(b)(1)).
	9 - ORM-B	An ORM-B is material, (including a solid when wet with water), the leakage of which could cause significant damage to the vehicle transporting it. Materials meeting one or both of the following criteria are ORM-it materials: (1) specifically designated by name in 49 CFR 172.101 and/or (2) a liquid substance that has a corrosion rate exceeding 0.250 inch per year(IPY) on non-clad aluminium. An acceptable test is described in NACE

		Standard TM-01-69.(49 CFR 173.500(b)(2)).
	9 - ORM-C	An ORM-C is material which has other inherent characteristics not described as an ORM-A or ORM-B, but which make it unsuitable for shipment, unless properly identified and prepared for transportation. Each ORM-C material is specifically named in 49 CFR 172.101. (49 CFR 173.500(b)(3)).
	9 - ORM-D	An ORM-D is a material such as a consumer commodity which presents a limited hazard during transportation due to its form, quantity and packaging. It must be a material for which exceptions are provided in 172.101. Shipping descriptions applicable to ORM-D materials are found in 49 CFR 172.101. (49 CFR 173.500(b)(4)).
	9 - ORM-E	An ORM-E is a material that is not included in any other hazard class but is subject to the requirements of this subchapter. Materials in this class include: (1) HAZARDOUS WASTE and (2) HAZARDOUS SUBSTANCES, as defined in 49 CFR 171.8. (49 CFR 173.500(b)(5)).

## Attachment N.2 – Kerosene Material Safety Data Sheet (MSDS)

<b>KEROSENE</b>		<b>0663</b> November 1998	
<b>CAS No:</b> 8008-20-6 <b>RTECS No:</b> OA5500000 <b>UN No:</b> 1223 <b>EC No:</b> 649-404-00-4		Kerosine Light petroleum Lamp oil Fuel oil no°1	
TYPES OF HAZARD/ EXPOSURE	ACUTE HAZARDS/SYMPTOMS	PREVENTION	FIRST AID/FIRE FIGHTING
<b>FIRE</b>	Flammable.	NO open flames, NO sparks, and NO smoking.	Powder, AFFF, foam, carbon dioxide.
<b>EXPLOSION</b>	Above 37°C explosive vapour/air mixtures may be formed.	Above 37°C use a closed system, ventilation, and explosion-proof electrical equipment. Prevent build-up of electrostatic charges (e.g., by grounding).	In case of fire: keep drums, etc., cool by spraying with water.
EXPOSURE	PREVENT GENERATION OF MISTS!		
<b>Inhalation</b>	Confusion. Cough. Dizziness. Headache. Sore throat. Unconsciousness.	Ventilation.	Fresh air, rest. Artificial respiration if indicated. Refer for medical attention.
<b>Skin</b>	Dry skin. Roughness.	Protective gloves.	Remove contaminated clothes. Rinse and then wash skin with water and soap. Refer for medical attention.
<b>Eyes</b>	Redness.	Safety spectacles.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then take to a doctor.
<b>Ingestion</b>	Diarrhoea. Nausea. Vomiting.	Do not eat, drink, or smoke during work.	Do NOT induce vomiting. Rest. Refer for medical attention.
SPILLAGE DISPOSAL		PACKAGING & LABELLING	
Collect leaking liquid in sealable containers. Absorb remaining liquid in sand or inert absorbent and remove to safe place. Do NOT let this chemical enter the environment (extra personal protection: self-contained breathing apparatus).		Xn Symbol R: 65 S: (2-)23-24-62 Note: H UN Hazard Class: 3 UN Pack Group: III	
EMERGENCY RESPONSE		STORAGE	
Transport Emergency Card: TEC (R)-551 NFPA Code: H 0; F 2; R 0;		Fireproof. Separated from strong oxidants. Cool.	
    			
<b>IPCS</b> <small>International Programme on Chemical Safety</small>		<small>Prepared in the context of cooperation between the International Programme on Chemical Safety and the European Commission © IPCS 1999</small>	
<small>SEE IMPORTANT INFORMATION ON THE BACK.</small>			

0663

KEROSENE

## IMPORTANT DATA

<p><b>Physical State; Appearance</b> LOW VISCOSITY LIQUID, WITH CHARACTERISTIC ODOUR.</p> <p><b>Physical Dangers</b> As a result of flow, agitation, etc., electrostatic charges can be generated.</p> <p><b>Chemical Dangers</b> Reacts with oxidants.</p> <p><b>Occupational Exposure Limits</b> TLV not established.</p>	<p><b>Routes of Exposure</b> The substance can be absorbed into the body by inhalation of its vapour and by ingestion.</p> <p><b>Inhalation Risk</b> No indication can be given about the rate in which a harmful concentration in the air is reached on evaporation of this substance at 20°C.</p> <p><b>Effects of Short-term Exposure</b> The substance slightly irritates the skin and the respiratory tract. Swallowing the liquid may cause aspiration into the lungs with the risk of chemical pneumonitis. The substance may cause effects on the nervous system.</p> <p><b>Effects of Long-term or Repeated Exposure</b> The liquid defats the skin.</p>
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## PHYSICAL PROPERTIES

<p>Boiling point: 150-300°C Melting point: -20°C Relative density (water = 1): 0.8 Solubility in water: none</p>	<p>Relative vapour density (air = 1): 4.5 Flash point: 37-65°C Auto-ignition temperature: 220°C Explosive limits, vol% in air: 0.7-5</p>
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## ENVIRONMENTAL DATA

The substance is harmful to aquatic organisms.

## NOTES

Physical properties vary, depending on the composition. Ingestion of kerosene (lamp oil) is a major cause of accidental poisoning in children.

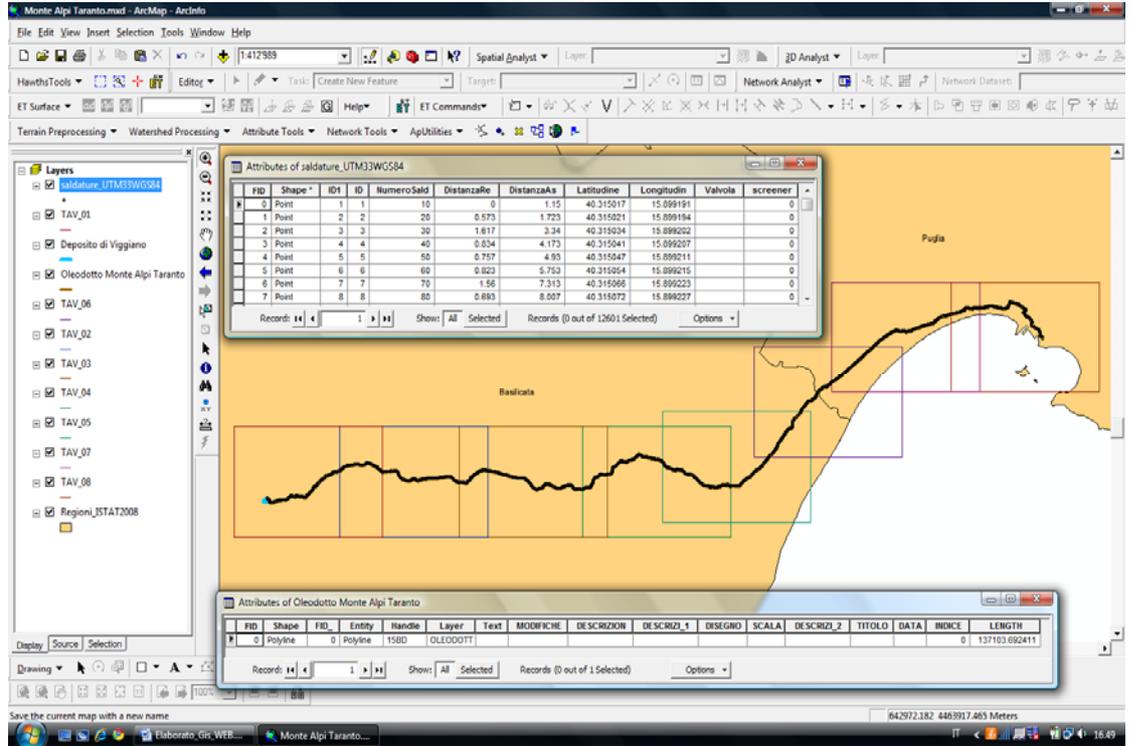
## ADDITIONAL INFORMATION

## LEGAL NOTICE

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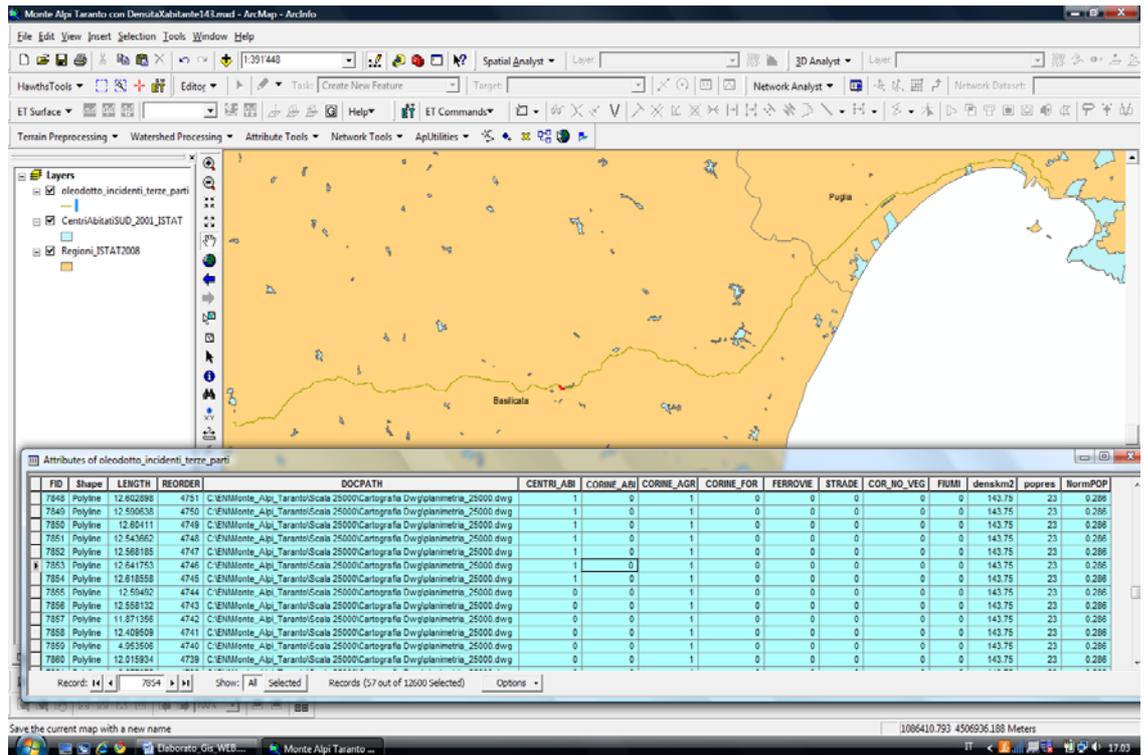
## Attachment N.3 – GIS and WEB-GIS platform and prototype



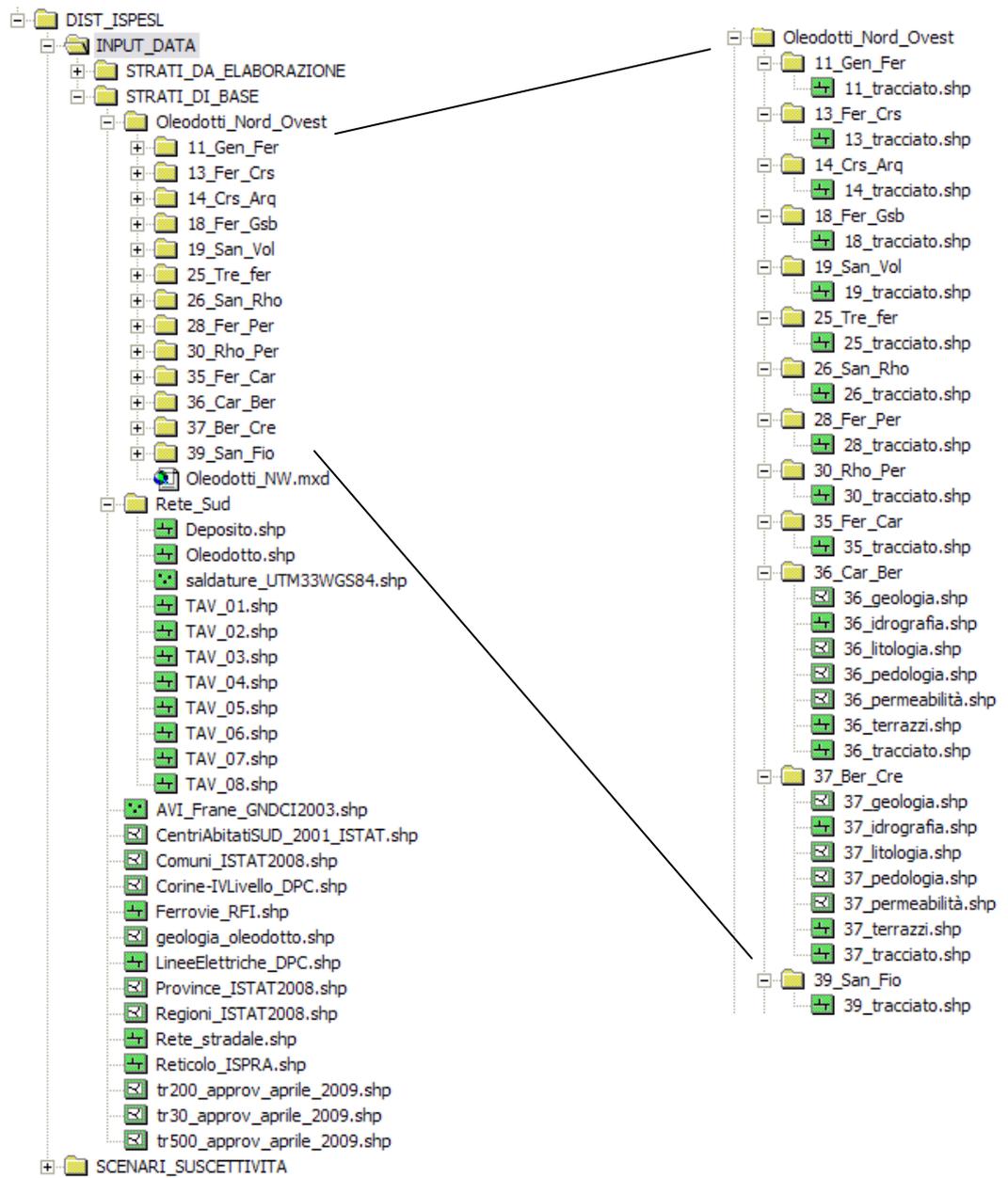
**ArcMap Workspace. Monte Alpi Taranto pipeline as a single polyline of 137.7 km in length. In support are displayed: the filing of Viggiano, eight tables framing the pipeline in different frames, welds, derived from the Tubes Book of the Pipeline and converted into shapefiles.**

FID	Shape	LENGTH	REORDER	DOCPATH	CENTRI_ABI	CORINE_ABI	CORINE_AGR	CORINE_FOR	FERROVIE	STRADE	COR_NO_VEG	FIUMI	denskm2	popres	NormPOD
0	Polyline	1.040281	12599	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
1	Polyline	3.341444	12598	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
2	Polyline	1.891383	12597	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
3	Polyline	0.772312	12596	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
4	Polyline	0.756554	12595	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
5	Polyline	0.756554	12594	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
6	Polyline	1.875624	12593	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
7	Polyline	1.323964	12592	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
8	Polyline	1.229401	12591	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
9	Polyline	3.70397	12590	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
10	Polyline	8.482039	12589	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
11	Polyline	3.644916	12588	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
12	Polyline	7.033703	12587	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
13	Polyline	5.132822	12586	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
14	Polyline	2.068839	12585	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
15	Polyline	11.55683	12584	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0
16	Polyline	3.289735	12583	C:\EN\Monte_Alpi_Taranto\Scala 25000\Cartografia Dwg\planimetria_25000.dwg	0	1	0	0	0	0	0	0	0	0	0

**Shapefile attribute table associated with Monte Alpi Taranto pipeline. Each record represents a number of factors associated to an accidents caused by activities of third parties.**

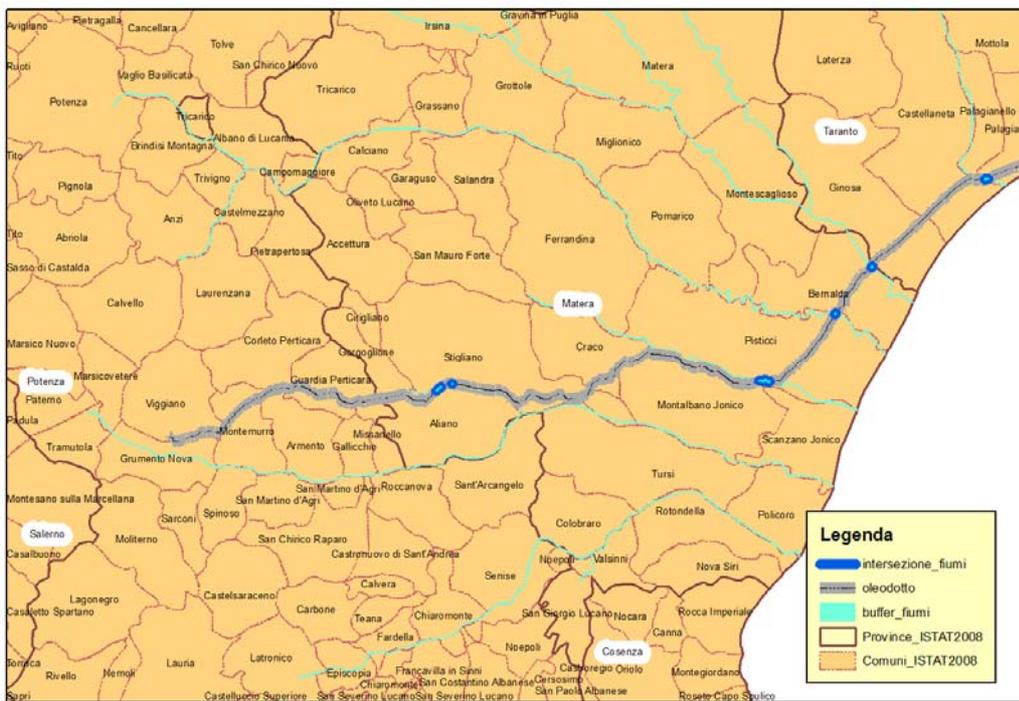
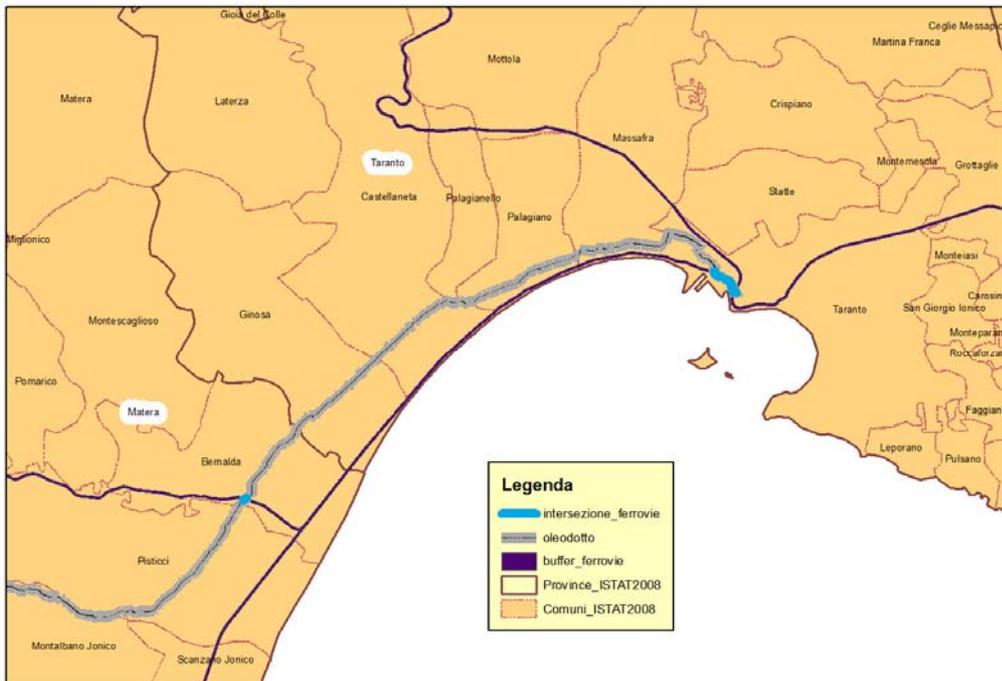


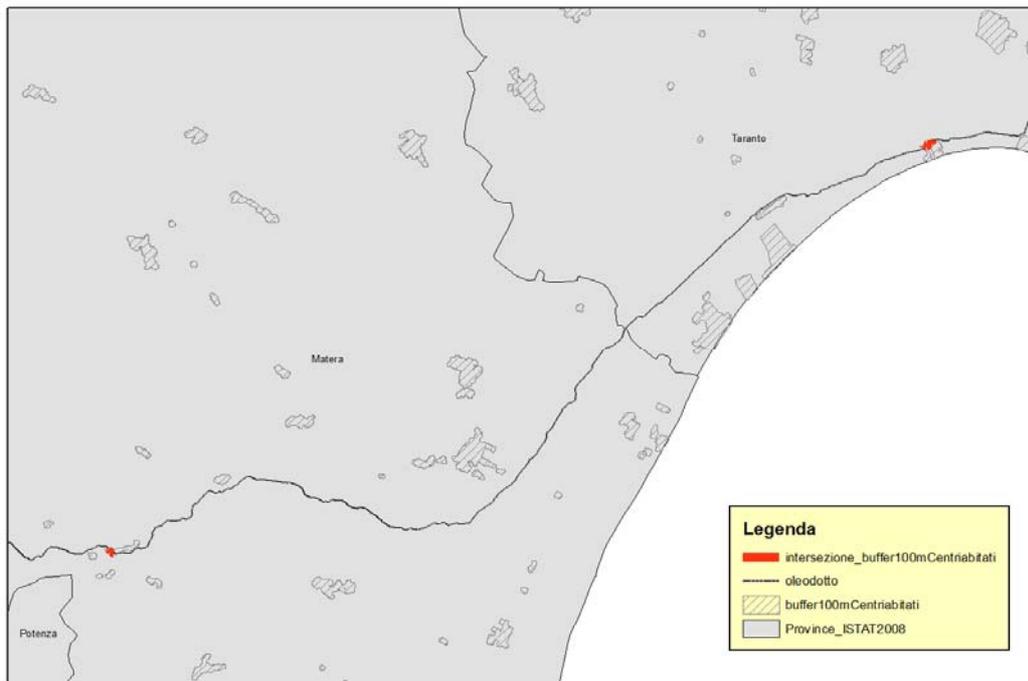
Using a query attribute that displays bars pipeline - hatching in red - that are associated with a population density of 144.75 people per sq. km. The attribute table has many records selected as there are bars with this feature.

