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Land Use Planning and Risk-Informed Decision Making

Aménagement du Territoire et Prise de Décision en Maitrise de Risques

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European Safety, Reliability & Data Association

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Abstract

Land use planning and management of cities and different zones of industrial/commercial activities represents a major challenge today. Decision makers have to consider complex sets of constraints of different nature and to integrate wider range of risks before taking decisions and committing resources for medium and long term planning. These constraints may be of societal, economical, geo-political and even ethical nature. They need rationalizing their decisions and minimizing potential risks in order to guarantee an acceptable level of global security. Risks could be of varying kinds: natural, man-induced, systemic or criminal. These different sources of risk are interacting in today's developed societies. Subsequently, rational and optimized land use planning decision-making process can't be guaranteed except through the development of multidisciplinary robust tools and methodologies based on full identification of risks.
The European Safety, Relability and Data Association (ESReDA) has organized its 43rd Seminar hosted at INSA, Rouen, in France, in October 2012. The present volume of Proceedings contains the papers and discussions at that Seminar.

Availability of previous ESReDA seminar proceedings

Proceedings of the 1st ESReDA seminar on the use of expert systems in safety assessment and management, J. Flamm and A. Poucet Eds, S.P.I. 91.31, Joint Research Centre.

Proceedings of the 2nd ESReDA seminar on safety of systems relying on computers, J. Flamm Ed., S.P.I. 92.20, Joint Research Centre, Ispra, Italy.

Proceedings of the 3rd ESReDA seminar on equipment ageing and maintenance, J. Flamm Ed., S.P.I. 93.13, Joint Research Centre.

Proceedings of the 4th ESReDA seminar on safety in transport systems, J. Flamm Ed., S.P.I. 93.25, Joint Research Centre, Ispra, Italy.

Proceedings of the 6th ESReDA seminar on maintenance and system effectiveness, J. Flamm Ed., S.P.I. 94.29, Joint Research Centre, Ispra, Italy.

Proceedings of the 7th ESReDA seminar on accident analysis, J. Flamm Ed., S.P.I. 94.66, Joint Research Centre, Ispra, Italy.

Proceedings of the 8th ESReDA seminar on reliability data analysis and use, J. Flamm Ed., S.P.I. 95.31, Joint Research Centre, Ispra, Italy.

Learning from accident investigations and emergency responses, Proceedings of the 9th ESReDA Seminar, J. F. Pineau and S. P. Arsenis Eds, S.P.I. 96.58, Joint Research Centre, Ispra, Italy.

Rotating machinery performance, Proceedings of the 10th ESReDA Seminar, H. Procaccia and S. P. Arsenis Eds, S.P.I. 97.36, Joint Research Centre, Ispra, Italy.

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Risk Management and Human Reliability in Social Context, Proceedings of the 18th Seminar ESReDA, Karlstad (Sweden), I. Svedung, G.G.M. Cojazzi, Eds, ISBN: 92-828-6738-2, Joint Research Centre, Ispra, Italy, EUR 20141 EN.

Operation Feedback Data & Knowledge Management for New Design, Proceedings of the 19th ESReDA Seminar, Lyon (France), C. Degrave, G.G.M. Cojazzi, Eds, ISBN: 92-828-6739-0, Joint Research Centre, Ispra, Italy, EUR 20142 EN.

Decision Analysis, Proceedings of the 20th ESReDA Seminar, Rome (Italy), C.A. Clarotti, G.G.M. Cojazzi, Eds., ISBN 92-894-7494-7, Joint Research Centre, Ispra, Italy, EUR 21164 EN.

Lifetime Management, Proceedings of the 21st ESReDA Seminar, Erlangen (Germany), J. Blombach, G.G.M. Cojazzi, Eds., ISBN 92-894-5665-5, Joint Research Centre, Ispra, Italy, EUR 20707 EN.

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Maintenance Modelling and Applications, Proceedings of the 32nd ESReDA Seminar, Held at Hotel dei Pini, Località Le Bombarde – Alghero (SS), (Italy), May 7-11, 2007, M. Eid, E. Zio, Giacomo G.M. Cojazzi, Eds., Office for the Official Publications of the European Union, Luxemburg, Printed in Italy, To be published in 2010.

Future Challenges of Accident Investigation, Preprint, Proceedings of the 33rd ESReDA Seminar, Hosted by JRC, Ispra, Italy, November 13-14, 2007, N. Dechy, G.G.M. Cojazzi, M. Christou, Eds. Office for the Official Publications of the European Union, Luxemburg, Printed in Italy, 2010.

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Land use planning and management of cities and different zones of industrial/commercial activities represents a major challenge today. Decision makers have to consider complex sets of constraints of different nature and to integrate wider range of risks before taking decisions and committing resources for medium and long term planning. These constraints may be of societal, economical, geo-political and even ethical nature. They need rationalizing their decisions and minimizing potential risks in order to guarantee an acceptable level of global security.

Risks could be of varying kinds: natural, man-induced, systemic or criminal. These different sources of risk are interacting in today's developed societies. Subsequently, rational and optimized land use planning decision-making process can't be guaranteed except through the development of multidisciplinary robust tools and methodologies based on full identification of risks.

Upper Normandy is known for its long history of industrial activities. Subsequently, the research in reduction of industrial risks and environmental impacts is emerging as a new technical underlying activity in the region. Upper-Normandy is engaged in supporting and encouraging the emerging research in this field and is willing to develop the relevant skills and knowledge.

Co-Editors
Mohamed Eid, CEA, France
Michalis Christou, IET-JRC

43rd ESReDA Seminar Final Schedule

1st day, Monday October the 22nd, 2012

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President of Valmaris
President of ESReDA
President of Upper-Normandy Regional Council

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Mohamed Eid
ESReDA

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Mohamed Eid – ESReDA

16:45-17: 30 **Plenary Closing Session**
President of ESReDA
President of Valmaris
General Director of the INSA
Official

17:30 **Delegates Farewell & Departure**

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Lessons learned from an industrial accident

Philippe ESSIG
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Abstract

In the wake of the explosion on the AZF ammonium nitrate plant in Toulouse, in September 2001, the French Prime Minister of the time asked me to coordinate a national debate on industrial risks, and to summarize the main conclusions and recommendations of the debate in a report, which I addressed to him in February 2002. The debate, and my report, highlighted a number of problems related to land-use planning around hazardous facilities.

Keywords: hazard, facilities, explosion, Seveso, AZF, LUP

The national debate on industrial risks

After the accident, the French Prime Minister of the time, Lionel Jospin, asked me to organize a national debate on industrial risks. Its objective was to collect inputs from a variety of stakeholders, in order to define an action plan which could improve the level of safety around Seveso-type establishments in France, through the implementation of new organizational, regulatory and legal measures. The debates were organized around three primary themes:

1. industrial production, safety and supervision by the competent authorities;
2. information and consultation procedures;
3. land use planning around hazardous establishments, in particular in urban areas.

Over a three month period, I organized a total of 27 debates in different French cities, with around 7000 participants in total.
A variety of groups and stakeholders participated in these meetings: leaders from industry, trade union representatives, local government officials, journalists, members of ONGs, researchers and representatives from national government and the competent authorities. The debate was sometimes passionate, in particular for the last meeting held in Toulouse (for understandable reasons), but a variety of points of view were expressed (there were no “taboo” subjects) and many suggestions were made.
I presented a report containing a summary of these debates and the suggestions made to the French Prime Minister in February 2002. I will focus on three issues which are

related to land use planning and the governance of industrial risks:
The land use planning components of the Seveso II directive, as transcribed into French law and implemented by local government officials over several decades of urban development, were not able to prevent the development of situations where hazardous industrial facilities were located too close to residential areas. The pressure from urban development had proven, over time, too strong for local government officials, who authorized building in locations which risk analysis showed to be dangerous.

- Many stakeholders considered that they were excluded from the decision-making process concerning industrial safety, and expressed a desire for a more inclusive consultation process;

- At a national level, the safety culture was insufficiently developed, and too many people had been encouraged to adopt a "zero risk" doctrine, leading to a lack of acceptance of each citizen's responsibility in terms of industrial safety;

New legislation concerning the prevention of technological risks was published in July 2003. It includes modifications to risk analysis methods (a change from deterministic to probabilistic frameworks for safety cases), to land use planning, and to information and consultation processes, which I will describe and comment in more detail.

Changes in risk analysis methods

Prior to the 2003 legislation, France used a deterministic approach to risk assessment, based on "worst case" scenarios. Detailed analysis of these "worst case" scenarios, with pessimistic assumptions of the failure of all active preventive or protective safety barriers, led to the definition of two geographic zones representing the level of exposure to the effects of the hazardous event:

1. Z1 was the 1% lethality zone, and comprised all areas where one out of a hundred people exposed to the effects of the hazardous event are expected to die;

2. Z2 was the limit zone for irreversible effects to health.

After a local consultation process, these zones were converted into land use planning zones called "close protection" and "distant protection". National recommendations existed concerning the types of industrial development, buildings and transport infrastructures which could be built in each zone.
Several criticisms were made of this deterministic approach:

- it provided insufficient guidance to local officials on which land use possibilities were compatible with the level of technological risk;

- the process of converting from zones of level of exposure to effects to land use planning zone was somewhat opaque, and in some cases local political pressures led to zoning decisions which were incompatible with sound risk management;

- lack of consistency in the choice of worst case scenarios led to differences in effect distances between plants using the same technologies;

- comparison with practices in other European countries, which often used more probabilistic approaches to risk assessment, was difficult.

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- the process of converting from zones of level of exposure to effects to land use planning zone was somewhat opaque, and in some cases local political pressures led to zoning decisions which were incompatible with sound risk management;
- lack of consistency in the choice of worst case scenarios led to differences in effect distances between plants using the same technologies;
- comparison with practices in other European countries, which often used more probabilistic approaches to risk assessment, was difficult.

Following the AZF accident, the law in France was changed to require the use of a probabilistic approach to risk assessment, which allows more risk-informed decision-making. A scenario-based approach is mandated: the industrial operator must identify a number of "representative" accident scenarios, which are then assessed using a semi-probabilistic (LOPA-type) analysis. The scenarios are placed in a risk matrix, in which certain positions are defined to be unacceptable, and others "ALARP".

The change in assessment methodology has required **significant extra workload** both from industrial operators, who undertake the risk assessment and write the safety case, and from the competent authorities, who analyze and approve the safety case. The increased workload has led to a significant increase in the use of subcontracting with expertise firms to assist in the risk assessment process and in writing the safety case. The number of inspectors working for the competent authorities has roughly doubled since the Toulouse accident.

Changes to land use planning legislation

Before 2003, French land use planning legislation only concerned new facilities, and was not able to affect local land use plans when an existing facility was modified, nor was it able to "correct" urban planning when a new risk assessment of an existing facility led to changes in the safety perimeter. The 2003 legislation introduced new instruments, called *Technological Risk Prevention Plans*, which were inspired by existing French legislation concerning flooding risk. These plans comprise several new features:

- the local consultation process is strengthened (involving both local government officials and local residents), and is open to the public. A national implementation doctrine limits the extent to which local consultation may affect land use plans.

- the authorities are able to expropriate inhabitants who live in areas which are exposed to a high level of risk (homeowners are forced to leave their home, and are compensated for its market value, estimated without the presence of industrial activity), or allow relinquishment (homeowners may require that the state purchases their home at its market value). Funding of these measures (which are sometimes extremely costly) is shared between the industrial operator, local government and national government.

- the authorities can require home owners in medium risk zones to implement protective measures in their homes (for example, reinforcing windows in areas exposed to explosion risk, and building a confinement room in areas exposed to a toxic risk).

Certain details of the implementation of the law are still somewhat unclear in 2012. For example, people who live close to an industrial facility and whose home is exposed to a medium level of risk, must implement constructive measures in their homes in order to protect them against the risk. The cost of these measures is borne entirely by home owners, but they can deduct a part of the cost (the percentage changes in each yearly budget) from their income tax[1]. The law specifies that homeowners have an obligation to implement such constructive measures, but does not anticipate how the obligation will be enforced, nor the implications for insurance coverage of possible victims of an industrial accident, who did not implement the prescribed constructive measures.

Better information and consultation of local populations

A last component of my report to the Prime Minister concerned the information given to local populations concerning industrial risk, their inclusion in consultation procedures and their degree of involvement in local decision-making. As is often the tradition in France, the decision-making process concerning industrial safety and land use implications was rather technocratic, with issues too often being decided by small groups of experts (from industry and from the competent authorities), with very little information provided to (and even less consultation of) local citizens.
My report suggested that information given to local citizens could be improved, with a greater degree of transparency in the process.
I also suggested that a move should be made from a process of *information* to a more **participatory process** (moving towards a "democracy of risk"), that local government officials should play a stronger role in the **mediation between industry and citizens**, and that alternative forms of expertise should be encouraged (despite the implications in terms of cost) and consulted. This reinforced citizen participation in discussion and decisions concerning industrial safety is in my mind a protection against the establishment of a routine, a reduction in the degree of vigilance with respect to different hazards.
In 2005, the law in France decreed the creation of local consultation bodies, called

[1] This measure introduces an asymmetry between households who pay income tax and poor households who do not pay income tax.

CLIC[2], around all top tier Seveso facilities. These bodies, comprising members from industry, the competent authorities, trade unions, local government and local citizens, meet approximately twice a year.

Information is provided concerning the management of technological risks and on incidents and accidents which occur on the plants. The creation of the CLIC was inspired by existing consultation bodies around nuclear power plants.

Experience has shown that the CLIC, as currently organized in most regions in France, function in an excessively rigid manner. They are presided by the *Préfet*, who represents national government regionally, and who traditionally adopts an authoritarian, rather than consultative, approach to government. In my opinion, whilst some progress has been made towards the objective of the Prime minister at the time of the AZF accident of reinforcing citizen's participation in governing technological risks, much remains to be done. Indeed, in practice the decision process remains fairly technocratic, and is still primarily governed by negotiation between experts from industry and from the competent authorities.

More flexible consultative bodies such as SPPPI (informal bodies which already existed in certain industrial regions in France at the time of the AZF accident), and recent experimental bodies such as the *Conférence riveraine* in Feyzin[3], suggest ways in which consultation practices should, in my opinion, evolve in the future.

A separate change to legislation following the Toulouse accident involves **simplified summaries of safety case reports**. Safety case documents for hazardous establishments are often written in such a technical language that they can only be understood by experts in risk assessment, generally working for industry or for the regulator. Other interested parties, such as technical advisers in local government authorities, trade union representatives and local citizens, were unable to comprehend the contents. The law has changed to require **non-technical summaries** of these documents, which help in the consultation process and assist the development of a safety culture around industrial facilities.

Political calendars and real-life implementation

The AZF explosion, which caused the death of 31 people, approximately 4500 injured, and significant damage to nearby buildings, naturally led to significant emotion. The Minister of the Environment at the time, Yves Cochet, stated two days after the explosion that the law would « certainly have to change ». Less than a week later, the Prime Minister confirmed, during a speech made in Toulouse, the need for a change of legislation, and gave an outline of the changes he intended.

The national debate was organized quickly, and concluded in December 2001; my report was presented to the Prime Minister in January 2002. The parliamentary inquiry into the safety of hazardous industrial facilities and research laboratories and the protection of people and the environment in case of a major industrial accident[4], which heard 400 witnesses and visited numerous industrial sites, concluded in February 2002.

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2 Comité Local d'Information et de Concertation

3 More information concerning the *Conférence riveraine* can be found at http://www.icsi-eu.org/.

4 http://www.assemblee-nationale.fr/11/dossiers/installations_industrielles.asp

The law was first presented to Parliament at the beginning of 2003[5], voted in July 2003 and the accompanying decrees were mostly promulgated in 2005. The guidelines written by the Ministry of the environment to assist in the implementation of the law were published between 2005 and 2007.
One of the principle consequences of the law, the *Technological Risk Prevention Plans* (421 in France, concerning 670 establishments), were initially intended to be completed in 2007. Today in 2012, less than half of them are concluded; the significant financial consequences of some of these plans, in today's difficult economic context, do not facilitate prompt resolution of these problems[6].
As is often the case, political focus on an issue is linked to its visibility by the public, and people's attention is very high after a catastrophe, but decreases quite quickly afterwards.

Creation of the ICSI in 2003

In 2003, I was approached by a small group of people from different backgrounds (industry, research, local government, trade unions) who planned to create a non-profit organization which would work to improve knowledge and dialogue on issues related to industrial safety and the cohabitation of hazardous facilities and local populations.
They asked me to become the President of this organization, the *Institute for an Industrial Safety Culture,* which today works to improve dialogue between all stakeholders concerned by industrial safety, organizes graduate-level and professional training on risk management and undertakes research aiming to improve safety and safety culture in Europe. Since 2003, the ICSI has undertaken a number of activities which contribute to a shared safety culture and cohabitation of industrial activity and other forms of land use:

- a working group in 2004, comprising representatives from local government, research, industry, trade unions and NGOs, developed a common understanding of a vocabulary (in French) concerning technological risk, consultation processes and decision-making, with an accompanying pedagogical toolkit which has been used in a number of initial sessions of CLIC consultation bodies;

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5 Intervening elections had led to a change in the government, and thus to a new Minister of the environment.

6 In ordinary circumstances, new expenditure for the government which is anticipated to result from a new law, should be included in the national budget. However, the costs which would be generated by measures resulting from the PPRT legislation were not included in the national budget at the time the law was voted, since the measures were conditional on each local plan being approved, and thus fairly remote in time. The significant costs to national government, local governments and industry of measures resulting from PPRT legislation were not readily apparent at the time the law was voted.

other forms of land use:

- a working group in 2004, comprising representatives from local government, research, industry, trade unions and NGOs, developed a common understanding of a vocabulary (in French) concerning technological risk, consultation processes and decision-making, with an accompanying pedagogical toolkit which has been used in a number of initial sessions of CLIC consultation bodies;

- a working group in 2005 and 2006 comprising representatives from industry, trade unions, research and NGOs wrote a document concerning appropriate management of subcontracting on Seveso-type facilities (subcontracting was one of the important issues discussed in the aftermath of the AZF accident);

- a working group in 2006 and 2007 produced a pedagogical document concerning the risk assessment process, which aims to help non-expert stakeholders to understand the safety case documents, and to assist authors of these documents in producing non-technical summaries which can be understood by lay people;

- other working groups have addressed issues including the management of fire hazards, human and organizational factors of safety, initiating event frequency databases for risk assessment, management of operational experience feedback, and communication on long-term health effects of industrial pollution. The working groups produce documents which are made freely available to the public in PDF format, and the ICSI organizes dissemination activities such as seminars, in order to inform interested stakeholders;

- a number of training courses, both Master-level and short courses for professionals, have been developed.

These activities contribute to the development of a real safety culture, shared by all stakeholders concerned by industrial risk, in which people understand the issues and are able to participate in an informed way in decision-making. It is a slow process, but it is important that risk become an issue of democratic debate, rather than a technical issue for a small number of experts.

Philippe ESSIG former President of the SNCF (French railways), is the author of a report requested by the French Prime Minister concerning a national debate on industrial safety, following the Toulouse AZF accident (2001). He is also President of the *Institute for an Industrial Safety Culture* (Toulouse, France), a non-profit organization which was created after the AZF accident.

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Design and development of public transport systems: how to keep them on track

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Abstract

This contribution explores the various levels of decision making, substantive arguments and changes in the plans and design alternatives as the appeared throughout various processes of infrastructural design. The contribution emphasizes the need for a more pro-active and structured approach in planning and developing safety in such projects in order to guarantee a consistent and consequent quality of the decision making and to assure coherence between all safety aspects in the design.

Keywords: safety assessment, infrastructural projects, decision making

1. Introduction

1.1 Opportunities

Realizing new infrastructure and upgrading existing infrastructure is a major societal mission because transport infrastructure is considered a carrier of economic development. In the past, expansion of infrastructure has been considered a mono-disciplinary design task. Nowadays, accommodating spatial demands becomes more and more difficult due to an intensified and multifunctional use of space. The complexity of the design task increases because more and more actors and interests are involved, while costs expand and societal benefits are debated. Such major projects are characterised by large uncertainties in the area of societal, technological and financial complexity. Such projects are organised by public-private partnerships, taking over governmental roles in control and management of the projects. Designing infrastructure is not only increasing in complexity, but new design aspects are involved, such as external safety, rescue and emergency demands and last but no least, terrorism and social safety issues.

The national policy decision making arena in the Netherlands has seen several misfits and deficiencies, leading to a series of Parliamentary Inquiries into the design, construct, financing and uncontrolled consequences of this development. Already in 2004, a report on the parliamentary inquiry into major infrastructure projects has been published, the Tijdelijke Commissie Infrastructuur (Temporarily Committee on Infrastructure) (TCI 2004). In one of the supporting chapters of the report, the safety aspect is elaborated, calling for developing a new tool in safety assessment, the Veiligheids Effect Rapportage (Safety Impact Statement).

Evaluating major projects indicates that it is undesirable to capture effects and consequences based on a single performance indicator. Instead, a series of critical decisions are involved, which are improved and supplemented during the process. Strategic and external effects can be evaluated with a variety of methods and techniques. In order to harmonize safety with the decision making process, analyses should be conducted in two phases. After a first qualitative phase, based on index parameters and clarification of the solution domains, a more detailed analysis is performed. Eventually, national politics decides, based on transparent and relevant information. In a first phase, bottlenecks, opportunities, and solution domains are involved, while in a second phase various project alternatives including technological options are substantiated and formal assessment procedures take place. Instruments such as cost-benefit analysis and environmental impact statements are performed preliminary in a first phase, while in a second phase, they are conducted at length. Safety can be positioned in each phase of the project life cycle:

- In the initial phase, a societal cost-benefit analysis is available, indicating the necessity and urgency of a new major project or policy making option. At this phase however, the safety aspect is missing. No safety related decision making support tool exists.

- In a second phase, a more detailed assessment of the consequences of the options is required, narrowing down the scope to preferential options based on a detailed environmental impact assessment and detailed cost-benefit analysis. At this phase there is room for a Safety Impact Statement as a tactical decision making tool

- In a third phase, the level of project development and management is elaborated, providing a project- or policy-option specific Safety Case for the justification of the selected safety strategy, principles and concepts as an input for the next phase.

- In this fourth phase a Safety Management System (SMS) is to be developed as the basis for the systems regular operational performance, including in-house incident and emergency handling.

- In cases in which this SMS is insufficiently equipped, in a fifth phase public rescue and emergency services and after care is to be provided by local authorities as a part of public crisis management policies. At this phase, a Critical Event Scenario approach has been developed which refers to allocation of rescue and emergency management resources.

By identifying these phases in safety assessment, national government is provided transparency in the safety life-cycle chain, starting with initiating project and policy options until organizing and deployment of rescue and emergency resources (TCI 2004.

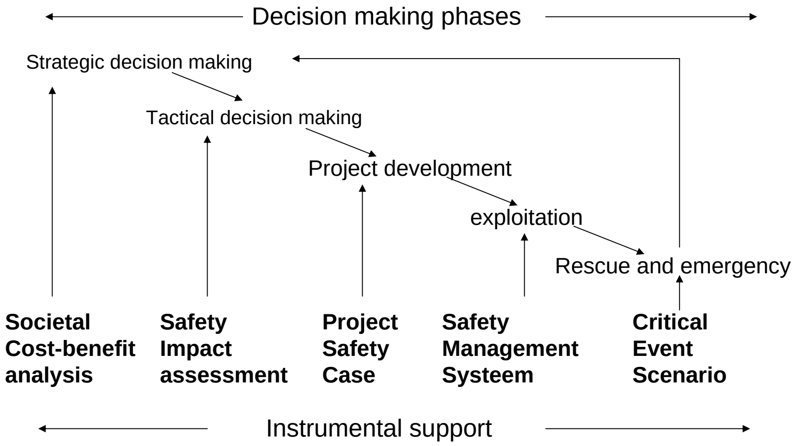

Fig 1. Flow chart decision making processes and instrumental support

1.2. Scenarios

1.2.1. Scenarios as a decision support tool

Analyzing the lessons learned from the design and construct of the High Speed Line-South railway project, questions were raised about the theoretical justification of the project fundamentals (Stoop and Beukenkamp 2002). New actors and safety notions in the area of rescue and emergency, external influences such as the Eschede ICI-train derailment and various tunnel fires in the Alp region emphasized the necessity to incorporate safety in the decision making process of the project management in a major infrastructure project.

Initially defined as a linear, loosely coupled and closed system design, based on proven technology, the HSL-South project demonstrated the need to incorporate external influences and new actors in the safety decision making process. Rather than compliance with quantitative risk standards and performance requirements at a detail engineering level as a part of the Construction and Operation Licensing procedure, a dynamic and open process approach proved to be necessary. Such a process should stimulate consensus among actors and involve rescue and emergency aspects in the early phases of the design and should document principal safety related decisions (Leeuwendaal 2001).

In this approach, the use of scenarios as decision support tools proved to be fundamental in order to achieve consensus among stakeholders and to allocate specific safety measures to improve the quality of the design. Such an approach eventually proved to be beneficial for introducing innovation in the design of a major tunnel for the HSL-South railway (Stoop and Beukenkamp 2003). However, the application of scenarios as design support tools remained obscure regarding their substantive development, procedural embedding and scope with respect to an integral safety approach. In a second project, the Spoorzone Delft, scenarios have been primarily applied as a design tool to explore their further substantive development.

Scenarios as a design tool

Scenarios were developed as a design support tool in order to support a substantive safety assessment in three phases of the design process and decision-making during the project management. In general, three steps are identified in a civil engineering design process:

- Step 1: a conceptual design phase in which design alternatives are based on a Program of Requirements, shared by all actors and encompassing all relevant design aspects. Such alternatives are collected in a Initiating Document (RIB 2002)

- Step 2: a functional design phase, in which a limited set of most preferable alternatives is selected, fit for further elaboration and detailing of critical design aspects of the final design option (RIB 2003).

- Step 3: a detailing phase in which the construction details and safety measures in the final option are elaborated into a construction planning phase (DHTrail 2003).

In each of these phases, safety should be assessed in combination with other relevant design aspects and external conditions. Eventually, a most cost-effective design should be realized. In order to integrate safety in these decision-making phases, a scenario analysis was applied to the Spoorzone Delft project (Prorail 2003).

Due to the fact that is impossible to evaluate and assess all possible scenarios, a selected number of five critical 'top' scenarios were identified by expert opinion and group discussion among stakeholders.

Their relevance was based on their ability to demonstrate the perceived critical consequences and their ability to indicate design strategies. They should facilitate optimization of design solutions for a wide variety of aspects. In a next design phase of detailing engineering, all possible scenarios should be evaluated in order to assess their influence on the project elements, technical installations and operational requirements to assess the safety of the final alternative.

2. A design case study: the Spoorzone Delft project

2.1 Case description

The municipality of Delft has been taken initiatives over the years to improve the quality of the urban area around the central station and railway track. At present the location of the tracks on a high fly-over disturbs the living environment and hampers the development of the city center nearby the station. Consequently, the municipality has commissioned a design for a railway tunnel in combination with local urban development and a multifunctional public transport hub as a replacement for the fly-over and station.

The first railway across Delft originates from 1847, replacing the Western city walls which were dismantled in the 19th century. From 1878 onwards, the city expanded in a Western direction, embedding the railway in the city itself. With the increase of railway and road traffic, in 1965 the railways were separated from the road infrastructure by creating a flyover facility over the former Western city canal, the

Spoorsingel. The disadvantages of this concept soon became apparent, due to the noise of the flyover, the barrier effect of the parking lots underneath the flyover and the esthetical aspects of the removing canals in old city centers like Delft.
A full reconstruction became an option when in 1996 in a neighboring city on the same railway line, a tunnel and underground station were designed with the support of Parliament as a part of the national traffic network development policy. A Masterplan for the railway station was ultimately accepted in 2005 with the approval of the Spoorzone Delft project. The project consists of a combination of a public transport node, combining a four track railway tunnel and underground station, with adjacent underground parking facilities for 450 cars, about 1500 appartments, 54.000 m2 office facilities of which 50% for the new town hall offices and a reconstruction of the city center western hemisphere road traffic network .

1.2.2. <u>Step 1: Safety as a conceptual design aspect</u>

In cooperation with the railway provider, Delft has taken a multidisciplinary approach in which the public transport hub is pivotal and an integral approach is favored for the spatial and transport issues. This approach should direct an urban infrastructure, and generate solutions for planning, construction method, alignment and possible optimizations. The municipality Delft, the regional authorities and the railway infra provider have drawn up a common Program of Requirements in order to conduct a modeling study into the location and outlines of the transport hub, in combination with the tunnel options and urban environment. Eventually, 14 alternatives were developed and assessed, based on the following characteristics:

- the construction method of the tunnel, such as cut-and-cover versus drilling, including the tunnel cross section
- the length of the tunnel, with a constant northern section length and a variable length of the southern section
- the vertical alignment, focusing on the local urban consequences of various spatial functions on the surface level
- horizontal alignment, depending on required removal of houses and crossing of traffic arteries and combination of transport routes
- location of the public transport hub, varying across the track as well as underground or surface level railway stations.

In total 16 alternatives were tested by expert opinion meetings, based on 12 criteria, among which social safety in the railway station environment and internal and external safety of the tunnels. As a result of this testing procedure, 5 preferential alternatives were chosen for further elaboration (RIB 2002).

1.2.3. <u>Step 2 Safety assessment of design alternatives</u>

In order to reach a further reduction in alternatives, the five preferential alternatives were assessed more in detail, in particular with respect to safety.
The following scenarios were selected for assessment of the five preferential alternatives:

1. fire in a passenger train stopping in the tunnel, possibly in combination with the presence of hazardous materials in a freight train. Due to smoke, heat and toxic substances, the focus is on the speed of evacuating passengers

2. collision of a freight train and passenger train at the underground station, releasing hazardous materials. This scenario foresees an expansion of the event into the underground platforms and adjacent station, requiring rapid evacuation of passengers and timely access for rescue workers

3. small crime and traffic accidents on the ground level station square, focusing on interactions between station, parking, transport hub and traffic environment

4. disturbance of public order and safety during the construction phase. This scenario deals with complications during construction and crowd control

accessibility of the site for rescue and emergency workers during major events in and around the tunnel, underground station, adjacent office blocks and parking facilities.

In the conceptual design the safety analysis focused on two questions:

- whether a difference in transport of hazardous materials in the present situation and a future option of unrestricted transport would affect the required safety measures

- or differences should exist for shorter and longer tunnel alternatives, taking into account underground or ground level positions of the railway platforms.

The Spoorzone Delft project has a number of characteristics, which argue for a group risk approach in terms of rescue and emergency resources and facilities. Passenger and freigth trains may occupy the tunnel simultaneously, during which a large population at risk may be involved in an incident, including the population at the underground station. Since the station has no separation between tubes, interactive scenarios may occur between station and both tubes. The sizes of the transport of hazardous materials and a coincidence with passenger transport are critical issues for a safety assessment of the tunnel design. Consequently, group risk may be a critical factor in incident handling. Such internal group risk may be triggered by transportation of hazardous materials or fire incidents in passenger trains, but no national, legal standards are available. Acceptable risk standards for passengers and populations at a railway station are defined only on an individual basis. The costs of the tunnel and concurrent safety measures to guarantee a sufficient safety level are substantial. The analysis focused on fire hazards and incidents with hazardous materials. Eventually, a safety philosophy was adopted by all stakeholders.

2.2 Safety philosophy

A prominent argument for designing a tunnel in the new Spoorzone project was the transport of hazardous materials by rail. The national policy on rail transport of hazardous materials in the Netherlands demands unrestricted access to all tracks on the railway network. This policy creates an external risk of transport of hazardous materials through city centers, which is considered critical in terms of Local Risk and

Group Risk standards. Tunneling would eliminate this politically sensitive external risk, creating a win-win situation with respect to external risk and elimination of city development barriers. However, simultaneously, an internal risk was created for internal safety in the tunnel and underground station. In the previous decade, several serious accidents have occurred with fires in road and railway tunnels, alerting the rescue and emergency community on the risks involved for railway passengers, their own staff and the governmental issues on responsibilities and liabilities. For these reasons, explicit attention was paid to this new internal risk in the early phases of the design. In 2000 a Working Group on Integral safety was established by the municipality of Delft, composed of any party involved in the risk domian. The scope covered both internal risk, external risk, occupational hazards, social risk, rescue and emergency aspects. In addition to the commonly applied Quantitative Risk Analysis, the scenario analysis was adopted, simultaneously covering several policy domains: rail transport of hazardous materials, urban planning and rescue and emergency. This approach should quarantee a continuous focus on safety throughout the Design and Construct phases of the project. The principles of the philosophy covered the notion of residual risk: not every risk could be eliminated or fully controlled. The structural integrity of the tunnel is designed for a two hours resistance to a fire load of cargo train. A residual risk of loss of structural integrity was incorporated, while based on risk calculations, the consequences of a hazardous material accident were not considered critical: a fire in a passenger train was dominant. The focus in designing a coherent set of safety measures was on the exclusion of a conflict between a cargo and passenger train in the same tube, the use of sprinkler systems in cargo trains and the design of a sophisticated ventilation system for the safe evacuation of passengers to either the tunnel ends or the underground railway station. To this purpose, the railway station was designated as a safe haven. In addition to the infrastructural measures dealing with fire resistant tunnel lining measures, operational measures were taken into account, dealing with limitations in access of hazardous materials cargo trains during rush hours and a strict separation of cargo and passenger trains in tubes and in the station. In order to create a consistent level of safety on the railway chain Rotterdam-Delft-Rijswijk-The Hague, safety measures were taken equivalent to the measures which already accomodated transport through the nearby Willemspoor tunnel and Rijswijk tunnel.

Consequently, two main packages of safety measures were designed, a Basic Package –without hazardous material transport- and a Plus Package –including this transport-. The detailed level of design incorporates most prominent safety measures such as a safe evacuation of tunnel and station by smoke management. The tunnel tube is designed as a safe have escape route, linking the adjacent tube to the accident tube by emergency exits. The pressure gradient provides a clean air situation at all times in the station, while office buildings and other spaces are disconnected from the ventilation and evacuation system in the railway system. At the south end of the tunnel, an unmanned fire fighting command post is foreseen, linked to the railway emergency center in Rotterdam, while the local fire station in Delft is situated close to the station

2.3 Delays and unforseen external developments.

First, the crisis in the real estate developments. Because the lead time of the project is about 10 years, several external developments exist which cannot be anticipated in the conceptual phase. The financial crisis has caused a delay of about two years in the appartment and office buildings markets. This crisis forces a temporarily exploitation delay, causes considerable additional work in phasing and logistics of the project despite the low technological innovative nature of the project. The transition from two tunnel tracks to the four track final configuration has seen a delay of about two years. In addition the safety assessment of the project ceates additional delays. The municipal office estates and the railway station facilities require separate emergency facilities; compartimentation of the project requires separate certification procedures. However, such certification is not yet fully developed for the social safety and risk perception and risk awareness components of certification

Second, the ground water level in the shallow levels creates unforeseen complications, because several assumptions with respect to the gradual raising of the level prove to be incorrect. This deficiency in assumptions has created uncertainty in the designed load and necessitates an extension of the support beams capacity in order to compensate for the increased load on the tunnel construction. Further raises in ground water levels are expected due to the termination of the peniciline production of the nearby DSM process industry facilities. Since these production processes require a high level of water, over decades a deep water supply facility has been applied, having a major impact on the deep water flows and stability of the soil in the environment. If the water supply should be terminated abruptly simultaneously with the termination of the production facility of DSM, a sudden change in deep water flow should occur in the wider environment, impacting an aera of about 80 km in diameter. In addition, due to such an increase in deep water levels, the tunnel construction could brake free from its foundation and flows in an upward direction.

3. Safety assessment: two assessment processes

During the design and development of the Spoorzone project, two main streams of safety issues have been covered: a substantive assessment of the safety of the design, introducing the notion of integral safety, and a process assessment of a democratic participation in all phases of decision making (Horvat 2001).

3.1 Substantive assessment

A substantive assessment of the safety has been conducted in two phases; the conceptual design and the preliminary design. A detailed safety design assessment is yet to come, while the safety management during operations will be derived from the residual risks that emerge from the design outcomes.

Three policy domains have been involve in the safety assessment. The Ministry of Transport and Infrastructure was involved from a railway safety perspective, covering the issue of safety throughout the hazardous materials network development. This perspecitve deals with external risk standards and risk contours regarding Local Risk and Group Risk as the safety aspect of the national Hazardous Goods Network. This project is embedded in the Long Term Planning for Infrastructure, Space and Transport, developing main-, brain and greenports. Co-financing by the national government is an option in case of supraregional developments, with delegated responsibility to regional and local government. As such the risk assessment in the Spoorzone deals with railway traffic volumes, traffic management, origin-destination issues and track allocation issues. The data are prospective, dealing with anticipating on future developments in the rail cargo sector. The Ministry of Housing and Spatial Development deals with safety from a perspective of multiple use of space, covering safety issues of densely populated areas, dealing with multifunctional and potentially conflicting use of spaces. The key policy issues in this perspective cover multifunctional use of space and Public Private Partnership project development. Finally, the Ministry of Internal Affairs is involved from a rescue and emergency perspective. This Ministry designated the Spoorzone project as a benchmark project for the development for a Safety Impact Statement as the counterpart of other already existing assessment methods for orther policy aspects such as environmental impact, economical impact and governance implications. The purpose of this Safety Impact Statement is to provide transparency and consistency throughout the design and development of the project with respect to safety. The characteristics of such a Safety Impact Statement are: integral safety, a safety chain –proaction, prevention, preparation, repression and after care- multiple scenario analysis in order to provide generic and specific insights, various planning phases of the project and a cyclic decision making procedure. During consecutive project phases, various instruments are applied, such as a Safety Case, Quick Scan, Quantitative Risk Analysis and certification standards. An encompassing analysis was performed dealing with decomposition of the project into several major components, identification of accident types and scenarios, system functions and mulit-actor involvement in the various lif cycle phases of the project.

3.2 Project process assessment

In urban planning, the redevelopment of city center station environments is a senitive and ctitical issue. Several tensions exist with respect to the role of local, regional and national governance, a multi-actor and multi-stakeholder arena on the local level considerably omplicates decision making processes (Petter 2005). Hinder and disruption may jeopardize public support for a lengthy lead time. While costs become visible per interested stakeholder in one phase, benefits may be obscured or allocated to other stakeholders in different phases of the process. In a comparative study on several railway projects on hazardous goods transport in an urban environment, four issues were assessed as critical: the design and construction process, the organisation and structure of the project, the presence of a safety manager as an advocate for safety as a strategic value and the influence of external developments which might interfere with the project. In Delft, the Spoorzone project was initiated or reasons of noise, urban planning and city development, focusing on the reduction of external risk. Safety was a strategic value, adressed by the Ministry of Internal Affairs early and high in the decision making process. This resulted in a pro active and structural involvement of safety in the decision making process from the beginning of the project. The national governancelevel was involved from the beginning of the process. In Arnhem, the project was designated as a Key Project in urban development, involving safety only late in the process, creating frustration and professional concerns in the fire fighting community. They assessed their involvement as ‘too little and too late’. Involvement of the Ministry of Housing and Urban Planning at the national level was present, but restricted to the Key Project safety aspects, not on integral safety as such. A major external influence appeared late in the project when BASF announced the termination of its production site across the German border. This facility is nearby the Arnhem station where all hazardous goods traffic have to pass, making obsolete all safety measures that had been taken into account. In a third project at Dordrecht, the Ministry of Transport and Infrastructure took the lead in the project development. Although the project started with a shared vision on the importance of safety as a critical design value, no further elaboration was performed. Measures were taken on an actor dependent basis, creating confusion and misunderstandings among stakeholders. The feasibility and effectiveness of various solutions was debated, creating tensions on the local level, questioning the validity and credibility of national standards on Group Risk and Local Risk.

From this survey, it was concluded that the results of a safety assessment highly depended on the focus, starting point and preferential policy of a ministry. In each case, where a different ministry took the lead, different results were produced. Active involvement of national government facilitated consensus, while in other case in their absence, local tensions and limited resources frustrated the progress, coherence of the decision making and quality of the substantive results. A general conclusion form this study was that cooperation between local stakeholders, regional and national gevernance enabled the achievement of a full safety picture, sharing of knowledge, increase of the feasibility of shared solutions. Cooperation created understanding among all parties involved, easing sensitive issues across different policy domains.

3.3 Separating process from content: the Rijn Gouwe Lijn experiences

In the mid 1990's public transport needs in the Western part of the Netherlands evolved into a series of plans for a light rail version of a classic heavy railway connection connecting the western and central parts of Holland. This lightrail system aimed to connect several coastal with Gouda in the middle of the Green Heart of Holland, crossing rural areas with a high environmental preservation value, while simultaneously penetrating deeply in the old city center of Leiden, connecting the railway system with heavy rail stations and the central station in Leiden and Gouda. During the project, a safety impact assessment was deemed necessary, requiring a mixed assessment framework for the safety assessment of the heavy rail system network, the safety impact on the road network while crossing the inner city traffic network of Leiden and urban traffic and road capacity planning requirements of the knock-on consequences on the wider traffic network in the Leiden environment. Simultaneously, a discussion on governmental competences and responsibilities emerged between the city of Leiden, the Province of Zuid-Holland an national traffic policy agencies, fuelled by local discourses among the population of Leiden and the local city council. In this public and governmental decision making environment, the usefulness of dedicated tools and decision making procedures for assessing safety prove to run deficient. The eventual consequences for road safety in the city center were adressed by an Independent Safety Asessor ISA, on a detailed level of design, measuring the safety performance of the new designs by the standstill principle and Sustainable Safe criteria for road traffic. Simultaneously, the same railway systems was assessed compliant with heavy railweay certification standards by a second safety impact assessment committee, while a third committee assessed the safety of the railway systems as a part of the formal environmental impact assessment procedures. During the design of the system, various design alternatives were developed, each dealing with fluctuating requirements, generated by changes in the political debate on the usefullnes and feasibility of the routing of the track through the city center. Eventually, the project was cancelled due to the financial crisis and replaced by a road infrastructure, passing along the southern part of the city.

4. Conclusions

In general, integral safety is not a common approach in practice in the design and development of major infrastructural projects. Such an integral safety requires explicit attention towards both a substantive and a process component. The substantive and process components in such an approach cannot be disconnected from each other. A dedicated instrument in a single phase of development, focus on a single critical issue –such as hazardous goods on railways or fire in tunnels and underground stations- is indispensable, but not sufficient. Several preconditions have to be met: a cooperation between all levels of governance, a project safety organisation and safety management should be available, while several dedicated safety assessment tools should be applied, among which a Safety Impact Assessment. Such a tool has proven its value in the Spoorzone project, but does not yet has a legal basis for standard application in the Netherlands. Finally, external interferences with other industrila processes and production sites may have a major impact on the desired and required level of safety in a major project as demonstrated by the BASF experiences and the oncoming termination of the DSM facilities in Delft.

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Updating Selection of hazardous Equipment for the Land use planning around Seveso Sites in Walloon Region after the CLP Regulation

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Abstract

Currently, the method of selection of hazardous equipment in Wallonia explained in the Vade-Mecum of the Walloon Region, namely used for land use planning is based on risk phrases defined in the Dangerous Substances Directive (67/548/EEC) and the Dangerous Preparations Directive (1999/45/EC). However, since December 2010, the Classification, Labelling and Packaging (CLP) Regulation (1272/2008) must be used for dangerous substances and from June 2015 for mixtures. Later, this Regulation will completely replace the two old Directives which will be abrogated from June 2015. In this context, it seems justified to adapt the current selection method in prevision of the future abrogation of these Directives. Ideally, the new selection method should identify as hazardous, the same equipment than the current method but it is obvious.

Keywords: CLP Regulation, adaptation, selection, hazardous equipment.

1. Introduction

The article 12 of the Seveso II Directive (1996) [1] requests that Member States assure that their land use policy takes into account the need, in the long term, to maintain appropriate distances between establishments covered by the Directive and various areas. In this context, the Walloon approach selected for the risk assessment and the determination of the vulnerable zones is a probabilistic one with particular assumptions [2, 3]. Note that to develop and to apply this method since 2004, Walloon authorities are helped by the Major Risk Research Centre (MRRC) of the University of Mons as technical expert.
According to this method, after the necessary step consisting in collection of the information about the Seveso plant around which a vulnerable zone must be drawn, the next step is to select the equipment which will be included in the risk assessment.

It is crucial not to select too few equipment in order to have a right assessment of the risk level, and not to select too much equipment, which would lead to a high time-consuming process. In the frame of land use planning issue, only equipment contributing to a risk beyond the fence of the plant must be considered.

For this purpose, the Walloon Region developed a method of selection of equipment based on risk phrases defined in the Dangerous Substances Directive (67/548/EEC) [4] and the Dangerous Preparations Directive (1999/45/EC) [5]. Initially, this method was developed in order to allow industrialists to determine hazardous equipment for which they must prove that the risk is under control. For the land use planning this method was chosen with particular assumptions. Indeed, in practice in this context, we disregard some specific risks because the aim is to quantify the risk of accident for human beings beyond the fences of the plant.

However, since December 2010, the Classification, Labelling and Packaging (CLP) Regulation (1272/2008) [6] must be used for dangerous substances and from June 2015 for mixtures. Later, this Regulation will completely replace the two old Directives which will be abrogated from June 2015. The aim of the CLP Regulation is to harmonize the classification of hazardous substances and preparations with the international Regulation. In fact, this European Regulation permits to apply the majority of the SGH recommendations in Europe. However, the CLP Regulation introduces some specific rules for Members States of the European Union, in particular for environmental matters. The impact of this new Regulation is very important because it introduces some new classifications, some new methods of classification and it changes some criteria of classification.

In prevision of the future abrogation of the two Directives and of the publication of the Seveso III Directive [7] (update of the Seveso II Directive, especially to take into account the CLP Regulation), a study was begun by MRRC to define a new methodology of selection of hazardous equipment.

2. The current Method of Selection of hazardous Equipment

The philosophy of this method is to consider equipment as hazardous if it contains a quantity of hazardous substance higher than a threshold quantity depending on the properties of substance. The detail of this method is presented in the Vade-Mecum of the Walloon Region [8]. The first step consists in attribution of a threshold mass (Ma) for the considered substance. In some cases, this mass must be revised in function of the volatility (for liquids) or possibilities of domino effects. The Table 1 presents the threshold masses in the current version of the Vade-Mecum [8].

Categories of hazard in this table are in fact the same as those of the Seveso II Directive [1] (Except for irritating or harmful for human being category which is a category added by Walloon authorities). However, the definition of these categories is based on the “Risk phrases” of substances [4, 5] which will be replaced with the CLP Regulation.

Note that in this table, the column “non-Seveso” concerns risk phrases added (Compared with Seveso II Directive) by Walloon authorities to extent the scope to substances which could be hazardous.

Table I: Threshold mass M_a according to the hazardous properties of a substance and its physical state [8]

Properties of the substance		Risk phrases		Threshold mass M_a (kg)		
		Seveso	**Non-Seveso**	**Solid**	**Liquid**	**Gas**
1	Very toxic for human being	R26-R27-R28	R39	1.000	100	10
2	Toxic for human being	R23-R24-R25	R40-R41-R45 R46-R47-R48	10.000	1.000	100
3	Irritating or harmful for human being	-	R20-R21-R22 R36-R37	100.000	10.000	1.000
4	Oxidizing	R7-R8-R9	-	10.000	10.000	10.000
5	Explosive	R2	R5-R6	500	500	-
6	Very explosive	R3		500	500	-
7	Flammable	R10		-	10.000	-
8	Highly flammable	R17	R11-R15-R30	10.000	10.000	-
9	Extremely flammable	R12	-	-	10.000	1.000
10	Very toxic for environment	R50	-	100.000	10.000	1.000
11	Toxic for environment	R51-R53	R51-R54-R55 R56-R57-R58	100.000	10.000	1.000
12	Other dangers	R14-R15	R29	10.000	10.000	-

3. Proposition for updating of the Table of threshold Masses

Ideally, the new table of threshold masses must enable to identify as hazardous, the same equipment than currently. However, this is not obvious with the important changes introduced by the CLP Regulation. To construct this new table, Walloon authorities chose the same method than to construct the current version (based on the Seveso Directive II [1]).
However, the future Seveso III Directive adapted to the CLP Regulation is always in discussion. Nevertheless, a proposal [7] is available and the categories already defined should not be revised.
In February 2012, the Walloon Region prepared a first version of the new method of selection of hazardous equipment adapted to CLP Regulation. This proposition is presented at the Table II and was submitted to the MRRC.

3.1 Missing Hazards from the Proposal

Although the Seveso II and Seveso III categories are largely different, a comparison of the Table I and Table II was realized. In the CLP Regulation, it is important to note that this work was not easy because the new hazard statements are less segregative than hazard categories. So risk phrases (Dangerous substances/mixtures Directives) have to be compared with hazards categories (CLP Regulation).
To highlight missing hazards in the new proposal, we had to compare risk phrases selected by Walloon authorities with categories proposed in the new proposal and hazard statements associated to each categories.

This work permitted to identify some hazards missing from the proposal while equivalent risk phrases (according to annexe VII from CLP Regulation [6]) are currently selected:

- Carcinogens, category 1 (H350/H350i equivalent to R45/R49);
- Carcinogens, category 2 (H351 equivalent to R40);
- Germ cell mutagenicity, category 1 (H340 equivalent to R46);
- Serious eye damage/eye irritation, category 1 (H318 equivalent to R41);
- Serious eye damage/eye irritation, category 2 (H319 equivalent to R36);
- Substances or mixtures with hazard statement EUH006 (equivalent to R6);
- Substances or mixtures with hazard statement EUH070 (equivalent to R39-41);
- Reproductive toxicity, category 1 and 2 (H360x, H361x equivalent to R60/R61/R62/ R63 which replace the R47 risk phrase).

Otherwise, some environmental risk phrases (R54, R55, R56, R57 and R58) do not have an equivalent with the new classification system and so, the information about these hazards will disappear with the application of the CLP Regulation. Indeed, in environmental matters, only hazards for aquatic environment and for ozone layer are considered in the CLP Regulation.

3.2 Threshold Masses

For each category at the Table II, Walloon authorities proposed new threshold masses, according to the physical state of the substance. Compared with the current version of Vade-Mecum, we notice some changes. It should be noted that these choices could have great consequences on the selection of hazardous equipment and lead to select more or less equipment than with the current method and therefore lead to changes for the vulnerable zones and land use planning without real changes on Seveso sites. These changes are detailed below.

3.2.1 Section “H” – Health Hazards

Most of the threshold masses in the Table II is coherent with the current threshold masses table (Table I). However, we notice discordance for the category H3 (Specific target organ toxicity, category 1). Indeed, this category is associated to the hazard statement H370 (Causes damage to organs) equivalent to risk phrase R39 (Danger of very serious irreversible effects) according to annexe VII from CLP Regulation [6]. Actually, the risk phrase R39 corresponds to the category very toxic for which, the threshold masses are 1.000 kg for solids, 100 kg for liquids and 10 kg for gases. So, with the current proposal (Table II), Walloon authorities would be less severe with this category of substance because the threshold masses are ten times smaller

3.2.2 Section “P” – Physical Hazards

First of all, for the explosives class there are two categories with different threshold masses. Note that classification method for explosives has changed considerably with the CLP Regulation so, it was complicated to make comparisons and changes will be important for this type of substance whatever are threshold masses chosen. Moreover, Walloon authorities make now the choice of two different threshold masses and are more severe for the first category (100 kg against 500 kg). This lower threshold mass for the first category is justified by the fact that quantities of explosives lower than 500kg could have an important impact on vulnerable zones around Seveso sites.

Table II: Proposal of new threshold mass M_a from Walloon authorities, February 2012.

Categories		Threshold mass M_a (kg)		
Seveso	**Non-Seveso**	**Solid**	**Liquid**	**Gas**
Section H – Health hazards				
H1 Acute Toxic Cat.1		1.000	100	10
H2 Acute toxic - Cat.2 - Cat.3, dermal and inhalation	- Cat.3, ingestion	10.000	1.000	100
H' Acute Toxic	- Cat.4,	100.000	10.000	1.000
H3 Specific target organ toxicity, Single Exposure - STOT Cat.1		10.000	1.000	100
H'' specific target organ toxicity, Single Exposure	- STOT Cat.2	100.000	1.000	100
Section P – physical hazards				
P1a Explosives - Unstable explosives or - Explosives, Division 1.1, 1.2, 1.3, 1.5, 1.6 - Explosive according method A.14		100	100	-
P1b Explosives, Division 1.4		500	500	-
P2 Flammable gases, cat.1 or 2		-	-	100
P3a Flammable aerosols 'Extr. flammable' or 'flammable' containing flammable gases cat.1 or 2 or flammable liq. cat.1		10.000		
P3a Flammable aerosols 'Extr. flammable' or 'flammable' not containing flammable gases cat.1 or 2 or flammable liq. cat.1		100.000		
P4 Oxidizing Gases, Cat.1		-	-	10.000
P5a Flammable liquids - Cat. 1, or - Cat. 2 or 3 maintained at a temperature above their boiling point, or - With a flash point ≤ 60°C, maintained at a temperature above their boiling point		-	10.000	-
P5b Flammable liquids - Cat. 2 or 3 where particular processing conditions, such as high pressure or high temperature, may create major-accident hazards, or - With a flash point ≤ 60°C where particular processing conditions, such as high pressure or high temperature, may create major-accident hazards		-	10.000	-
P5c Flammable Liquids - Cat. 2 or 3 not covered by P5a and P5b		-	10.000	-
P6a Self-reactive and organic peroxides, type A or B		100	100	-

P6b Self-reactive and organic peroxides, type C, D, E or F		500	500	-
P7 Pyrophoric liquids and solids, Cat.1		1.000	1.000	-
P8 Oxidizing liquids and solids, Cat.1,2 or 3		10.000	1.000	-
Section E – environment hazards				
E1 Hazardous to the aquatic environment in cat. acute 1 or chronic 1		1.000 x LC_{50} for fishes (ppm)		
E1 Hazardous to the aquatic environment in cat. chronic 2	Cat. chronic 3 or 4	10.000 x LC_{50} for fishes (ppm)		
Section O – other hazards				
O1 Substances or mixtures with hazard statement EUH014		10.000	10.000	10.000
O2 Substances and mixtures which in contact with water emit flammable gases, Cat.1		10.000	10.000	10.000
O3 Substances or mixtures with hazard statement EUH029		10.000	1.000	100

We also note that the second category of explosives concerns only explosives from the division 1.4 which have the hazard statement H204 (Fire or projection hazard). But this classification was made taking into account the packaging of the substance. So, the CLP Regulation specifies explicitly that if an explosive from division 1.4 is unpacked or repacked, this substance is classed in the division 1.1 without new test.
The threshold mass for flammable gases is ten times lower than the current one. This will lead to increase the number of equipment selected. Furthermore, with the current threshold masses there is no difference between vessels containing gas or liquefied gas for the same substance.

As with the current version of selection of hazardous equipment, the new proposal fixes a same threshold quantity for all flammable liquids. However, we note that changes with the CLP Regulation are important for flammable liquids because, the flashpoint limit to be considered as flammable is now 60°C instead of 55°C.
The categories flammable aerosols are new and the Walloon authorities had to define thresholds quantities. In fact, the difference between these two categories is function of the type of propellant (flammable gases, flammable liquids, etc.). On this basis, Walloon authorities could have proposed a thresholds value similar to the propellant threshold but the choice to be less severe was done. To justify this choice, Walloon authorities argue the fact that risks fearing towards aerosols are lower because quantities of propellant are low. For the second aerosols category, Walloon authorities did the choice of threshold ten times less severe because hazards are lower.

By analogy with the current table of threshold masses (Table I), the threshold quantity for oxidizing gases was fixed at 10.000 kg. However, with the CLP Regulation, a substance will be now considered as oxidizing if the oxidising power is greater than 23,5% (instead 21% with dangerous substances/mixtures Directives). The threshold quantity for oxidizing solids is the same as for gases (as with the current Vade-Mecum) but it is fixed at 1.000 kg for liquids without obvious justification.

The categories P6a and P6b self-reactive and organic peroxides are new categories introduced with the CLP Regulation. These categories regroup on the one hand self-reactive substances formerly considered as explosives, flammables or not classed and on the other hand organic peroxides formerly considered as explosives or oxidizing. For these categories, Walloon authorities chose to fix same thresholds as for the two explosives categories. For the first one (P6a), this choice is logical because we find in this category all self-reactive and organic peroxides for which there is a risk of explosion. However, in the P6b category, risks of explosion are excluded so the threshold quantity (500 kg) seems to be very severe in comparison with thresholds quantities for flammable and oxidizing substances (10.000 kg). Moreover, we will find in this category, substances not formerly classed.

For the new category pyrophoric liquids and solids in which we find solids and liquids formerly classed as highly flammable (10.000 kg), the threshold quantity was fixed to 1.000 kg. So, the number of selected equipment should be higher.

3.2.3 Section “E” – Environment Hazards

The both categories E1 and E2 correspond respectively to very toxic and toxic for environment categories in the current version of Vade-Mecum [8]. In this proposal, Walloon authorities decided to define particularized thresholds for each substance to better take into account hazards for fish even at low concentration (10^{-4} to 10^{-5} ppm). So, the threshold quantity for this type of substance should be based on lethal concentration for fish (LC_{50}). The LC_{50} is defined as the concentration of a chemical in water that kills 50% of the test animals in a given time (usually ninety-six hours) for a single dose. To obtain the threshold we must multiply the LC_{50} by 1.000 for the E1 category and 10.000 for E2 category. However, we note that for substances which have a LC_{50} higher than 1 ppm for fish, there is a risk to be much less severe compared with the current version of the selection method of hazardous equipment (see Table I).

3.2.4 Section “O” – Other Hazards

Hazards covered by O1, O2 and O3 categories are the same as those covered by risk phrases R14, R15 and R29 in the other hazards categories of the current version of Vade-Mecum of Walloon Region. Formerly, the same threshold quantity (10.000 kg) was defined for these hazards. In the proposal, it is always the case for the O1 and O2 categories. However for the O3 category (Substances and mixtures which in contact with water emit flammable gases, Cat.1), the threshold quantity should differ in function of the physical state of the substance.

4. Impacts of the Application of the proposed Table

In addition to the remarks made here above, it is necessary to analyse the impact of the new proposed thresholds described above. The aim of this approach is to verify that no comment about the threshold masses table was forgotten and to measure the potential impact of noted changes in this proposal.

As far as land use planning is concerned, four conditions are required for a change in the selection of hazardous equipment which has an impact on the quantitative risk assessment:

1. There is a modification of the threshold mass for a substance in the new selection;
2. This change leads to select an equipment no selected with the current method or conversely;
3. An accident associated with this equipment must affect human beings beyond the fences of the site (otherwise, this event will not be modeled);
4. This event must significantly contribute to the global risk (otherwise, the changes will be imperceptible).

The potential impact of the current proposal of selection of hazardous equipment adapted to the CLP Regulation was tested on three Seveso sites in Wallonia. In this paper, the results for one of this site will be presented below. Moreover it should be remembered that the selection method can concerned other aspect than land use planning such as the safety report (Seveso II Directives) for example.
The industrial site presented here is a lower tier Seveso site specialised in paper production.

4.1 Substances

Twelve different hazardous substances are concerned for this plant. For each substance, we searched risk phrases, hazard statements, categories associated and threshold masses for the two selection methods (Table I and Table II).

Risk phrases are provided by the industrialist to authorities. Contrariwise, hazard statements are not yet provided so this information was obtained in priority from the table 3.2 of the CLP Regulation [6] (The list of harmonised classification and labelling of hazardous substances from Annex I to Directive 67/548/EEC is listed in the separate Volume IIIb), by direct equivalence for substances not present in this table or other sources if necessary.

The Table III lists all substances for which there is a change of the threshold mass in the new proposal. In this case, the impact of changes of threshold masses could be important because concerns 75% of hazardous substances on this Seveso plants. In some cases (Chlorine dioxide 1%, sodium bisulfate, light and heavy fuel), an application of the proposal (Table II) would lead to not select these substances. For others substances, thresholds quantities would be drastically lowered.

Table III: Substances concerned by changes noted in threshold masses by implementation of the method of selection of hazardous equipment proposed for the lower tier Seveso site studied.