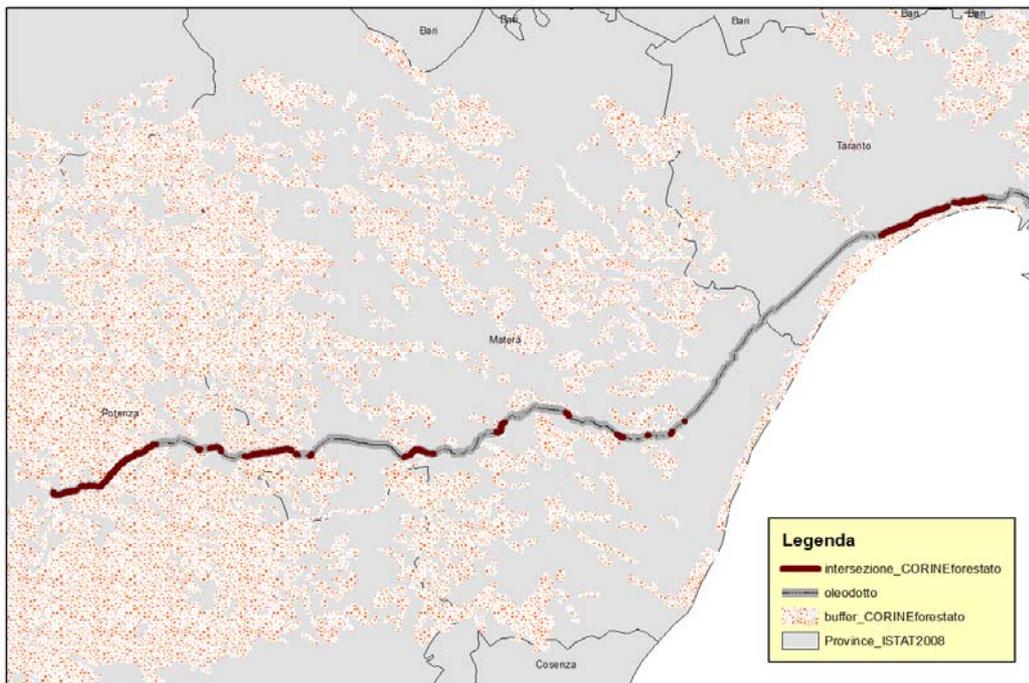
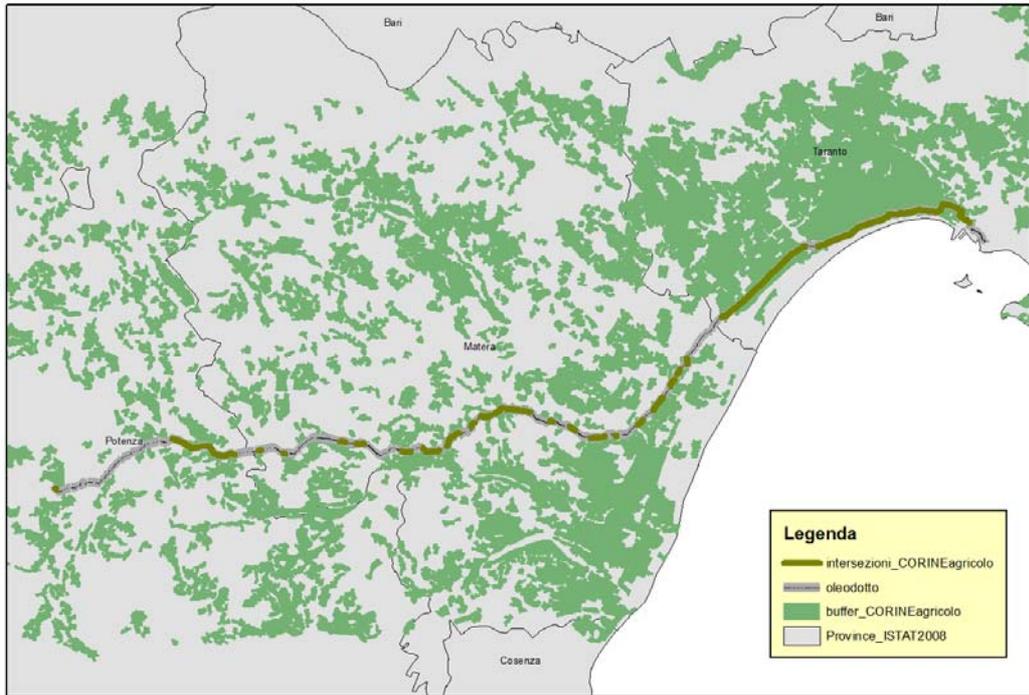


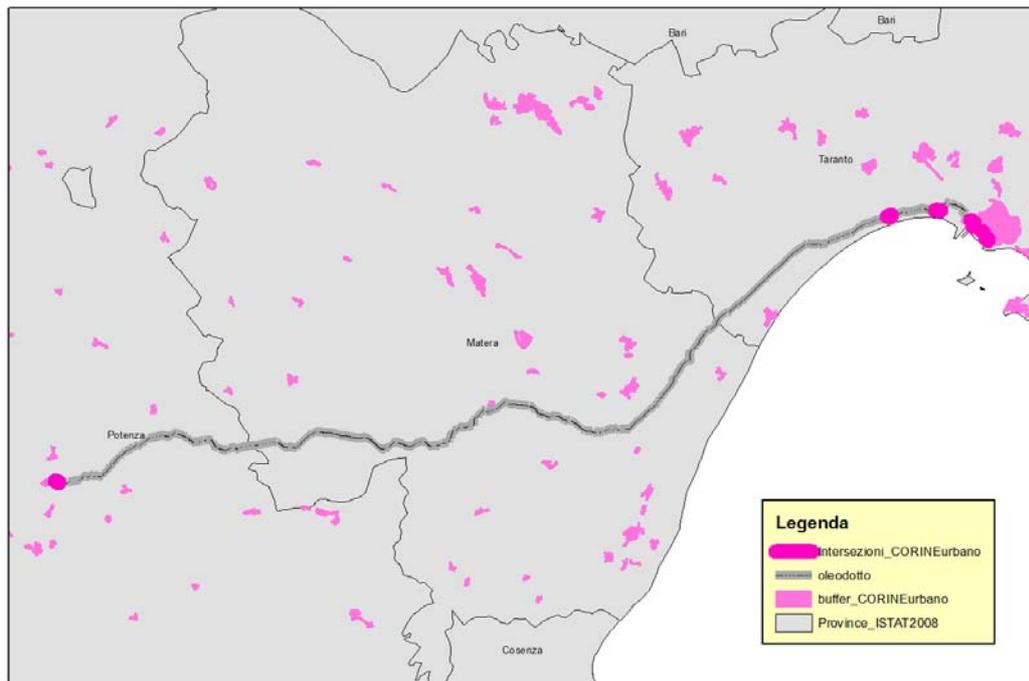
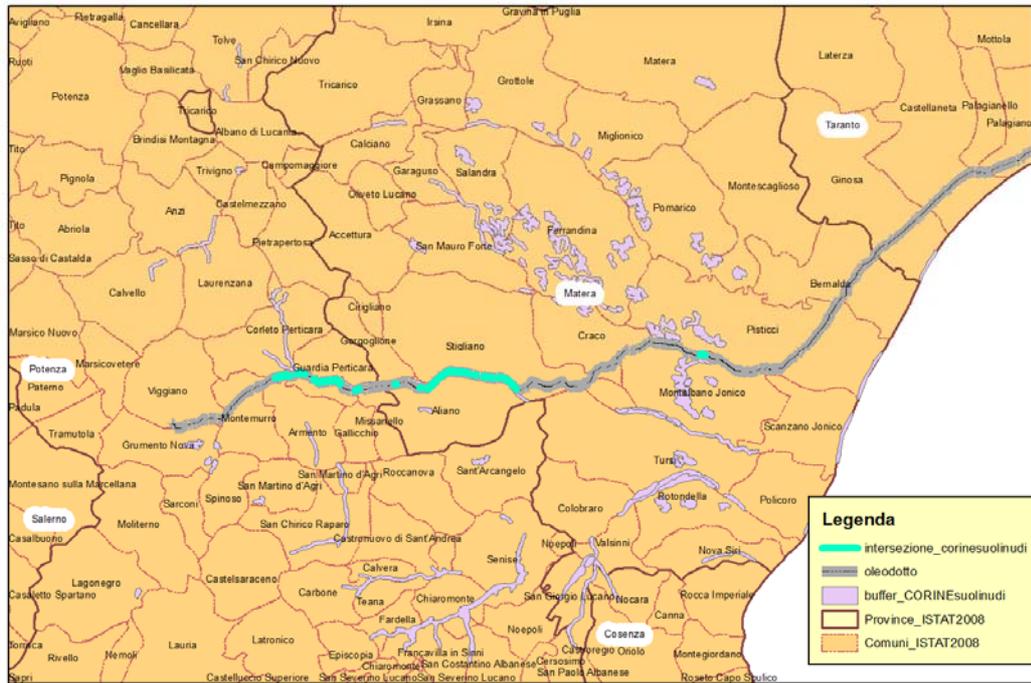
**Archive data base.**

# 01\_THIRD PARTIES ACTIVITIES ACCIDENT SCENARIO

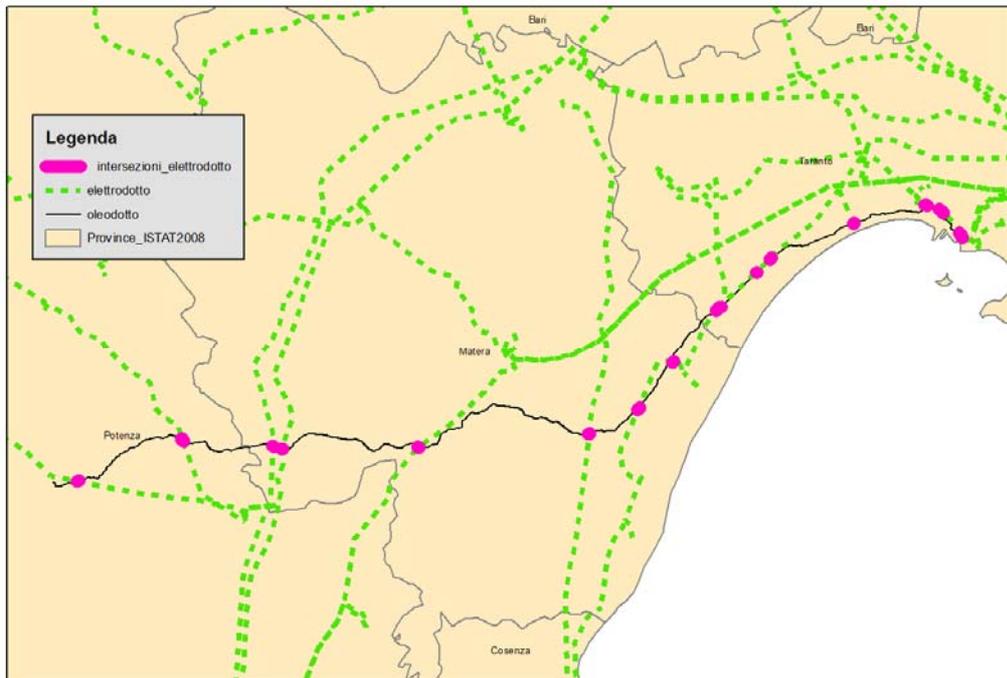


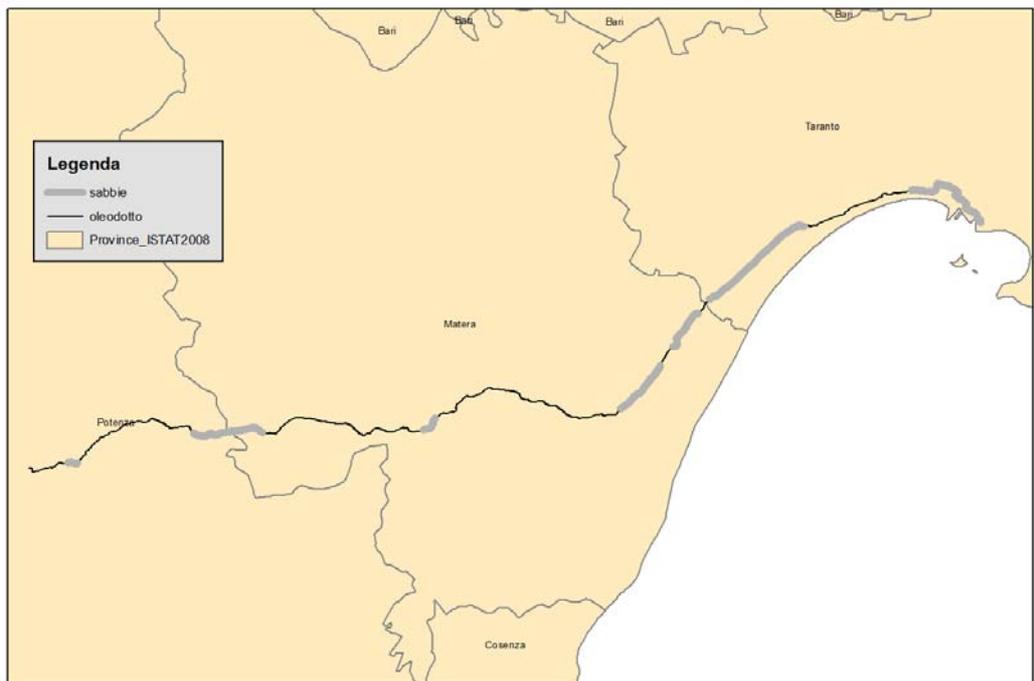
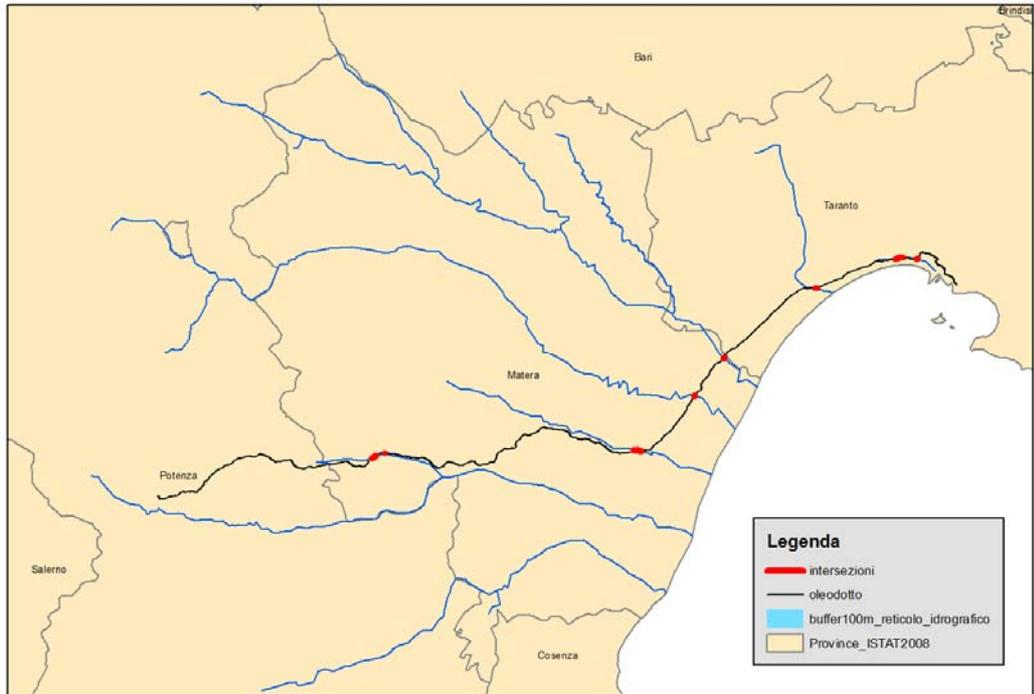