Substance	*Old threshold mass*	New threshold mass	Justification of the change of threshold mass
Sodium chlorate (solid)	10.000 kg	600 kg	New threshold mass calculated in function LC_{50} for fishes (the lowest)

LPG (liquefied gas)	10.000 kg	100 kg	Threshold lowering and suppression of differentiation in function physical state in use
Propane (liquefied gas)	10.000 kg	100 kg	Threshold lowering and suppression of differentiation in function physical state in use
Chlorine dioxide 1% (liquid)	10.000 kg	-	Equivalent to the risk phrase R36 not taking into account
Hydrogen peroxide 50% (liquid)	10.000 kg	1.000 kg	Now, differentiation in function physical state for oxidizing
Sodium bisulfate (solid)	1.000 kg	-	Equivalent to the risk phrase R41 not taking into account
Light fuel	1.000 kg	-	Equivalent to the risk phrase R45 not taking into account
Heavy fuel	1.000 kg	-	Equivalent to the risk phrase R40 not taking into account
Hydrogen sulfide	10 kg	2 kg	New threshold mass calculated in function LC_{50} for fishes (the lowest)

At this subject, an important remark must be made about propane and LPG, both liquefied gases. Indeed, in the current version of the Vade-Mecum [8], the risk phrase associated is R12 (Extremely flammable) and so the threshold is chosen in function of the physical state of the substance in the equipment (10.000 kg for liquid or 1.000 kg for gas). So, for equipment containing liquefied propane, the threshold quantity is 10.000 kg. With the new classification and labelling Regulation, propane or LPG have the hazard statement H220 (Extremely flammable gas) and belong to the flammable gases category 1. So, these substances belong to the P2 category of the new selection table for which, Walloon authorities propose a threshold quantity only for gases (100 kg). Therefore, it is impossible to take into account the fact that these gases are liquefied.

4.2 Selected Equipment

As most of substances have their threshold masses considerably changed, it is logical that the selection of a high number of equipment is affected too. These changes are presented at the Table IV.

Table IV: Impact of the proposal of the Walloon Region for the selection of hazardous equipment adapted to the CLP Regulation.

Equipment	*Substance*	**Threshold mass Ma (kg)**		**Correction factor S**	**Corrected mass Mb (kg)**		**Real mass (kg)**	**Selection?**	
		Now	**Proposal**		**Now**	**Proposal**		**Now**	**Proposal**
Propane tanks (1&2)	Propane	1.000	100	3,7	2.692	100	1.500	*No*	*Yes*
MAGFUEL tank	Light fuel	1.000	-	1	1.000	-	13.050	*Yes*	*No*
Light fuel tank	Light fuel	1.000	-	1	1.000	-	26.100	*Yes*	*No*

IE9110 tank	Light fuel	1.000	-	1	1.000	-	6.960	*Yes*	*No*
Light fuel tray	Light fuel	1.000	-	1	1.000	-	2.610	*Yes*	*No*
Heavy fuel tanks (N&S)	Heavy fuel	1.000	-	1	1.000	-	1.600	*Yes*	*No*
Heavy fuel tank inter	Heavy fuel	1.000	-	1	1.000	-	30.000	*Yes*	*No*
Heavy fuel tray	Heavy fuel	1.000	-	1	1.000	-	10.000	*Yes*	*No*
Caustification	Heavy fuel	1.000	-	1	1.000	-	5.000	*Yes*	*No*
Spain Babcock	Heavy fuel	1.000	-	1	1.000	-	35.000	*Yes*	*No*
Chlorine dioxide stock north	Chlorine dioxide 1%	10.000	-	1,1	9.120	-	300.000	*Yes*	*No*
Chlorine dioxide stock south	Chlorine dioxide 1%	10.000	-	1,1	9.120	-	65.000	*Yes*	*No*

4.3 Land use planning

During the previous land use planning study concerning this plant, fuels (light and heavy) were not considered because associated risks are low and do not generate effects beyond the fences of the site. Despite this, we can note a visible impact of the new proposal on curves obtained by comparing the Figure 1 representing the original curves of the global risk generated by the Seveso plant with the current method of selection of hazardous equipment and the Figure 2 representing the curves of global risk generated following the new proposal.

Indeed, we note that the cyan curve (individual risk of 10^{-5}/year) underwent a slight modification due to suppression of chlorine dioxide stock hazards. The red curve (individual risk of 10^{-6}/year) greatly expanded in south due to the addition of propane tanks hazards. These two figures clearly show that risk curves used for land use planning could be modified by the application of the proposal of selection method adapted to CLP Regulation. In this case, modifications only concern the industrial zone (in purple) and so, the residential zone (in red and white) is not impacted by the curves modification having decisional interest for land use planning in Wallonia (individual risk higher than 10^{-6}/year). However, it is likely that curves modification on other Seveso plants may have more impacts.

5. Elaboration of a new Proposal

All the remarks presented here highlighted the necessity to modify the consideration of some hazards or the definition of some threshold masses in order to limit the inevitable impacts of the application of the new method of selection of hazardous equipment on risk curves already defined. However, these changes could not be totally avoided because for some hazards, threshold values or classification method are fundamentally changed.
Following this work the Walloon authorities, in May 2012, respond at most of remarks and critics presented here above. An extract of the new threshold masses table giving all modifications done is presented at the Table V.

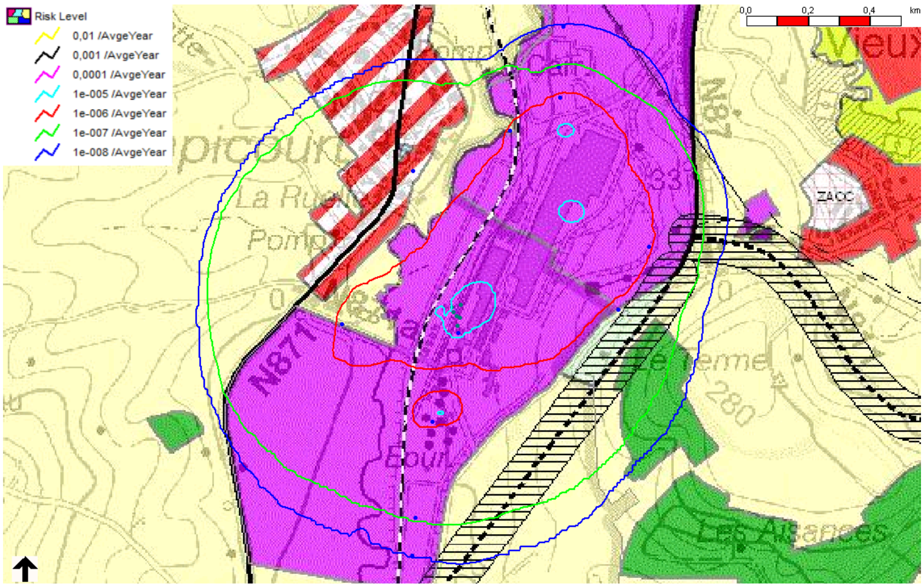

Figure 1. Original curves of the global risk generated by the Seveso plant with the current method of selection of hazardous equipment

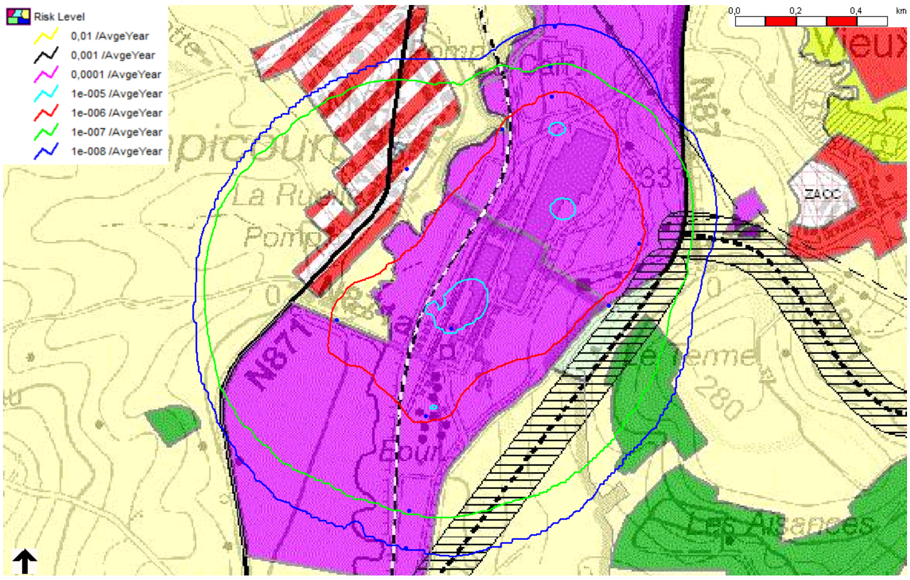

Figure 2. Curves of global risk generated following the new proposal

Table V: Extract of the proposal of new threshold mass M_a from Walloon authorities, May 2012.

Categories		**Threshold mass M_a (kg)**		
Seveso	**Non-Seveso**	**Solid**	**Liquid**	**Gas**
Section H – Health hazards				
H2 Acute toxic - Cat.2 - Cat.3, inhalation	- Acute toxic Cat.3, **dermal** and ingestion - **Germ cell mutagenicity, cat.1** - **Carcinogens, cat.1 and 2** - **Reproductive toxicity, cat.1 and 2**	10.000	1.000	100
H’	- Acute Toxic Cat.4 - **Serious eye damage/eye irritation, cat.1**	100.000	10.000	1.000
H’’	- Specific target organ toxicity, Single Exposure - STOT Cat.2 - **Serious eye damage/eye irritation, cat.2**	100.000	1.000	100
Section P – physical hazards				
P2 Flammable gases, cat.1 and 2		-	-	**1.000**
P8 Oxidizing liquids and solids, Cat.1,2 or 3		10.000	**10.000**	-
Section E – environment hazards				
E1 Hazardous to the aquatic environment in cat. acute 1 or chronic 1		1.000 x LC_{50} for fishes (ppm) **if LC_{50} < 1. Otherwise 1.000.**		
E1 Hazardous to the aquatic environment in cat. chronic 2	Cat. chronic 3 or 4	10.000 x LC_{50} for fishes (ppm) **if LC_{50} < 1. Otherwise 10.000.**		

Although this new proposal takes into account most of the critics made on previous version of table of threshold masses adapted to the CLP Regulation, some remarks are still applicable because rejected by Walloon authorities. For example, the hazard statement EUH006 is still not taken into account. Likewise, the Walloon Region maintains his wish to be more or less severe for some categories of substances.

6. Conclusion

Without any doubt, to take the CLP Regulation into account, it is necessary to adapt the method of selection of hazardous equipment used by the Walloon Region for land use planning. However, this adaptation is not easy.
This paper presents and criticizes a proposal of the Walloon authorities. Practically speaking, we were interested by two aspects, on the one hand the kind of hazards considered and on the other hand the threshold masses associated to each category. Moreover, to illustrate our analysis, we applied the proposal to some Seveso plant.
By this work, it was demonstrated that an implementation of the first version of the new proposal for the selection of hazardous equipment could have a great impact for

industrialists. Indeed, it appeared that the number of hazardous substances concerned in a plant could be very important (75% in our example) leading to modifications of selected equipment. Moreover, in the case of lower tier Seveso site, risks curves used for land use planning could be also impacted by the application of the new threshold masses proposed by Walloon authorities.

Thanks to remarks highlighted in this work, the Walloon Region authorities elaborate a new version of the method of selection of hazardous equipment. However, despite that most of the critics were considered, there are some remarks not taken into account by Walloon authorities. In most cases, these differences result from the will to be more or less severe for some categories of substances.

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Land use Planning around Major Risk Installations: from EC Directives to Local Regulations in Italy

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Abstract

This paper offers some reflections regarding the application of regional and provincial laws concerning major industrial risks and urban and land use planning, and focuses on their application problems and capabilities with reference to some practical cases. The European Directive "Seveso 2" was implemented in Italy with two national laws, and in Piedmont they were enforced with the "Guide Lines for the assessment of industrial risk in land use planning". According to the Guide lines, the municipalities had to introduce into their urban and land use planning instruments new criteria for the areas around Seveso plants. The application of the Guide lines requires a multidisciplinary approach but Local authorities are often not sufficiently prepared for this kind of multilevel analysis, because they don't have the human or economic resources or even the technical abilities necessary to conduct it. As a result, they can underestimate the importance of a correct urban and land planning in the areas around major risk installations...

Application of the National and Regional Seveso normative

The 334/1999 - Legislative Decree on the implementation of 96/82/EC for the control of major accident hazards involving dangerous substances, entered into force in October 1999. This decree, which represents the adoption of the Seveso 2 European Directive, establishes, for the very first time, the adoption of minimum safety requirements concerning land use planning for those areas in which there are major risk industrial installations. The adoption of the 09/05/2001 - Ministerial Decree on the minimum requirements for land-planning and urban-planning in areas in the vicinity of major risks installations, introduced important novelties: provinces and municipalities are now obliged to update their urban planning instruments (*Piani di Coordinamento Provinciali* and *Piani Regolatori Comunali* – Provincial

Coordination Plans and City Plans) to 334/1999 Legislative Decree, and to draw up a Technical Document which, in relation to the location of the Seveso installations, identifies and disciplines the areas that have to be subjected to specific regulations. In order to draw up the Technical Document, also known as RIR – *Rischio di Incidente Rilevante* (Major Risk Accident), it is necessary to conduct a detailed analysis of the territorial and environmental vulnerability of the land, dividing urban areas and buildings into vulnerability classes in relation to the land building index and to the number of people that are generally present, as foreseen by the 09/05/2001 - Ministerial Decree.

According to what has been established in the 09/05/2001 - Ministerial Decree, the coordination between the regulations that derive from 334/1999 Legislative Decree and the urban and land use planning and environmental protection instruments is the duty of the regions, which in turn have to arrange the planning procedures between all the territorial organisations that are involved. In Piedmont was approved on 26 July 2010 the 17/377 - Regional decree and Guide lines for the assessment of industrial risk in land use planning: Strategic Environmental Assessment and Technical Report on Large Industrial Risks.

The 17/377 - Regional decree and Guide lines offers detailed information on the contents and ways of drawing up the RIR Technical Document, but the municipality administrations point out some difficulties about it, due to both a lack of financial and human resources and to an insufficient scientific and technological preparation relative to the required expertise. The drawing up of the document is in fact based on environmental and land analyses, but also on evaluations of a chemical engineering nature.

Another problem related to the drawing up of the RIR Technical Document pertains to the particular physiognomy of the built up landscape in Italy: the entire national territory is in fact characterised by towns and urban agglomerates with high housing densities, which, in many cases, have grown without any control and without the use of Town Planning instruments. The situation is further complicated in hilly areas, or at the foot of mountains, where the land available for urban development is very limited and where a jumble of residential and industrial zones has been created, with consequent problems concerning the protection of the areas surrounding the industrial plants.

In a similar context, the drawing up of the RIR Technical Document appears more and more necessary in order to guarantee the safety of the citizens and the safeguarding of the environment as well as of the historical-architectonic patrimony: with this document, the municipalities can obtain in depth and updated knowledge concerning the environmental and territorial receptors, but also about the elements of pressure that are present throughout the municipality territory, and they can then arrange planning measures for the areas surrounding the Seveso activities, in this way offering controlled and safe development and growth conditions to both industries and other urban functions.

Drawing up of the RIR Technical Document (Regional Guidelines)

According to the Regional Guidelines, the RIR Technical Document should be drawn up by municipalities with a Seveso plant on their territory and by municipalities not housing a Seveso company, but interested by the damage of a possible accident occurring in a company that is hosted by a nearby municipality. The drawing up of RIR has three different phases: 1) Data collection of the production activities, and of the territorial and environmental receptors; 2) Evaluation of the territorial and environmental compatibility; 3) Planning.

Data collection

The first stage of the RIR Technical Document foresees an extensive data collection throughout the entire municipality territory, and it involves very different types of investigations: this ranges from information of a naturalistic type to other of an urban-architectonic type, and even of a purely engineering type. A constant interaction between the various municipality offices is however necessary (above all between the Technical Office and the Environmental Office), and a great capacity to summarise and document the collected data is essential.
The Guidelines established that all the non-craftsman type productions throughout the municipality territory should be identified and characterised. Safety Reports and Notifications can be used for the characterisation of Seveso activities, while it is necessary to prepare a questionnaire for all the other activities in order to understand which hazardous substances are detained, the storage methodology, the presence of high pressure/high temperature processes or ionizing radiation, the prevention and protection measures adopted, but also the transport modalities of the hazardous goods. The collection of the data relative to non Seveso activities can create some problems as the companies are under no obligation to denounce the substances they use in their manufacturing processes.
The data collection stage is also conducted in relation to the territorial and environmental receptors; as far as the former are concerned, all the areas, buildings and infrastructures that are characterised by a significant presence of people, and which in some way constitute sensitive objectives in the case of accidental events, are considered vulnerable territorial elements. According to the 09/05/2001 – Ministerial Decree and to the 17-377 Regional decree and Guide lines, vulnerable elements should be divided into 6 categories (from A to F, ref. Table 1) on the basis of the number of people that are present, the attendance frequency and the mobility capacity of the people.
As far as environmental vulnerable elements are concerned, both the 09/05/2001 – Ministerial Decree and the 17-377 Regional decree and Guide lines define a series of factors that should be considered, including protected natural areas, areas suffering from hydrogeological instability, historical-environmental-landscape areas of high value, zones with high vulnerability aquifers, etc. All the environmental receptors identified as vulnerable throughout the municipality territory should be grouped, on the basis of the Guidelines, into two categories: very high environmental vulnerability elements and relevant environmental vulnerability elements.

The territorial and environmental compatibility evaluation

A territorial and environmental compatibility analysis requires that the data from the industries are crossed with those relative to the territorial and environmental shape, and the interaction between industrial activities and urban functions, the road conditions and the environmental characteristics of the examined area are evaluated case by case. Very different disciplines and professional expertise come into play at this stage: a good capacity to analyse and read the territory and the ecosystems is necessary, together with the capability of interpreting the mapping of the consequences of accidental events, and the potential hazards connected to the substances stored in the industrial activities.

As far as territorial compatibility is concerned, the 17-377 Regional decree and Guide lines offer a detailed definition of each step of the evaluation process: the damage areas for Seveso activities defined in the Safety Reports or in notifications should be superimposed onto the territorial area category identified during the previous data collection stage. The regulations define the compatibility cases on the basis of the category of the effects of the accidental event - Elevated Lethality, Start of Lethality, Irreversible Damage and Reversible Damage – and of the probability of occurrence.

For example, for an "unlikely event (10^{-4}> p $\geq 10^{-6}$), in the "Reversible Damage" zone, the BCDE and F categories are considered compatible; for a "probable" event in the "Reversible Damage" zone, only structures classified as DE or F can be present (see Figure 1).

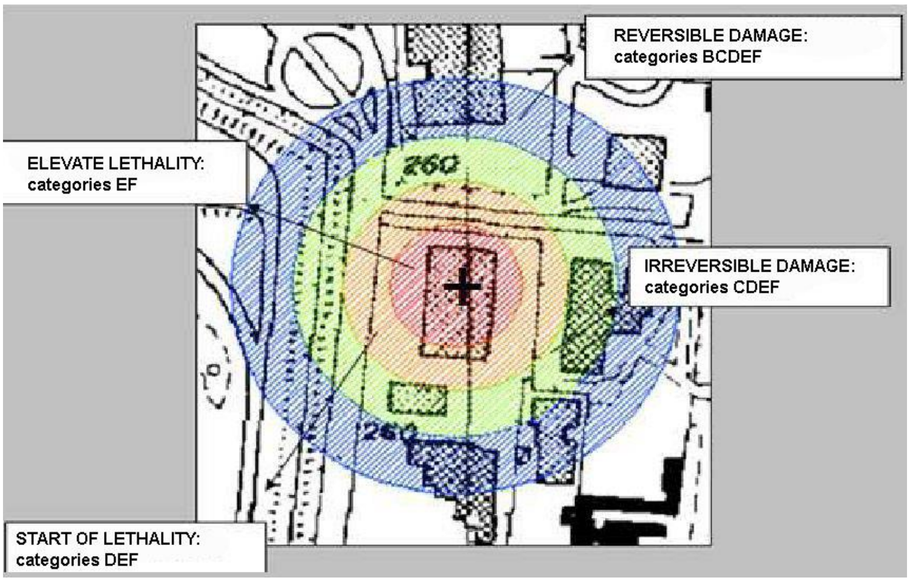

Figure 1: Example of the compatibility of the effects of an accidental event with the territorial categories

As far as non-Seveso activities are concerned, a territorial criticality assessment is performed and circular areas are plotted that indicate the potential damage connected to the type of substance that is stored. A ranking of "very critical/critical/not critical" is assigned to each activity, on the basis of the area and/or point vulnerable territorial elements that are inside the plotted areas. For example, if the company stores toxic substances, and territorial elements that have been classified as "A" fall into the potential damage circles, the company will be evaluated as "Very critical"; however, this criticality evaluation can be decreased on the basis of the prevention and protection measures the company adopts.

The approach is more complicated as far as environmental compatibility is concerned: the Guidelines only offer some examples of incompatibility and specify that the adoption of prevention and protection measures by the company can reduce the danger for environmental receptors. Since the actual criticality of an industrial activity depends on a series of variables – the type of substance stored, the foreseen accidental events (energetic-toxic with environmental effects), and the vulnerable environmental elements that are present – the Guidelines ask for a case by case environmental compatibility evaluation. It is obvious that the reliability of the analyses depends on both the accuracy of the previously collected environmental information and on the capacity of interaction of the different expertise at play: in order to evaluate the effects of an industry on the territory, it is necessary to understand how the specific accidental event acts over a vast range of possible environmental conditions (for example, the spilling of certain substances can cause a certain effect on cultivation A, but not on cultivation B).

Planning

The planning stage impose the restraints pertaining to the areas surrounding the activities and can request the adoption of specific prevention and protection measures for individual companies in order to mitigate the hazardous territorial and/or environmental situation. In this case, a further effort is requested of those who draw up the RIR Technical Document, in that they have to set up the rules that will then be transferred and harmonised inside the Technical Actuation Rules of the Municipality Regulation Plans, and this inevitably leads to a series of difficulties connected to the previous planning previsions for the areas surrounding the companies, and to limitations of the building possibilities that are often necessary to introduce.

The planning stage starts with the definition of two concentric areas of respect, named "Exclusion area" and "Observation area" for the Seveso activities and for the other activities, whenever judged "critical" or "very critical". The two areas are drawn up starting from the border of the plant and have sizes that depend on the level of criticality that has been assigned. The exclusion area can be of 100, 200 or 300 m, depending on the case, while the observation area must extend to at least 500 m from the plant boundary. The adoption of management measures relative to the control of the traffic conditions, in the case of an accident, should above all be foreseen inside the observation area, while more restrictive measures, including the prohibition of carrying out modifications that involve an increase in the anthropic load, and the prohibition of introducing new urban functions that fall into categories A and B, must be introduced inside the exclusion area. However, a careful evaluation of the measures that should be adapted to safeguard the environment and the already existing buildings in order to protect these buildings and activities is necessary case by case.

Drawing up of the RIR Technical Document (Provincia di Torino Guidelines)

The Provincia di Torino is the only province that has so far elaborated a Variation of the Territorial Coordination Plan in order to update it to the prescriptions of the 09/05/2001 – Ministerial Decree. The so-called "Seveso Version" of the Plan was approved by the Regione Piemonte only on 12 October 2010.
The indications of the Seveso Version to the Provincial Coordination Plan are analogous to those of the 17-377 Regional decree and Guide lines (see paragraph 2); however, the Province introduced further obligations for plant managers, which are

not considered in the Regional Regulations. The managers in fact have to draw up a Territorial and Environmental Compatibility Report for new installations of Seveso factories, or for changes to already existing Seveso factories that could involve an increases in the risk of accidental events. These reports should be sent to the municipality offices, which will then decide on the request on the basis of the actual compatibility of the intervention. As far as territorial compatibility is concerned, the factory manager should make a classification, according to the categories outlined in the 09/05/2001 – Ministerial Decree, of all the areas that fall into the observation area of the activities (500 m); the Municipality will then verify whether either categories A or B fall into the exclusion area, and will determine whether the new installation or modification is feasible or not.

Case study

This examined case study refers to the drawing up of the RIR Technical Document for the Municipality of Omegna in the Province of Verbano Cusio Ossola; this experience proved to be particularly interesting, both because it was one of the first application cases of the application of the new Regional Guidelines in Piedmont, and because the analysis zone presented some particular features which certainly made the drawing up of the RIR Technical Document more complex - but also more interesting.

The town of Omegna looks onto the northern edge of the Orta lake, and is a typical area at the foot of the mountains, characterised by the first signs of the foothills of the mountain relief of the Ossola and Strona Valleys; urban growth has always been concentrated in the areas at the end of the valleys, between Lake Orta and Lake Maggiore, and over the years a connection has formed between the bordering municipalities of Casale Corte Cerro and Gravellona Toce. During the twentieth century, many municipalities in the zone, including Omegna, underwent a rapid development in production activities, above all connected to the taps and fittings sector, and the industries developed inside town centres without any regulation, with a consequent series of inconveniences connected above all to the problem of pollution. In spite of the transformations that these territories have undergone over the last century, the zone still has a very elevated landscape value, due to the presence of the lakes. In recent years, the beauty of the landscape and architecture in the zone has encouraged touristic fruition.

As far as Omegna is concerned, the duty of drawing up the RIR Technical Document fell to the Municipality, as there are two Seveso activities on its lands: the first is a galvanic slime depurator, while the second is a galvanic activity. According to what has been established in the 31-286 - Regional Decree of 5 July 2010, the Administration could not approve variations that would lead to modifications in the areas at risk to Seveso activities (*areas of direct impact from an accident originating from production activities)*, until the RIR Technical Document had been approved. Since the Omegna industries are often located within residential or commercial areas, or are surrounded by disused areas whose reconversion is foreseen, the Municipality had an urgent need to understand where the areas of risk were in order to be able to go ahead with the normal planning activities.

The drawing up of the RIR Technical Document started with the data collection phase, which required a great deal of time to find and subsequently organise the data;

the research activities were conducted both by consultants and by the Municipality offices, and these activities require a continuous feedback and monitoring of the information. As far as the production activities were concerned, the consultants identified the Seveso and sub-threshold Seveso activities on the basis of the regional databanks (named SIAR), while the other potentially hazardous activities were identified on the basis of the ATECO codes recorded in the Chamber of Commerce lists; they were arranged according to their sub-threshold and the other activities in the questionnaire, which was sent out and also collected by the Municipality. The Municipality offices also dealt with collecting the data relative to the presence and frequency of shopping centres, churches, hospitals, schools and nursery schools, while the data relative to the environmental matrices were deduced by the consultants on the basis of regional and provincial cartography.

Once this phase was finished, the companies and environmental vulnerability elements were characterised and after this, a verification of environmental and territorial compatibility was conducted. This latter activity pointed out possible critical situations for 7 companies in the Omegna territory. The exclusion and observation areas were identified for these companies, on the basis of the degree of criticality that had been assigned, and the consequent planning actions were agreed upon: since many of these activities are located in the vicinity of the edge of the Strona Torrent, in areas of very high environmental vulnerability, the exclusion areas were 200 m. The companies located close to the stream are reported in the Figure 2, with the relative exclusion and observation areas.

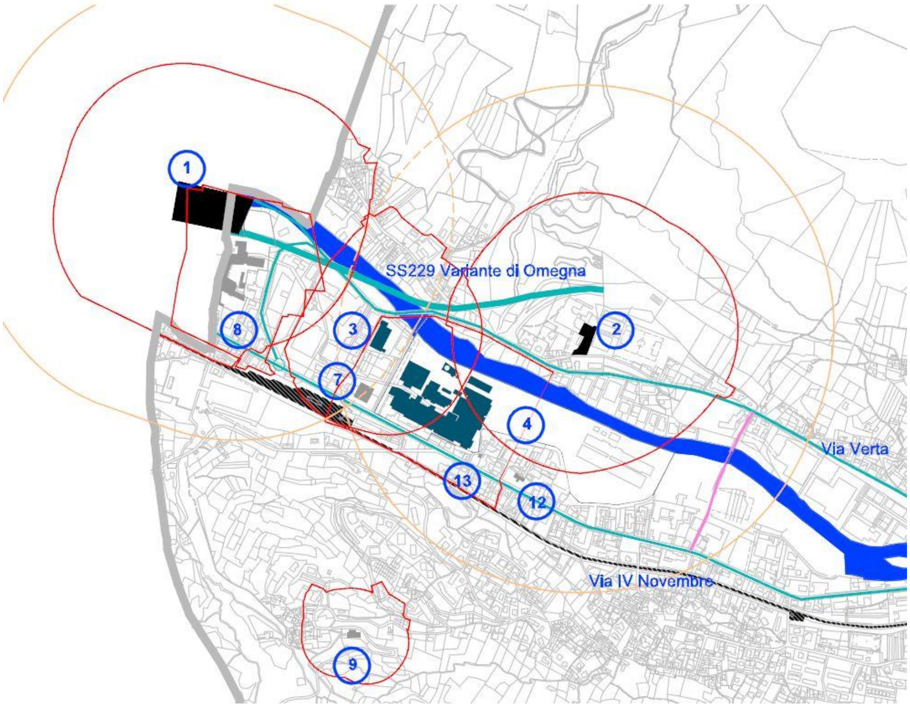

Figure 2: The exclusion and observation areas of the Omegna industries

Some difficulties were encountered by the Administration and the technicians, during the execution of the various phases concerning the comprehension of the necessity of an analysis extended to the entire Municipality, rather than just around the Seveso activities. As foreseen in the Regional Guidelines, the territorial and environmental vulnerability categories should in fact be defined for the entire territory of the municipality, and not only the effects of the Seveso activities were evaluated, but also those of the other production activities: this led to a multiplication of the areas subjected to constraints (the exclusion areas), which in fact limited the potential building in many areas of the Municipality. However, investigations extended to the entire territory of a municipality allows the administration offices to have detailed and complete knowledge of the environmental and territorial receptors present throughout the entire territory that can easily be updated. This knowledge is useful to establish criteria for new installations and modifications of Seveso activities for production areas or harmful activities in general. Furthermore, the inclusion and analysis of non Seveso activities allows the municipalities to collect more detailed information on industries which, although often storing large quantities of hazardous substances, are not subject to any controls as they do not fall into the categories mentioned in the 334/1999 Legislative Decree.

Another problem was encountered during the translation phase of the contents of the RIR Technical Document into the urban regulations: the Regional laws in fact impose that the RIR Technical Document should be contained in a structural version, which should be subjected to approval by the Region, but the insertion of the specific technical dispositions regarding the Seveso activities and the constraints concerning the exclusion areas in the regulations of the Regulation Plan is not so easy. The Guidelines generically prescribe that anything that falls into categories A and B should not be constructed in the exclusion areas, and that no interventions that would involve increases in the anthropic load should be activated: however, the Technical Offices of the municipality have to define precise urbanistic parameters with which to outline the building possibilities and the distinction of use in the exclusion areas, and this can in fact be a contradiction of the very same previsions of the PRG in force or even of the National and regional laws. However, this translation phase of the dispositions of the RIR Technical Document of the plan regulations was followed very closely by the Region and by the Province during the planning activities: the informal meetings, but above all the planning conferences in which the proposing Municipality participated together with the two organisations, helped to clearly define the modalities of drawing up the final RIR Technical Document and the structural variations.

Conclusions

On the basis of the work experience that have been undertaken, it is possible to state that the RIR Technical Document is a fundamental instrument for the planning of the territory and to obtain knowledge of the territory itself, but also that the levels of close examination and specificity requested in the investigations are often not part of the expertise of the municipality offices, and this makes drawing up the document very difficult for the municipality offices themselves. The same problem has been encountered in the drawing up of the Compatibility reports, a duty which falls to the managers of the factories and which are foreseen in the Guidelines of the Seveso

Variation to the Territorial Coordination Plane of the Province of Turin. It should be pointed out that it would surely be of help for the Piedmont municipalities if all the provinces were to update their Territorial Coordination Plans to the 09/05/2001 – Ministerial Decree and to the 17-377 Regional decree and Guide lines; this superordinated urban instrument has a vast and strategic baggage of information at its disposal which, at a municipality level, would not be possible, and it constitutes an important point of reference for the drawing up of all the RIR Technical Documents of a certain Province.

Moreover, although it is important to safeguard the health of citizens and the environment, it is also in the interest of the local communities and of the region that these productions should continue. The regions, provinces and municipalities should therefore demonstrate a sufficient level of sensitivity and be able to mediate between the requirements of the production activities and those of the environment, which, at the same time, are the conditions that are necessary for sustainable development: the planning phase of the RIR Technical Document is also certainly the most suitable occasion to sustain the requests of the productive world, in this way drawing up regulation elaborations that are as fair as possible for everybody concerned.

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Incidents learned-Lessons Sharing in French Oil Industry

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Abstract

The aim of this presentation is to describe the various ways used by current oil industry operated in France to share incidents lessons learned. There are several ways, developing more diversified approaches as long as the major oil companies are splitting (sales or shutdown) all or part of their activities in numerous smaller companies. These new smaller actors are not necessarily sized to handle this ‘"Experience Return" (REX in French, standing for Retour d'Expérience). Therefore, they contract REX, explicitly or implicitly, to inter professional bodies such as: GESIP founded in 1953; BARPI, a French government body in charge of populating an incident database called ARIA; UFIP gathering several events related to REX, in close relation with UIC; other bodies (such as AFIAP, ImdR) participate also partially to this activity.

1. Introduction

1.1. Why do we need REX ?

Basically, REX efforts are motivated to avoid reoccurrence of a given past incident (in a given unit). It is easily enlarged to other similar or quasi-similar units or processes. In these cases, management must ask himself the question: does this incident could have been occurred in my unit? REX is requested by EU Seveso directives. It is also a great help for risk assessments and scenario exercises, which are also requested by EU Seveso directives through the Safety Management System (SMS). It should be noted that non Seveso sites can also find great profits in these activities. In some cases, unknown phenomena can be discovered through exhaustive root causes analyses, which will be an other reason to share largely this type of discovery**.**

Lastly, while the REX approach looks relevant for major incidents, it should be pinpointed that it has also credits for "weak signals", from which management should select what is frequently called "high potential near miss".

1.2. How do we do REX ?

There are various ways to present an incident analysis (fish bones, root cause, fault tree, Taproot or equivalent model, etc.). All of them request however to firstly establish a non ambiguous factual chronology of the events, whatever committed or involved interests are. Legal potential consequences should not jeopardize this process**.**

The following sections describe some of REX sharing ways currently existing and used in France**.**

2. Main vectors dealing with REX

Some large international oil companies may have developed internally their own incident databases. However, they can hardly be shared with other companies for proprietary and computer hardware reasons. In addition, even the biggest company is … too small to cope with all the type of risks, even within its core activity. This is why several shared tools have been implemented within various NOIA's.

GESIP

GESIP association was founded in 1953. It holds a quarterly meeting focused on incidents or accidents shared by its various members. Presentations are available on the internet GESIP's site freely for association members (ca 60 oil, gas, chemicals companies or bodies). It has handled in the past a database called Victor with several thousand reported incidents, which can still be consulted even if it is no more populated. GESIP publishes various technical reports on safety issues. For instance, a report was dedicated to the ZIP effect on storage tanks review over the last 70 years.

BARPI

The BARPI is a French government body in charge of populating an incident database called ARIA. It has gathered more than 40 000 incidents, national and international, the most important of them being deeply investigated and analyzed, including root causes when available (sometimes several years after the incident). Every year, BARPI publishes an inventory of technological accidents for Seveso sites, dams, road & rail transportation, gas and rocks activities. For 2012, BARPI director emphasized on "enrich and add value to the experience return" with some statistics and root causes analysises.
BARPI periodically issues monographies on a specific thematic. Last one was related to the failure of safety captors/instruments as a root cause of incident. A symposium is held periodically called IMPEL at the European level. A CD is then issued with many incidents reports on a given topic (e g quick opening of storage tank).

UFIP

UFIP is responsible for gathering significant materials/metallurgical incidents reported by refineries inspection sections. Commonly with Chemical equivalent body, the database is now rich of more than 115 leaflets. Every single year, UFIP organizes a two days meeting in order to sharing significant incidents and lessons learned: the 26th edition occurred in Dunkirk on last June 27/28, 2012 with French administration partial participation. Two booklets of ca 200 pages have been distributed to the 55 participants. One of the most interesting item was related to an incident which occurred in Anacortes (Tesoro US refinery) where 7 people were killed, nearby an exchanger which suddenly exploded. Following this tragedy, the referenced Nelson's curves, used for more than half a century, on hydrogen attack on carbon steel have been reviewed to increase the safety margin on operating pressure/temperature. During their quarterly meeting, national inspectors meeting reviewed also the best strategy to adopt with the administration.

New technical documents are then issued and officially recognized by the administration (ex: how to control valves quality, following a major quality incident on Chinese imported defective valves in dangerous process in 2009). Every year, UFIP holds two safety meetings for national unions representatives. One of it is related to incidents sharing (last March 2012, two incidents were analysed: difficulties in firefighting in Singapore refinery in September 2011; furnace explosion in Donges French refinery and associated action plan). Every quarter, the French SHE coordinators meeting organized by UFIP reviews significant incidents and requested action plan in the national level if any.

IFPEN

IFPEN hosts the inspection incident database mentioned here above.

Pipelines specific case

Following a major spill on August 7, 2009 in a crude pipe in south of France (5000 tons released above the ground), a research program has been funded to assess and determine rigorously the root causes of such a failure (overall costs evaluated to more than 50 M€). All potential mechanisms have been in depth understood and presented in a new yearly meeting to the French administration and to all the pipeline operators in France. In addition, a new exhaustive incident database has been demanded by administration, covering the 5000 kms of oils/chemicals pipes, and the 50 000 kms of gas transportation pipes. It is now fully operational within GESIP supervision. More detailed than the EEGIP European consolidated database, it is therefore complementary to it. French regulations have been reinforced to control and monitor such pipes submitted to "pressure swing cycle" due to process requests. As far as France is concerned, they must be inspected every 6 years (vs 10 years previously). An other significant incident occurred in a gasoline pipe on May the 1st, 2010 within an underground storage area. Deep analyses led to a plan of changing several old pipes for a current cost in the range of 10 to 20 M€.

AFIAP

AFIAP is a professional body which edits two reference books called CODRES level 1 (for construction of new tanks) and level 2 (for operation and maintenance of tanks) and also a guide for Acoustic Emission. Depending upon structured experience feedback, those three guides are regularly updated to take into account the real experiences of various operators, engineering and contractors companies, both positive and negative. Meetings are regularly held to manage efficiently the required changes in a timely manner, and in close relation with normative body.

IMdR

Last May 31st, 2012, IMdR organized a full day on "Interests and values of technical experience feedback". Cross functional approach was used, with people from nuclear, chemical, transportation, automobile, aeronautic and space industries. Periodic meetings (several per quarter) are organized on this multiple industries approach relative to risk management for both safety and security concerns.

3 Conclusion

Input for Hazard study

To perform the "hazard study" requested by the French administration, number of failures probability figures are needed. Even if some specific specialized international data bases already exist, any change from them can be argued and accepted base on the use of French REX data bases.

These hazards studies are a key entry point for complying with the French legislation called PPRT (*) around large Seveso sites. This is why it is important to get figure as reliable as possible regarding the various failures probability.
(*) PPRT have been created after the AZF catastrophic explosion in Toulouse on September 21st, 2001. It is a plan defining zones around Seveso sites where it is forbidden to build/live and/ or where reinforcement of existing buildings is mandatory. It is anticipated to cost to all the implied parties up to around 3 B€.

Example for distribution/retail activities

An example can be given on the probability of being fired while feeding a car with gasoline with a mobile phone in service. It has been reported by US Federal government that approximately 200 cases of persons have been lighted while filling their cars with petrol over 10 years (1991-2000) for 17 billions of filling cars acts. Induced probability is then computed to be around 10 ** - 9 per year. Adaptation of this figure to the French case requests to recognize that gasoline sales are roughly 5 times less than diesel which cannot be ignited easily, due the higher flash point (55 to 60 °C vs - 45 °C). Moreover, the possibility to block open the oil gun into the vehicule tank is prohibited in France, while commonly used in the US. This drastically reduced the similar risk in France. These two factors allowed us to estimate this risk 10 times below the US one, to 10**-10. In addition, the 200 US reported events covered all sort of incidents (portable tanks filling, smoking, etc..). The mobile phone as a root cause is probably 10 times or more below this value. This is why no big research program is justified regarding the mitigation of this risk. A simple "warning leaflet" posted on gasoil dispensers is largely enough… essentially to cover the residual legal risk. A US federal program tried unsuccessfully to ignite gasoline vapor by a mobile phone in a normalized test. It has been then induced that the very few events, if any, of gasoline ignition with mobile is likely related to malfunctioning mobile (such as opened battery).

Various ways, not a single answer

In term of industrial risk regulation, debates occurred regularly between the so called "determinist" and / or "probabilistic" approaches, and also between "lumpsum" and "integral full computing" approaches. To help to discriminate the best, or most likely the less worst, answers, usage of incidents database appears to be powerful tools, complementary of basic cost/benefits approaches.

A virtuous cycle to progress

A traditional approach of safety improvement shows interrelations between equipment integrity, safety management system and behavior based system, in addition to the strict compliance to law and regulations. Thorough and in depth root causes analysis is a key entry to improve these three basic components. Specifically, the regulator should periodically review its own technical regulated demands in view of their effectiveness in practical life. This question should be addressed both at the local and/or national levels depending upon the issues. In some cases, it will need reinforcement (for instance, tragic examples in France where safety valve in LPG tanks on passenger vehicles was in the first place prohibited); in other cases, it could lead to simplification. Some "intrinsically safe" technical solution should be favored as often as possible (ie very resilient to most technical or human failures). A future development may lead to identify some "*safe* technology", subject to legal impact assessment of its implementation. This approach could be enlarged to many various economical sectors, and even in the private life, such as domestic, transportation - including commuting -, leisure activities.

This type of cycle should be organized in reference to the PDCA (Plan, Do, Check, Act) wheel: for instance, new regulations should be checked and appraised in regards to their pertinency/ability to have avoided old accidents "if they were implemented" at the time of the incident ("what if " past approach).

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Reducing flood risk by integrative land use planning

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Abstract

The reduction of flood risk is a crucial and complex issue. In order to reduce flood risk an integrative land use planning (LUP) on a catchment level, the relevant hydrological scope, is of high importance. By LUP measures for mitigation of risk but also for adaptation to flood risk can be identified and specified. Within the EU project SAWA a method was developed to identify target areas of high relevance and for pooling measures in order to realise an efficient planning and also realisation of measures.

By the development of an integrative river basin management plan in a participatory approach with regional stakeholders allocated information were produced which could be easily integrated in already existing planning instruments such as land use plan, landscape plan or water management plans.

Keywords: flood risk, integrative river basin management planning, target area analysis, cascading GIS analysis

1 Introduction

The number of natural hazards, especially meteorological and also hydrological events, has increased significantly since 1980 (MunichRe 2012). The number of flood disasters has increased significantly, from 524 to 1,729 over the same period (CRED 2011).

Thus, the reduction of flood risk is essential but also a complex issue. An important feature of flood risk management is to integrate ecological, economic and social aspects on prevention and mitigation measures. The realization that absolute flood protection is never attainable, and that structural flood protection measures, such as dams, dikes and levees cannot be the only solution to flood management – has moved the general thinking in flood management from flood protection towards flood risk [7] management (FRM). Therefore the European Directive on the assessment and management of floods, which came into force in 2007, is not focusing only on protection but also on prevention and mitigation.

The Flood Directive (Art. 7) requires taking into account inter alia soil and water management, spatial planning, land use, and nature conservation. Against this background it is crucial to integrate land use planning into the FRM system.
Land use plans can designate areas to keep them free of urban development, it can support adaptive development (architecture or type of use) or it can mitigate the dimension of the hazard by land uses which retain water in the catchment.
Different types of land use such as wetlands, agriculture, urban development, forestry, or water management are especially relevant for flood issues.

However, aspects of water and flood management are often either badly or too late included into the land use planning process. Furthermore, there is the challenge to implement the measures which were identified and described. Another problem is that flood and planning issues are not regarded and handled on the level of river basins but on administrative areas.

Within a case study in Germany (river basin of the river Ilmenau which is a tribiutary to river Elbe) we developed an integrative river basin management plan as an interactive and participatory planning process. By cascading GIS-Analyses target areas for synergetic and most efficient measures were identified and displayed in an Atlas with referenced pdf-maps. A regional stakeholders group was working out a matrix of measures, each from her or his perspective in order to reduce flood risk. The integrative river basin plan can be integrated into other planning instruments such as master plans or landscape plans.
An integration of FRM and land use planning based on a participatory process could support key elements of sustainable development.

2 The European Flood Risk Management Directive - a short description

[7] Risk is understood here as the product of the probability and intensity of a hazard and the potential damages.

Within the European Union Directives are central legal instruments to influence and steer environmental and land use policies and planning.
In 2007 the Directive on the assessment and management of floods came into force. Its aim is:

> *... to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community'* (EC 2007, Article 2).

Under the directive, member states should first carry out a preliminary assessment to classify and identify the river basins and associated coastal areas at risk of flooding (Article 4). For such zones they would then need to produce flood maps and indicative flood damage maps (Article 7).

The second stage is the development of flood hazard maps and flood risk maps for areas with potentially significant flood risks. These maps have to indicate flood extent, water depths and, where appropriate, flow velocities or the relevant water flows in the following three scenarios:
(a) floods with a low probability, or extreme event scenarios; (b) floods with a medium probability (likely return period 100 years); and (c) floods with a high probability, where appropriate.
The flood risk maps have to show the potential adverse consequences in these three scenarios. The deadline for the flood hazard and flood risk maps is 22 December 2013.

Even more interesting from an integration and land use planning point of view is the need for flood risk management plans (FRMP) (Article 9) *by 22 December 2015* as an important instrument for integrative flood risk (and river basin) management. Article 9, paragraph 1 of the Directive requires that a flood risk management plan at the level of river basin district or sub-river basin is developed which should address all phases of the flood management cycle and focus on prevention, protection and preparedness.
The FRMP have to contain "appropriate objectives" for the management of flood risks, focusing on the reduction of potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity, and, if considered appropriate, on non-structural (such as information, prediction etc.) initiatives and/or on the reduction of the likelihood of flooding (art. 7.2). The plans also have to include measures for meeting the goals. Furthermore, they have to take relevant aspects into account, such as costs and benefits, areas with a potential for retaining flood water, such as natural floodplains, the environmental objectives of the Water Framework Directive (2000/60/EC), soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure. The plans "*may also include the promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event*" (art. 7.3).

The central characteristics of this directive can be described as follows:
- a transboundary approach
- flood management on a river basin scale
- integration of aspects in the catchment related to flood risk and an assessment of the risk with regard to the potentials of reduction

- coordination with the Water Framework Directive.

3 Case study: Integrative River Basin Management Planning

In order to identify land use planning aspects and allocated measures a case study on a specific catchment was carried out. With the example of the river Ilmenau catchment in Northern Germany a methodology for identifying target areas within an integrative river basin management planning approach was worked out where synergetic effects are identified and certain focus areas for certain measures are analyzed. This study was carried out within the European project Strategic Alliance of Water Management Actions (SAWA) (www.sawa-project.eu).

By an integrative river basin management approach a tool, the integrative river basin management plan (IRBMP), was developed for improving the coordination and implementation processes in river basin and land use planning with the aim to promote flood mitigation resp. flood-neutral spatial development (Evers & Rubach 2010).
The IRBMP contains a series of maps which are compiled in a river basin atlas. The maps contain following data and information:

- Distributed data and information of the various sectoral planning (e.g. from water management, conservation, spatial planning and agriculture) are collected, visualized and made available to the professional public
- Synergy and conflict potentials between the spatially-relevant planning are presented
- The pooling of resources through prioritization of measures is supported.

The information was developed by the following procedure:
(1) Providing the basis for trans-sectoral catchment-based coordination and planning:

- GIS-based spatial analysis for identification of relevant flood areas to control measures for a preventive flood risk management
- development of an catchment-based Atlas in pdf-format with geo-referenced maps and background information on data and applied methodologies
- Preparation of data and the current action plan in line with international standards (Open Geospatial Consortium (OGC)) to enable data exchange and compatibility

(2) Recommendations and prioritization of measures in the catchment area of the Ilmenau, together with key stakeholders (representatives of technical authorities on different fields and levels):

- Identification of fields of action and measures based on the spatial analysis and the package of measures for a precautionary flood risk management
- Develop an Integrative River Basin Management Plan (IRBMP)

For identification of action priorities and options we have undertaken following working steps (see fig. 1).

The process for identifying main target areas within a catchment starts on the general, non-spatial specific level by doing a synopsis of relevant guideline, directives and other legally binding frameworks. Against this background more specific goals and quality standards have to be categorized such as protected areas or water quality standards to be met.

Furthermore, a regional assessment of the area-specific quality standards and a status quo analysis is conducted in order to identify the regional deficits. This analysis is based on monitoring data, geo data, documents, expert interviews etc.
Based on this assessment the range for cascading analyses can be made out in order to run a series of related analyses like (1) identification of river stretches with high flood risk, (2) discover hydromorphological structure with a bad status and (3) indicated areas for restoration of floodplains as compensation measures or due to a habitat management plan. By doing so priority areas can be determined and mapped precisely on the local level.

Catalogue of flood reduction measures and their implications with other planning fields

Together with regional stakeholders from Land use planning, water management, agriculture, nature conservation and forestry a catalogue of measures was developed. The catalogue is a compilation of adaptive measures and instruments which can be applied to reduce flood risk. It provides a quick overview for stakeholders and with the European Floods Directive and also all relevant planning institutions which are involved in the process of generating Flood Risk Management Plans in accordance fields. The catalogue is structured along types of measures for a) Preservation of existing and potential flood retention areas, b) Recovery / Extension of retention areas, c) Increase retention in the catchment, d) Minimizing the damage potential.

The fields of planning and action addressed are: Spatial Planning, Urban Land Use Planning, Agriculture, Forestry, Landscape Planning / Nature Conservation, Water Management, Private Preventive Action.

Target Area Analysis

The aim of target area analysis is to examine important hydrological issues which are relevant for preventive flood risk management, such as areas with significant flood risk, flood retention potential but also other water related aspects as fine sediment flux or the issue of water shortages. The principle of the target area analysis is by means of the intersection of several thematic maps in GIS, focusing on areas that are especially relevant to the particular analysis and therefore worth to be considered as potential areas for the implementation of measures. Through the query in several steps, the cascading analysis, areas can be narrowed down further and further until finally the target areas for focussing measures are covered (see fig. 2).

By this approach a comprehensive overview of the main problem areas can quickly and with relatively little effort be identified for the catchment area. Within this, the analysis of the retention potential is an important result and the basis for further analysis. From the representation of multiple target area analysis results, synergies can be derived.
This information is processed and provided via a catchment-based Atlas in pdf-format with geo-referenced maps (see fig. 3). The different layers of these maps can be made visible or invisible by clicking on the respective layer. The Atlas contains also background information on data and applied methodologies and on predicted regional climate change data.

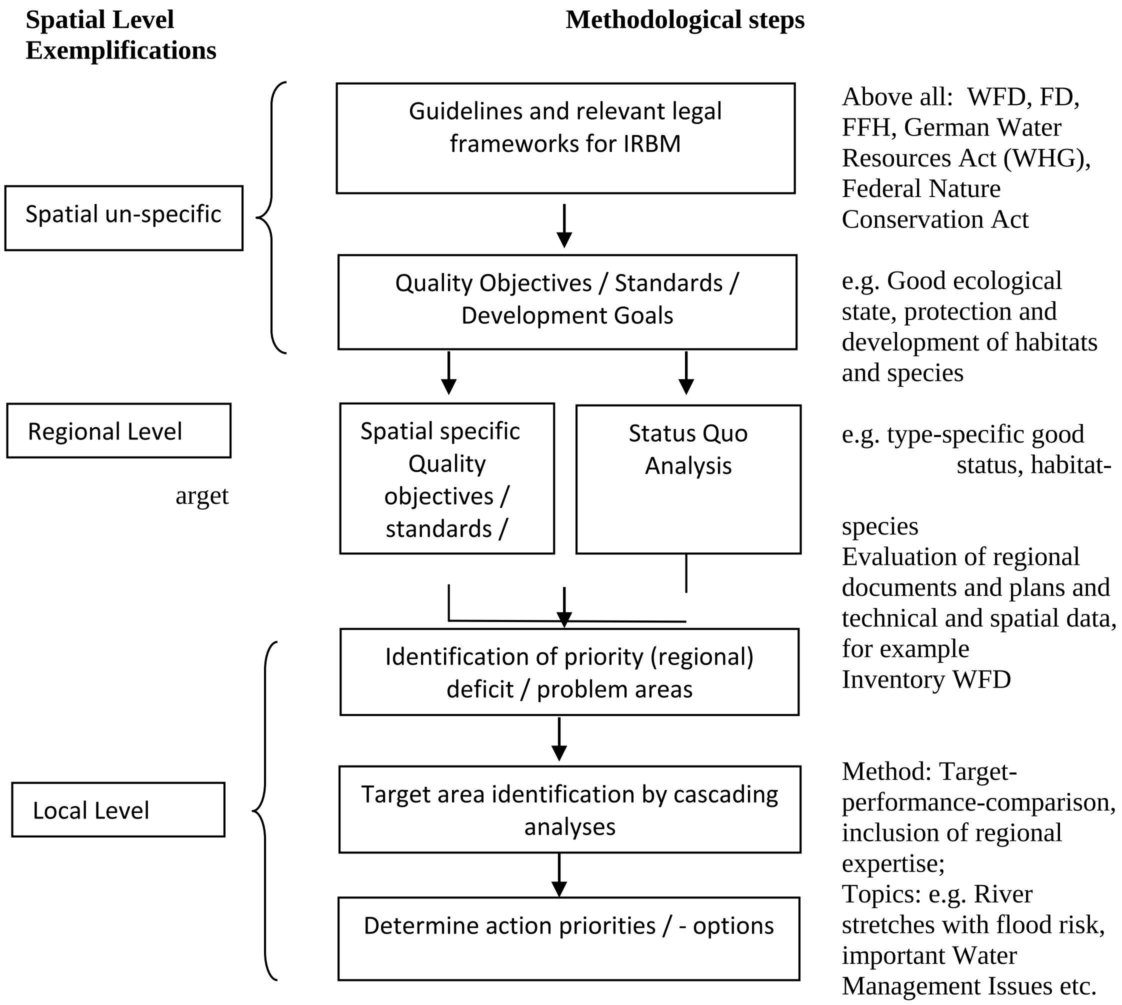

Fig. 1: Methodology for Identification of Target Areas

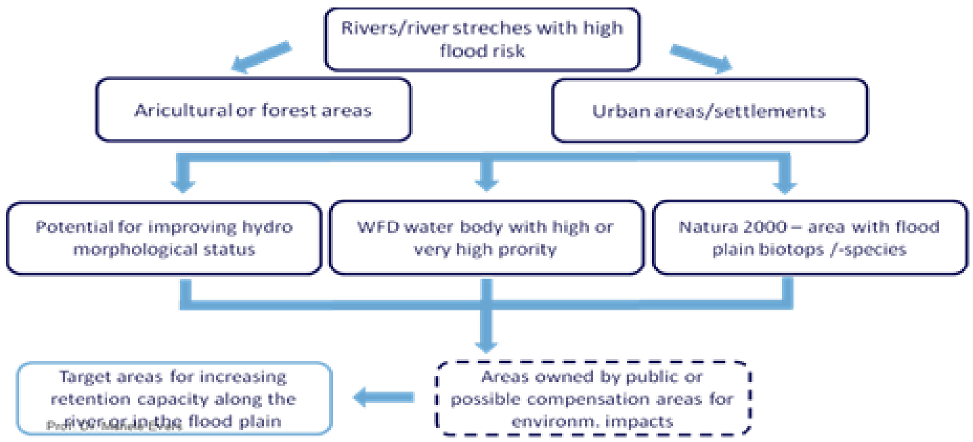

Fig 2: Example for a cascading analysis – here to identify most suitable areas for increasing retention capacity in the flood plain

4 Summarising remarks

The described approach of an integrative river basin management plan(ning) is based on two tools and the coordinated and participatory process of their development.
One tool is the Atlas which contains a series of analyses of basic information such as retention capacities in the river basin, environment qualities or planned activities. The investigations are following iterative cascades of (mainly GIS-)analyses. It is also a sample of maps which are showing target areas for measures for improving water/environmental quality AND reduction of flood risk. These maps are gathered in a digital Atlas for the catchment of the river Ilmenau.

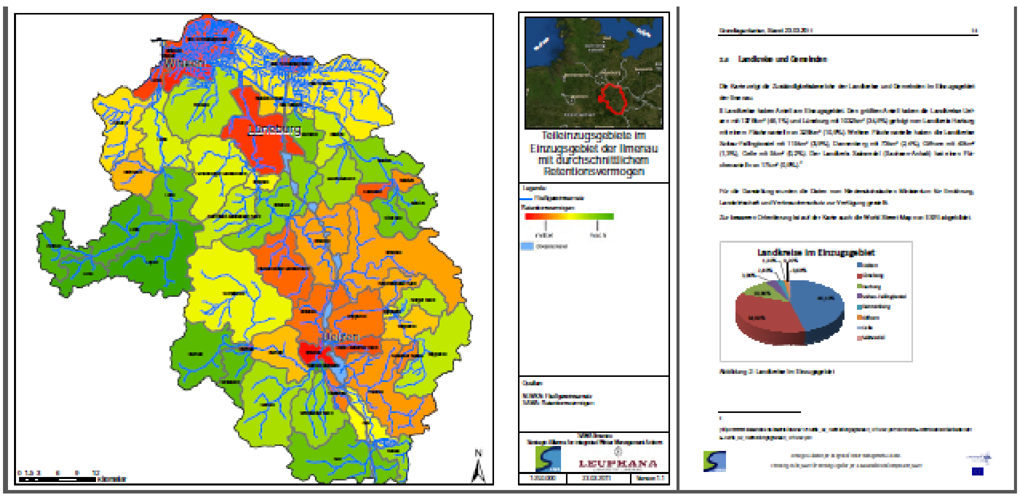

Fig. 3: Extract of the Ilmenau-Atlas (includes general spatial information, flood risk specific analysis such as retention potential and target areas, identified by cascading GIS-analysis)

The other tool is a catalogue of measures which shows a series of measures for better water and environment quality as well as for reduction of flood risk. The measures are structured along different planning and management sectors; by structuring them this way an overview is given not only for possible measures and perspective

implementation measures. It is also showing clear synergies between different sectors, e.g. between water management, spatial planning and agriculture.
Both tools were developed in coordination with regional stakeholders by a series of expert interviews and two workshops where the approaches were discussed and respective input was integrated.
The content of this plan can easily be integrated in divers relevant planning tools such as land use plans, landscape plans, water management plans and others.

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Optimal safety against catastrophic disasters using risk-based decision theory

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Abstract

One of the major difficulties in decision making consists in setting the target reliability according to optimal cost-benefit balancing. As this issue is a matter of society consideration of risk acceptability, which is neither intrinsic nor time-invariant, the challenge is to define a framework that ensures low sensitivity regarding socio-economic changes and preferences.

The present paper discusses the risk aversion regarding catastrophic events, in the scope of preventing large-scale losses that cannot be afforded by the decision maker. In addition to multi-objective and robust optimization procedures, the cost-benefit balancing is considered through reduction of the sensitivity regarding cost parameter uncertainties. In case of high-consequences low-probability events, the indirect failure costs are considered through interdependent cost-reliability function, in order to achieve better decision making for engineering practice.

Keywords: Cost-benefit balancing, Risk aversion, Reliability, Decision theory.

1. Introduction

One of the major difficulties in decision-making is to estimate the involved costs, especially time-variant costs due to degradation, failure and maintenance. The monetary value depends not only on inflation and discount rates, but also on national and international economy, and particularly on the society choices and preferences. It is interesting to see how the European and North American citizens are ready to spend much more money today for safety, quality and environment protection, than twenty years ago. This trend is expected to be more involved in the future, as long as no special events or crises appear. The high increase of oil price in recent years changes the optimum cost/reliability balance, as transport costs become higher and local products, although expensive, may remain cheaper than low cost overseas products. The same analysis can be performed for metal prices, especially for steel. The problem is almost the same when talking about the target reliability constraint, as setting the target reliability is a matter of society appreciation of risk acceptability, which is not neither intrinsic nor time-invariant choice. As cost-benefit balancing is very sensitive to failure cost estimations [1], the challenge is therefore to define a framework that ensures low sensitivity regarding socio-economic changes and preferences.

According to the expected utility theory, the possible losses are assumed to be sustained by the expected profit, as a result of the large number law. It is therefore assumed that the utility function is linear in terms of probability. This can be accepted in production where failure consequences affect only the economic balance of the manufacturing process. The behaviour of people and firms is very different, as high consequence events (involving human and high economic losses) are weighted differently, whether the probability is low or not. Consequently, the assumption that failure cost is independent of the failure probability is clearly wrong, and the utility function should be a nonlinear function of probability. This kind of contradiction between optimality and risk acceptability could be solved by the integration of failure cost-probability dependence, leading to more consistent economic balance for design and maintenance.