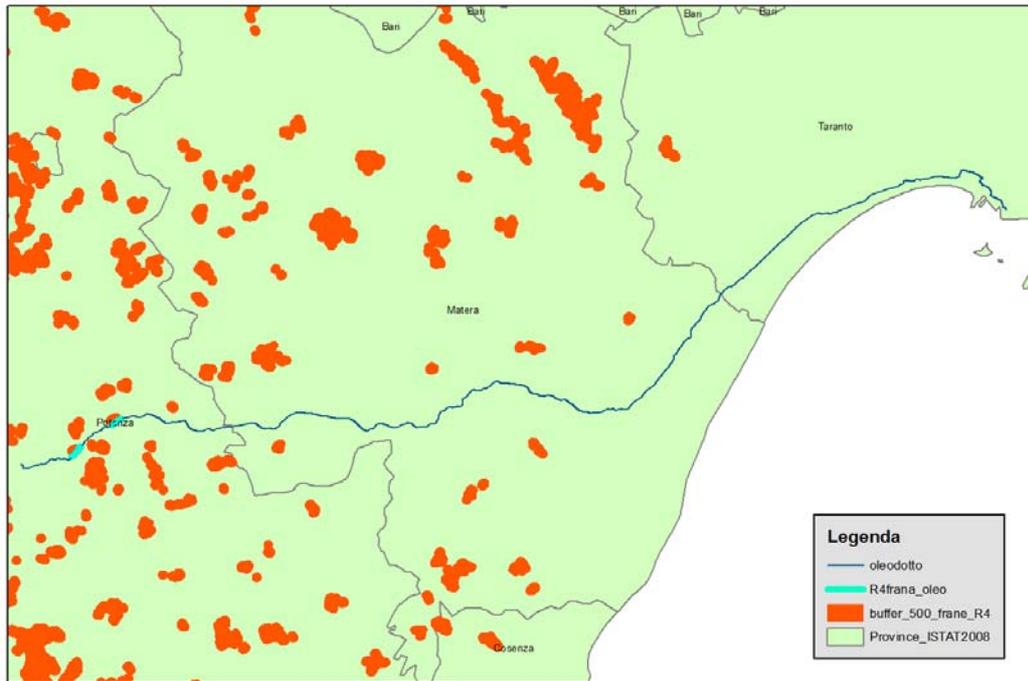


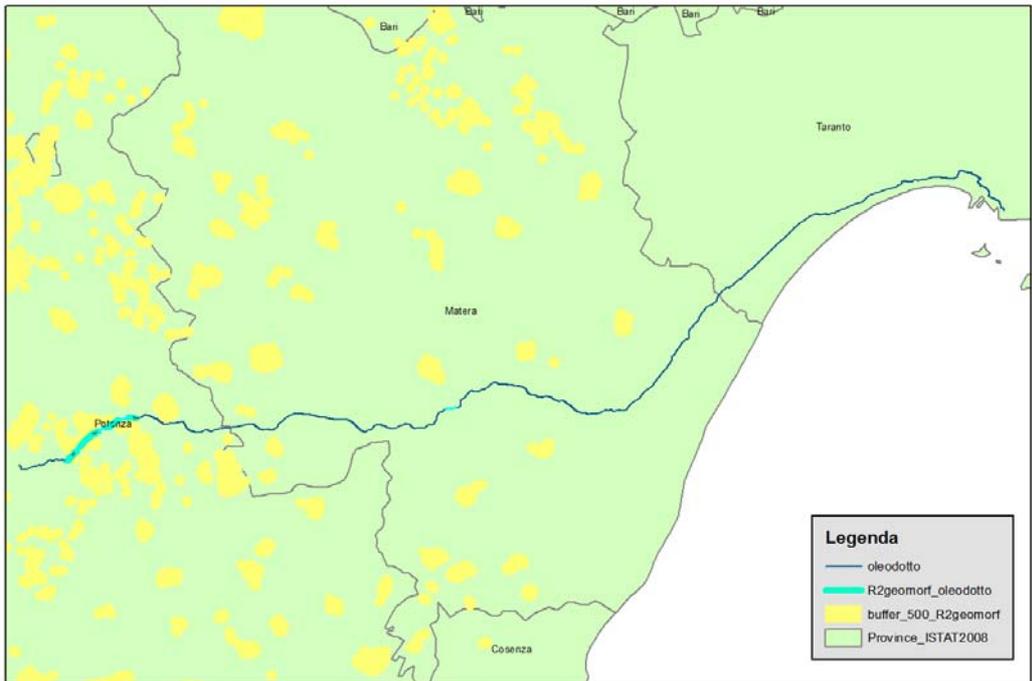
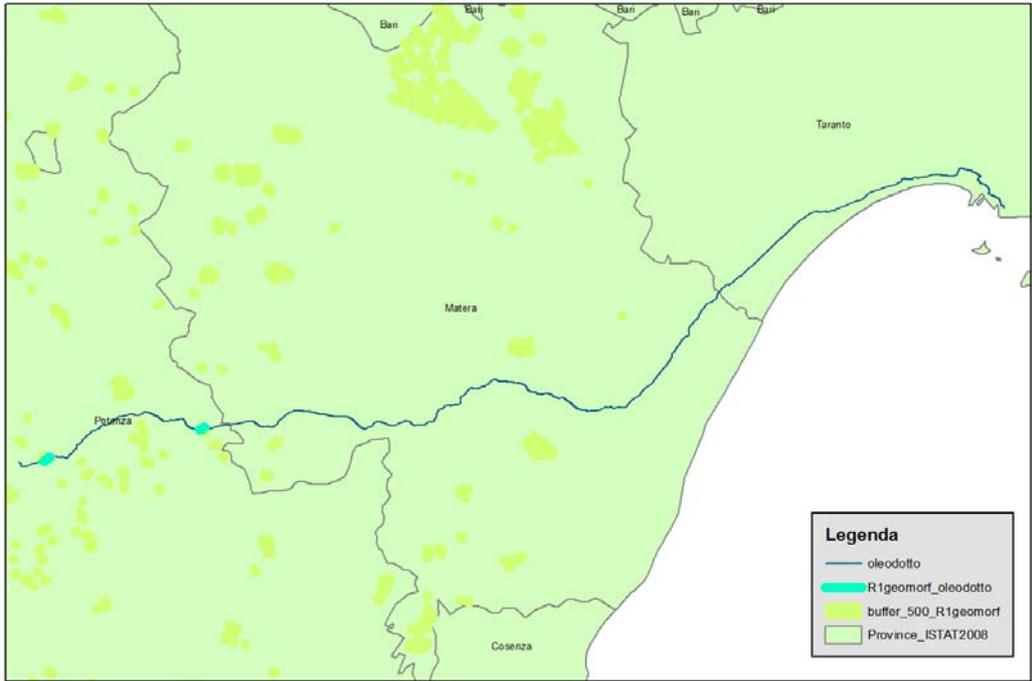
## 02\_CORROSION ACCIDENT SCENARIO

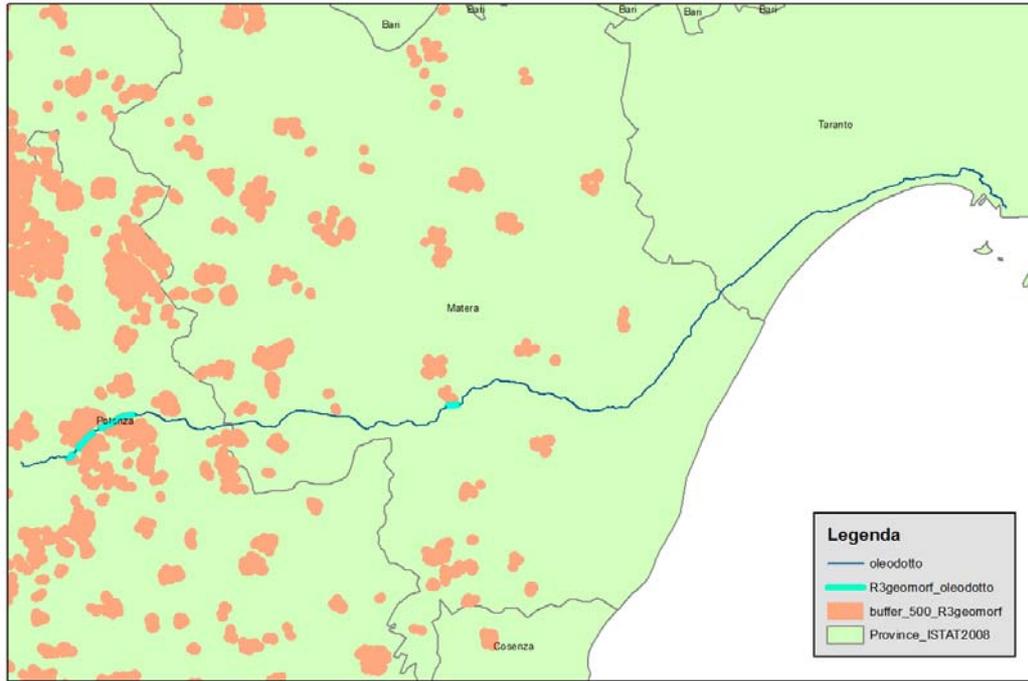




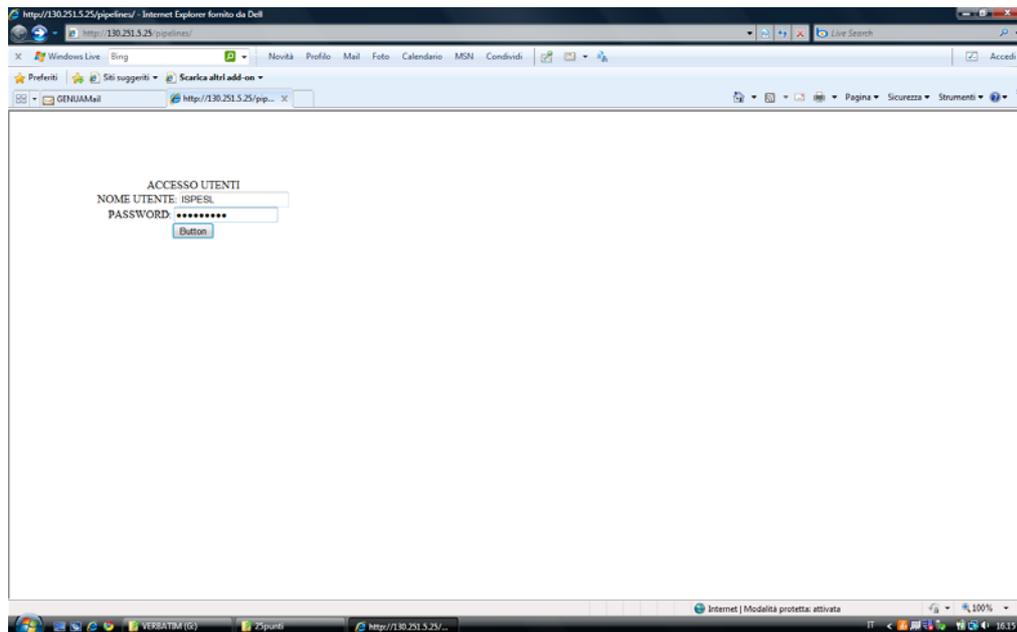
### 03\_MECHANICAL FAILURE ACCIDENT SCENARIO

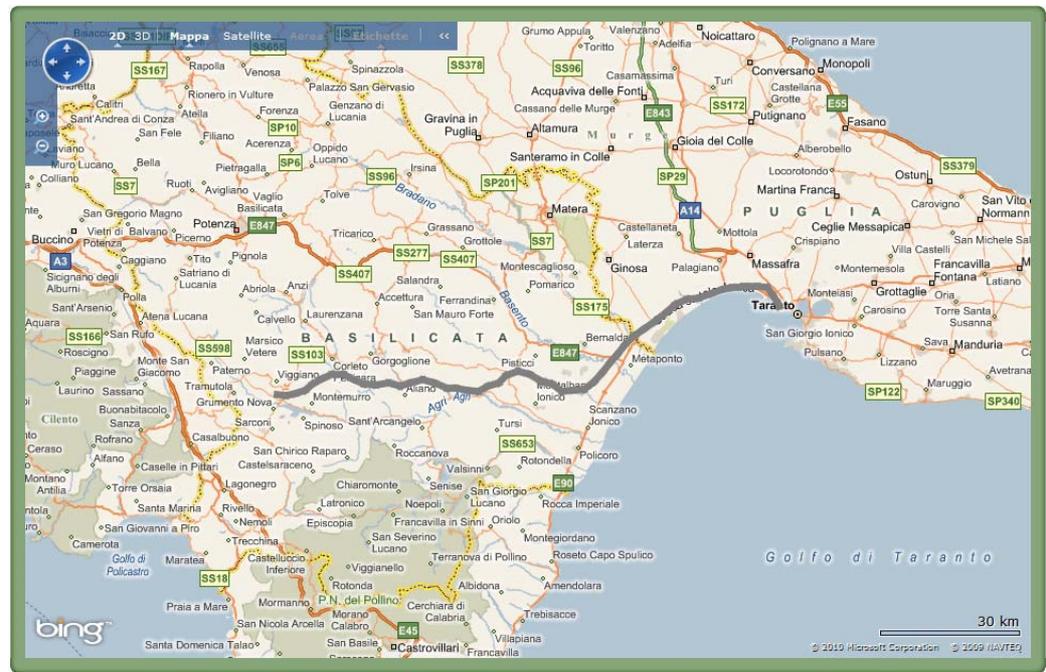
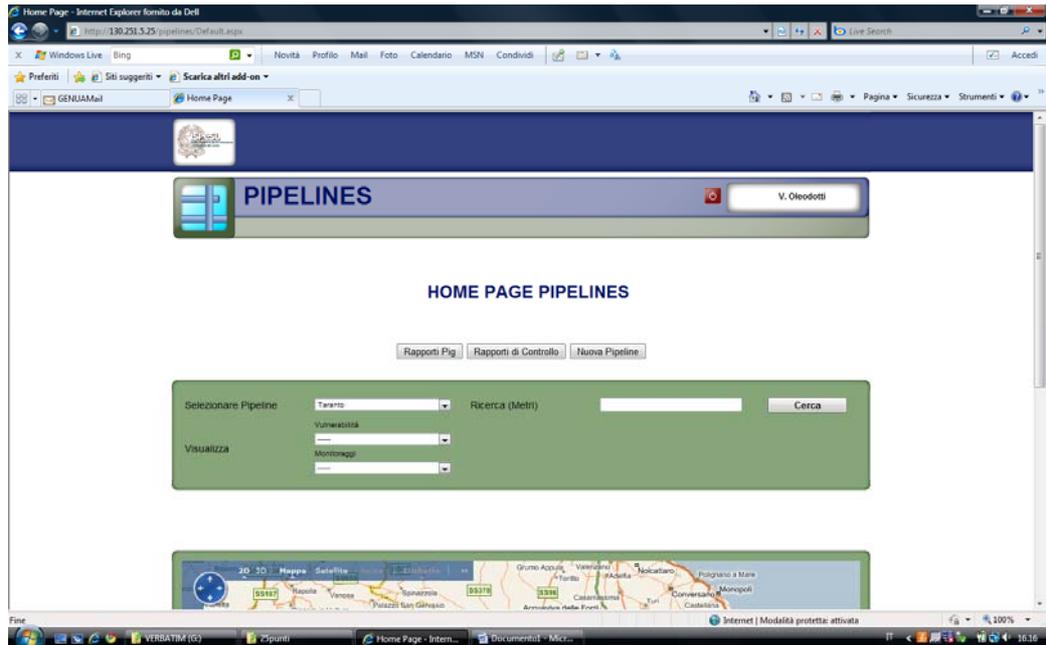


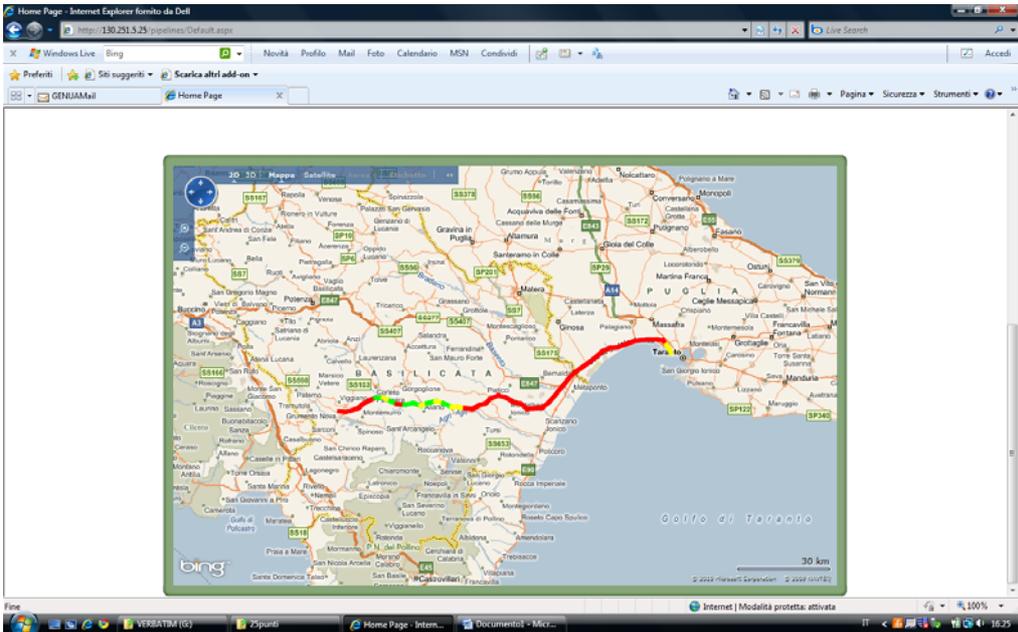


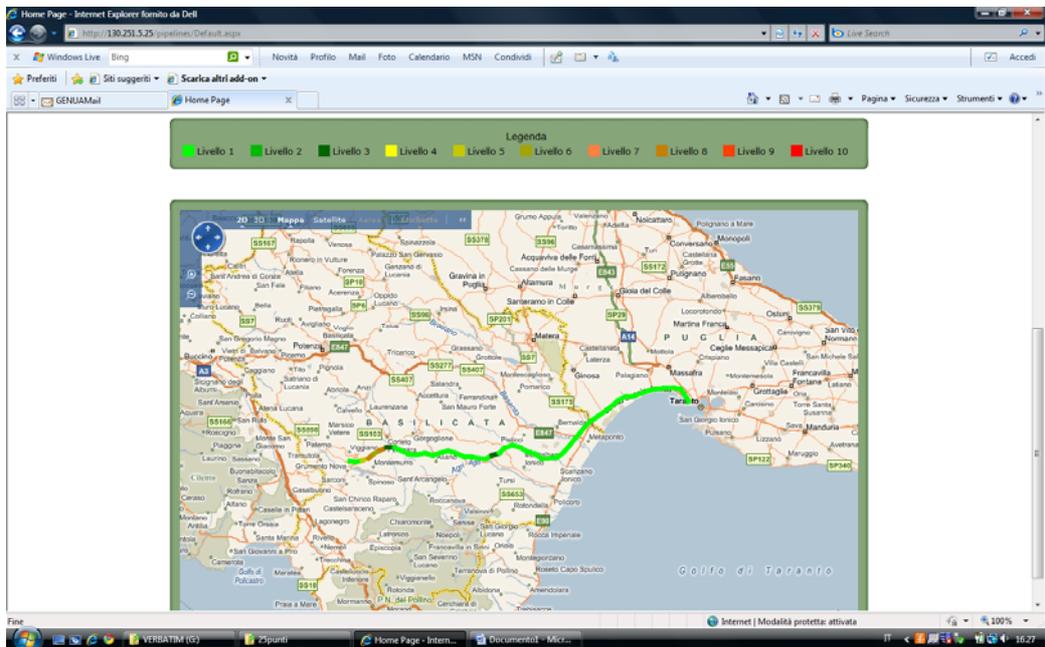
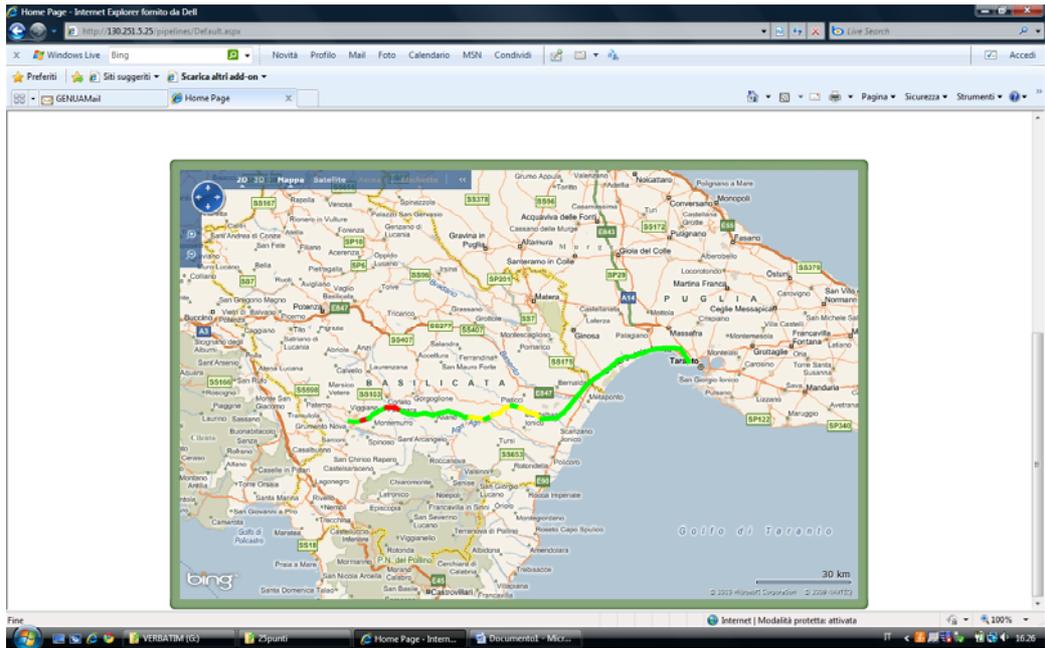