In this paper, the cost-benefit formulation of safety against catastrophic disasters is discussed in the framework of risk-based decision theory. The expected cost formulation is criticized from the risk aversion point of view. The reliability-based optimization is reformulated to improve its robustness and efficiency as a decision-making tool. It is suggested to minimizing the dispersion of the total cost as an additional target to ensure robust analysis. Simple numerical examples are provided to illustrate the discussed ideas.

2. Decision theory and risk aversion

2.1 Expected utility theory

For a vector of decision variables **d**, the capital gain $Z(\mathbf{d})$ can be seen as a lottery outcome which can be either $z(\mathbf{d}) = B(\mathbf{d}) - C_0(\mathbf{d})$ in case of good operation or $z(\mathbf{d}) = B(\mathbf{d}) - C_0(\mathbf{d}) - C_f(\mathbf{d}, P_f)$ in case of failure (fig. 1), where $B(\mathbf{d})$ is the benefit, $C_0(\mathbf{d})$ is the initial investment, $C_f(\mathbf{d}, P_f)$ is the cost of failure consequences and P_f is the failure probability. The expectation of the random outcome $Z(\mathbf{d})$ is given by:

$$\begin{aligned} E[Z(\mathbf{d})] &= (B(\mathbf{d}) - C_0(\mathbf{d}))(1 - P_f(\mathbf{d})) + (B(\mathbf{d}) - C_0(\mathbf{d}) - C_f(\mathbf{d}, P_f))P_f(\mathbf{d}) \\ &= B(\mathbf{d}) - C_0(\mathbf{d}) + C_f(\mathbf{d}, P_f)P_f(\mathbf{d}) \end{aligned} \tag{1}$$

Depending on the industrial application, the benefits may or may not depend on the design variables. In civil and mechanical engineering, the benefits of using the system are often independent of the design variables (e.g. structural dimensions, steel ratio, etc.) and the maximization of the expected gain can be equivalently seen as the minimization of the expected total cost, which can also be written: $E[Z(\mathbf{d})] = -E[C_T(\mathbf{d})]$.

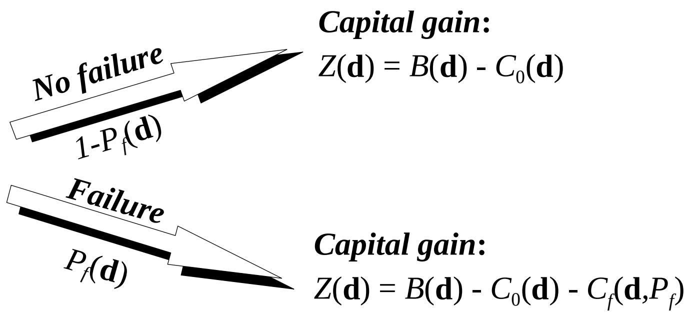

Figure 1. Capital gain function for structural systems.

The expected utility theory [2, 3] is widely applied to model designer's preference. According to this theory, the decision maker has to put the consequences in a value scale to preserve the preference ordering through a suitable utility function (fig. 2), such as the payoff z_1 is preferred to z_2 if:

$$z_1 \succ z_2 \quad \Leftrightarrow \quad u(z_1) \geq u(z_2) \tag{2}$$

where $u(\cdot)$ is the chosen utility function, depending on which, the decision maker can be *risk neutral* when he/she is indifferent between lottery and its expectation $u(E[Z]) = E[u(Z)]$, *risk averse* when he/she prefers the expectation $u(E[Z]) \geq E[u(Z)]$ (implying that $u(z)$ to be strictly increasing and concave function), or *risk attracted* when he/she prefers the lottery $u(E[Z]) \geq E[u(Z)]$. Under risk aversion, the decision maker preference corresponds to maximizing the expected utility (i.e. sum of utilities of each state weighted by their probabilities). When two alternative designs are compared (fig. 2), the risk-averse designer takes less risk to choose the expectation than to choose one of the two offered solutions. The certainty equivalent z_{CE} is the amount of money that the decision maker is willing to accept with certainty instead of facing the lottery: $u(z_{CE}) = E[u(Z)]$. The risk attitude is quantified by the risk aversion index, known as the Arrow-Pratt measure, developed independently by Pratt [4] and Arrow [5]. The absolute and relative risk aversion measures are respectively: $A_u(z) = -\dfrac{u''(z)}{u'(z)}$ and $R_u(z) = -\dfrac{u''(z)\, z}{u'(z)}$; a decision maker is *risk averse* if these measures are positive. In this way, agents' risk attitudes are entirely determined by the shape (i.e. concavity) of the utility function. Constant Absolute Risk Aversion (*CARA*) holds for $u(z) = a - b\exp(-A_u\, z)$ and Constant Relative Risk Aversion (*CRRA*) holds for: $u(z) = z^{1-R_u} /(1-R_u)$.

Consider a given capital gain z subjected to a random cost "shock" η with zero mean and standard deviation σ_η, the risk premium Π corresponds to the maximum amount of money that one would be willing to pay in order to eliminate the shock (i.e. to have a sure return):

$$u(z - \Pi) = E[u(z + \eta)] \tag{3}$$

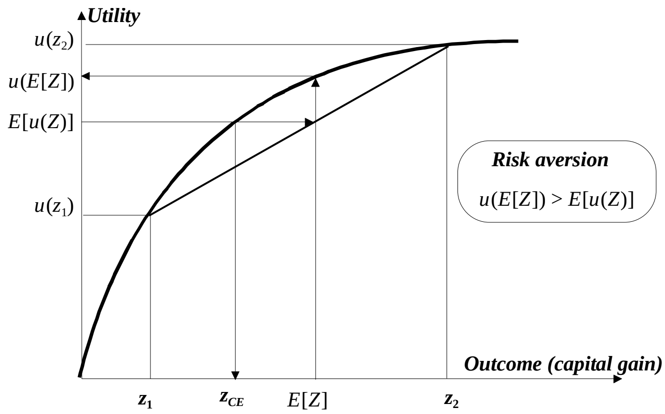

Figure 2. Utility function and risk aversion.

Second order expansion for both sides of the above equation allows us to approximate the risk premium by:

$$\Pi = \frac{\sigma_\eta^2}{2} A_u(z) \tag{4}$$

This expression means that risk premium depends on the variance of the cost shock weighted by the risk aversion (i.e. agent's attitude). It is important to note that in Reliability-Based Optimization (RBO), the utility function is systematically taken as either the capital gain $u(z) = z = B - C_T$ or the total cost $u(z) = -C_T$:

$$\min_{\mathbf{d}} E[u(Z(\mathbf{d}))] = u(B(\mathbf{d}) - C_0(\mathbf{d})) \times (1 - P_f(\mathbf{d})) + u(B(\mathbf{d}) - C_0(\mathbf{d}) - C_f(\mathbf{d}, P_f)) \times P_f(\mathbf{d}) \tag{5}$$

In this case, the utility function is rather linear which means that the decision maker is risk neutral.

2.2 Criticism of the expected utility theory

Although the expected utility theory is routinely used to evaluate projects and public funds, it underestimates and disregards rare events that could have catastrophic consequences. Neglecting rare events has led to increasingly paradoxical predictions. People decisions under uncertainties give large weight to rare events, showing that we do not make decisions based on expected utility alone, by averaging risks.
A troubling dilemma with the expected utility theory is that low-probability/high-consequence events (e.g. airplane accidents) will be valued no differently from the same risks generated by independent trials (e.g. automobile accidents). Indeed, valuing the former more than the latter may even be considered immoral to the extent that one values lives lost collectively more than those same lives lost individually. It comes out that utility theory is insufficient for modeling risk attitudes adequately [6].

Violations of expected utility theory were firstly recognized as a result of the work by Allais [7] who showed that decision maker weigh both expected outcomes and probabilities associated with these outcomes (i.e. expected utility functions are not linear in probabilities). The weighting of probabilities is intuitively linked to individual's attitudes towards risk. It seems plausible that people weigh catastrophic losses or gains (with low probability) differently than they weigh normal losses or

gains. Rabin [8] has shown that expected utility takes too simplistic a view towards risk. By only assuming increasing and concave utility functions, agents will behave absurdly to large stakes bets if they act risk averse to more moderate bets.
Allais, Ellsberg and Petersburgh paradoxes did not cause expected value to be supplanted as economists' canonical model of individual choice behavior over lotteries. Note that to get an expected utility function, and not just an ordinal utility function, we need stronger assumptions about the consistency of preferences: in addition to completeness and transitivity, we need independence and Archimedian conditions. Human behavior is contradictory to transitivity assumption when the difference between various choices is small. Machina [9] demonstrated that individuals do not necessarily conform to many of the key assumptions or predictions of the expected utility model of choice under uncertainty. Systematic violations of the expected utility model can be categorized into [9]: (i) violations of the Independence Axiom (Allais' Paradox), (ii) violations of the hypothesis of probabilistic beliefs (Ellsberg's Paradox) and (iii) violations of the model underlying assumptions of descriptive and procedural invariance (such as reference-point and response-mode effects).
To overcome the above difficulties, non-expected utility theories represent a very active research field in economic science. Weighted expected utility, rank dependent utility, and cumulative prospect theory are three prominent alternatives to expected utility [10]. Each is capable of accommodating the common consequence effect and thus able to explain the Allais's paradox. Although these theories are very different in some aspects, they have at least one feature in common: the probabilities of the various outcomes enter the utility function in a nonlinear manner. For instance, the application of these economical models to cost-benefit engineering models still requires to be tested regarding the robustness of the decision making process.

2.2 Risk aversion in public and private context

The law of large numbers is a powerful rationale for public decision, as it provides an undisputed role for governments and for public actions all over the world and creates a basis for profitable cooperation between the public and the private sectors. However, there are cases where the law of large numbers has limited use: when the risks are interconnected and correlated, as is the case in large catastrophes like the tsunami and Katrina hurricane. The outcome of the law of large numbers depends on the relative size of the pool of people affected over the total population, and therefore may require sharing the risks across nations.
From the point of view of public sector, the target is essentially to set the acceptance criteria in order to ensure safety (e.g. human lives saving, damage reduction and environment protection), economy (e.g. creation of jobs and tax paying) and service (e.g. improving the facilities and life quality) for the society. The prescribed regulations should be valid for a large class of structures and systems, with various levels of design and construction capabilities.

From the point of view of private sector, the target is to define the design and the operating conditions allowing us to maximize the net capital gain. It can also consist in minimizing the human and monetary losses in case of failure (especially for

sensitive industries such as nuclear power plants) as well as the economic and political impacts on the firm.
For lotteries involving monetary or other quantifiable payoffs, a special case of a utility maximizing individual is a risk neutral utility maximizer, who maximizes the expected value. Risk neutral attitude would apply to “large firms” that have enough money to sustain a possible loss on a business where they can make a substantial profit otherwise [11, 12]. In other words, the expected utility theory assumes a kind of averaging between losses and gains, where losses can be sustained and compensated with gains. However, if losses are very high, this leads to a kind of “end of the game” and the lottery process will be suddenly stopped.
Naturally, the two decision makers (public and private) have partly conflicting ordering of preferences. To deal with these targets, several researchers [13-15] have defined a maximum failure cost that should be respected with a given probability. This condition prevents the risk that unaffordable losses for private and public decision makers. The RBDO is thus written as:

$$\begin{aligned} &\min_{\mathbf{d}} : E\left[C_T(\mathbf{d})\right] \\ &\text{subject to}: \Pr\left[C_T(\mathbf{d}) \geq C_U\right] \leq P_{ad} \qquad \textit{and} \qquad g_j(\mathbf{d}) \leq 0 \end{aligned} \tag{6}$$

where P_{ad} is the admissible probability for the extra-cost risk and $g_j(\mathbf{d})$ are deterministic constraints for the decision space.

3. Optimal design considering uncertainties

3.1 Epistemic utility formulation

In practice, the expected utility is always conditioned by the assumptions related to cost and probability evaluations (i.e. epistemic variables $\boldsymbol{\theta}$). The unconditional expected utility can be written as:

$$E[u(Z(\mathbf{d}))] = \int_{C_f} \int_{C_0} \int_{\boldsymbol{\theta}} E\left[u(Z(\mathbf{d})) \middle| C_0, C_f, \boldsymbol{\theta}\right] f_{\boldsymbol{\theta}}(\boldsymbol{\theta})\, d\boldsymbol{\theta} \;\; f_{C_0}(C_0)\, dC_0 \;\; f_{C_f}\left(C_f\right) dC_f \tag{7}$$

where $E\left[u(Z(\mathbf{d})) \middle| C_0, C_f, \boldsymbol{\theta}\right]$ is the conditional expected utility for a given set of initial and failure costs, and epistemic variables; the probability density functions $f_{\boldsymbol{\theta}}(\boldsymbol{\theta})$, $f_{C_0}(C_0)$ and $f_{C_f}\left(C_f\right)$ are respectively related to epistemic variables, initial cost and failure cost. While the initial cost can be often well estimated, it is practically impossible to evaluate precisely the failure probability and the failure costs.
Although optimal design is very sensitive to different risk attitudes, the classical optimal decision is widely applied by using conditional expected utility, where costs and reliability estimations are considered as deterministic. A common major difficulty appears when applying optimization to real engineering systems: that is, the distributions (or at least the standard deviations) of costs and other epistemic data should be characterized in order to get unconditional expectation and probability.

Therefore, it is practically impossible to calculate the unconditional expectation of the total cost or even the probability of exceeding affordable costs, which makes the usefulness of cost-benefit balancing very limited in engineering practice. If the unaffordable cost C_U can be specified by the designer, the decision problem can be formulated such that:

$$\min_{\mathbf{d}} : \Pr\left[C_T(\mathbf{d}) \geq C_U\right] \qquad \text{subject to} : g_j(\mathbf{d}) \leq 0 \tag{8}$$

where $\Pr[\ ]$ is the probability operator, $C_T(\mathbf{d})$ is the total cost and $g_j(\mathbf{d})$ are decision constraints. Contrary to expression (17), the minimization of the probability in equation (19) leads to a double minimization of cost mean and variance. The impact of failure cost uncertainties is thus minimized, whatever the estimation of the cost variance. The unaffordable cost C_U can be defined as the threshold above which the company cannot survive (due to high losses either in design and construction/manufacturing costs or in failure-induced costs).

3.2 Robust risk-based formulations

The robustness concept is an appropriate alternative, as it does not require accurate information about the values of the standard deviations of costs and other epistemic data. For each performance property, the robust design objective could be generalized into two aspects, namely, “optimizing the mean of performance” and “minimizing the variation of performance”; the tradeoff between these two aspects cannot be avoided.

3.2.1 Total cost formulation

The robust total cost formulation can be written as:

$$\begin{aligned} &\min_{\mathbf{d}} : C_{T_\alpha}(\mathbf{d}) = (1-\alpha) E\left[C_T(\mathbf{d},\mathbf{X})\right] + \alpha \sqrt{Var\left[C_T(\mathbf{d},\mathbf{X})\right]} \\ &\text{subject to} : g_j(\mathbf{d}) \leq 0 \end{aligned} \tag{9}$$

with α a weighting parameter and $Var[.]$ is the variance operator. This expression follows the robust optimization philosophy (e.g. [16]), with the difference that the total cost is considered instead of the initial cost.

The above problem can be equivalently expressed in terms of the percentile of the total cost, in order to avoid undesired high costs:

$$\begin{aligned} &\min_{\mathbf{d}} : C_{T_k}(\mathbf{d}) = E\left[C_T(\mathbf{d},\mathbf{X})\right] + k \sqrt{Var\left[C_T(\mathbf{d},\mathbf{X})\right]} \\ &\text{subject to} : g_j(\mathbf{d}) \leq 0 \end{aligned} \tag{10}$$

where C_{T_k} is the total cost percentile, k is a number corresponding to the prescribed percentile (it does not assume normal distribution of cost, as it can be computed for any distribution type); it is to note that k can also be seen as a weighting parameter.

In general, the formulations (20) and (21) allow us to reduce both the expectation and the standard deviation of the cost, which is illustrated in fig. 3 by showing the expected cost and the upper and lower percentiles as functions of the design variable. As the role of the design variables is different for the mean and standard deviation of the total cost, the optimal design for the percentile is usually shifted with respect to the optimum based on the expected cost. This is due to the non-constant dispersion of the cost function with respect to design variables.

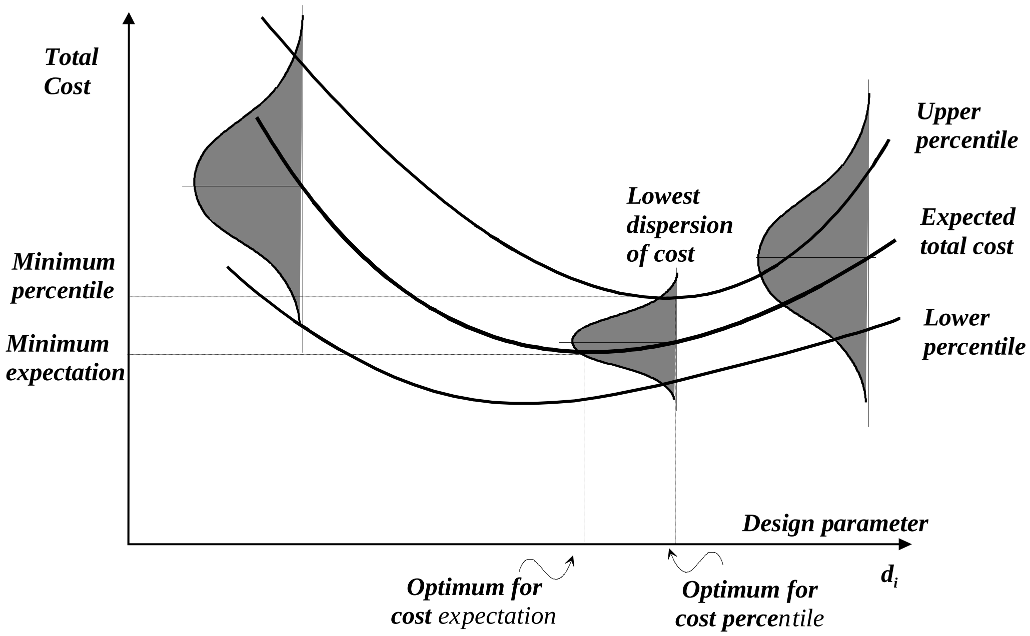

Figure 3. Cost expectation and percentiles.

3.2.2 Example on the lack of robustness

Consider the simple case of optimizing a design capacity r to support a random demand S, which is normally distributed with mean m_S and standard deviation σ_S. The initial cost is given by: $C_0 = c_0\, r$ (c_0 being the initial cost per unit capacity), and the cost of failure consequences C_f is uncertain with mean m_{C_f} and standard deviation σ_{C_f} (normal distribution is assumed). For the mean and characteristic costs: m_{C_T} and C_{T_k}, the optimal design capacities are respectively r_m^* and r_k^* given by:

$$
\begin{aligned}
r_m^* &= m_S + \sigma_S \sqrt{-2\ln\left(\frac{c_0\ \sigma_S \sqrt{2\pi}}{m_{C_f}}\right)} \\
r_k^* &= m_S + \sigma_S \sqrt{-2\ln\left(\frac{c_0\ \sigma_S \sqrt{2\pi}}{m_{C_f} + k\sigma_{C_f}}\right)}
\end{aligned}
\tag{11}
$$

It is easy to verify that the solution r_k^* is risk-averse compared to r_m^*, the difference $\Delta C_0 = c_0\left(r_k^* - r_m^*\right)$ represents the willing to pay in order to overcome the potential losses. By introducing the risk premium expression in the condition $\Pi = \Delta m_{C_T}$, we can write the absolute risk aversion measure in terms of design capacity and failure cost variance:

$$A_u = \frac{2}{\sigma_f^2} \frac{c_0\left[r_k^* - r_m^*\right] + m_{C_f}\left[\Phi\left(-\frac{r_k^* - m_S}{\sigma_S}\right) - \Phi\left(-\frac{r_m^* - m_S}{\sigma_S}\right)\right]}{\left[\Phi\left(--\frac{r_m^* - m_S}{\sigma_S}\right)\right]^2} \tag{12}$$

For illustration purpose, consider the parameters: $m_S = 300$ MPa, $\sigma_S = 40$ MPa, c_0 = 10 €/ MPa, $m_{C_f} = 10000$ € and $\sigma_{C_f} = 5000$ €. The optimal strengths are found to be: $r_m^* = 385.8$ MPa with a failure probability 1.6×10^{-2} and $r_k^* = 401.4$ MPa (*k* = 3) with a failure probability 5.6×10^{-3}; the corresponding expected costs are respectively 4018 € and 4071 €. The risk premium corresponding to the willing to pay for risk aversion is 156 € (i.e. 4% of increase of initial cost), and the absolute risk aversion measure is: A_u = 0.0165.

From the cost functions illustrated in fig. 4.a, it can be observed that the cost percentile penalizes more the designs with high failure probability (i.e. low design capacity). Fig. 5.b shows the CRRA expected utility with risk aversion R_u = 0.0, 0.5 and 0.95 (for illustration purpose, the utility functions are scaled from 0 to 1). While the optimal design capacity is 385.8 MPa for R_u = 0.0 (risk neutral), it goes to 393 MPa and 401 MPa for R_u = 0.5 and 0.95, respectively. The solution obtained by robust reliability-based optimization corresponds therefore to high risk aversion level, confirming the soundness of the approach.

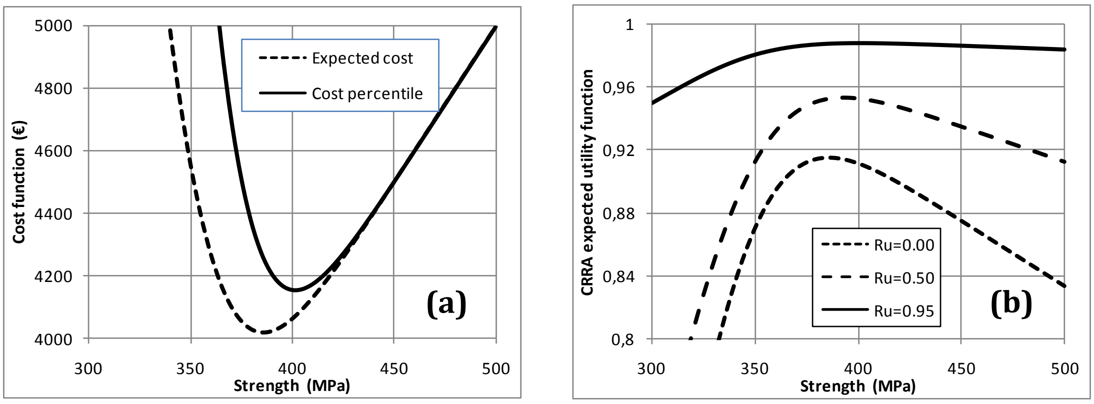

Figure 4. a) Cost expectation and percentile and b) Expected utility.

Fig. 5 plots the probability density functions for the expected costs according to the two design capacities r_m^* and r_k^*. It is clearly observed that the robust RBDO solution leads to less scatter of the expected total cost regarding failure cost uncertainties; the solution has therefore low sensitivity to under- or over-estimation of failure consequences. For example, if the failure cost were wrongly under-estimated, and the actual value is as much as twice the prior estimation, the expected costs would be

$m_{C_f}(385.5) = 4178$ € and $m_{C_f}(401.4) = 4127$ €, showing that the second design is less affected by the increase of failure costs.

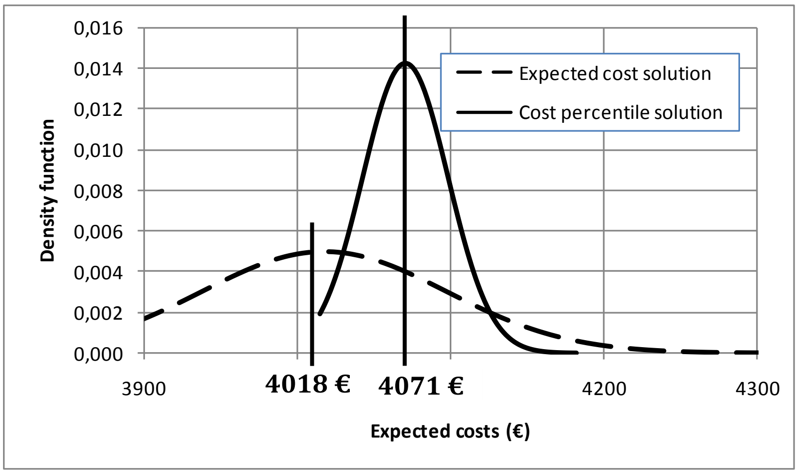

Figure 5. PDF of the expected total cost in terms of two design strengths.

3.3 Multi-objective decision making

The drawback of the formulations (9) and (10) lies in the uncontrolled balancing of the reductions of cost expectation and variance. Balancing is mandatory as it fits better the design requirements in terms of optimality and robustness. It is therefore difficult to set the percentile and weighting parameters, α and k, as they are arbitrary, in addition to the fact that the failure cost distribution type and variance are not known in advance. Even if a normal distribution is assumed, the variance of the failure cost cannot be accurately predicted by statistical methods along the structural lifetime. Therefore, the choice of the weighting or risk parameter, α, k or R_u, has a significant influence on the selected optimal solution. It is also required to minimize the sensitivity to uncertainties related to cost parameters, m_{C_0}, m_{C_f}, σ_{C_0} and σ_{C_f}, as well as to other epistemic modeling parameters. It can be possible to overcome these difficulties by defining a multi-objective optimization formulation, avoiding the weighting between expectation and variance.

3.2.1 Multi-objective formulation

The multi-objective problem can be defined as the minimization of both the cost expectation and variance:

$$\begin{aligned} &\min_{\mathbf{d}} : \{E[C_T(\mathbf{d},\mathbf{X})] \ ; \ Var[C_T(\mathbf{d},\mathbf{X})]\} \\ &\text{subject to}: g_j(\mathbf{d}) \leq 0 \end{aligned} \tag{13}$$

This multi-objective problem offers a set of dominant solutions and the decision maker has to select the appropriate solution according to his/her preference. The drawback of this approach lies in the selection step, which still remains affected by subjective human opinion and preferences.

3.3.2 Multi-objective optimization example

To illustrate the above idea, let us consider the inference model with the limit state function G defined by: $G = R_1 + R_2 - S$, where R_1 and R_2 are two additive component capacities and S is the demand. Table I provides the means and coefficients of variation of the various parameters.

Table I: Parameters of the bi-dimensional design problem.

Model type	**Variable**	**Symbol**	**Mean**	**C.O.V.**
Reliability model	Capacity of component 1	R_1	m_{R1}	0.05
Reliability model	Capacity of component 2	R_2	m_{R2}	0.15
Reliability model	Demand	S	12.00 MPa	0.20
Cost model	Initial cost	C_0	2599 €/MPa	0.15
Cost model	Failure cost	C_f	2×10^6 €	0.25

The optimal points obtained by applying the different formulations are provided in Table II. The comparison of the first two cases (i.e. minimization of cost expectation and standard deviation, respectively) shows two opposite trends: the first case gives a large amount of the component with low C.O.V. (i.e. component 1) and a strong reduction of the component with high C.O.V., in order to achieve the optimal reliability, while the second case tends to reduce the component with large effect on cost dispersion (i.e. component 1). In case 2, the expected cost is higher but its percentile is still lower. Here also, the percentile minimization (case 3) appears as a good compromise between the above formulations.

Table II: Optimal solutions for different one-dimensional formulations.

Case	**Cost variable to minimize**	$m^*_{R_1}$	$m^*_{R_2}$	β	m_{C_T} (k€)	σ_{C_T} (k€)	C_{T_k} (k€)
1	Expectation	17.97	2.00	3.086	51.9	6.8	72.3
2	Std deviation	9.23	11.19	2.842	55.6	4.9	70.4
3	Characteristic (k=3)	12.29	7.94	2.994	53.3	5.2	69.0
4	Expectation under std deviation optimality	12.02	8.01	2.920	53.6	5.2	69.1
5	Std deviation under expectation optimality	16.73	3.23	3.074	52.0	6.5	71.3

The minimization of the expected cost under standard deviation optimality conditions (case 4) enforces the standard deviation to be minimum and searches for the best expected cost; it leads to a solution similar to that for percentile optimization (robust design formulation). Finally, the minimization of the standard deviation of cost, under expected cost optimality conditions (case 5), leads to the best configuration as both cost expectation and standard deviation are reduced. This solution is similar to the first case (classical formulation) in terms of expected cost (with only 0.1% of increase), but with the advantage of reducing the standard deviation by 5%. This is achieved by slightly decreasing capacity 1 and increasing capacity 2. The resulting cost percentile is better than the classical formulation, but still being slightly higher than the percentile formulation with the advantage of a better safety level ($\beta = 3.074$ instead of $\beta = 2.92$).

3.4 Interdependence between cost and reliability

When applied to real problems, the utility theory shows a lack of consistency coming from the use of fixed cost for failure consequences (e.g. losses, reconstruction costs, direct damage, pollution,…). When the failure cost C_f is independent of the failure probability P_f, the expected failure cost can be written: $E[C_f] = C_f \times P_f$. This formulation leads to inconsistent optimization results as indicated by Ditlevsen and Madsen [17], compared to engineering practice and acceptable safety levels. In fact, the independence assumption holds as long as the failure rate remains very low under a commonly accepted level. However, with increasing the failure rate, the failure cost C_f should be considered as a function of the failure probability, as indirect damage (e.g. bad propaganda, market losses, public opinion on the company/authority, accelerated effects,...) induces much higher losses than direct economic losses.

3.4.1 Cost-probability relationship

The relationship between failure consequences and probability is necessarily nonlinear. A rational approach can be established by explicitly introducing the cost-reliability dependence as a nonlinear function where the failure cost strongly increases with high failure probabilities; i.e.:

$$E\left[C_f(\mathbf{d})\mathbf{1}(\mathbf{d},\mathbf{X})\right] = C_f\left(\mathbf{d},P_f\right)\times P_f \tag{14}$$

where $C_f\left(\mathbf{d},P_f\right)$ is the failure cost function, which plays the role of penalty function when failure rate becomes high. Compared to classical approaches with explicit reliability constraint, this penalization can better reflect the human appreciation of consequences, as well as indirect cost impact when the failure rate is increased.

3.3.2 Illustrative example

The idea behind cost-reliability dependence can be illustrated by considering the example of the inference model in section 3.3.2: the reliability-independent failure cost $C_{f_o} = 2\times 10^6$ is now replaced by a nonlinear function, leading to the expected total cost:

$$C_T\left(m_R\right) = C_0 m_R + \left[C_{f_0} + \frac{C_{f_1}}{1+\exp\left(\mu\left(1-P_f / P_{f_0}\right)\right)}\right]\times P_f\left(m_R\right) \tag{15}$$

with the acceleration parameter $\mu = 5$, the failure probability threshold $P_{f_o} = 10^{-4}$, the basic failure cost $C_{f_0} = 2500$ €/MPa and the extra-cost due to indirect losses is $C_{f_1} = 10\, C_{f_0}$. This expression assumes that high-rate failure cost is up to ten times the single failure cost. Table III compares the optimal solution, obtained by this cost function with classical cost function using constant failure cost. The reliability-dependent failure cost creates an implicit penalty constraint, as the failure cost strongly increases when approaching the probability threshold; the reliability index at the optimum is raised from $\beta = 2.783$ ($P_f = 2.7\text{x}10^{-3}$) to $\beta = 3.45$ ($P_f = 2.8\text{x}10^{-4}$). As illustrated in fig. 6, it is unlikely to get solutions with low reliability levels (i.e. low m_R), as failure cost increases drastically. For high reliability levels (i.e. $m_R \geq 30$ MPa), the two functions become identical.

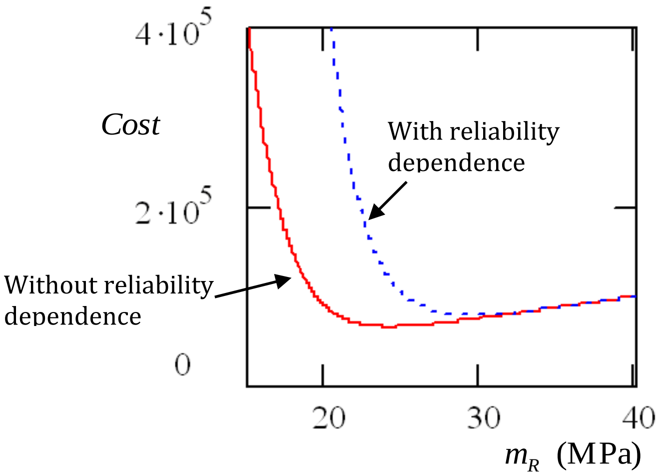

Figure 6. Total cost with and without reliability-cost dependence.

Table III: Optimal solutions with and without reliability-cost dependence.

Failure cost	**Optimum capacity**	**Reliability index**	**Expected cost (k€)**
Reliability independent	24.06	2.783	65.54
Reliabiliyt dependent	29.25	3.450	79.31

4. Conclusion

In this paper, it is shown that the expected utility concept is not sufficient to deal with catastrophic events, as the solution and cost dispersions cannot be controlled. Robust decision-making tools have to be developed in order to set the best compromise between cost and safety. The cost-reliability dependence leads to more consistent formulation than for classical approaches, with is conformal to engineering practice and social risk acceptability.

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Development of a GIS-based approach for the vulnerability assessment of a territory exposed to a potential risk

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Abstract

The assessment of potential threats is an important concern for population, industries or decision makers. In order to take the right decisions, stakeholders must base their analysis on the knowledge of potential hazards, but also on intrinsic vulnerabilities concerning the surrounding population and territory, in the aim to have a pertinent representation of the risk not only based on hazards. The present development proposes a global approach to the vulnerability of populations located in the vicinity of a potential risk and to the vulnerability of a territory from a functional point of view, to help decision makers in their risk management process. To reach this goal, a specific methodology has been developed based on land use data and a multi criteria decision method (Saaty) to obtain a semi quantitative approach of vulnerability. This methodology has been implemented in the MapInfo GIS (Metehor tool) to obtain different layers of vulnerability assessment.

Keywords: Vulnerability, Risk assessment, Industry, Territory, Geographical information system

1. Introduction

The consideration and assessment of risk is a major concern for our societies, whether its origin is natural, industrial or terrorist. The consequences are often significant oe even critical for people, environment and stability of our societies. Nowadays this assessment is based primarily on a very thorough characterization of the hazard (Tixier, 2002), especially through the detailed description of scenarios, assessment of the likelihood or impact by quantifying the consequences. The idea proposed in this work starts from the premise that this hazard-based approach must be complemented by a vulnerability-based one. This will include the advantage of having a representation of the intrinsic vulnerability status of a territory in an independent way of any specific accident situation and to allow authorities to take into account vulnerability as a self-consistent variable. This last point is crucial, since, it is impossible to know the exact scenario that may happen. The expert must make assumptions and it automatically generates uncertainties on the outcome of the evaluation. This approach will enable decision makers to have a critical look at the

elements from the quantification of the consequences and the uncertainties induced. In this paper, we focus on potential threats due to dangerous substances. In France more than 19 450 accidents occurred in the period 1992-2004, and 46 % of them led to dangerous material releases in the environment (Barpi, 2005). In order to take the right decisions to protect populations after such accidental emissions, the hazard generated by the release must be studied. This is generally done by experimentations and/or modeling of the phenomena but the surrounding population and the territory are rarely accounted for in a vulnerability assessment approach.
A global a priori vulnerability assessment of the stakes of a territory exposed to potential threats could give stakeholders a valuable tool. In this aim a twofold approach has been developed to assess vulnerability:

- a quantitative description of human vulnerability, by population categories, which are located in space and time

- a qualitative and quantitative approach dedicated to assess the vulnerability level of specific structures (functions) being a part of the overall stability of a society.

2. Generalities on vulnerability

The concept is largely defined by several authors (paragraph 2.2) and its interest for risk assessment is pointed out but only few approaches and methods are really operational.

2.1 The vulnerability challenge

The challenge consists in the assessment of the vulnerability of a territory exposed to a potential threat, generated for instance by industrial activities like chemical, petrochemical sites or others.

Figure 1: vulnerability assessment: stating the problem

Figure 1 illustrates the challenge addressed when defining the vulnerability of a territory, which may be summarized as follows: is area 1 (on the left), which is composed of human, environmental and material stakes, more or less vulnerable than area 2 (on the right) also composed of human, environmental and material stakes, but in different quantity and of different nature?

2.2 Vulnerability definitions

A preliminary work has collected thirty-seven definitions of "vulnerability" from different sources and scientific areas.

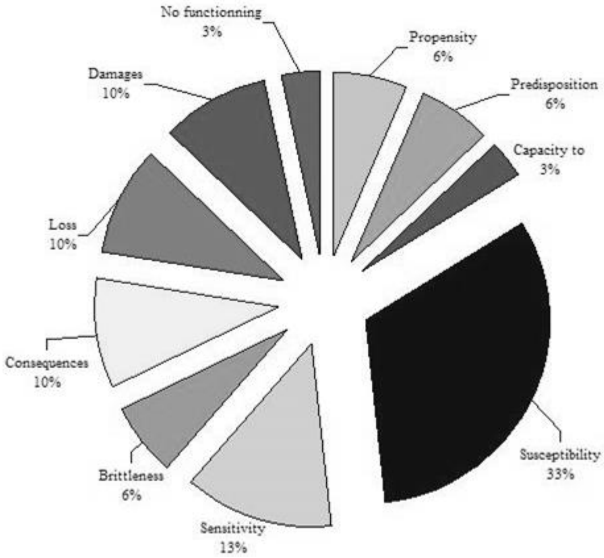

Figure 2: Parameters of the vulnerability

The concept of vulnerability is old (18th century). It derives from the Latin noun "vulnerabilis" and the Latin verb "vulnerare", which expresses the character of what can be wounded, exposed. There is not one single definition but several definitions of the vulnerability, depending on the discipline of study, and of the culture of the authors (Figure 2). The definitions can be sorted according to three principal dimensions: the dimension of susceptibility, the dimension of consequences and a dimension including the two previous ones. But the definitions of vulnerability can also be classified according to their mode of study, which could be a qualitative approach, a quantitative approach or a semi-quantitative one.
For summary, the vulnerability has three aspects:

- The first aspect corresponds to the character of vulnerability of the stakes and this state is influenced by vulnerability factors (qualitative approach).

- The second aspect of the vulnerability is coupled with the concept of consequences. It attempts to study the elements which are likely to be exposed by a hazard (quantitative approach)

- The third aspect of the vulnerability is a composite concept resulting from the others. The vulnerability is thus at the same time a character and a consequence (semi quantitative approach).

So, the vulnerability is a concept with the multiple facets and is the subject of many approaches, not always consensual.

2.3 Classical approaches to assess vulnerability

Some risk analyses have been developed at a local level. These local studies are generally based on a deep analysis of the hazard with a probabilistic approach in order to quantify for instance accident rates as a function of the features of a road (plane road or not, bridge, ...) (Fabiano, 2002) or by the way of F/N curves and impact areas of accident (Bubbico, 2004). Stakes have been generally taken into account through an average population density near the area of interest as a function of impact area of accident (Bubbico, 2004; Bubbico, 2006). Millazo (Millazo, 2002) also used population density and vulnerable centres (as shopping centres, hospitals, schools ...) in order to better describe the spatial distribution of human stakes.
From the presented methodologies, it can be pointed out that the hazard is properly taken into account with such a probabilistic approach. Concerning the stakes only the concept of average density or specific density at local level are used. It is clearly linked to the quality of available cartographical databases. Another important point is the fact that only human stakes are taken into account and not natural and materials ones. A last point concerns the ranking of vulnerability of specific types of stakes which has not been yet attempted in transport risk analysis.
To overcome these limitations, an original approach is proposed which was previously initiated during the European project Aramis (Tixier, 2006) based on the ranking of the importance of stakes on the territory in order to assess the vulnerability in a more representative way.

3. Objectives and definitions

The idea here developed is to define a vulnerability index applied to all possible stakes located in the surroundings of an industrial site (vulnerability mapping) or any other potential threat. This would require first to choose the study area and define the stakes of interest, then to identify and quantify the stakes into the study area and, finally, to assess their vulnerability: this last step needs a specific methodology. In this work, two complementary approaches have been developed:

- The first one is the quantification of human vulnerability by the way of a census of selected stakes on the territory completed by a repartition as a function of the time of the day (day or night) to obtain a more realistic representation of the distribution of the population.

- The second one is the assessment of functional vulnerability (critical networks or elements to maintain the main functionalities of the society). A semi-quantitative approach to assess the vulnerability is adopted, which is a multi criteria decision method (Saaty's method) based on expert judgments. This method allows taking into account both the "status" of a specific stake (qualitative approach) and the "census" of that stake (quantitative approach). This approach relies on the collection of expert opinions on the relative importance of each element which provides a "photography" at a certain time of a situation. This is the main difference with an expert system which can provide rules to characterize the situation and include a learning step. The main advantage consists in providing a transposable approach in order to compare different types of areas exposed to a potential hazard.

This approach has been conveniently developed in the form of GIS tools (Map Info and Open GIS to be defined) in order to assess the vulnerability in the zone of interest.

4. Methodology developed to assess the vulnerability of a territory

The vulnerability of a territory is composed of two contributions, one from human vulnerability, the second from functional vulnerability.

4.1 Human vulnerability

4.1.1 Definition

The human vulnerability assessment has for goal to make a spatial and temporal (day/night) census of human stakes by considering people as independent persons.

4.1.2 Typology of human stakes

It is necessary to propose a set of human stakes to characterize with accuracy the territory, while keeping in mind the required transferability of the method and its flexibility. Indeed, it is important to find a proper balance between the number of the type of human stakes to be accounted for and the limited precision of cartographical databases available to describe the territory. [INSEE, 1999, IGN, 2004].
Here the characterization will be based on four categories of stakes:

- The site staff: For this type of human stake the potential danger is close to its maximum value they are located in an area very close to the source of danger.
- Local populations: This type of stake allows taking into account population distribution according to the variable population density of an inhabited area. A distinction of population density may be based on the type of land use, three types can be identified:
    - rural Type
    - peri urban Type
    - urban type.
- People present in public assembly building (ERP). This type of stakes is specific, because these establishments have the potential to host an important number of people. The ERP taken into account are related to:
    - Transportation: railway station, airport, port,
    - Trade: stores and shopping malls,

- Leisure time: restaurant, hotel, pub, multi-purpose hall, summer camp, school outdoor and sports facilities,
- Culture: library, documentation centre, trade mart, museum, religious facilities,
- Health and service: healthcare facility, education institution, banking, and business places.

- Users of communication networks. This type is characterized by a density of traffic depending on the type of communication networks:
    - Roads (motorways, national…)
    - Railway lines,
    - Waterways.

This typology of stakes allows making a census of population in a given territory but it is essential to obtain a spatial distribution of these populations.

4.1.3 The spatial distribution of the population

The first layer of vulnerability information consists in a count of the location of human population on a territory. The relevance of this layer will depend heavily on cartographic databases used in the study. To illustrate this point, two examples are shown below:

- 1st level: the association of the map layer characterizing the limits of districts on the territory with the population census of 1999 conducted by INSEE provides a macroscopic view of people in private housing in a district with a homogeneous distribution (there is no identification of real populated sub-zones).
- 2nd level: on the basis of map data selected for the realization of the first level, a characterization function of land use is proposed. The type of land use is generally:
    - continuous urban area
    - discontinuous urban area
    - rural area

From these elements and through the use of factors of population repartition according to the type of land use, the result provides a better representation of reality. In our approach, the second way is used.

4.1.4 Population distribution as a function of a Day/Night criterion

Another main point consists in the distribution of the population with day/night criterion. On the basis of INSEE studies (which is the French institute making the census of population), the following categories can be proposed (INSEE, 1999; INSEE, 2005):

- Out of school child
- Schooling children and students
- Population in professional activities
- Unemployed population
- Inactive population
- Retired population

On this basis, the more effective distribution of population should be based on the area of life (which is the aggregate of a set of districts) but there is no cartographical data available to do it this way. So a simplified approach is realized by district where the data are the most usually available. The following table (Table 1) summarizes the distribution of population at the scale of French districts (day / night location and percentage of population based on INSEE Studies).

Table 1: Distribution of the population (day/night)

Population	**Day location**	**Night location**	**% of total population of a district**
Out of school child	Family dwelling	Family dwelling	2,36
Schooling children and students	Education structures	Family dwelling	25,07
Population in professional activities	Establishments	Family dwelling	40,91
unemployed population	50% Family dwelling 50% establishments (culture, population services, administration, …)	Family dwelling	6,01
Inactive population	50% Family dwelling 50% establishments (culture, population services, administration, ...)	Family dwelling	7,48
Retired population	50% Family dwelling 50% establishments (culture, population services, administration, …)	Family dwelling	18,17

The proposed approach allows quantifying the human vulnerability of a territory and highlighting population distribution differences between the day and the night time.

4.2 Functional vulnerability

4.2.1 Definition

The functional vulnerability has for aim to assess the stability of a society exposed to a potential risk. To reach this goal, the critical networks which contribute to the

balance of the society must be identified and weighted to assess their relative importance, as a function the type of the loss (total or partial) and the duration of the loss (small or long). In order to provide a support to decision-makers, there is a necessity to set up priorities so the global vulnerability state of a territory could be provided and end users can adopt specific measures to reduce the existing vulnerability, in the framework of a risk management process.
In a general way, decision-making is a complex process which is not only based on a set of information about a subject, but depends also on the representations of the members of the decision group regarding their vision of the reality. Furthermore, personal preferences and persuasion can have more importance in the process of decision than a clear and rigorous logic. A multicriteria hierarchical method brings an organization of information and appreciation which intervenes in the process of decision-making.

4.2.2 Multicriteria decision method of Saaty

The purpose of the Saaty's method is the assessment of priorities. To this end, the first point is to have a consensus on the objective, then in a second time to decompose the complex and unstructured situation in its main components. The types of results can be a classification, an allocation of numerical values of subjective judgments or the aggregation of judgments to determine criteria having the highest priorities. The multi criteria hierarchical method allows obtaining a decision-making by a group in a consensual way due to a better coherence of judgment.
The multi criteria hierarchical method of Saaty (Saaty, 1984) is based on four steps:

- a description of the studied system (some elements and criteria are proposed in order to characterize the situation)
- a construction of hierarchies (to organize elements and criteria to answer the problem) ;
- an assessment of priorities (based on expert judgments);
- a validation of coherence.

The construction of a hierarchical structure requires the creation or the identification of links between the various levels of this structure.

Each element or criteria of a hierarchical structure takes place at a given level of the structure. Its upper level corresponds to the global objective (or dominant element). Some binary comparisons are done between all the elements of a given level according to the element of the upper level, in order to rank the elements among them. The various levels of a hierarchy are, consequently, interconnected.
A complex situation can be analyzed by a systematic approach with the help of this hierarchical structure. The priorities have to be assessed. This process is done by a comparison of elements two by two (binary comparison). It gives the ranking of elements according to their relative importance. Finally, the logical coherence is confirmed on the whole applied process. To do the binary comparisons, it is necessary to use a scale based on classic numerical variables or more qualitative variables contributing to take into account qualitative aspects.

From this definition and from hierarchical structures and the functions of the vulnerability index are deduced. The expert judgments are collected by a questionnaire for the evaluation of each coefficient of the vulnerability functions.

4.2.3 Methodology to assess the functional vulnerability of a territory

The assessment of functional vulnerability relies on Saaty's multi criteria decision method (Saaty, 1984). In order to define the vulnerability of a territory in terms of critical networks potentially exposed to the consequences of hazards, the first step is to describe the territory by the mean of categories of critical networks and criteria to assess a specific weight for each of them. So, the territory is described by categories of functionality (Lutoff, 2000; MATE 2001). We choose 12 categories:

- Private dwelling (PD)
- Governmental structures and administrations (GSA)
- Structures dedicated to energy and water management(SEW)
- Structures dedicated to communication services management (SCS)
- Structures dedicated to transport (ST)
- Structures dedicated to production (SP)
- Structures dedicated to healthcare and homeland security (SHS)
- Structures of cult (SC)
- Structures of education and research (SER)
- Structures of culture (SCULTU)
- Structures dedicated to the population services (SPS)
- Natural area (NA)

Two criteria are used to qualify the weight of vulnerability, the type of loss (total or partial) and the duration (small or long).
In a second time, hierarchical structures are built in order to organize the information, and the importance of each category is assessed by the way of binary comparison by experts as a function of the type of loss and the duration. Then, for each category, the importance of the sub-structures is evaluated in the same way (Figure 5).
From this hierarchical structure, it can be deduced two sets of analytical functions:

- The value of vulnerability as a function of the relative importance of categories
- For each category, a function describing the relative importance of all functionalities.

In a third time, it is relevant to complete the characterization of the functional vulnerability by a qualification of the type of destruction of each identified type of functional stakes in terms of level of loss and in terms of duration before rehabilitation.
For the type loss, two levels are assumed, the total loss (TL) or partial loss (PL), for rehabilitation time three levels are retained short-term (ST), medium term (MT) or long term (LT).
These last set of hierarchical structures (Figure 6) will compare the relative importance in the case of a partial loss of a category of functionality compared to a total loss and the relative importance in the case of a short, medium or long term loss. These two criteria are used to correct the functions of vulnerability.

From this approach, the matrixes and the functions are derived by combining the quantification factors of the stakes and their vulnerability factors to give the vulnerability index. After treatment, the following equations are obtained:

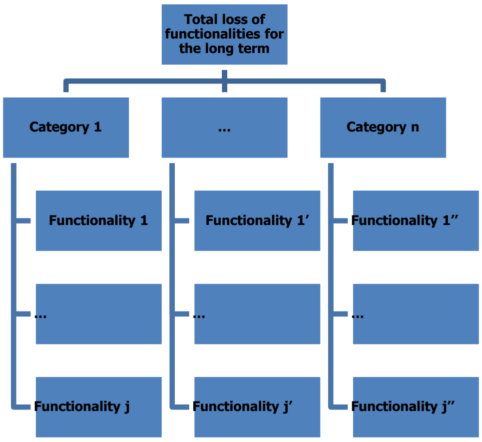

Figure 5: example of hierarchical structure

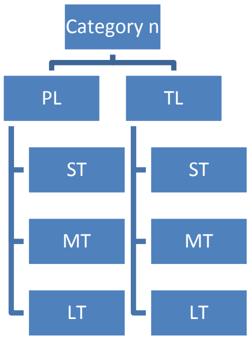

Figure 6: generic hierarchical structure for evaluating the importance of loss and duration before rehabilitation.

Vfunctional = 0.112 x PDcor + 0.022 x GSAcor + 0.112 x SEWcor + 0.009 x SCScor + 0.023 x STcor + 0.032 x SPcor + 0.192 x SHScor + 0.028 x SCcor + 0.17 x SERcor + 0.069 x SCULTUcor + 0.201 x SPScor + 0.030 x NAcor

With:
GSAcor= [0.53 x GS + 0,47 x A] x (TLGSA + DLGSA)
SEWcor= [0.354 x WAT + 0.354 x ELEC + 0.085 x PETR + 0.207 x GAS] x (TLSEW + DLSEW)
STcor = [0.500 x RON + 0.118 x RAN + 0.089 x WW + 0.293 x AS] x (TLST + DLST)
SHScor = [0.63 x H + 0.37 x PS] x (TLSHS + DLSHS)

At this stage only few persons have been consulted, the objective being to show the ability to realize this approach, so the numerical values may be changed with the consultation of other experts. Two categories of weights have been obtained:

- a high weight for structures dedicated to the population services (SPS), structures dedicated to healthcare and homeland security (SHS), education and research institution (SER), Private dwelling (PD), structures dedicated to energy and water management (SEW)

- a low weight for Governmental structures and administrations (GSA), structures dedicated to communication services (SCS), structures dedicated to transport (ST), structures dedicated to production (SP), structures of cult (SC), structures of culture (SCULTU), natural areas (NA)

Table 2 summarizes the weight for correction factors to take into account the type of loss and the duration of loss for each category.

Table 2: Correction factors in function of the type of loss

	Total Loss (TL)			**Partial Loss (PL)**		
	Long Term (LT)	**Mid Term (MT)**	**Short Term (ST)**	**Long Term (LT)**	**Mid Term (MT)**	**Short Term (ST)**
PD	2	1,179	1,135	1,135	0,372	0,313
GSA	2	1,200	1,135	1,147	0,384	0,325
SEW	2	1,194	1,164	1,164	0,569	0,446
SCS	2	1,147	1,135	1,135	0,541	0,314
ST	2	1,165	1,111	1,121	0,358	0,299
SP	2	1,194	1,164	1,164	0,401	0,328
SHS	2	1,147	1,135	1,111	0,348	0,289
SC	2	1,200	1,164	1,179	0,585	0,486
SER	2	1,161	1,135	1,135	0,372	0,299
SCULTU	2	1,179	1,164	1,164	0,402	0,342
SPS	2	1,200	1,135	1,121	0,359	0,299
NA	2	1,237	1,200	1,200	0,532	0,400

The correction factors due to the type of loss are more important for the total loss than for the partial loss (about 40% of decrease for long term and about 70% of decrease for a mid and short term). For a total loss, almost the same value is obtained if it is a short or a mid term duration loss while for a partial loss, it is observed a decrease of weight from the long term to the mid term (about 60% of decrease) and from the mid term to the short term (about 20% of decrease) of duration of loss.
From these equations, a spatial vulnerability can be assessed by the use of a geographical information system.

5. GIS tool and vulnerability mapping

On one hand, computer science is the domain of scientific, technical and industrial activities related to automatic processing of information. On the other hand, geomatics covers the discipline of gathering, data-mining, analyzing, and delivering spatially referenced information. Because geomatics is the source of geographic information and computer science gives rules for programming methods able to automate complex treatments, the interaction between these domains quickly emerged as mandatory in order to develop the final code of vulnerability analysis. However, the most widely used GIS software are generalists. They offer a catalog of standard tools and are said to be “horizontal software” or “productivity software" because they can’t respond directly to specific problems. Adding its own components to a G.I.S. is possible and consists in the implementation of packages that are designed for a specific application. Then, these specific add-ons make “vertical software”.

Developing a specific G.I.S. add-on requires a thoughtful approach in users’ requirements and technical options of implementation. In particular, the analysis of the technical elements such as the software, data and characteristics of the future G.I.S. tool, are to be studied (Ayral, 2010). That is why the relations and constraints due to this kind of software development will be explained through the following steps: what is the study area, which G.I.S. approach was followed, to conclude by some examples of maps resulting from analysis.

5.1 Characterisation of the study area

The Lot is a department of 5,230 km² split in 340 administrative areas, identifiable by the presence of a large number of economic, historical, touristic, cultural, and natural stakes. Two major rivers and a large regional park contribute to its environmental richness. The census conducted in 1999 established the population at 160,097 people. The urbanization rate is equal to 33% and the average population density is 31 inhabitants per km². The following table (table 3) summarizes the distribution of population (by age) in this study area compared with France, and indicates that the area can be considered as representative of a larger scale territory.

Table 3: distribution of population

	Department	France
Under 20 years old	20,3 %	25,9 %
20 to 59 years old	48,6 %	53,8 %
60 and older	31,1 %	20,3 %

The Lot has an economical network composed by many small and medium industrial enterprises which can be regrouped in four main activities: mechanical, food processing, electrical engineering and electronics. This territory is also an interesting study area because it includes a balanced number of functional stakes (see table 4) that generate employment:

Table 4: balance number of functional stakes

	Services		Employees	
	Total	%	Total	%
Hotels, catering and other accommodations	1045	12.5	1751	6.0
Transport et communications	428	5.1	1073	3.7
Financial services and insurance	340	4.1	1458	5.0
Real estate	186	2.2	188	0.6
Business Services	1434	17.2	4744	16.2
Community and personal services	2562	30.8	2548	8.7

Education	459	5.5	4249	14.5
Health and social services	1302	15.6	7056	24.1
Administration	579	7.0	6219	21.2
Total	8335	100	29286	100

In order to characterize the study area, the territory will be cut into meshes (by default 250x250m) by the GIS tool (METEHOR) to provide a pertinent representation of the features of the area.

5.2 G.I.S. tool METEHOR

A specific tool dedicated to the evaluation of the vulnerability (METEHOR) is developed in order to implement the methodology of vulnerability evaluation described in this paper. METEHOR is the acronym in French of « Module d'Evaluation de la vulnérabilité d'un Territoire pour les Enjeux Humains et ORganisationnels » which aims to assess human and functional vulnerability and to produce cartographical results. It has for goal to automate the vulnerability analysis on the MapInfo GIS, by the way of specific steps (Ayral, 2010). The first step concerns the configuration of cartographical databases to link the stakes typology of commercial databases to the ones defined in our methodology. The second one is consist in the creation of a spatial discretization grid (mesh) composed of a number of cells. The third one is to assess the vulnerability in each cell automatically. And the last one is to visualize the different layers of vulnerability.

5.3 Examples of vulnerability maps

With the help of the specific tool developed on the MapInfo GIS, different kind of vulnerability maps can be obtained. The following example maps (Figures 7, 8) concern a map of human vulnerability during the day (Figure 7, left), during the night (Figure 7, right) and a map of functional vulnerability (Figure 8)

These maps allow performing a multi scale analysis:

- at department / region scale to have a global view of the vulnerability state
- at town or town area scale in order to highlight potential vulnerability spots

In the example shown below (Figure 7, 8), the global vulnerability of a given area was calculated and gave the possibility for the user to visualize both the human vulnerability (during day and night) and functional vulnerability. It shows that human stakes might be strongly impacted in case of an accident during the day especially in cities and on main roads (first map from the left) due to the traffic of workers or tourists and goods transportation. But during the night (second map), the vulnerability of the same stakes is more homogeneous because there is a diminution of human activity and transportation at night.
One the other hand, it is possible to see on the third map that the functional vulnerability is greatly spread on a large proportion of the territory: intuitively, the area may be containing sensible or critical stakes able to impact the functional balance of the department studied.

This study allows obtaining a new representation to qualify the territory exposed to hazards. For potential accidents with very large consequences, as is it the case of toxic gas dispersion, decision makers will have an integrated vision of the territory potentially exposed with:

- the spatial repartition of people (day or night) and an easy identification of the most vulnerable part of the territory,

- a location of main functionalities on the territory

These data could be used in order to adapt risk analysis for an industrial site and its surroundings.

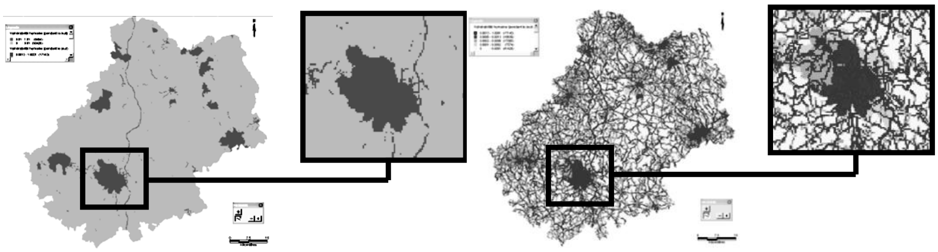

Figure 7: map of human vulnerability during the day (left) and the night (right)

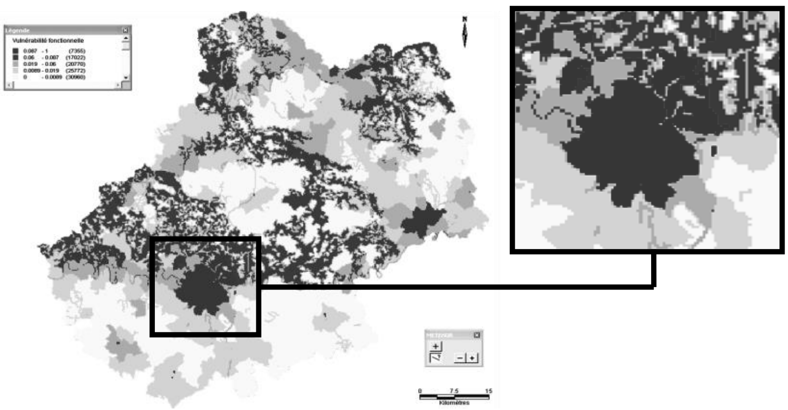

Figure 8: map of functional vulnerability of a French department

6. Conclusions

A structured methodology is proposed to map the vulnerability of territory submitted to an industrial accident. This methodology is based on two approaches; the first one (quantitative) realizes a census of population following a structured way; the second one (semi quantitative) qualifies the vulnerability of stakes which contribute to the stability of the society. These two complementary approaches give an answer to the problem of vulnerability assessment and on the quantification of the different types of territorial stakes within the area. In order to qualify this vulnerability, the Saaty's methodology is used, which is based on the use of expert judgments and hierarchical structures. The treatment of experts' judgments allows obtaining weighting factors relative to each type of stakes. The methodology has been implemented within a GIS (MapInfo) to make available an operational tool for risk managers, like competent authorities or risks experts to assess the vulnerability maps (human or functional vulnerabilities). The required information about the stakes can mainly be extracted from commercial databases, and the user is assisted in all the steps from the selection of the study area and the grids, to the identification and quantification of the stakes, while the vulnerability calculations are completely automated. Using this tool, the end users will have a formalized representation of the situation of the vulnerability of the territory in order to suitably manage industrial risks. Further developments must be considered, namely:

- accounting for the interaction between networks which is essential to assess the functional vulnerability in a more realistic way,
- defining new geographic levels of analysis named "area of attractivity" which is an aggregation of different districts in interconnection.
- adding other levels of vulnerability, such as psycho-sociological or media related ones.