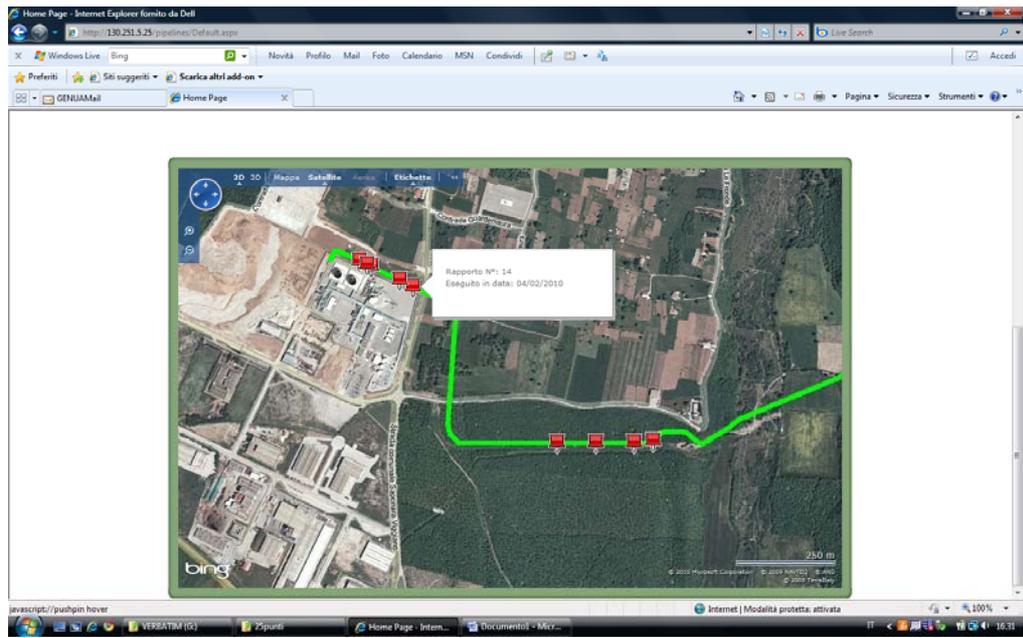
## 04\_WEB-GIS PROTOTIPE

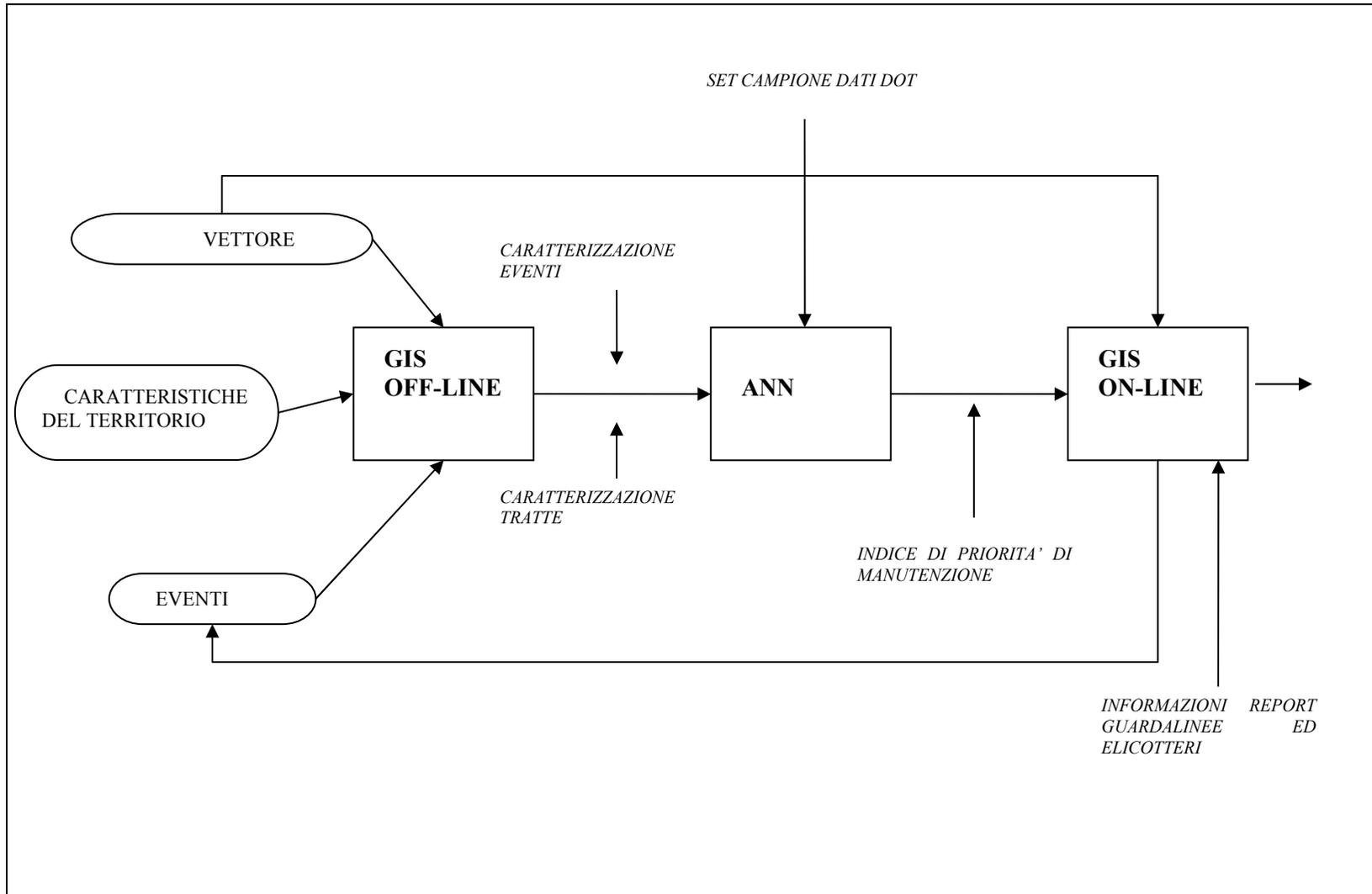






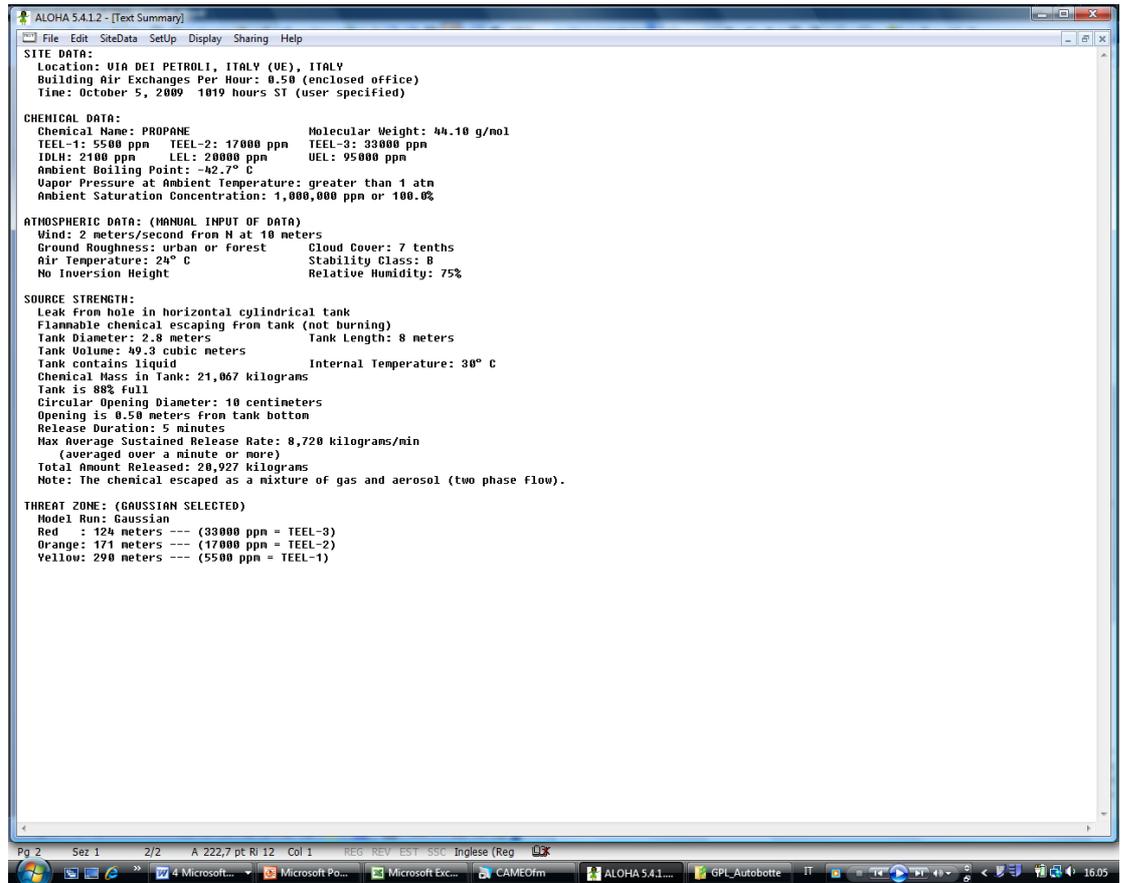






DSS architecture for the pipeline system describe in this study.

## Attachment N.4 – Acciden scenario from TIP to ALOHA

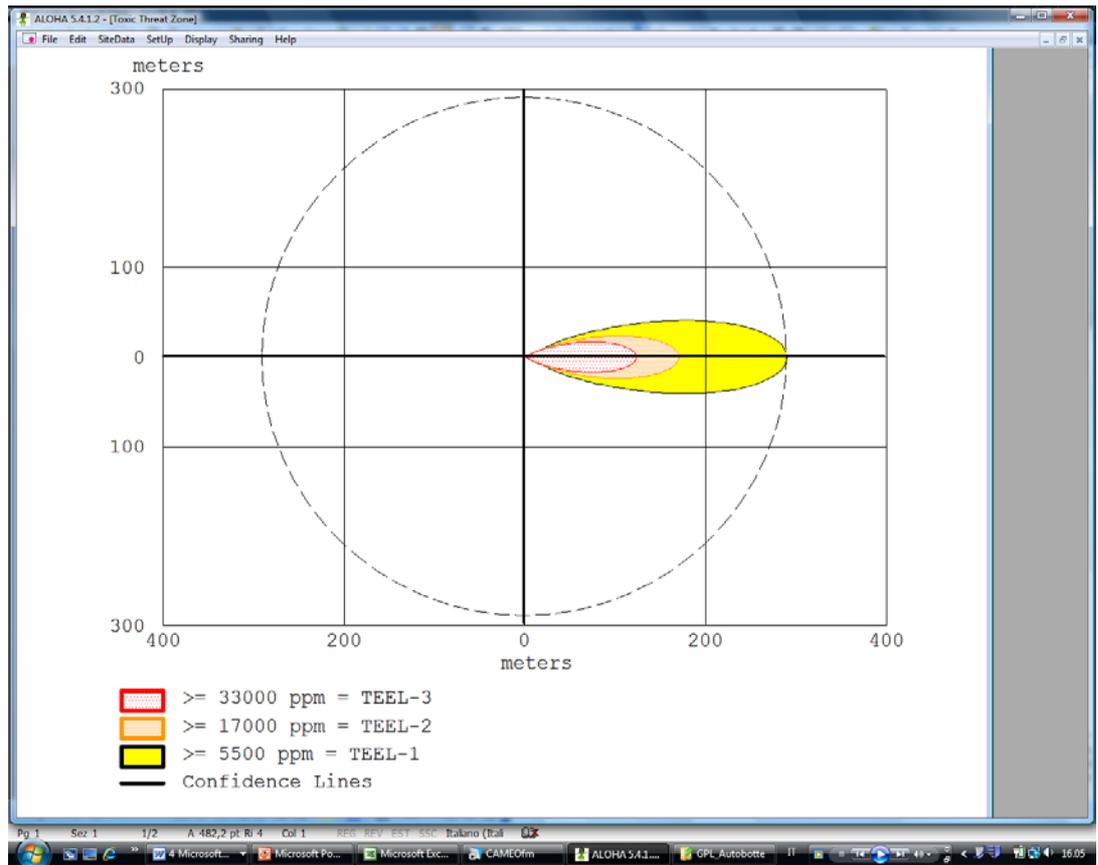


CLASS OF DATA:	TYPE OF DATA:	VALUES:
SITE DATA	Location:	VIA DEI PETROLI, ITALY (VE), ITALY
	Building Air Exchanges Per Hour:	0.50 (enclosed office)
CHEMICAL DATA	Time:	October 5, 2009 1019 hours ST (user specified)
	Chemical Name:	PROPANE
	Molecular Weight:	44.10 g/mol
	TEEL-1	5500 ppm
	TEEL-2	17000 ppm
	TEEL-3	33000 ppm
	IDLH	2100 ppm
	LEL	20000 ppm
	UEL	95000

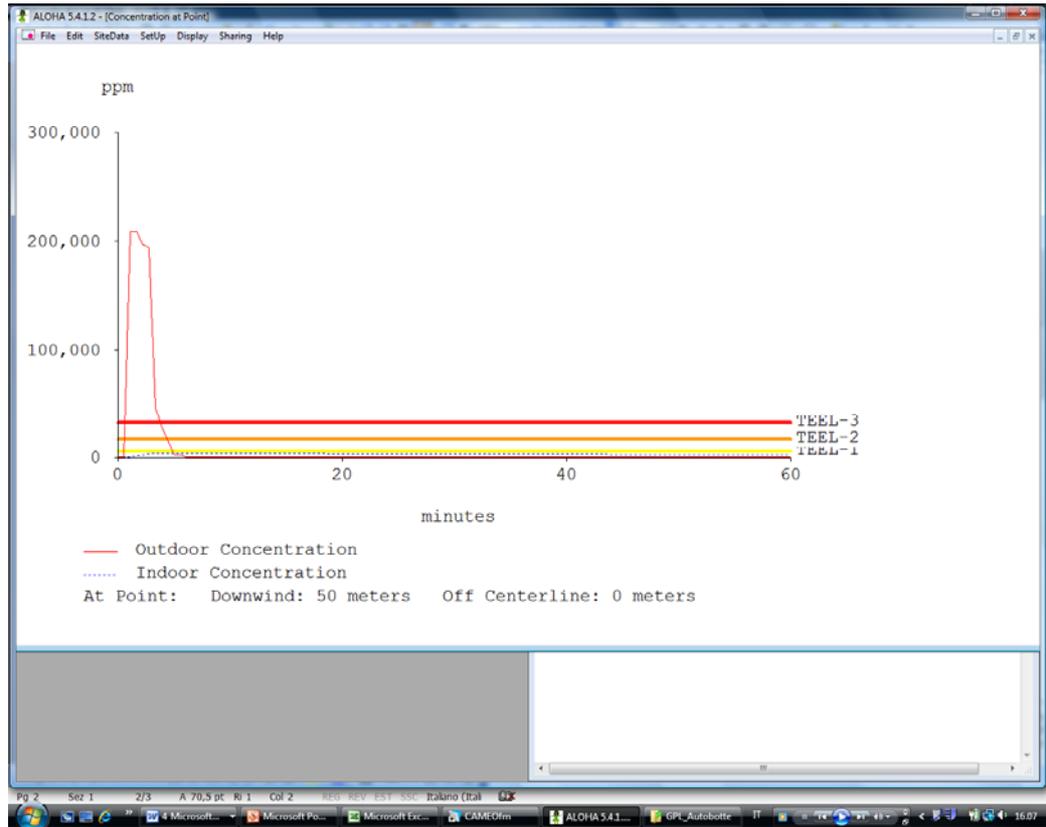
	Ambient Boiling Point:	-42.7° C
	Vapor Pressure at Ambient Temperature:	greater than 1 atm
	Ambient Saturation Concentration:	1,000,000 ppm or 100.0%
ATMOSPHERIC DATA (Manual Input of Data)	Wind:	meters/second from N at 10 meters
	Ground Roughness:	urban or forest
	Cloud Cover:	7 tenths
	Air Temperature:	24° C
	Stability Class:	B
	Inversion Height:	No
	Relative Humidity:	75%
SOURCE STRENGTH	Description:	Leak from hole in horizontal cylindrical tank Flammable chemical escaping from tank (not burning) Tank contains liquid Tank is 88% full
	Tank Diameter:	2.8 meters
	Tank Length:	8 meters
	Tank Volume:	49.3 cubic meters
	Internal Temperature:	30° C
	Chemical Mass in Tank:	21,067 kilograms
	Circular Opening Diameter:	10 centimeters
	Opening is:	0.50 meters from tank bottom
	Release Duration:	5 minutes
	Max Average Sustained Release Rate:	8,720 kilograms/min (averaged over a minute or more)
	Total Amount Released:	20,927 kilograms
	Note:	The chemical escaped as a mixture of gas and aerosol (two phase flow)

THREAT ZONE:		
	Model Run:	Gaussian
	Red :	124 meters --- (33000 ppm = TEEL-3)
	Orange:	171 meters --- (17000 ppm = TEEL-2)

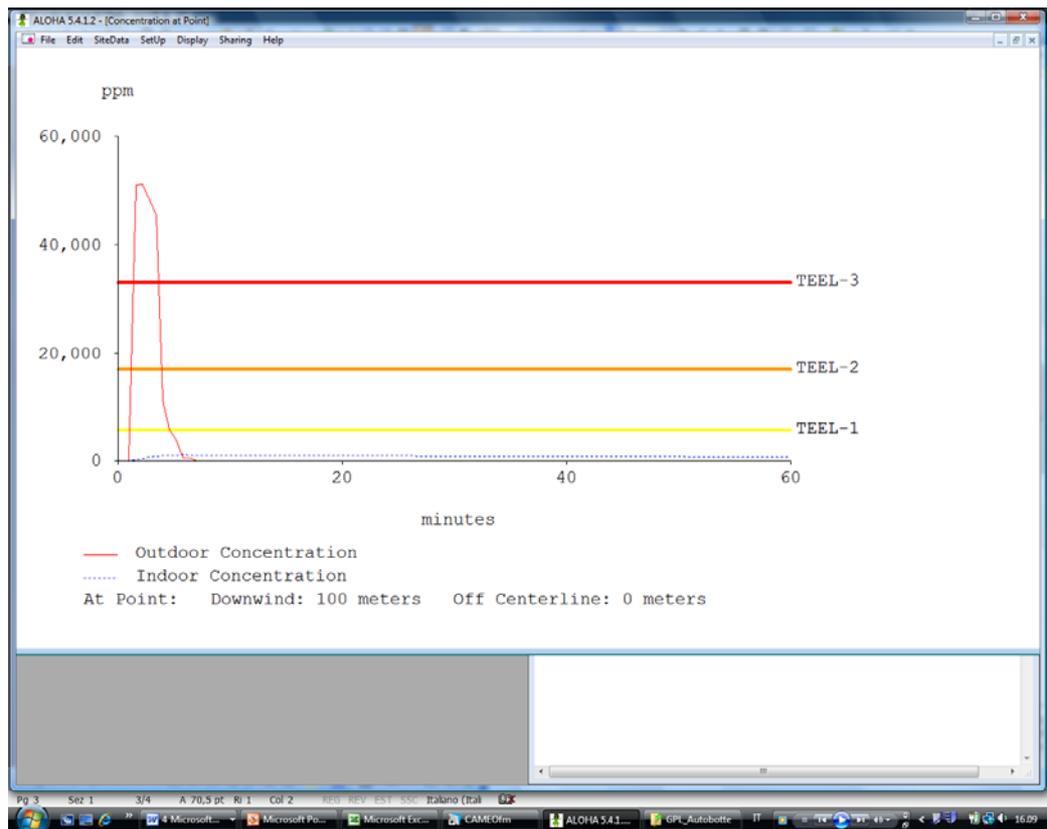
	Yellow:	290 meters --- (5500 ppm = TEEL-1)
THREAT AT POINT:		
Concentration Estimates at the point:	Downwind - 50 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 205,000 ppm	Indoor - 4,000 ppm
Concentration Estimates at the point:	Downwind - 100 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 50,800 ppm	Indoor - 1,050 ppm
Concentration Estimates at the point:	Downwind - 150 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 22,200 ppm	Indoor - 450 ppm
Concentration Estimates at the point:	Downwind - 200 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 12,300 ppm	Indoor - 235 ppm
Concentration Estimates at the point:	Downwind - 250 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 7,440 ppm	Indoor - 151 ppm
Concentration Estimates at the point:	Downwind - 300 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 5,140 ppm	Indoor - 103 ppm
Concentration Estimates at the point:	Downwind - 350 meters	Off Centerline - 1.48 meters
Max Concentration:	Outdoor - 7,440 ppm	Indoor - 151 ppm