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Land Use planning based on Risk Criteria

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Abstract

This paper presents a framework for supporting land use planning decisions around hazardous chemical facilities using a Multi-Criteria Decision Analysis (MCDA), which incorporates the special needs of the area under consideration. The decision is facilitated by a procedure that generates the efficient alternative solutions (land use patterns, LUPs) by examining the consequences associated with each alternative. The results are presented on the map of the area, which gives an overview of the impact of each alternative. The decision maker (planner) can modify the proposed solution according to personal preferences and thus can judge the effectiveness of the new alternative. The proposed methodology has been applied to a case study where an expansion alternative of a hazardous chemical facility is considered along with (a) existing and proposed uses of land, (b) the expansion necessities of the nearby community and (c) the overall environmental and social impact.

Keywords: Hazardous chemical facilities, land use planning, risk assessment, MCDA.

1. Introduction

One possible way for managing the risk around chemical sites is through limiting the possible consequences of a major accident controlling the population exposed to the risks through appropriate land use planning (LUP) schemes. Member states in the European Union having recognized this necessity have undertaken the obligation to develop such plans under the so called SEVESO II directive of the European Council (1996). Indeed, it has been shown by several studies that protection of public health, worker's health and of the environment can be greatly achieved through sound land use and emergency response plans. This problem, however, has not a unique solution, as different European Member States apply their own legislation. There are three general philosophies regarding Risk Analysis ranging from a purely "deterministic" approach to one exhibiting an, as complete as possible, quantification of the uncertainties faced in this risk analysis. The methodology presented here has been proposed by the Systems Reliability and Industrial Safety Laboratory (SRISL) of the NCSR "DEMOKRITOS" and aimed at facing these problems based on the results of an earlier research project named "LAND USE PLANNING AND CHEMICAL SITES (LUPACS)" funded by the Commission of the European Union under contract No ENV4-CT06-0241 (DG12-DTEE). The present paper is based on a quantified

example taken from the industry; namely the establishing of land use decisions in the expansion of a stainless steel manufacturing plant is considered taking into account the existing and proposed uses of land in the area together with the environmental and social impact.
The rest of the paper proceeds as follows: Section 2 gives a short description of the principles of the multicriteria analysis methodology used in the Land Use Planning process. Section 3 presents the case study and Section 4 gives the problem definition. In Section 5 the results of the case study and discussion on them are presented. Last, Section 6 contains the conclusions of the methodology application.

2. The Multicriteria Analysis Methodology

Decision making in real environments, especially when more than one stakeholders are present, becomes complicated by various constrains, such as the negotiations among a group of people with different background, the defeasible reasoning of each party and the varying level and quality of information, to name few of them. Additionally, decision makers have to be proficient in mathematics and have good handling of computer tools.

The classical approach to a multicriteria decision problem can be distinguished in four steps, as mentioned by Keeney and Raiffa (1993):

1 Determination of alternatives;
2 Determination of consequences (which serve as decision criteria);
3 Preference assessment, and
4 Determination of “best” alternative

The first two steps are common in all MCDA problems. Differentiation occurs in the last two, where the specific methodology for assessing preferences and “best alternative” may differ among various researchers. In this work the notion of the “Efficient Frontier” is used, as explained in Papazoglou et al. (1998 and 2000). The steps of the methodology are briefly presented below.

2.1 Step 1, Generation of alternatives

This step includes determination of the available alternative courses of action from which one must be chosen. In the land use planning context, alternative uses of land around a hazardous site constitute alternative courses of action and hence alternatives in the sense of the MCDA paradigm. On the other hand the use of land around a site could be given and fixed and the alternative causes of action could consist in the sitting of a new installation or an extension of an existing installation. In both of these cases, however, the changes in the sources of risk must have a geographical dimension in order to be characterized as a land use planning alternative. As a result, one might have either only a few alternatives to choose from or a lot. The developed methodology can handle either case but is more useful when there is a great number of alternatives to choose from, as the first case is trivial.

The fundamental concept of the proposed methodology is that the area under consideration is divided into a number of smaller parts called cells, defining next a number of alternative land development types (LDT) for each and every cell. A Land Use Pattern (LUP) is being defined over the area of concern whenever the LDT for each and every cell in the area has been determined and represents an alternative course of action. The number of possible LUPs represents the number of alternatives to choose from. This latter number depends on two quantities: Firstly on the number of cells comprising the area of concern, and Secondly on the number of alternative LDTs available for each cell.

The number of cells of an area depends on the shape and the dimensions of each cell. Any shape and dimension is acceptable by the methodology and the particularities of each cell are to be determined by the governing concerns of the land-use planners. Nevertheless, the developed methodology has considered the following types of cells:

- Orthogonal Cells of User Defined Size

This was actually an approach employed in earlier attempts to develop the methodology and it is presented here for the shake of completeness.

- Ring Shaped Cells of Specified Dimensions

This approach is equivalent to the 'safety zoning' concept, where 'zones' around a hazardous installation are defined in terms of distances.

- Iso-risk Cells of Any Shape

These cells are defined as areas characterized by the same level of individual risk or by a level of individual risk within a certain range. Individual Risk is defined as the per annum death probability of an individual living at a specific distance from the hazardous facility, as a result of any accident that might occur in this facility.

- General Cells of Any Type

This type comprises any type of shape and size of cells where these characteristics are determined by other land-use planning (e.g. existing development patterns), or geographical considerations. For this cell type the development of a GIS-based tool has proven particularly helpful.

The second element in the generation of alternatives is the land-development types available for each cell. The methodology accepts in general alternative LDTs that may be different for each cell. Of course similar alternative LDTs for every cell are possible. A fundamental property that an alternative course of action must have in order to be meaningful in a decision analysis context is that it must differentiate itself in terms of the expected consequences from other alternatives. For this reason the LDT ought to be defined in terms of characteristics that change the consequences that are part of the problem. That is why an alternative approach to the problem set up and to the methodology would be to first define the consequences against which the alternative courses of action are to be evaluated. In any event the two stages of the methodology i.e. generation of alternatives and consequence assessment are interrelated and interactive in nature, so that they ought to be meaningful in the context of risk informed land use planning. For example, two different building development types having different economic value but resulting in the same population density although of interest from a number of reasons (e.g. employment) are not of interest in the context of problem set-up if the set of consequences does not distinguish among various economic consequences. If only a comprehensive overall economic consequence is considered the LDT with the best performance will always

be better from the other since they will be equivalent from the risk view point (owing to the same population density). Since the developed methodology was mainly focused on the risk aspects of the problem, the LDTs considered and developed were those that differentiate the risk-related consequences.
Another aspect of the alternating course of actions is that they refer to the eventual steady-state conditions. This means that if a particular LDT is chosen for a cell this represents the final state of development. Present population density might be lower but whatever density is implied by the LDT chosen at the end might be achieved sometime in the future.

2.2 Step 2, Determination of objectives and of consequences

This step of the methodology consists of the development of the set of attributes that are used to evaluate each alternative course of action. As mentioned in the previous step of alternative-generation these two steps are in practice interactive and iterative in sequence. Firstly a hierarchy of objectives is developed. The hierarchy is such that elements at each level represent sub-objectives serving the satisfaction of the objectives of the immediate level above. The development of the hierarchy stops when each and every objective at the lowest level of development can be quantified by a scalar quantity. Since our interest was mainly focused on the risk aspects of the problem, the set of the objectives developed has been detailed in the risk area and is more general in other areas of concern. An example of the objectives and associated criteria or attributes is the following:

Table I: Types of Objectives and associated attributes.

Objectives	Attributes
Reduce the number of fatalities in the general Population (resulting from an accident)	Potential Loss of Life (PLL) (=expected number of deaths)
Reduce the number of fatalities in sensitive segments of the population (resulting from an accident)	Potential Loss of Life in sensitive segments (PLLS)
Reduce the number of injuries (resulting from an accident)	Expected number of Injuries
Reduce the level of risk at which population is exposed	Number of People exposed to a certain level of individual risk
Reduce the level of noise at which population is exposed	Number of People exposed to a certain noise level (in dbs)
Increase the overall Socio-economic well being of the population	Total Socio-economic Benefit

In order to calculate the consequences, i.e. the value of each attribute for each alternative course of action the following are necessary.
For health and environmental type of consequences two types of information are necessary. First, one must measure the intensity of the potential impact from a major accident in the chemical facility over the whole area, i.e. for health impact measured in terms of loss of life the individual risk profile is needed. This profile gives for each point in the area of interest (on which a fine rectangular grid has been applied), the probability per year that an individual of the general population will die as a result of an accident in the chemical facility. Similar profiles for risk of death for sensitive individuals or for risk of injury are necessary for the corresponding attributes. For

environmental impacts other types of profiles as concentration of a particular substance at each point of the area of interest is necessary. Such profiles are obtained from detailed quantitative risk analysis. Second, necessary element for attribute evaluation is the population profile exposed to the various types of health risk or environmental impacts.
If the location of the hazardous sources is given and invariable for the problem, the risk profiles and the environmental impact profiles are given and fixed for each and every alternative course of action. What changes in this case with each alternative is the population profile exposed to each type of risk. If the location of the hazardous sources are varying as part of the alternative courses of action and the land use patterns are fixed then the population profiles are also fixed, while the risk profile ought to be recalculated with each alternative. Finally, both risk profiles, as well as, population profiles are allowed to vary with each alternative.

2.3 Step 3, Generation of the Efficient Frontier

Classical MCDA approaches, after the determination of alternatives and the evaluation of each alternative on the set of attributes, involve two final steps: the assessment of preferences by the decision-maker and the choice of the most preferred alternative. This in general comprises the assessment of a value function and/or of a utility function quantifying preferences among certain and uncertain alternatives, respectively, as described in Keeney and Raiffa (1993). This approach, however, is not very practical or useful in a policy context where these decisions are negotiated among a number of policy actors. As a result we have adopted a different approach. The corner stone of this approach is the fact that value tradeoffs among highly debated issues, as for example, economic benefits and public health consequences are not formally set. Such tradeoffs are unavoidable and are always made implicitly or explicitly when the final decision is made. The methodology, we propose aims not at making such a decision but rather at creating a platform to facilitate the final choice by the appropriate people at the appropriate bodies. In order to achieve this scope the concept of dominance is introduced.
An alternative (I) is said to dominate another (II), if (I) is either better or equivalent in each and every attribute of evaluation and strictly better in at least one attribute. Comparison in one attribute is rather easy since it does not involve value tradeoffs. For example, if an alternative solution results in 40 deaths on the one hand and 106 monetary units of benefit on the other, it is definitely preferred to one that results in 50 deaths and 106 monetary units of benefit. In this case alternative (II) is said to be dominated by alternative (I). An alternative is called dominant or efficient, if there is no other alternative in the feasible set of solutions that dominates it. The set of all efficient alternatives constitutes the efficient set or the efficient frontier, as described in Keeney and Raiffa (1993). The efficient set is usually a small subset of the original set of all possible alternatives. Determination of the efficient frontier for continuous decision variables is achieved with the help of techniques of multi-objective optimization. In the proposed approach both the decision space and the consequence space are discrete. A particular mathematical algorithm is adopted that allows for the fast determination of the efficient alternatives out of the very large number of alternatives under certain conditions, as explained in Papazoglou, Bonanos and Briassoulis (2000) and in Papazolglou and Christou (1997).

2.4 The GIS-based tool

It is often the case that the types of decisions that are made by public or private sector organizations involve geographically related data and information, a large number of feasible alternatives, as well as conflicting and incommensurate evaluation criteria. The use of a GIS environment offers in this case a solution. Indeed, a GIS application gives the decision maker the ability to interact with information from different sources. Such sources could be vector or raster maps of the wider considered area, information representing the distribution of parameters that will be considered (e.g. population), information of specific areas that are more sensitive and more special than others (e.g. schools, hospitals, parks, lakes etc.) and finally results of studies or models related to the risk induced by the operation of industrial installations like the Isorisk Curves. Such a GIS tool has been developed in the framework of this methodology and helps a lot in the visualization of information related with the decision process of land use planning based on the efficient frontier.

The present project has been developed under ESRI's Arcview©. The areas of interest (cells) are defined as vector polygons. Pre-calculated individual risk for the study area is used to calculate mean risk in each cell. Any other spatial or non-spatial data as population distributions, price of land etc. is also incorporated into the project. An external module is then invoked which generates the efficient frontier. The user is then provided with the following abilities:

- She/he can select an efficient point in the consequence space and the corresponding LUP is presented in the main GIS window, or

- She/he can create a LUP at will and observe the consequences this LUP invokes in the consequences space graph.

It must be noted here that the visualization of the efficient frontier for more than two evaluation criteria (e.g. x1, x2, x3) is presented as its 2-D projects in all the planes defined by the criteria axes (e.g. the x1x2 plane, the x2x3 plane and the x3x1plane), while in Figure # 4, a screen shot of this tool is presented, where the efficient frontier is depicted together with the area digitized map and the LTDs applied.

3. Case Study description and alternative building

The hazardous installation is a stainless steel manufacturing plant established approximately 200 years ago and revamped on several occasions in the meantime. Since the early 1990s the company is one of the competing companies in the steel world market. The plant is situated north of a city with 8000 inhabitants. The original part of the city is built very close to the industrial area (for historical reasons) and contains some old wooden houses and the old church, all built in the era of the industrial revolution. There were changes since then as the old houses were demolished and new two and three storey residential houses were built together with a new shopping center, schools and day-nurseries at distances not longer than 900m from the plant. Two small rivers and a canal run through the town stemming from the nearby lake. Water supply is of great importance to the factory owing to the steel annealing process it applies and is satisfied from this lake. For this reason severe environmental monitoring is exercised on the use of lake water, as it can potentially be endangered by the plant operation. On the other hand, along the shores of the lake

there are a lot of summer houses, some of which are also used for permanent living, a situation which has put pressure on the Land Use Planning authorities and the politicians to make decisions about detailed Development Plans of the town and the greater area in the early 1970s.
The dangerous substances handled in the plant, potentially harmful both to humans and the environment, are: a) Hydrogen Fluoride (HF) which is stored in a 30 m3 tank with a total use of 804 tons per annum; in the form of gas HF is very harmful and can be fatal to people, b) LPG (butane/ propane) stored in a 200 m3 tank rather close to the HF-tank; in the case of a leakage and fire a 20-80 m jet flame can cause severe injuries, together with the Boiling Liquid Evaporating Vapour Explosion (BLEVE) accident, and c) Oil stored and used in buildings where there is a potential risk of fire; burns and injuries from the fire and suffocation from the smoke could be the result.
In 1976 the company wanted to acquire more land for expansion of the plant (area 1 + 2, see Figure # 1). In parallel to the company's wish to expand, the community was also discussing the idea of allowing the building of 110 semi-detached houses for the employees on land owned by the company. This plot of land is situated to the west of the plant (see Figure # 1). After some debate with the planning authorities a decision was made that only half of the area was included in the Development Plan (area 2, see Figure # 1).

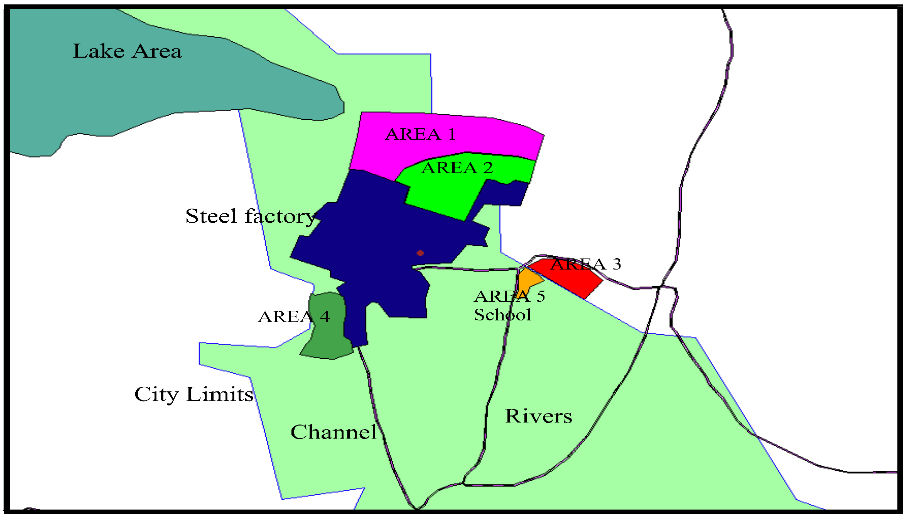

Figure 1: General view of the installation and surroundings division in regions

The authorities were concerned with the unwanted consequences regarding the expansion, which include the following:

- An accident at the plant with HF or LPG involved could be fatal to people both on-site and off-site;
- An accident while transporting HF or LPG to the plant could be fatal off-site;
- A breakdown of the sewage system and other safety premises of the plant could be disastrous to the environment.

While the positive impact can be summarized as:

- New houses offered by the company to their employees;
- Continuous production at the plant (5 shift schedule) could make it convenient to live close to the plant;
- The company objective to be involved in the LUP-process was deemed favorable for the local authorities.

These general concerns and social conflicts have been formulated in an MCDA problem setting, resulting in the following alternatives (see also Figure # 1):

1. Build or not 25-30 houses in Area 1.
2. Expand or not the plant in Area 2.
3. Build or not 20-30 houses in Area 3.
4. Build or not 30-50 houses in Area 4.
5. Add or not 250 children to school in Area 5, or remove school from Area 5.

4. Case Study description and alternative building

The three main steps of the methodology described in section 2 have been applied as follows:
The first step, i.e. the generation of alternatives, is to define the regions for which a decision has to be made in the area around the site and the area of the possible expansion, as in Figure # 1. Then, according to the methodology alternative Land Development Types (LDT) are being defined in each cell reflecting the philosophy and the needs of the local or regional planners. However, one should stress that, in the case of already existing community plans and regulations regarding allocation/position of existing and future land-use patterns (as in this case study), there is little freedom in defining new land development types. Possible options are to propose restrictions on population densities in the direct vicinity of the plant. The economic benefit of both land-use pattern and plant extension has been determined in terms of capital gain (net present value). This includes: value of land (mainly based on the marked value of houses and industrial estate, which as mentioned in Luttik (2000) may be substantially differentiated in relation to their vicinity to the installation). As a consequence of that, for each cell one can assign two alternative Land Development Types (LDT) in each one of the areas 1,3 and 4 and three in Area 5. Note that for Area 2 the question raised was not that of alternative LDTs, but rather a question that changes the risk profile itself. Each LDT, when applied to a cell, defines the population distribution and economic benefit in it, as presented in Table 2.
In step 2, calculation of consequences, the criteria used in this case study in order to measure the consequences of each LUP are the following: a) Potential Loss of Life (PLL), which represents the expected number of fatalities among the population around the facility owing to an accident in the facility over a period of 50 years (plant operation “life-time”), and b) Net Economic benefit, which is calculated as the sum of the economic benefits implied by the LDT of each region in the area using the data provided by local authorities.
The second of the criteria is related to the benefit of the land uses and is calculated according to the values that are presented in Table 2. Restricted areas, having a use

that cannot be changed or areas that are blocked do not affect the calculation of the value of the corresponding land. For any other LDT encountered within the problem, the decision maker has defined a value for the land that is assigned to the corresponding use. For the calculation of the first criterion (PLL), Individual risk along with population distribution implied by each LUP are used through the elaboration of two quantified risk assessment (QRA) studies (one for the existing condition of Area 2 and one for the plant expansion in Area 2).

Table II: Setting of the problem.

AREA No	Existing population	Proposed population	Existing benefit (monetary units)	Proposed Benefit (monetary units)
Area 1	10	109	10915	26897
Area 2		Risk Increase	0	Benefit from Plant Expansion
Area 3	115	235	29578	199979
Area 4	123	323	52795	144070
Area 5 (school area)	350	600 OR 0 (2 alternatives)	64590	129180 OR 0 (2 alternatives)

Synthesis of the Individual Risk (over an operation period of 50 years) resulted in the overall risk profile according to the methodology described in Papazoglou et al. (1992, 1996) which is presented in Figure # 2 in the form of isorisk curves of death probability of 10^{-6} to 10^{-8} per year.

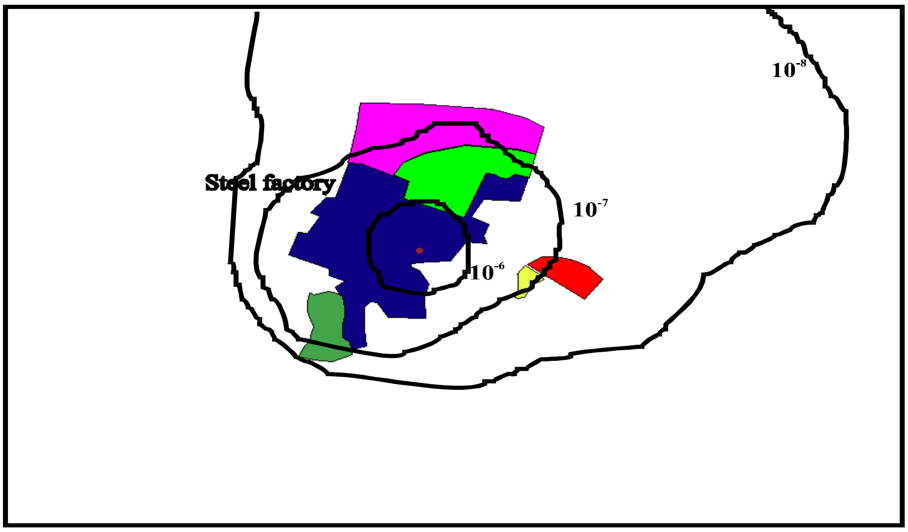

Figure 2: Individual Risk Contours owing to plant operation

In step 3, the generation of the efficient frontier, the objectives in this case study were formulated as follows: a) Minimize the potential loss of life (PLL), and b) Maximize the economic benefit. There are 24 different LUPs for each alternative of Area 2. However, of interest is the set of efficient or non-dominated LUPs that is those solutions for which there is no other solution that is equal or better in both criteria set.

Two efficient frontiers were generated, one for each alternative in Area 2, containing eight efficient solutions for the non-expansion alternative and seven for the expansion one. These frontiers are synthetically presented in Figure # 3 assuming an expansion benefit of 200000 monetary units for the society as a whole.

5. Results and Discussion

As discussed in Section 4, both options a) non-expanding the existing facility, or b) expanding it, are associated with an efficient frontier representing the available land use patterns in the general area of the installation, as given in Figure # 3a and 3b. As the economic benefit of plant extension is being determined in terms of both of capital gain (net present value) and of social gain (employment increase), its value is influenced by many factors. Different working assumptions have shown that the curve in Figure # 3b is shifted upwards assuming higher values for the economic benefit of plant expansion. For the sake of analysis 200000 monetary units of expansion benefit have been assumed in Figure # 3b. Following the constraints set forth by the planning team one tries to peruse the efficient frontier calculated for the expansion case (Figure # 3b). Point A in the efficient frontier corresponds to the solution with maximum benefit and maximum PLL, with houses built wherever allowable. An alternative land use pattern is the one corresponding to point B.

Moving from A to B means that not a full blown urbanization schema is followed. On the other hand if all restrictions in the uses of land are exercised, one is left with point E corresponding to the solution with the absolute minimum PLL and economic benefit for the expansion case (Figure # 3b). At this point the efficient frontier can form the basis for a discussion on the available alternatives without formally establishing value tradeoffs. For example, it can be argued and easily accepted by the various stakeholders that solution (B) would be more preferable than solution (A) (see Figure # 3b) since it implies a substantial decrease in PLL while the corresponding decrease in benefit might be judged as not equally significant. Furthermore, it could be argued that D is preferred to E since the latter solution implies a large decrease in benefit with marginal decrease in PLL. The whole discussion can then concentrate around point C and on whether the gains in PLL from the level implied by point A to the level implied by point B justifies the corresponding reduction of benefits. If the answer is affirmative and if, moreover, further gain in PLL from D to E is judged marginal, then any solution around point C might represent an acceptable solution.

These considerations can be further facilitated by the simultaneous perusal of the implied LUP by each point of the efficient frontier on the GIS platform where the map corresponding to a chosen point in the efficient frontier is also visualized. In Figure # 3c the “superimposed efficient frontier” of the two decision possibilities (i.e. expansion – no expansion) in area A is presented, assuming again an expansion benefit of 200000 monetary units. Perusal of this frontier shows that this represents a synthesis in the decision space, as its lower part contains the efficient solutions of the “no expansion” decision, coupled with its upper part which contains points of the efficient frontier of the factory “expansion” decision. In other words, as it is common in everyday life, land use development decisions are tightly connected with the overall gain attributed to them compared to the risk they induce to the public. So both expansion and no-expansion of the company could be interesting for the local society, if surveyed from different viewpoints.

It is noteworthy, that in the efficient frontier of Figure # 3c certain decision couples are automatically excluded from the efficient set, as sub-optimal, e.g. expansion of facility and increase of school population. A final supportive use of the efficient frontier is that of sensitivity analysis where the variation of the most preferred solution as a function of the implied value tradeoffs between benefit and potential loss of life can be explored, if, for example, linear value functions, that is, a constant "exchange rate" between benefit and potential loss of life are assumed (cf. Papazoglou et al., 2000). Additionally, the use of the GIS tool, with an external module for the generation of the efficient frontier has proven very helpful.

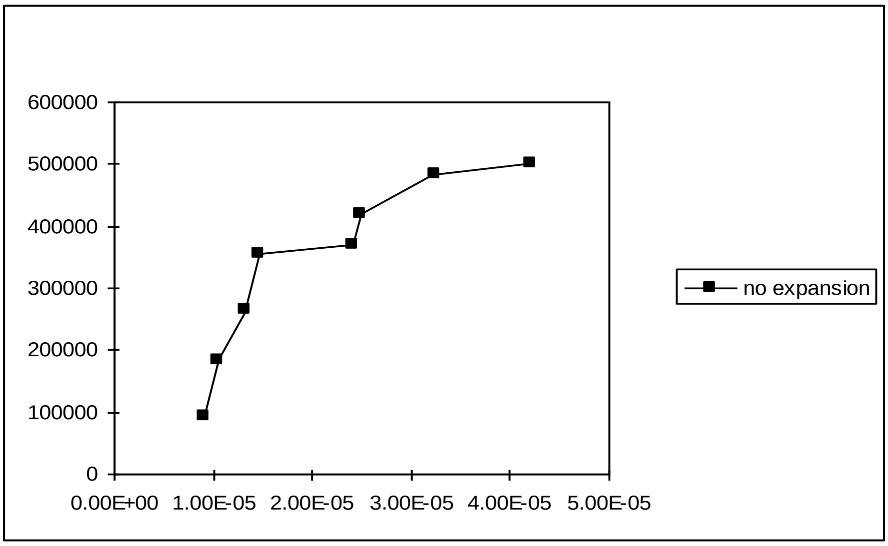

Figure 3a: The efficient frontier for the option of non-plant expansion in Area 2

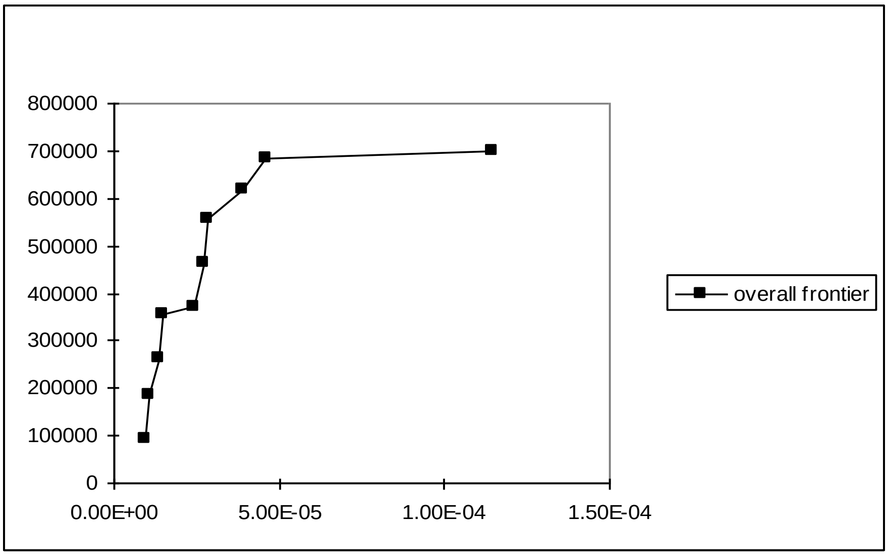

Figure 3b: The efficient frontier for the expansion option of the plant in Area 2 assuming that the expansion benefit is 200,000 MONETARY UNITS

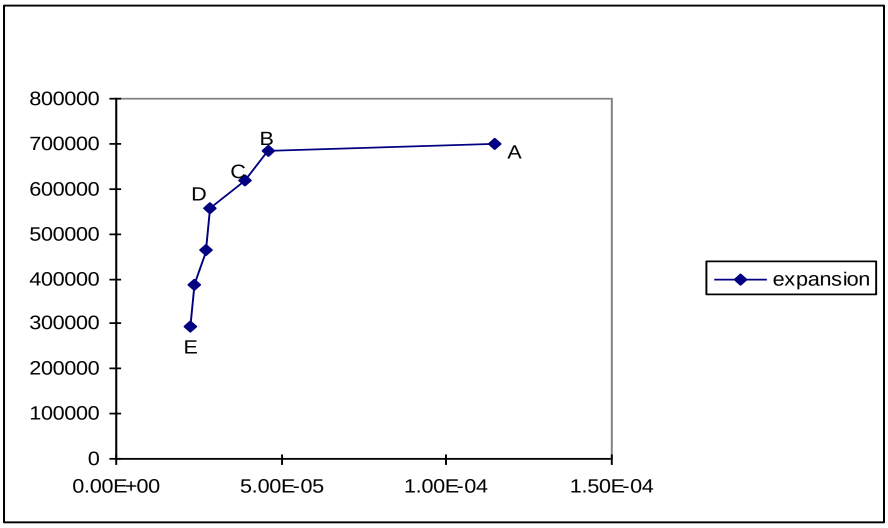

Figure 3c: The overall efficient frontier including the expansion option of the plant in Area 2 (expansion benefit is assumed 200,000 MONETARY UNITS).