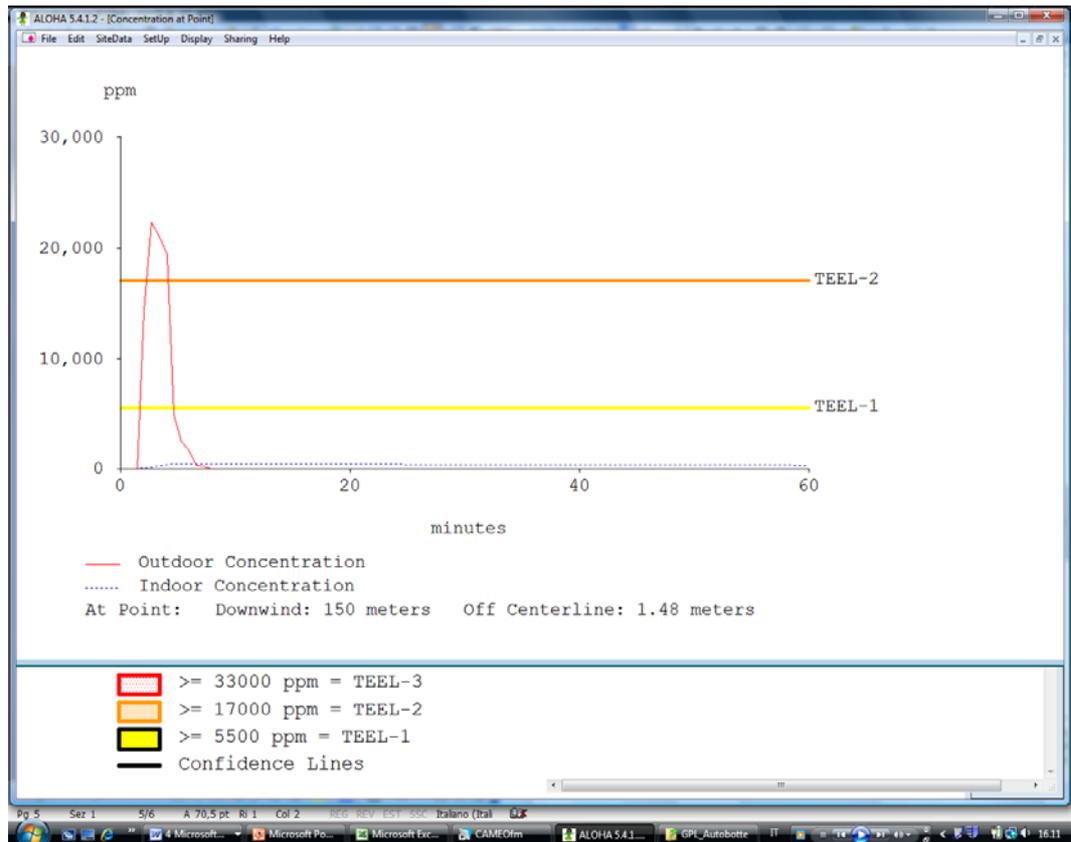
### Concentrazione a 50 m:



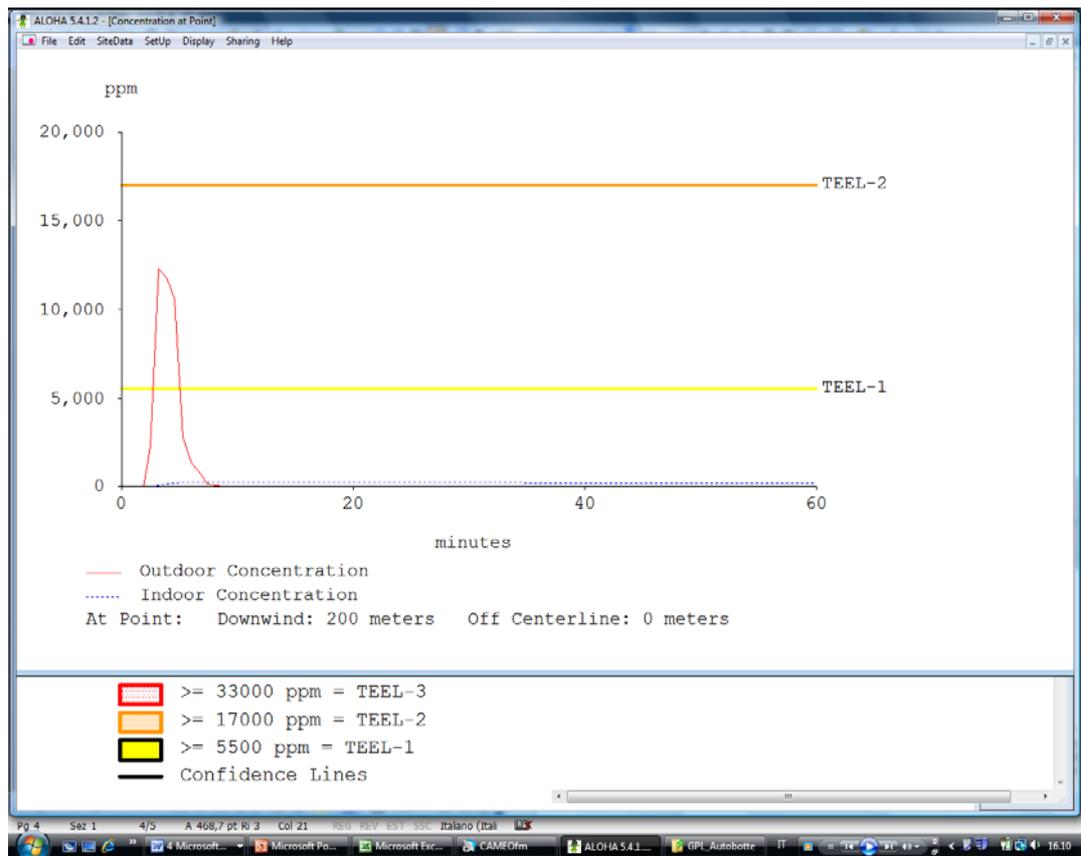
### Concentrazione a 100 m:



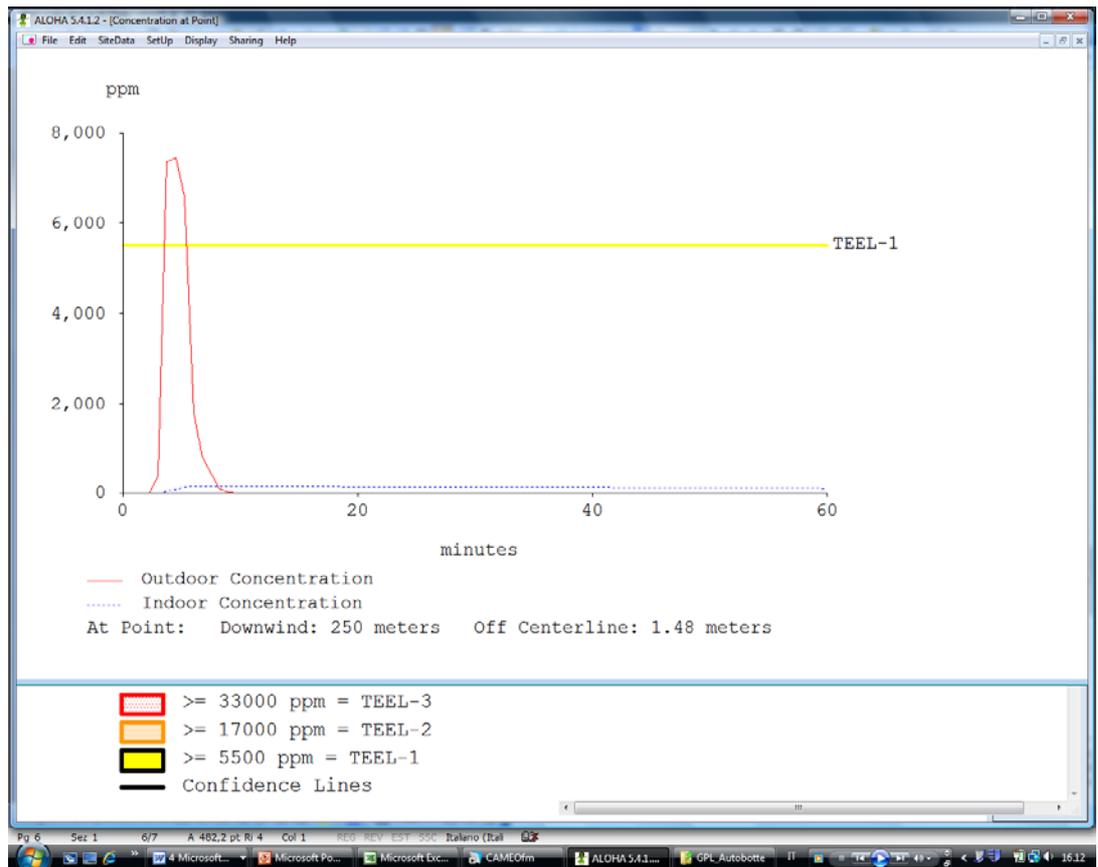
Concentrazione a 150m:



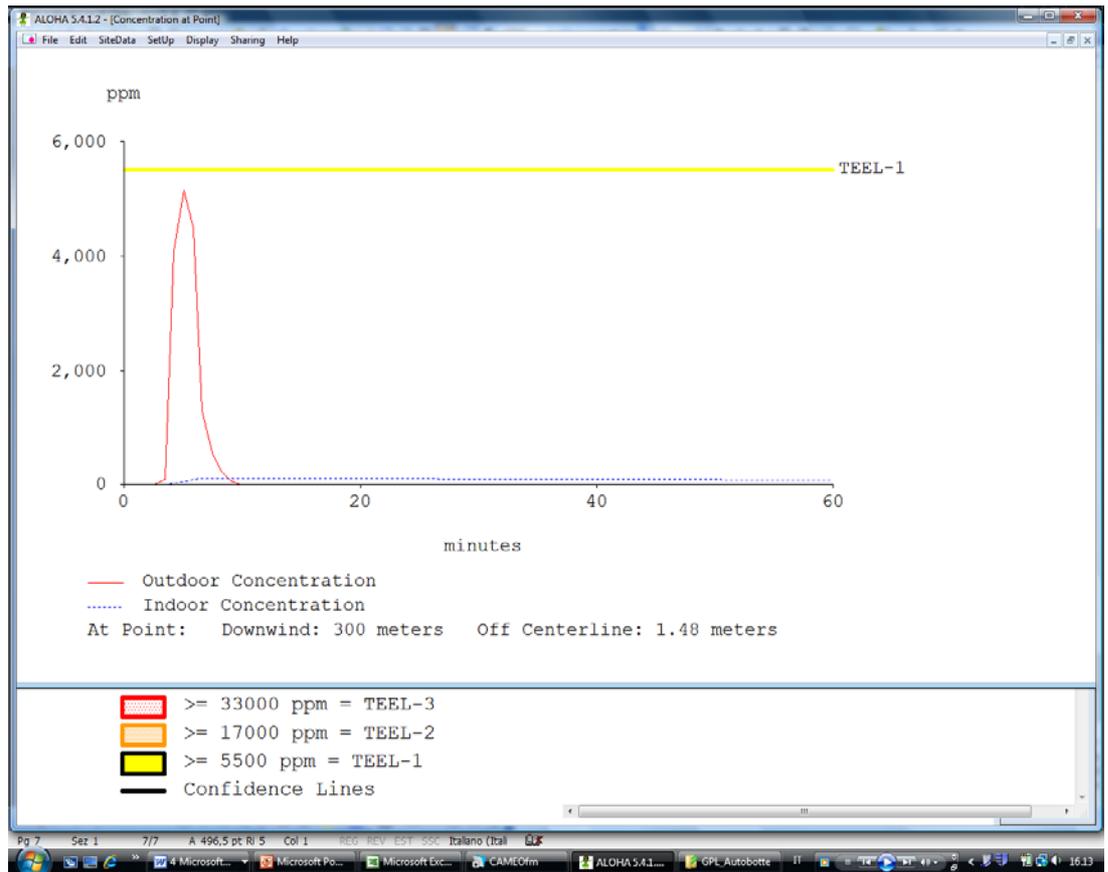
Concentrazione a 200 m:

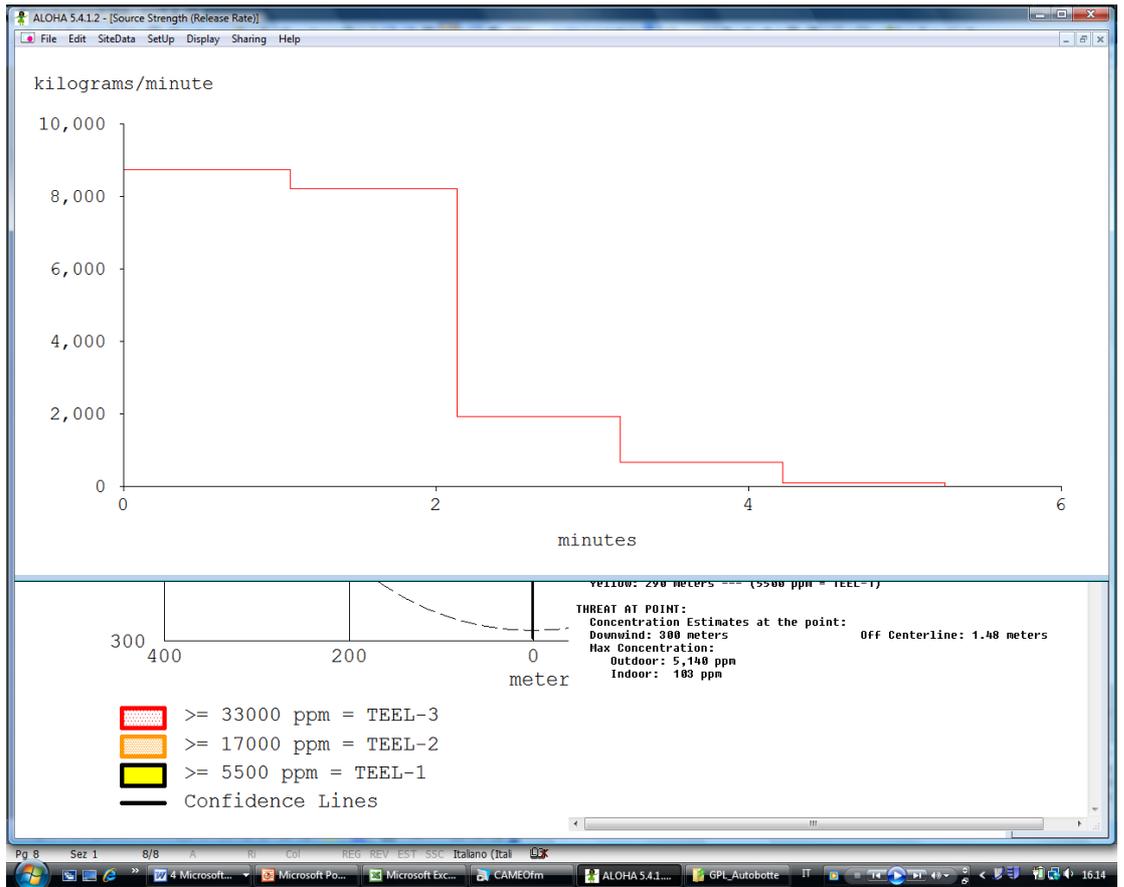


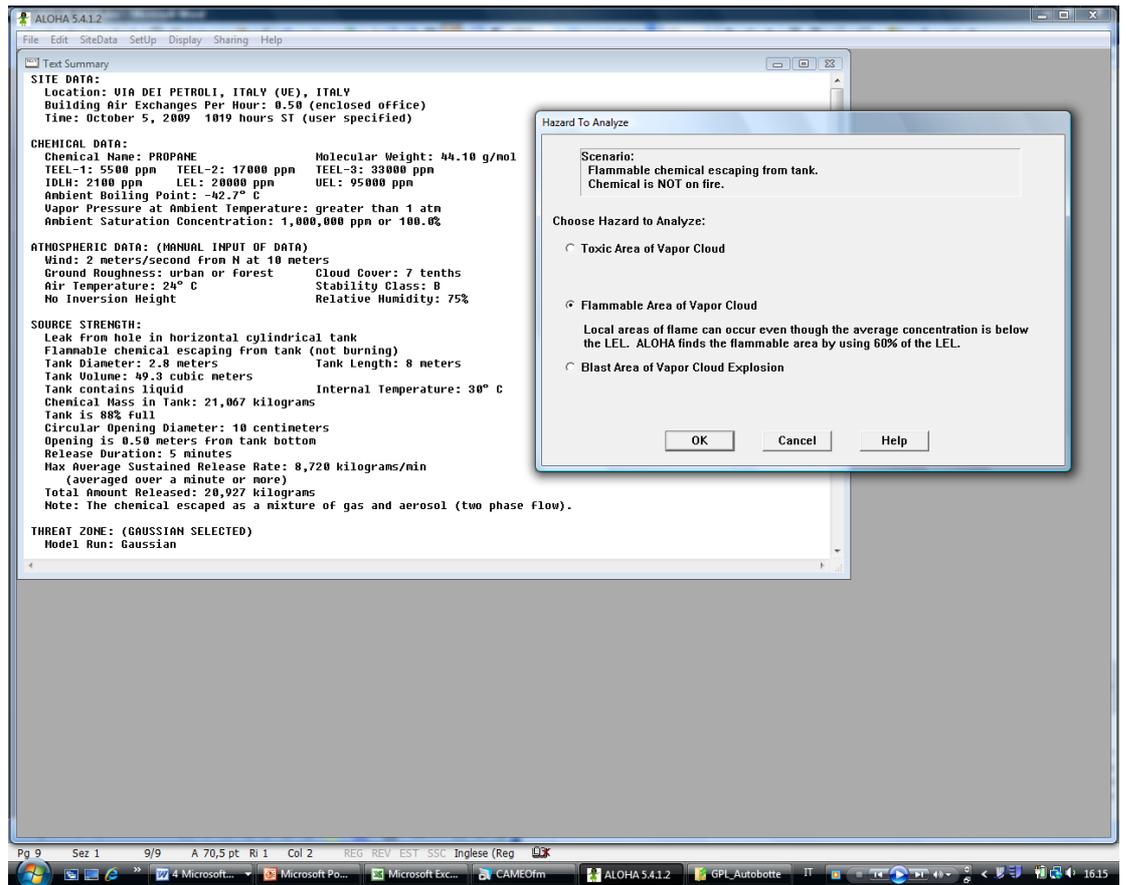
Concentrazione a 250m:

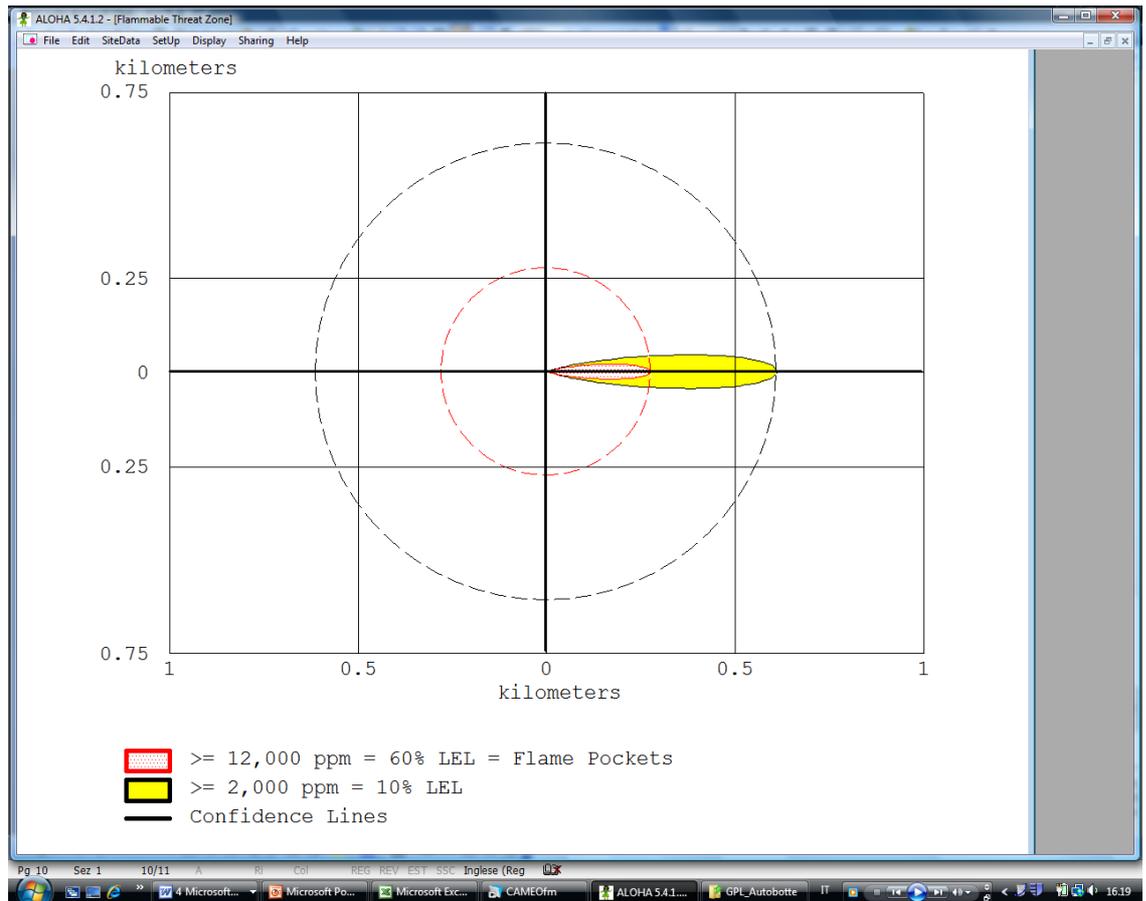


Concentrazione a 300m:









**THREAT AT POINT:**

Concentration Estimates at the point:

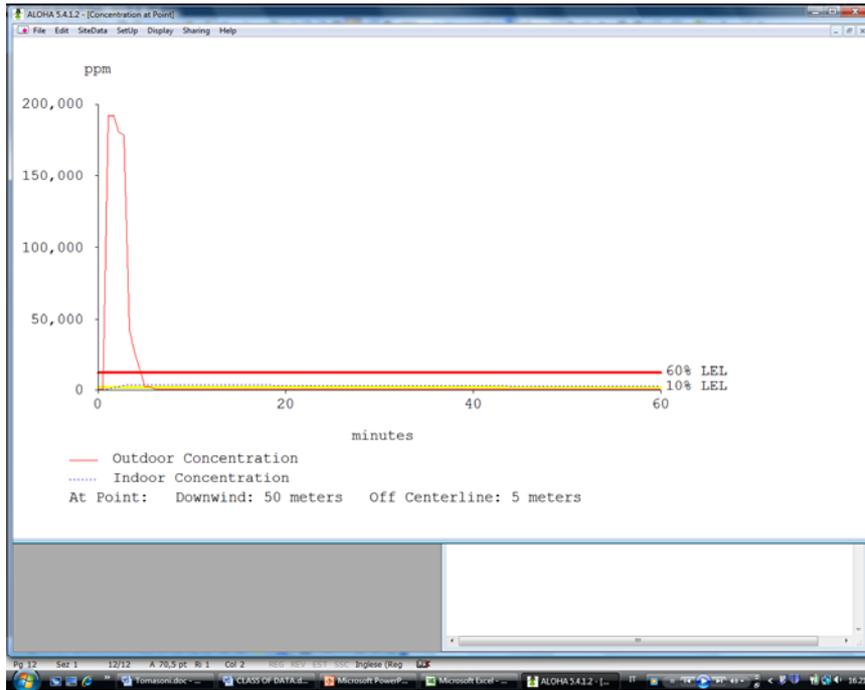
Downwind: 50 meters

Off Centerline: 5 meters

Max Concentration:

Outdoor: 192,000 ppm

Indoor: 3,740 ppm



**THREAT AT POINT:**

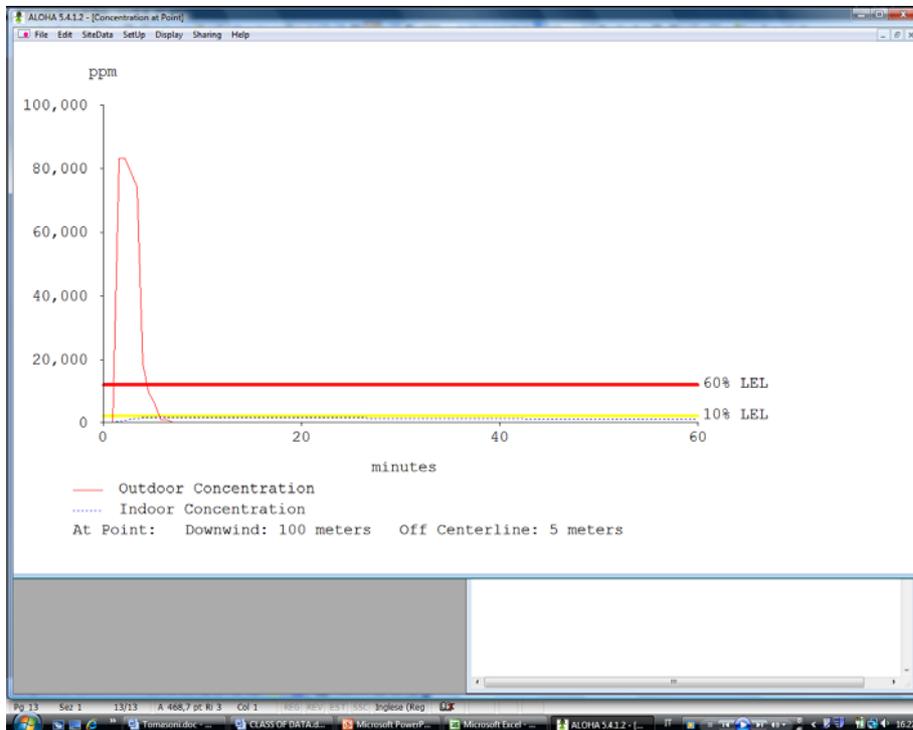
Concentration Estimates at the point:

Downwind: 100 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 83,200 ppm

Indoor: 1,720 ppm



THREAT AT POINT:

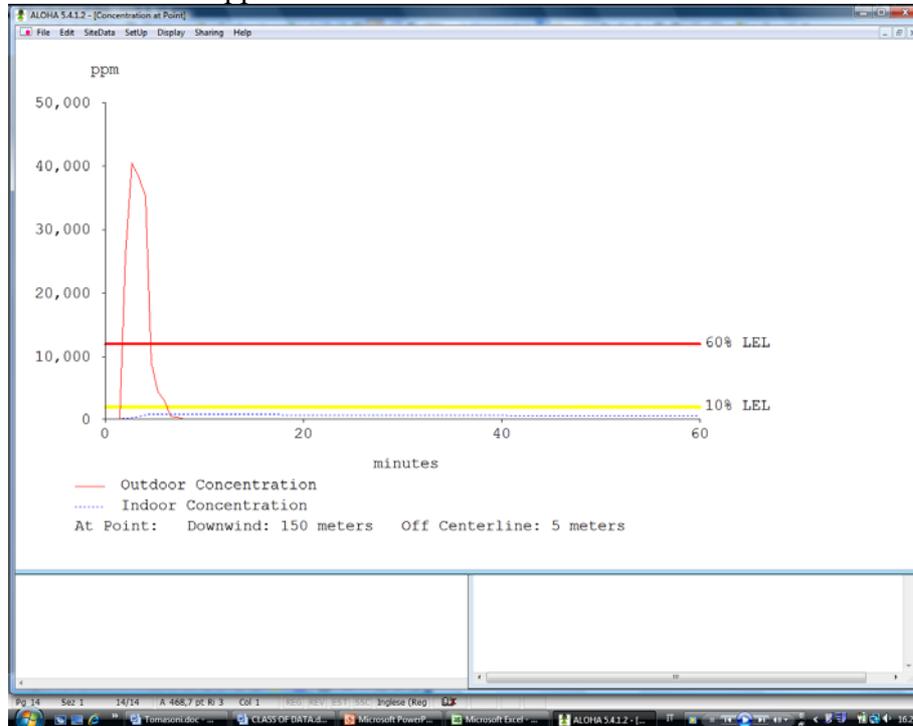
Concentration Estimates at the point:

Downwind: 150 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 40,300 ppm

Indoor: 817 ppm



THREAT AT POINT:

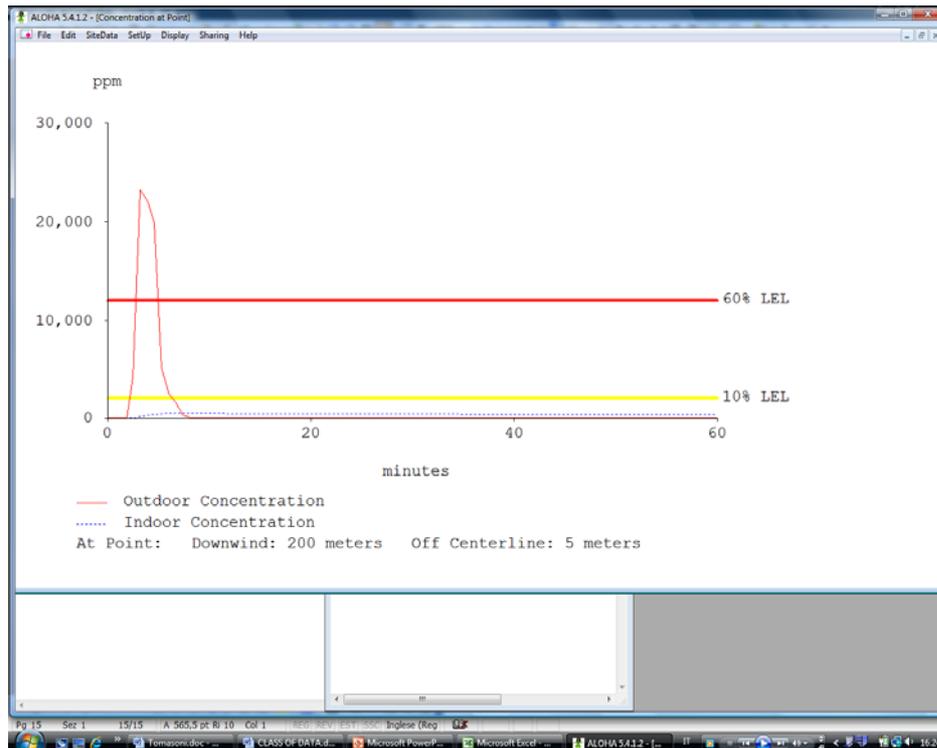
Concentration Estimates at the point:

Downwind: 200 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 23,100 ppm

Indoor: 442 ppm



**THREAT AT POINT:**

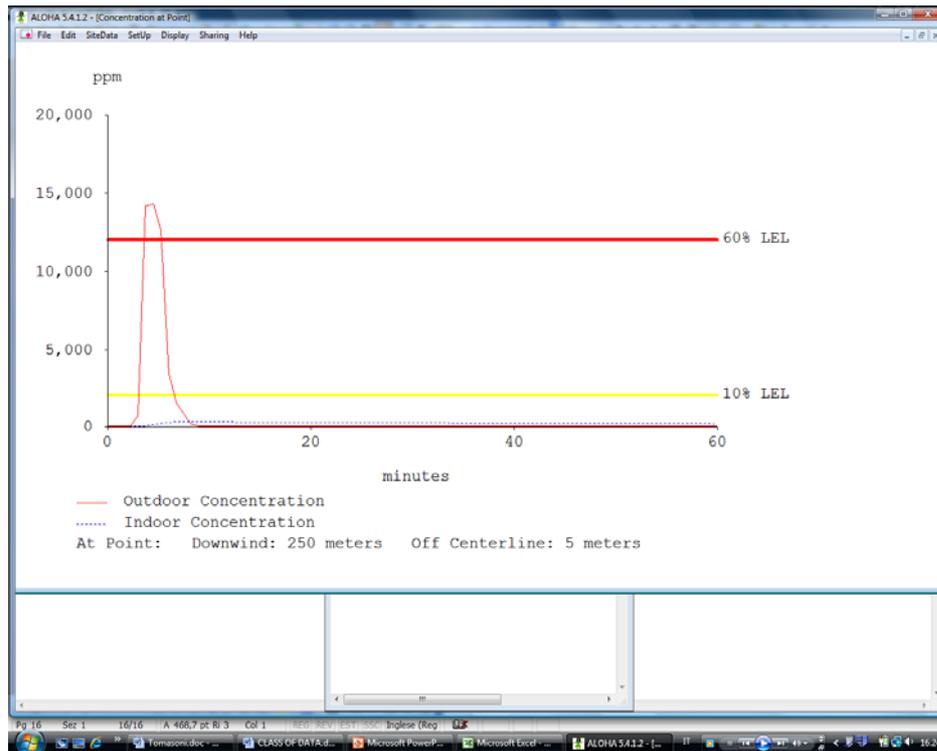
Concentration Estimates at the point:

Downwind: 250 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 14,300 ppm

Indoor: 288 ppm



**THREAT AT POINT:**

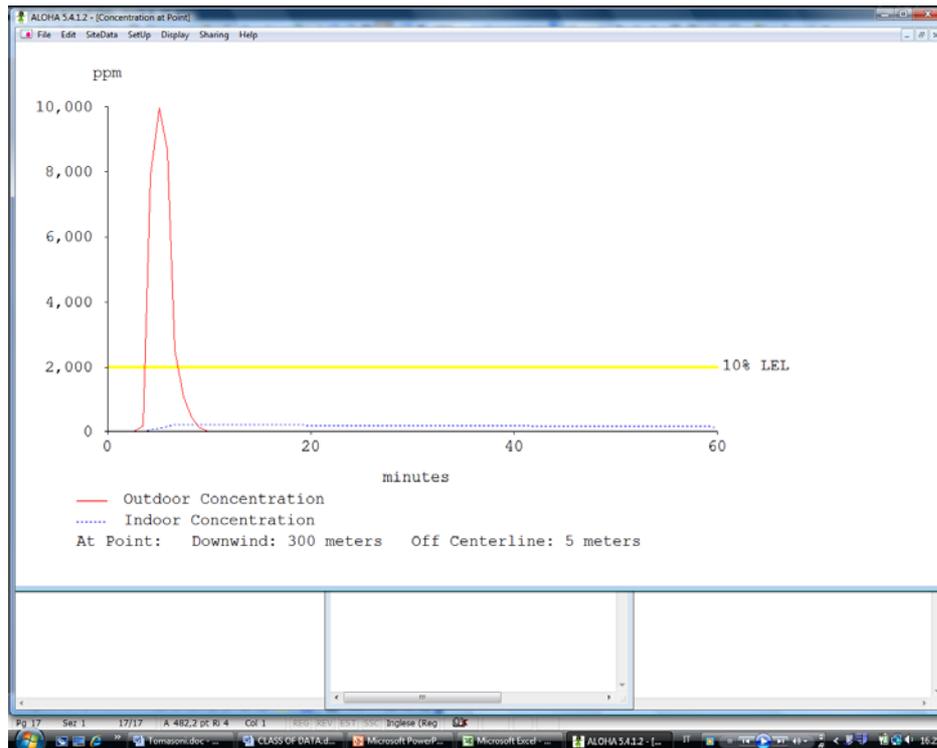
Concentration Estimates at the point:

Downwind: 300 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 9,930 ppm

Indoor: 200 ppm



#### THREAT AT POINT:

Concentration Estimates at the point:

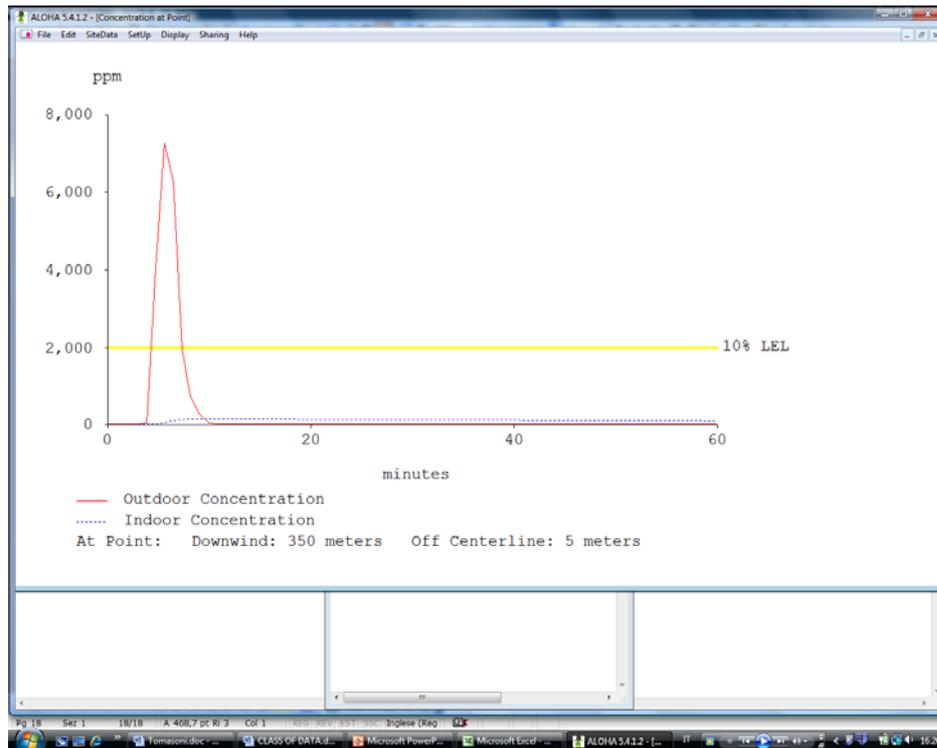
Downwind: 350 meters

Off Centerline: 5 meters

Max Concentration:

Outdoor: 7,240 ppm

Indoor: 143 ppm



**THREAT AT POINT:**

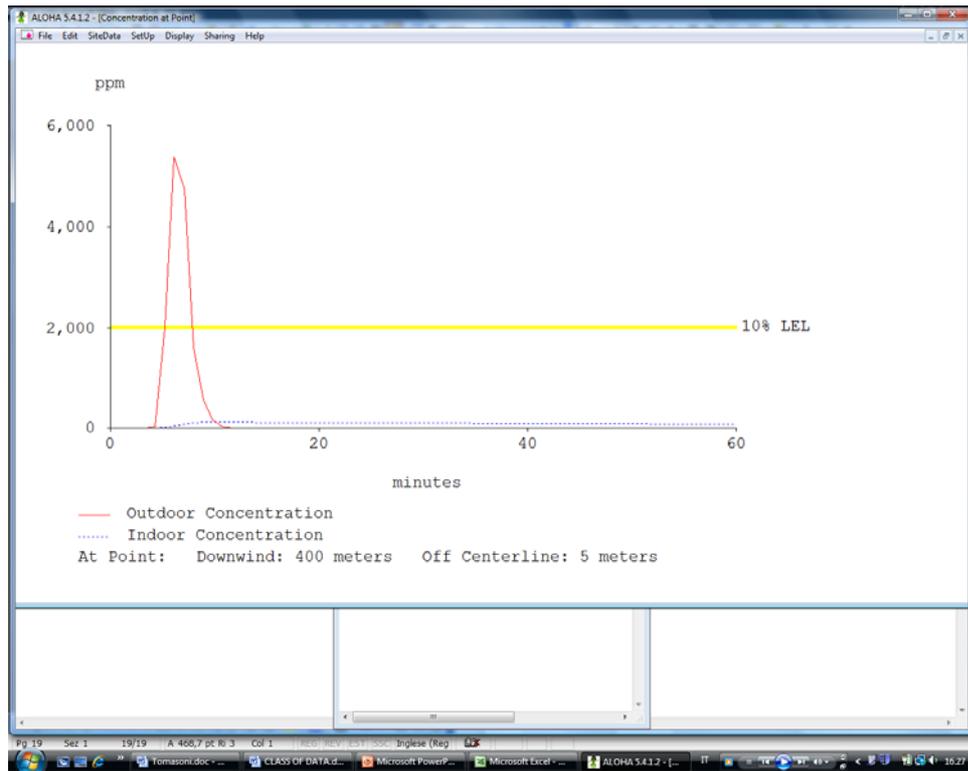
Concentration Estimates at the point:

Downwind: 400 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 5,380 ppm

Indoor: 108 ppm



**THREAT AT POINT:**

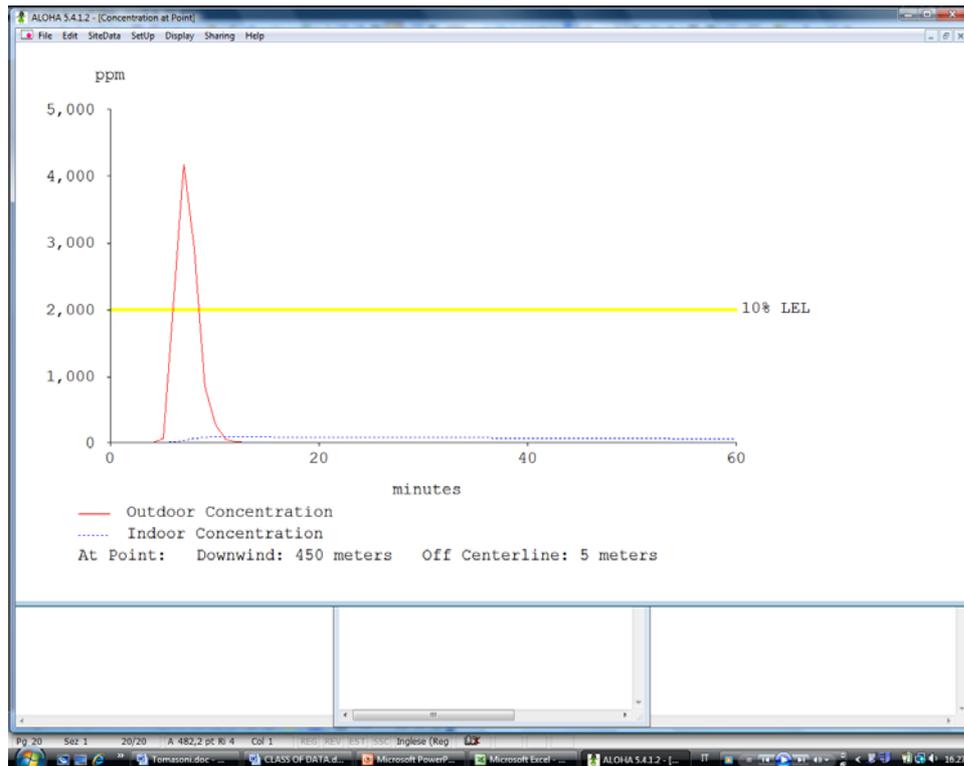
Concentration Estimates at the point:

Downwind: 450 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 4,170 ppm

Indoor: 84.6 ppm



#### THREAT AT POINT:

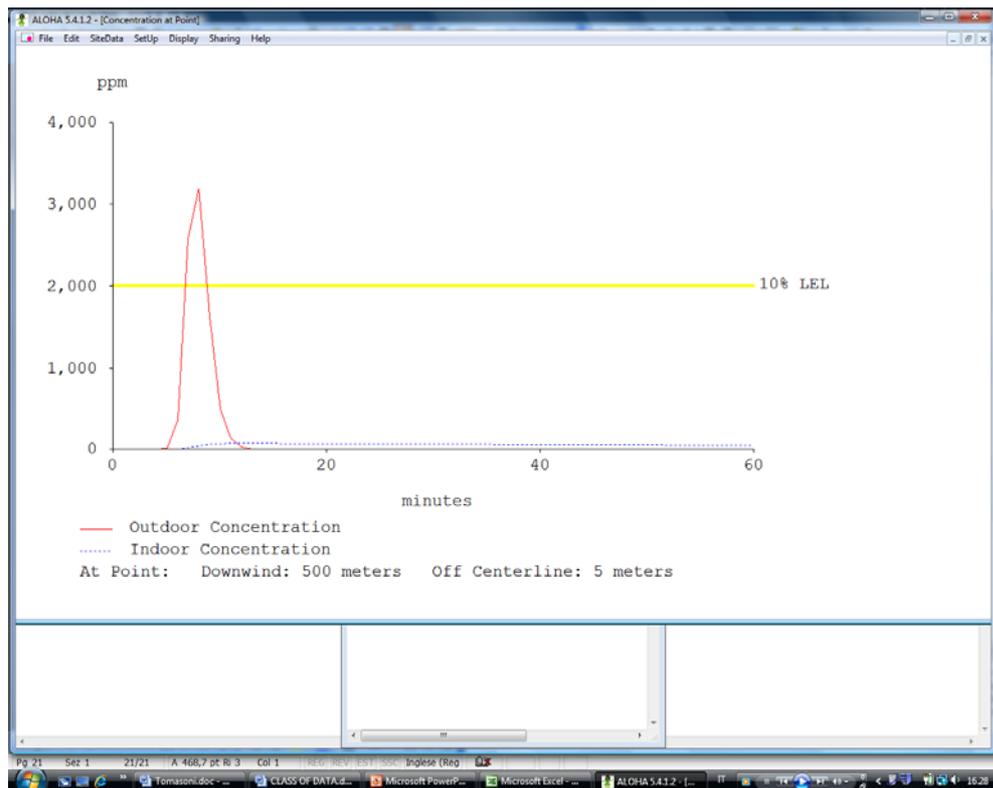
Concentration Estimates at the point:

Downwind: 500 meters Off Centerline: 5 meters

Max Concentration:

Outdoor: 3,180 ppm

Indoor: 67.4 ppm



#### THREAT AT POINT:

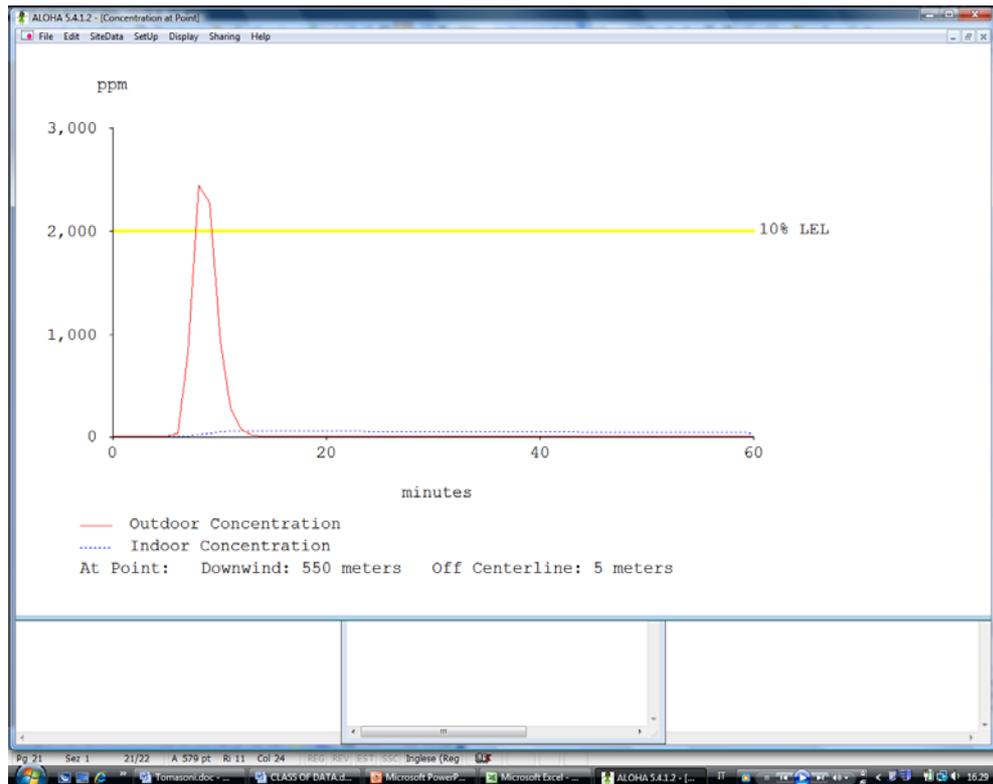
Concentration Estimates at the point:

Downwind: 550 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 2,440 ppm

Indoor: 55 ppm



**THREAT AT POINT:**

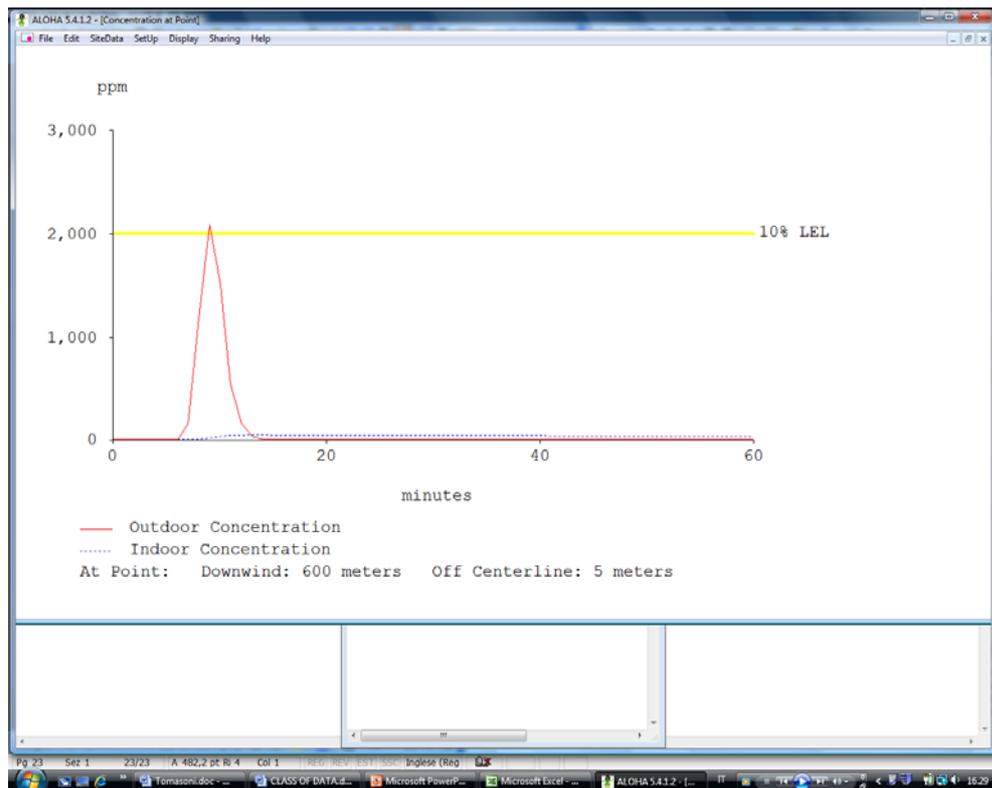
Concentration Estimates at the point:

Downwind: 600 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 2,090 ppm

Indoor: 45.7 ppm



**THREAT AT POINT:**

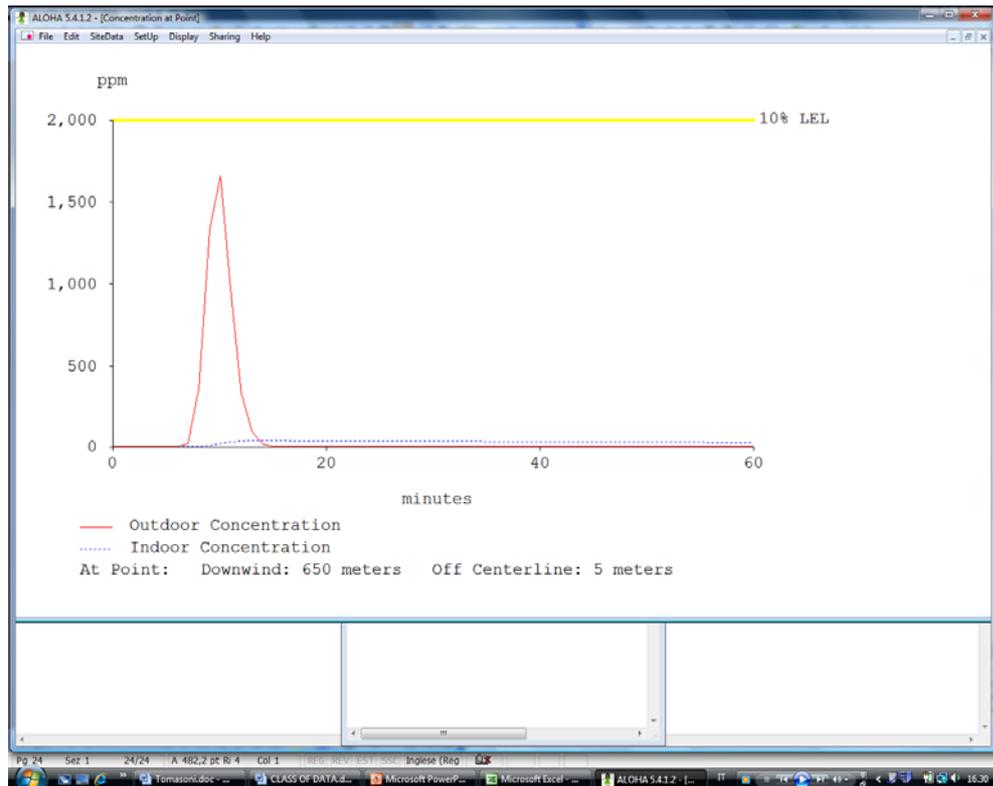
Concentration Estimates at the point:

Downwind: 650 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 1,660 ppm

Indoor: 38.4 ppm



#### THREAT AT POINT:

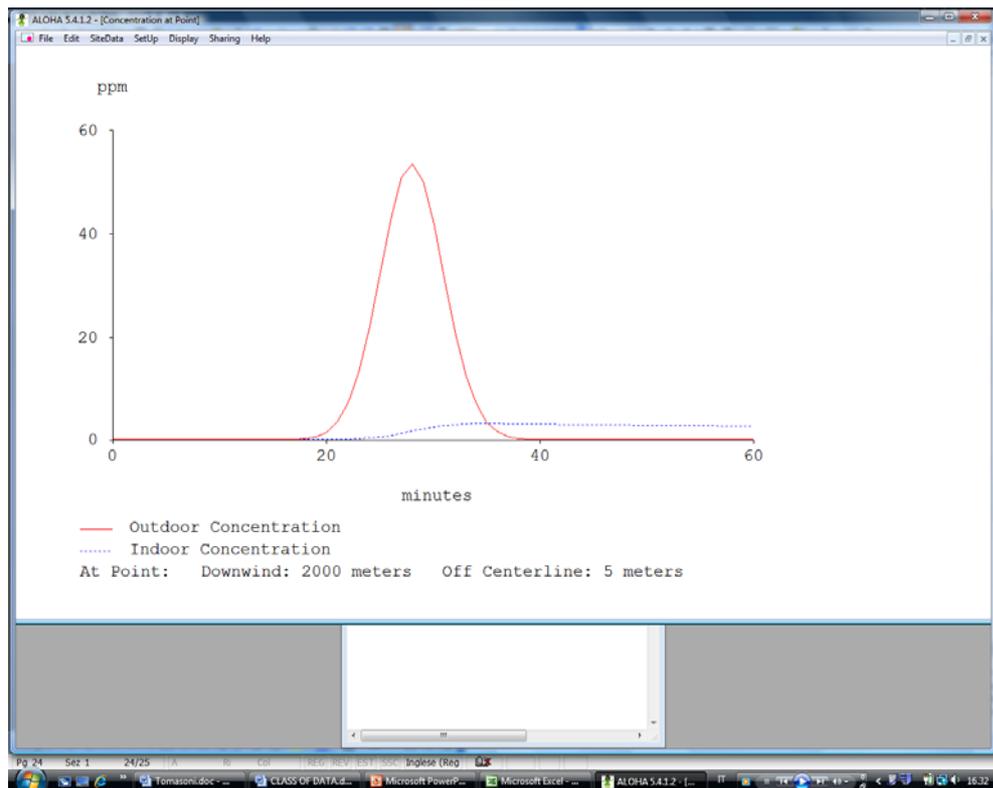
Concentration Estimates at the point:

Downwind: 2000 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 53.4 ppm

Indoor: 3.1 ppm



#### THREAT AT POINT:

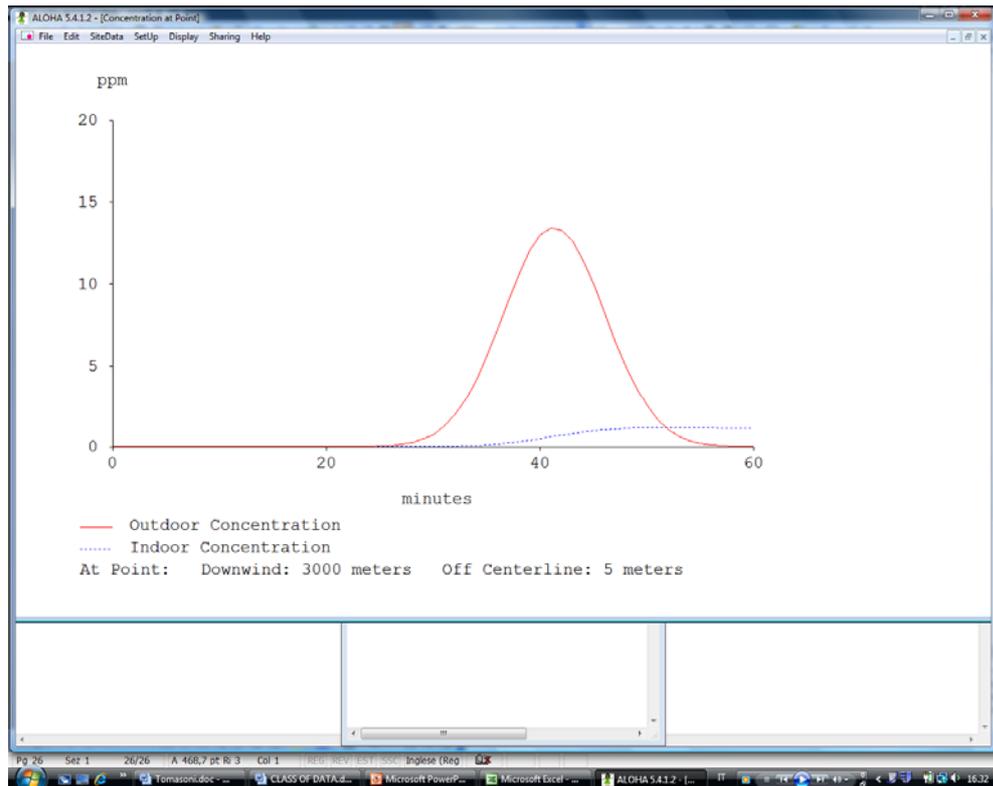
Concentration Estimates at the point:

Downwind: 3000 meters                      Off Centerline: 5 meters

Max Concentration:

Outdoor: 13.4 ppm

Indoor: 1.2 ppm



ALPHA 5.4.1.2 - [Text Summary]

File Edit SiteData SetUp Display Sharing Help

**SITE DATA:**  
Location: VIA DEI PETROLI, ITALY (VE), ITALY  
Building Air Exchanges Per Hour: 0.50 (enclosed office)  
Time: October 5, 2009 1019 hours ST (user specified)

**CHEMICAL DATA:**  
Chemical Name: PROPANE Molecular Weight: 44.10 g/mol  
TEEL-1: 5500 ppm TEEL-2: 17000 ppm TEEL-3: 30000 ppm  
IDLH: 2100 ppm LEL: 20000 ppm UEL: 95000 ppm  
Ambient Boiling Point: -42.7° C  
Vapor Pressure at Ambient Temperature: greater than 1 atm  
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

**ATMOSPHERIC DATA: (MINIMAL INPUT OF DATA)**  
Wind: 2 meters/second from N at 10 meters  
Ground Roughness: urban or forest Cloud Cover: 7 tenths  
Air Temperature: 24° C Stability Class: B  
No Inversion Height Relative Humidity: 75%

**SOURCE STRENGTH:**  
Leak from hole in horizontal cylindrical tank  
Flammable chemical escaping from tank (not burning)  
Tank Diameter: 2.8 meters Tank Length: 8 meters  
Tank Volume: 49.3 cubic meters  
Tank contains liquid Internal Temperature: 30° C  
Chemical Mass in Tank: 21,067 kilograms  
Tank is 88% full  
Circular Opening Diameter: 10 centimeters  
Opening is 0.50 meters from tank bottom  
Release Duration: 5 minutes  
Max Average Sustained Release Rate: 8,790 kilograms/min  
(averaged over a minute or more)  
Total Amount Released: 20,927 kilograms  
Note: The chemical escaped as a mixture of gas and aerosol (two phase flow).

**THREAT ZONE: (GAUSSIAN SELECTED)**  
Threat Modeled: Flammable Area of Vapor Cloud  
Model Run: GAUSSIAN  
Red : 277 meters --- (12,000 ppm = 60% LEL = Flame Pockets)  
Yellow: 611 meters --- (2,000 ppm = 10% LEL)

**THREAT AT POINT:**  
Concentration Estimates at the point:  
Downwind: 4000 meters Off Centerline: 5 meters  
Max Concentration:  
Outdoor: 0.98 ppm  
Indoor: 0.515 ppm

**Hazard To Analyze**

Scenario:  
Flammable chemical escaping from tank.  
Chemical is NOT on fire.

Choose Hazard to Analyze:

Toxic Area of Vapor Cloud

Flammable Area of Vapor Cloud

Blast Area of Vapor Cloud Explosion

OK Cancel Help

ALPHA 5.4.1.2 [Text Summary]

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**SITE DATA:**  
 Location: VIA DEI PETROLI, ITALY (UE), ITALY  
 Building Air Exchanges Per Hour: 0.50 (enclosed office)  
 Time: October 5, 2009 1019 hours ST (user specified)

**CHEMICAL DATA:**  
 Chemical Name: PROPANE Molecular Weight: 44.10 g/mol  
 TEEL-1: 5500 ppm TEEL-2: 17000 ppm TEEL-3: 33000 ppm  
 IDLH: 2100 ppm LEL: 20000 ppm UEL: 95000 ppm  
 Ambient Boiling Point: -42.7° C  
 Vapor Pressure at Ambient Temperature: greater than 1 atm  
 Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

**ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)**  
 Wind: 2 meters/second from N at 10 meters  
 Ground Roughness: urban or forest Cloud Cover: 7 tenths  
 Air Temperature: 24° C Stability Class: B  
 No Inversion Height Relative Humidity: 75%

**SOURCE STRENGTH:**  
 Leak from hole in horizontal cylindrical tank  
 Flammable chemical escaping from tank (not burning)  
 Tank Diameter: 2.8 meters Tank Length: 8 meters  
 Tank Volume: 49.3 cubic meters  
 Tank contains liquid Internal Temperature: 30° C  
 Chemical Mass in Tank: 21,067 kilograms  
 Tank is 88% full  
 Circular opening diameter: 10 centimeters  
 Opening is 0.50 meters from tank bottom  
 Release Duration: 5 minutes  
 Max Average Sustained Release Rate: 8,778 kilograms/min  
 (averaged over a minute or more)  
 Total Amount Released: 20,927 kilograms  
 Note: The chemical escaped as a mixture of gas and aerosol (two phase flow).

**THREAT ZONE: (GAUSSIAN SELECTED)**  
 Threat Modeled: Overpressure (blast force) from vapor cloud explosion  
 Type of Ignition: Ignited by detonation  
 Model Run: Gaussian  
 Red : 294 meters --- (8.0 psi = destruction of buildings)  
 Orange: 419 meters --- (3.5 psi = serious injury likely)  
 Yellow: 890 meters --- (1.0 psi = shatters glass)

Vapor Cloud Explosion Parameters

Time of vapor cloud ignition: Help

unknown (show composite threat zone from all possible ignition times)  
 known, ignition time is :

---

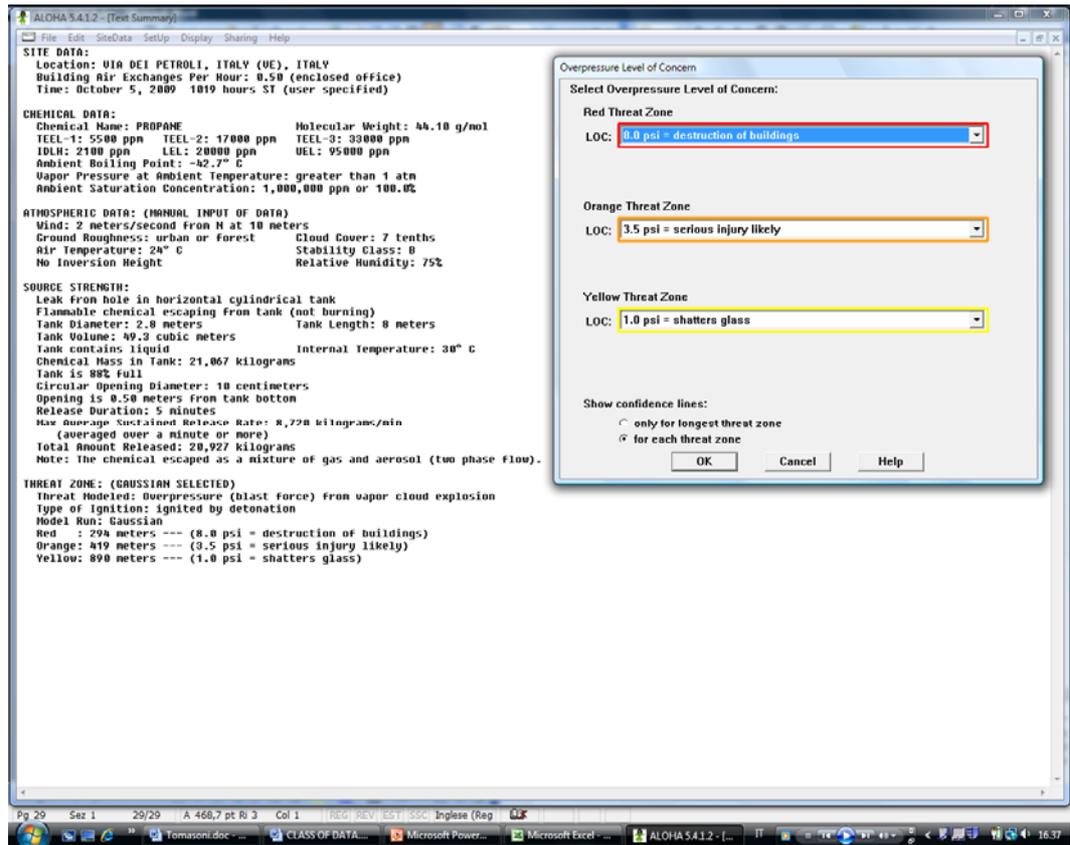
Type of vapor cloud ignition: Help

ignited by spark or flame  
 ignited by detonation

OK Cancel

Pg 30 Sez 1 30/30 A 70.5 pt R1 Col 2 REG REV EST SSC Inglese (Reg)

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### THREAT ZONE: (GAUSSIAN SELECTED)

Threat Modeled: Overpressure (blast force) from vapor cloud explosion

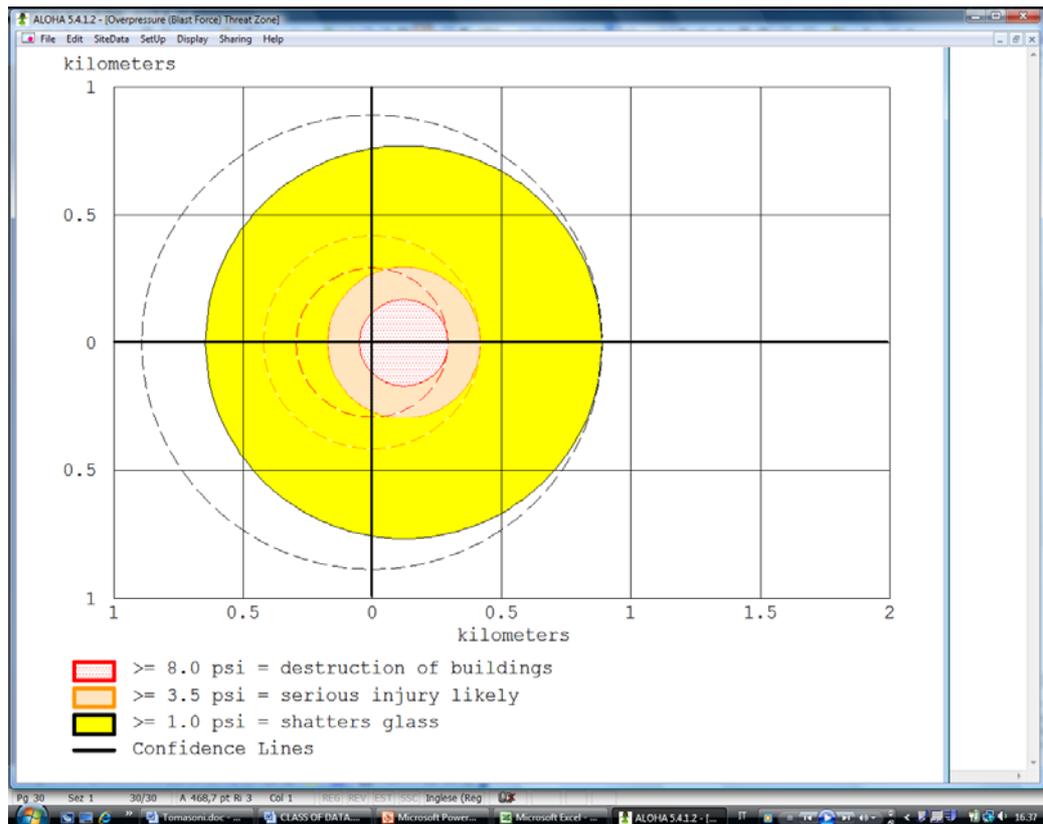
Type of Ignition: ignited by detonation

Model Run: Gaussian

Red : 294 meters --- (8.0 psi = destruction of buildings)

Orange: 419 meters --- (3.5 psi = serious injury likely)

Yellow: 890 meters --- (1.0 psi = shatters glass)



THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 50 meters

Off Centerline: 5 meters

Overpressure: 285 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 100 meters

Off Centerline: 5 meters

Overpressure: 285 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 150 meters

Off Centerline: 5 meters

Overpressure: 285 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 200 meters

Off Centerline: 5 meters

Overpressure: 43.9 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 250 meters

Off Centerline: 5 meters

Overpressure: 13.2 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 300 meters                      Off Centerline: 5 meters

Overpressure: 7.56 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 350 meters                      Off Centerline: 5 meters

Overpressure: 5.15 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 400 meters                      Off Centerline: 5 meters

Overpressure: 3.85 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 450 meters                      Off Centerline: 5 meters

Overpressure: 3.04 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 500 meters                      Off Centerline: 5 meters

Overpressure: 2.5 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 550 meters                      Off Centerline: 5 meters

Overpressure: 2.12 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 600 meters                      Off Centerline: 5 meters

Overpressure: 1.83 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 650 meters                      Off Centerline: 5 meters

Overpressure: 1.61 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 700 meters                      Off Centerline: 5 meters

Overpressure: 1.43 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 750 meters                      Off Centerline: 5 meters

Overpressure: 1.29 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 800 meters                      Off Centerline: 5 meters

Overpressure: 1.17 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 850 meters                      Off Centerline: 5 meters

Overpressure: 1.07 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 900 meters                      Off Centerline: 5 meters

Overpressure: 0.985 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 950 meters                      Off Centerline: 5 meters

Overpressure: 0.911 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 1000 meters                      Off Centerline: 5 meters

Overpressure: 0.847 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 1500 meters                      Off Centerline: 5 meters

Overpressure: 0.488 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 2000 meters                      Off Centerline: 5 meters

Overpressure: 0.336 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 2500 meters                      Off Centerline: 5 meters

Overpressure: 0.254 psi

THREAT AT POINT:

Overpressure Estimate at the point:

Downwind: 3000 meters                      Off Centerline: 5 meters  
Overpressure: 0.202 psi

THREAT AT POINT:

Overpressure Estimate at the point:  
Downwind: 3500 meters                      Off Centerline: 5 meters  
Overpressure: 0.168 psi

THREAT AT POINT:

Overpressure Estimate at the point:  
Downwind: 4000 meters                      Off Centerline: 5 meters  
Overpressure: 0.142 psi

THREAT AT POINT:

Overpressure Estimate at the point:  
Downwind: 4500 meters                      Off Centerline: 5 meters  
Overpressure: 0.123 psi

THREAT AT POINT:

Overpressure Estimate at the point:  
Downwind: 5000 meters                      Off Centerline: 5 meters  
Overpressure: 0.109 psi

THREAT AT POINT:

Overpressure Estimate at the point:  
Downwind: 5500 meters                      Off Centerline: 5 meters  
There is no significant overpressure at the point selected.



## ***Attachment N.5 – Risk adverse decision making code***

---

```
sets:
!a(link,path)= 1 se il link fa parte del percorso k;
!b = -1 se nodo origine ,1 se destinazione - NON SERVE;
!c= rischio sull'arco;
!p = probabilità di uso del link;
!q = probabilità condizionale di di incidente del link;
!h = probabilità che il percorso k sia scelto;
!path= ho già sei percorsi fissi;
!MI = matrice dei percorsi- (-1) arco uscente-(1)arco entrante - NON
SERVE;

n/1..9/: b;
time/1..8/:costo;

link/1..12/:rischio_link_i;

path/1..2/;

OD/1..2/;

rit/1..4/;

!rischioxtempo(link,time):risk,richio_link_t;

matrice(link,path,OD,time): use;

percorso(link,path,OD,time,rit): perc;

prob(path,OD,rit):h;

prova_rischio(link,time,rit):rischio_link;
prova_rischio_2(link,time):risk,rischio_link_t,rischio_link_1,rischio_1
ink_2,rischio_link_3,rischio_link_4;

scrivi_percorso(link,path,time):
percorso_1_1,percorso_1_2,percorso_1_3,
percorso_1_4,percorso_2_1,percorso_2_2,percorso_2_3,percorso_2_4;

!decisionale(path,delay):sched;

!rischio_su_arco(link,path,sim_t,camion):temp;

!tratta(link,percorso):a;
!trattadue(percorso,link):g;
endsets

data:

perc=@OLE ('bell_prova_rischio_costante.xls', 'perc');
risk=@OLE ('bell_prova_rischio_costante.xls', 'risk');!rischio;

@OLE ('bell_prova_rischio_costante.xls', 'h')=h;
```

```

@OLE ('bell_prova_rischio_costante.xls',
'rischio_link_t')=rischio_link_t;
@OLE ('bell_prova_rischio_costante.xls',
'rischio_link_i')=rischio_link_i;

@OLE ('bell_prova_rischio_costante.xls',
'rischio_link_1')=rischio_link_1;
@OLE ('bell_prova_rischio_costante.xls',
'rischio_link_2')=rischio_link_2;
@OLE ('bell_prova_rischio_costante.xls',
'rischio_link_3')=rischio_link_3;
@OLE ('bell_prova_rischio_costante.xls',
'rischio_link_4')=rischio_link_4;

@OLE ('bell_prova_rischio_costante.xls', 'percorso_1_1')=percorso_1_1;
@OLE ('bell_prova_rischio_costante.xls', 'percorso_1_2')=percorso_1_2;
@OLE ('bell_prova_rischio_costante.xls', 'percorso_1_3')=percorso_1_3;
@OLE ('bell_prova_rischio_costante.xls', 'percorso_1_4')=percorso_1_4;

@OLE ('bell_prova_rischio_costante.xls', 'percorso_2_1')=percorso_2_1;
@OLE ('bell_prova_rischio_costante.xls', 'percorso_2_2')=percorso_2_2;
@OLE ('bell_prova_rischio_costante.xls', 'percorso_2_3')=percorso_2_3;
@OLE ('bell_prova_rischio_costante.xls', 'percorso_2_4')=percorso_2_4;
enddata

!min= c +10*@sum(time(t):costo(t));

!obiettivo 1;
min= c;

!obiettivo 2;
!min= @sum(time(t):costo(t));

!@for(link(i): @for(time(t): (@sum(rit(tau):@sum(path(k):
@sum(OD(v):(risk(i,t)*perc(i,k,v,t,tau)*h(k,v,tau))))))< costo(t)));

@for(link(i): @for(time(t): (@sum(rit(tau):@sum(path(k):
@sum(OD(v):(risk(i,t)*perc(i,k,v,t,tau)*h(k,v,tau))))))< c ));

!@for(link(i): @for(path(k):@for(veh(v):
@for(time(t)|t#lt#10:perc(i,k,1,t+1,1)=use(i,k,1,t)))));
!@for(link(i): @for(path(k):@for(veh(v):
@for(time(t)|t#lt#9:perc(i,k,1,t+2,2)=use(i,k,1,t)))));
!@for(link(i): @for(path(k):@for(veh(v):
@for(time(t)|t#lt#10:perc(i,k,2,t+1,1)=use(i,k,2,t)))));
!@for(link(i): @for(path(k):@for(veh(v):
@for(time(t)|t#lt#9:perc(i,k,2,t+2,2)=use(i,k,2,t)))));

@for(OD(v): @sum(path(k): @sum(rit(tau):h(k,v,tau)))=1);

```

```

!@for(OD(v): @for(path(k): @for(rit(tau):@bin(h(k,v,tau)))));

@for(link(i): @for(time(t):@for(rit(tau):
rischio_link(i,t,tau)=
@sum(path(k):@sum(OD(v):(risk(i,t)*perc(i,k,v,t,tau)*h(k,v,tau)))) ));

@for(link(i):
rischio_link_i(i)=@sum(time(t):@sum(rit(tau):rischio_link(i,t,tau)) );

@for(link(i):@for(time(t):
rischio_link_t(i,t)=@sum(rit(tau):rischio_link(i,t,tau)) ));

!scrivi;

@for(link(i): @for(path(k): @for(time(t):
percorso_1_1(i,k,t)=perc(i,k,1,t,1))));
@for(link(i): @for(path(k): @for(time(t):
percorso_1_2(i,k,t)=perc(i,k,1,t,2))));
@for(link(i): @for(path(k): @for(time(t):
percorso_1_3(i,k,t)=perc(i,k,1,t,3))));
@for(link(i): @for(path(k): @for(time(t):
percorso_1_4(i,k,t)=perc(i,k,1,t,4))));

@for(link(i): @for(path(k): @for(time(t):
percorso_2_1(i,k,t)=perc(i,k,2,t,1))));
@for(link(i): @for(path(k): @for(time(t):
percorso_2_2(i,k,t)=perc(i,k,2,t,2))));
@for(link(i): @for(path(k): @for(time(t):
percorso_2_3(i,k,t)=perc(i,k,2,t,3))));
@for(link(i): @for(path(k): @for(time(t):
percorso_2_4(i,k,t)=perc(i,k,2,t,4))));

@for(link(i): @for(time(t): rischio_link_1(i,t)= rischio_link(i,t,1));
@for(link(i): @for(time(t): rischio_link_2(i,t)= rischio_link(i,t,2));
@for(link(i): @for(time(t): rischio_link_3(i,t)= rischio_link(i,t,3));
@for(link(i): @for(time(t): rischio_link_4(i,t)= rischio_link(i,t,4));

```

## Attachment N.6 – Optimal control in a tunnel - code

---

```
SETS:
  Time/1..15/:V,X,I,N1, N2, vel1, vel2, Y,Z, NUMERO1, numero2, HAZ1,
  ETAH1, HAZ2, ETAH2, NUMTOT;
END SETS

!in metanet suggerisce di fare simulation step 10s, free speed 100-
120 km/h, lunghezze di 300-800 metri;

TSUP=14;
I(1)=0;
N1(1)=0;
N2(1)=0;

!Coda;
@FOR(Time(t) | t#LE#TSUP: I(t+1)=I(t)+V(t)-X(t));

!Tratto uno;
@FOR(Time(t) | t#LE#TSUP: N1(t+1)*L1=N1(t)*L1-Y(t)+X(t));

!Tratto due;
@FOR(Time(t) | t#LE#TSUP: N2(t+1)=N2(t)+Y(t)/L2-Z(t)/L2);

!i flussi;
@FOR(Time(t): Y(t)=N1(t)*vel1(t)*dt);
@FOR(Time(t): Z(t)=N2(t)*vel2(t)*dt);

@FOR(Time(t):NUMERO1(t)= N1(t)*L1);
!@FOR(Time(t):NUMERO1(t)= Y(t)+Z(t)+I(t));

@FOR(Time(t):NUMERO2(t)= N2(t)*L2);

@FOR(Time(t):NUMTOT(t)= Numero1(t)+Numero2(t) );

!ore;
!dt=1;
!secondi;
dt=10;
!km;
!L1=100;
!L2=100;

!metrilunghezza;
L1=800;
L2=800;

!vincolo stabilità velocità < L/dt;

!Obiettivo;
```

```

MIN=@SUM(Time(t):
lambda*I(t)+alfa*(N1(t)^2)+beta*(N2(t)^2)+gamma*(N1(t)-
N2(t))^2+delta*(Z(t)^2));

!MIN=@SUM(Time(t): I(t)+alfa*(N1(t)^2)+beta*(N2(t)^2)+gamma*(N1(t)-
N2(t))^2+delta*(@smax(Z(t)-1,0)));

!MIN=@SUM(Time(t): 10*I(t));
lambda=1;
alfa=20000;
beta=20000;
gamma=20000;
delta=200000;

!Vincoli non neg;
!@FOR(Time(t): X(t)>=0);
!@FOR(Time(t): N1(t)>=0);
!@FOR(Time(t): N2(t)>=0);
!@FOR(Time(t): Y(t)>=0);
!@FOR(Time(t): Z(t)>=0);

!non-neg;
@FOR(Time(t): @FREE(X(t)));
@FOR(Time(t): @FREE(N1(t)));
@FOR(Time(t): @FREE(N2(t)));
@FOR(Time(t): @FREE(Y(t)));
@FOR(Time(t): @FREE(Z(t)));

@FOR(Time(t): @FREE(numtot(t)));

@FOR(Time(t): vell1(t)=16.6);
@FOR(Time(t): vell2(t)=16.6);

!Risk assessment;

@FOR(Time(t): HAZ1(t) = ETAH1(t)*N1(t)*L1 );
@FOR(Time(t): HAZ2(t) = ETAH2(t)*(N2(t)*L2+Z(t) ));

HAZTOT= @sum(Time(t): HAZ1(t)+HAZ2(t));

@FOR(Time(t): ETAH1(t) =10 );
@FOR(Time(t): ETAH2(t) =10 );

DATA:
V=10 3 2 0 0 0 0 0 0 2 3 0 0 0 0;

!in km/h;
!vell = 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60;
!vell2 = 60 60 60 60 60 60 60 60 60 60 60 60 60 60 60;

!in m/s;
!vell = 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6
16.6 16.6 16.6 16.6;

```

```
!vel2 = 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6 16.6  
16.6 16.6 16.6 16.6;
```

END DATA