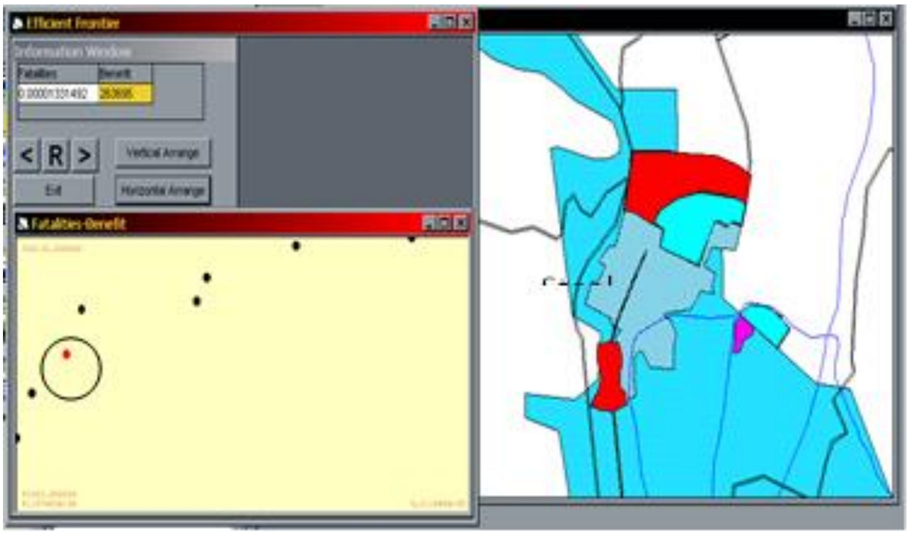

Figure 4: Screen shot of the developed GIS tool depicting a point on the efficient frontier and the associated LUP.

6. Conclusions

A framework that supports decisions for land use planning around hazardous chemical facilities using the advantages of a GIS environment has been presented. The proposed scheme contains all the stages that are necessary for the planner to define the problem in detail incorporating also the peculiarities of the area under consideration. The decision is supported by a procedure that generates the most efficient alternative solutions (LUPs) according to the consequences that each one of them causes, so that the decision maker can then choose one or more of them. The results are presented on the map of the area giving an accurate overview of the effect that each alternative will have on the area. The decision maker (planner) can modify the proposed solution according to personal preferences or societal needs and thus judge the effectiveness of the new alternative. The use of the “efficient frontier” is proposed since it provides a platform that can facilitate the discussion between the various stakeholders as it removes from the debate a large number of “what if” questions by keeping only those solutions that cannot be rejected on “technical” or “scientific” arguments.

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Hazardous areas extension in explosive atmospheres caused by free gas jets

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Abstract

This paper regards the validation procedure of the Italian Guide CEI 31-35 formula, used to calculate the hazardous areas extensions in places where explosive gas atmospheres may be present. In industrial activity, a typical event which cause explosive atmosphere consists of damaging and leakage from unions, gaskets, valves of pipes and vessels. At this purpose, in this work it has been taken into account the accidental discharge of flammable gas into a quiescent atmosphere through an orifice. Validation has been performed by comparing calculated values with experimental data. Two gases have been taken into account: methane and hydrogen. Different scenarios have been analyzed, each one differing from the others in the gas release cross section and in the vessel pressure. Results show that the formula fits well not catastrophic industrial accident situations.

Keywords: Risk Analysis, Explosive gas atmospheres, Hazardous Areas Extension.

1. Introduction

Object of this paper is the risk assessment in industrial activities as regards releases of flammable gases from pressure systems, which can imply the potential for an explosive atmosphere. Such releases into the atmosphere can be expected to occur periodically or occasionally during normal operation from, for example, relief valves ('Primary releases'). On the other hand, accidental releases, which are not likely to occur during normal operation ('Secondary releases') are to be taken into account; this kind of releases regards for example small leaks from pipe-fittings, joints, flanges, valve glands, seals of pumps.
In the work here described particular attention has been paid to gases lighter than the air, such as hydrogen and methane.

In order to guarantee the safety and health protection of workers potentially at risk from explosive atmospheres in industrial activities, hazardous area classification should be carried out as an integral part of the risk assessment to identify areas where controls over ignition

sources are needed, as regards construction, installation and use of equipments. Area classification is based on the frequency and persistence of the potentially explosive atmosphere and on the degree of ventilation provided to ensure that any explosive atmosphere does not persist for an extended time.
The work here described particularly regards the determination of the hazardous area extent. The area where the concentration of the considered flammable substance is higher than the LEL ('Lower Explosive Limit') is, by definition, an hazardous zone; the area outside the LEL boundary may be considered a non dangerous zone, if the gas concentration is enough lower than LEL. Authors previously had studied a formula to calculate hazardous area extent whenever dangerous quantities and concentrations of flammable gas may arise; this formula had been analytically found out, based on the diffusion theory of a free turbulent round jet and it had been compared both with calculations performed by the analytical software 'Effects' and with numerical simulations carried out with the Computational Fluid Dynamics code 'Phoenics' [1], [2] [3]. This study had been performed by taking into account: methane, ammonia and hydrogen, but also heavier gases as propane and butane. Furthermore the formula had been introduced in the Italian Guide CEI 31-35 [4], "Guide for classification of hazardous areas", which, in compliance with the European Standard IEC EN 60079-10 [5], regards the classification of hazardous areas, whenever dangerous quantities and concentrations of flammable gas or vapour may arise.
This paper illustrates the validation procedure of the formula, by comparing it with experimental data.

2. Materials and methods

2.1 Method for calculating hazardous area extent

The Italian Guide CEI 31-35 reports eq. (1) able to calculate the extent of hazardous area when a flammable gas is discharged into a quiescent atmosphere through an orifice. Looking at eq. (1), the distance d_z is the distance from the orifice, along the central axis of the jet, at which gas concentration is reduced to the lower explosive limit ('LEL') of the gas.
This equation had been analytically found out by studying the released gas behaviour (subsonic or sonic), which depends on the containment vessel pressure value, P_r respect to the atmospheric one, P_a. Besides, it had taken into account the relationship among the concentration profile of gas, along the axis of the jet, the distance to the orifice and the jet discharge diameter. Finally it had to be considered the strong dependence between the discharged gas concentration and its density (thus its molecular mass) related to the surrounding air [6],[7],[8],[9],[10],[11].

$$\mathrm{d_z} = \frac{5{,}2}{\mathrm{k_{dz}\,LEL}}\sqrt{\mathrm{P_r}}(\mathrm{M})^{-0{,}4}\sqrt{\mathrm{S}} \qquad (1)$$

where
- k_{dz} is a safety coefficient applied to the LEL for the calculation of d_z
- P_r is the absolute pressure inside the vessel [Pa]
- S is the cross sectional area of the outlet [m^2]
- M is the gas molecular mass [kg/kmol]
- LEL is the lower explosive limit of the gas [% vol].

Fig. 1 shows an indoor jet flow of methane computed by the Computational Fluid Dynamics software Fluent. Different colours indicate the concentration of methane in air. The parameter

d_z represents the distance from the source of release at which the gas concentration (X_m%) along central axis, related to the gas concentration at the outlet, is reduced to the LEL. The area where the concentration of the gas is higher than its LEL is, by definition, an hazardous zone; the external area may be considered a non dangerous zone, if the gas concentration is enough lower than LEL; in fact, actually, the hazardous area is increased by the safety factor k_{dz} (whose typical values range from 0,25 to 0,75 [4]), i.e. the distance d_z is calculated at the k_{dz} ·LEL boundary.

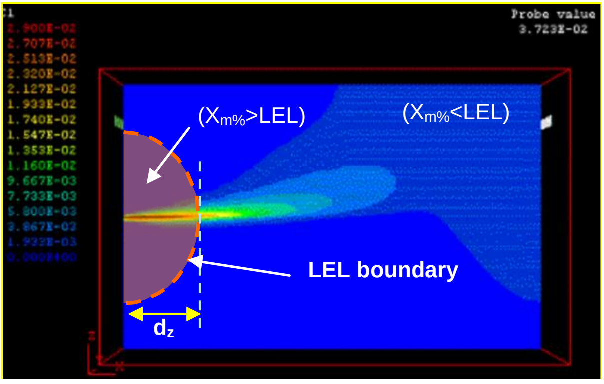

Figure 1. Hazardous zone around a jet flow of methane

Referring to the distance d_z, the hazardous zone can be computed. Fig. 2 shows, as example, a gas release from a damaged flange. The explosive volume can be approximately calculated by considering the volume of a cone having height d_z and depending on the jet direction The hazardous zone around the pipe is a sphere resulting from the envelope of all the possible explosive volumes.

2.2 Experimental data

In order to assess the validity of the d_z formula, shown in eq. (1), experimental tests have been considered. The first one consists in natural gas (92% methane) supplied from a vessel via a pressure regulator (ranging from 3.5 to 71 bar) to a nozzle whose internal diameter is equal to 2,7 mm [7].
The second configuration consists of hydrogen leak through a circular orifice whose diameter is 0,5 mm. Hydrogen comes out from a 19 l vessel. By means of a valve connected with a pressurizing system, it is possible to change the storage pressure from 50 to 400 bar [12].

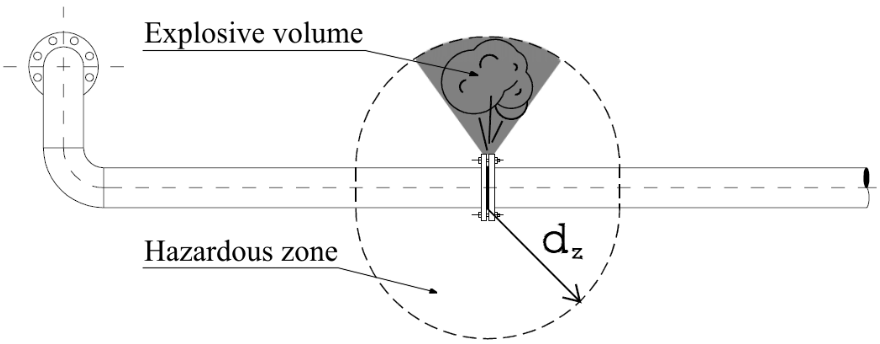

Figure 2. Hazardous zone around a jet flow of gas

The third configuration consists of hydrogen releasing at 400 bar, through a 0,2 mm nozzle [13].
The fourth configuration consists of hydrogen release, from a tank pressurized to 100 bar, through a 3 mm nozzle [14].
For both methane and hydrogen, gas-air mixture concentrations have been measured along jet axis, at different distances from the release source.

As regards source diameters, they are of the order of magnitude which is typical of small leaks. In fact these experimental data are used to validate eq. (1) which had been studied referring to releases from small orifices.
It can be noticed hydrogen pressures are higher than methane ones; this is due to the fact that normally hydrogen is stored in gas cylinders at higher pressures than the ones at which natural gas is distributed.

3. Results and discussion

Fig.3 shows, for different vessel pressures, both experimental (points) and calculated (continuous lines) d_z values which are function of methane concentration (% in volume) data. Source diameter is equal to 2,7 mm.

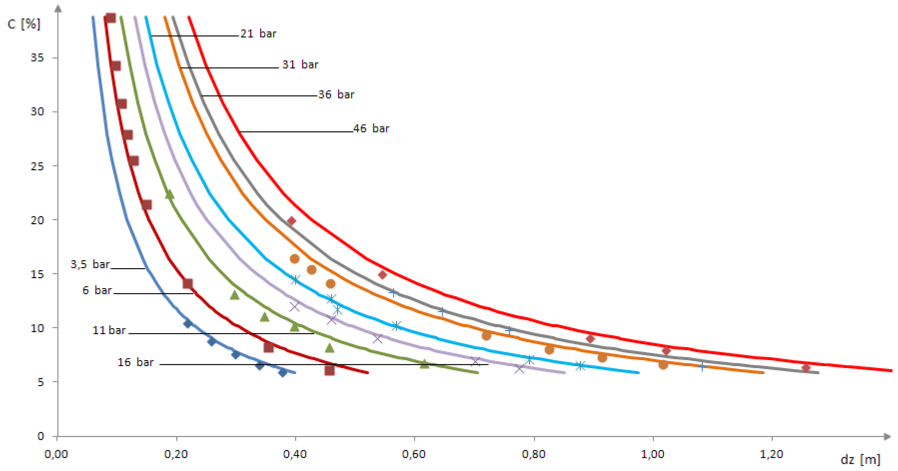

Figure 3. Comparison between experimental and calculated d_z values for methane releases

Figg.4 and 5 show, for different vessel pressures, both experimental (points) and calculated (continuous lines) d_z values which are function of hydrogen concentration (% in volume) data. Source diameters are equal to 0,2 mm, 0,5 mm and 3 mm.

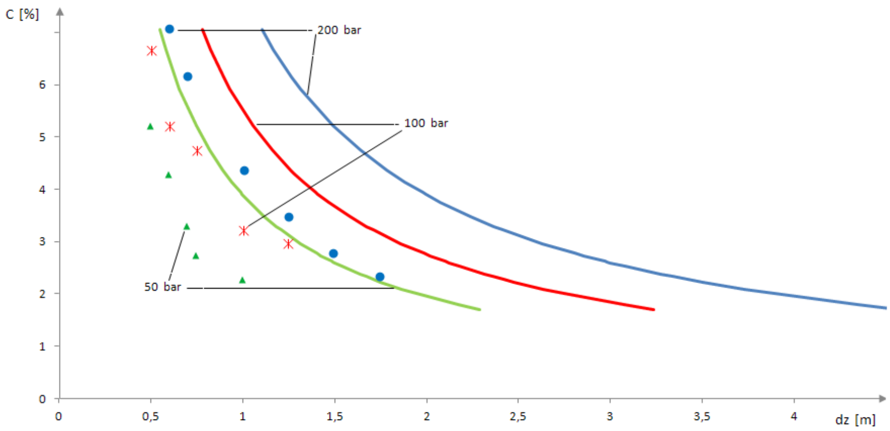

Figure 4. Comparison between experimental and calculated d_z values for hydrogen release (0,5 mm)

In order to compare d_z experimental data with the ones calculated by eq. (1), LEL has been substituted with the measured gas concentration values and k_{dz} has been considered equal to 1.

As it regards both methane (releasing from 2,7 mm nozzle) data and the ones regarding hydrogen releasing from 3 mm nozzle, it comes out that the maximum percent deviation between experimental and calculated values is very low (11%).
Instead, as it regards hydrogen leak from 0,5 mm nozzle, the calculated d_z values are about 1,7 times the correspondent experimental data and, as it regards hydrogen leak from 0,2 mm, the calculated d_z values are about 1,1 times the correspondent experimental data. It is important to note that all hydrogen experimental d_z data are lower than the ones calculated by eq. (1). Therefore, eq. (1) is precautionary and it turns to safety advantage, thus it can be used in order to assure that, at distances higher than the calculated d_z, gas concentration is lower than LEL.

Besides, it has to be taken into account eq. (1) estimates gas outflows without considering friction and contraction effects during discharging from the holes. This formula had been found out assuming an ideal maximum value of mass flow rate. Actually it has to consider a discharge coefficient. Literature [5] suggests discharge coefficient, C_d, values ranging from about 0,3 to about 0,9; obviously this factor is as higher as discharge section has lower values. Furthermore, the discrepancy between calculated and experimental data could be due to the fact that for small jets, there are more fluctuations in the resulting plume, which implies lower averaged measurements [15].

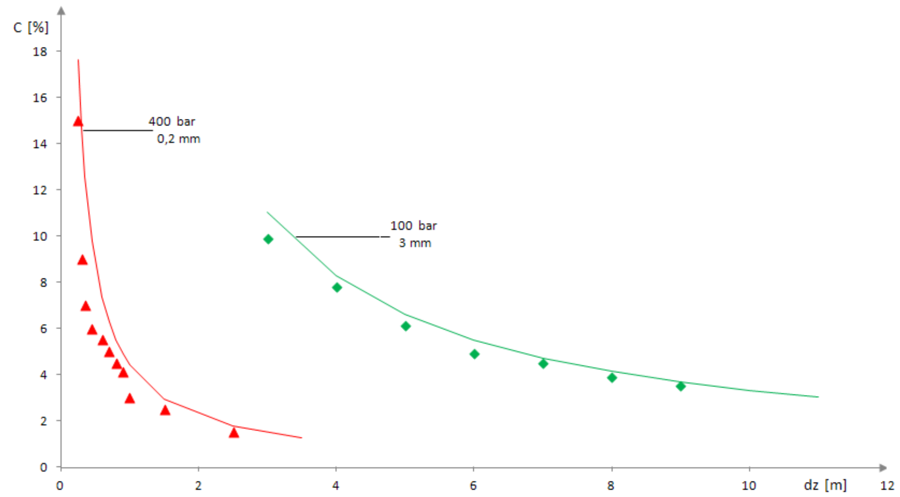

Figure 5. Comparison between experimental and calculated dz values for hydrogen release (0,2-3 mm)

4. Conclusions

The work here described regards the determination of the hazardous area extent in places where an explosive atmosphere may occur, whenever sonic releases of methane or hydrogen from high pressure sources may arise. At this purpose the formula which had been introduced in the Italian Guide CEI 31-35 has been validated by experimental data on axial decay of gas from under-expanded methane and hydrogen jets. Results confirm the validity of d_z formula as regards not catastrophic events where source diameters are of few millimetres. It is to understand in greater detail the over prediction for leakages from very small nozzles.
Future development regards eq.(1) validation against experimental data regarding heavy flammable gases as propane and butane.

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Thermal Fatigue life prediction of solder joints interconnects using numerical probabilistic approach

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Abstract

Field failures of embedded electronic systems are often caused by fatigue failure of the solder joints of the electronics components of their assembly. Solder joint fatigue results from thermo-mechanical damage accumulation induced by the component operating conditions. Finite element methods are broadly used to predict numerically the solder joint fatigue life. However, these simulation tools are based on a deterministic approach and thus do not take into account of the variability of the input parameters having an impact on the fatigue lifetime. In this paper, the probabilistic approach is developed to predict solder joints fatigue lifetime by taking account the variability of the input parameters

Keywords: Reliability, electronic packaging, probability, fatigue, Finite element

Introduction

Today, the European directives forbid to the electronics industry the use of lead in the electronic products. Environmental concern and public health have greatly encouraged this regulation. However, the leadfree alloys, generally named as SAC (SnAgCu) is not yet been fully characterized. A scientific and technological challenge should be made in order to conduct the transition of lead to lead-free technologies. The use of lead-free in new electronic packaging impact the reliability, where thermal loading influences greatly the response of the lead-free solder joints. In operation, the electronic components of embedded electronic products are often exposed to harsh conditions combining thermal cycling, high temperature, power cycling and vibrations. These severe operating conditions produce thermomechanical stress on the solder joint interconnects of the electronics assembly. The accumulation of stress cycles damage gradually the solder joints which leads to product failure. In order to be able to predict the reliability of an embedded electronic product, it is necessary to develop a rigorous fatigue model of the solder joint interconnects under thermomechanical stress.

Most of failure in electronic packaging is due to fatigue failure of solder joints related to the thermomechanical damage mechanisms during the component operation life. The finite element method is usually used to modelling the physical failure in solder joints subjected to temperature cycling and to predict numerically the solder joint fatigue life. Nevertheless, these simulation tools are based on a deterministic approach, where the variability of the input parameters is not considered. In fact, uncertainties related to design, loading, and operational conditions lead to structural behaviour which does not correspond to the expected reliability.

A more rigorous approach for predicting the fatigue life and the reliability of electronic packaging should consider the uncertainties arising from the random nature of the temperature fluctuations caused by power transients and thermal environment changes, the thermal expansion mismatch of the different materials of the assembly, the material properties and the fabrication process. In this study, a probabilistic model is developed and applied to assess the number of cycles to failure of the critical solder joint of a fine pitch package assembled circuit board of an embedded electronic product. This model is based on finite element modeling and on statistical methods such as Response Surface Method and Monte Carlo Simulations. The model takes into account the nonlinearities of the solder joint material properties and the uncertainties arising from the variability of the geometric and material properties of the elements of the assembly and from the thermal fluctuations in use conditions. It shows that uncertainties have a significant effect on the lifetime of the electronic packaging.

Finite element modelling

In order to predict reliability in service, it is a good practice in the mechatronics industry to perform a physics of failure approach in order to have a deeper understanding of the failure mechanisms. Experience shows that the reliability of a electronic assembly is often affected by thermal fatigue damage. For example, when damage accumulation in a solder joint reaches a certain critical level, this

leads to an electrical or a mechanical failure. The physics of failure approach requires models that predict the stress and strains in the packaging materials of the assembly when the device is operational and subjected to external environmental conditions.
Several authors have developed sophisticated models based on the finite element method and on the failure mechanisms of the electronic package subjected to thermal cycling. Finite Element Method (FEM) is often used to predict numerically the mechanical solder joint degradation. This degradation evolves with repeated thermal and power cycling and ultimately causes solder joint cracking, fissure propagation and interconnect failure. Generally, experimental studies are performed in order to establish a fatigue failure relationship between the inelastic strain deformation and the number of cycles before failure initiation. FEM is then combined with this fatigue failure relationship obtained experimentally and with various thermal fatigue life measurements. Moreover, life prediction modelling of solder joints is used to virtually qualify a package without extensive test data.

In Finite Element Modelling a precise description of the materials behaviour of each component of the electronic packaging is critical. FEM of solder joints is usually based on a physical model which includes solder viscoplasticity and creep behaviour. Generally, in the literature the solder behaviour is dependent on strain rate, stress and temperature. Therefore, the deformation of solder is described by time dependent viscoplasticity constitutive laws or time dependent creep combined with time independent plasticity [1].

The most commonly accepted models employing the finite element method for thermal fatigue predictions are grouped in five categories. The first category uses a nonlinear slice model; the second category uses a global model with linear super element and nonlinear solder; the third category uses a linear global model with non linear submodel; the fourth category uses a nonlinear global model and nonlinear submodel and finally the fifth category uses only a global nonlinear model with fine mesh. This last category requires more computation time [1]. In this study a linear global model with nonlinear fine mesh submodel is used.

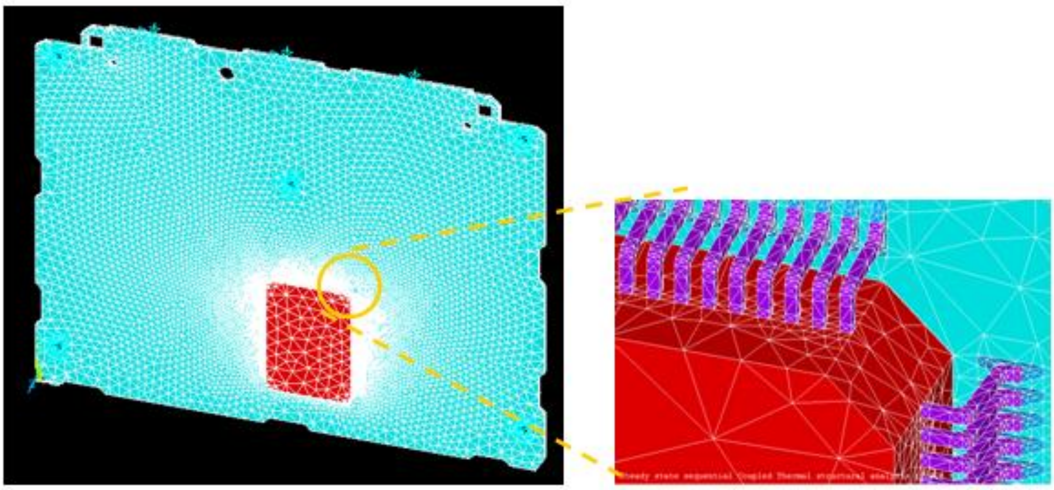

Figure 4. Global finite element model of the 256-PQFP

Global finite element model

The electronic package under investigation is a 256-pin plastic quad flat package with 0.5 mm pitch gull-wing leads. Figure 1 shows a perspective view of the meshed global model. The model is based on the geometry of the Printed Circuit Board (PCB), the component moulding compound and its solder interconnects and gull-wing leads. The material properties are assumed to be linear. The PCB is the FR-4 and is defined by the orthotropic material properties presented in Table 1 and by in plane (x y) and out of plane (z) thermal coefficients of expansion.

All the finite element models of this study are performed wit the commercial finite element code ANSYS. The global finite element model contains 117258 elements and 238884 nodes. The 3-D tetrahedral structural solid finite element named SOLID187 with ten nodes is used. To simulate the entire assembly, boundary conditions are applied on the screw holes of the circuit board: all nodes of the screw holes are constrained to zero displacement in the x, y and z directions. The thermal loading defined by the thermal cycle profile given in Figure 2 is applied on the global model. This cyclic temperature loading alternates between 0°C and 125°C, as shown in figure 3. The ramp rate is 15 °C/min and the dwell time is 30 min.

Finite element submodel

Calculus of the full model for one thermal cycle has a very high computational cost. In order to reduce the computational time, a submodel of the worst case solder joint is developed. This submodel is based on the geometry of the full model as shown in Figure 3.

This submodeling technique allows us to model precisely the inelastic strain of the solder joints. It consists in describing the worst case solder joint with fine mesh elements and in taking into account material nonlinearities. The solder material is assumed to have a rate dependent plasticity. This finite element submodel is solved for one thermal cycle as shown in Figure 2. Table 1 presents the material properties used in this analysis.

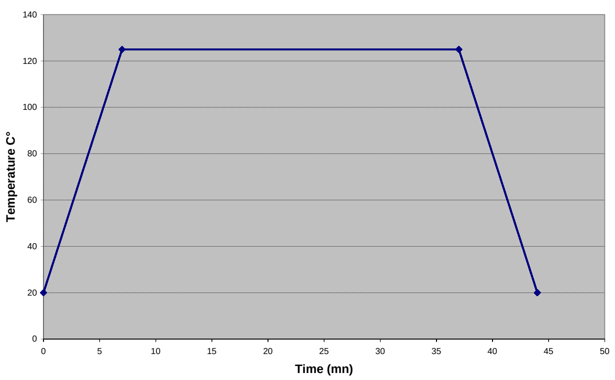

Figure 5. Cyclic temperature profile

In the thermo-mechanical analysis of the submodel, the moulding compound and the Cu materials are assumed to be isotropic and linear. FR-4 PCB material is orthotropic and linear. The gull-wing leads are in copper, where is assumed to follow a linear behaviour. The SAC (SnAgCu) solder material is assumed to follow elasto-plastic-creep behaviour, as creep plays a very important role in deformation behaviour of solder joint at homologous temperature [2].
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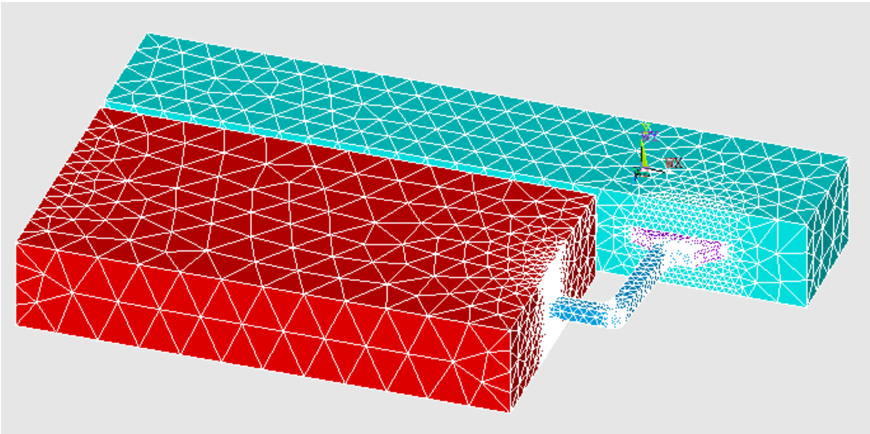

Figure 6. Finite element submodel

Material properties

In solder joint materials, the development of inelastic strains is dependent on the rate of loading. Many authors have studied the response of lead free (SnAgCu) and eutectic (SnPb) solder joints during creep and proposed constitutive equations. One of the equations developed is Anand's model which incorporates viscoplasticity and time-dependent plasticity. Wang *et al.*, [3] proposed a unified framework for the viscoplastic behavior of SnAgCu solder materials which are referred to the Anand constitutive equations. The Anand model is supported by the ANSYS code. The material parameters of the Anand model for SnAgCu solders are obtained from experimental results and by the separated elasto-plasto-creep constitutive relations. These material parameters of SAC solder (96.5Sn3.5Ag) are shown in Table 2 as given by [3].The constitutive equation for Anand's model is:

$$\dot{\varepsilon}_p = A\exp^{\left(-\frac{Q}{RT}\right)}\left[\sinh\left(\xi\frac{\sigma}{s}\right)\right]^{\frac{1}{m}} \qquad (1)$$

where $\dot{\varepsilon}_p$ is the inelastic strain rate, A the pre-exponential factor, Q the activation energy, R the universal gas constant, T the absolute temperature, σ the tensile stress ξ is the stress multiplier, m the strain rate sensitivity of the stress and s is the deformation resistance. In addition, $\dot{s}$ is an internal state variable whose evolution is described by:

$$\dot{s} = \left\{ h_0 \left| 1 - \frac{s}{s^*} \right|^a \text{sign}\left(1 - \frac{s}{s^*}\right) \right\} \dot{\varepsilon}_p \tag{2}$$

where h_0 is the hardening or softening constant, a the hardening or softening strain rate sensitivity and s^* is the saturation value of associated with a given temperature and strain rate pair and is described by:

$$s^* = \hat{s} \left[\frac{\dot{\varepsilon}_p}{A} \exp^{\left(\frac{Q}{RT}\right)} \right]^n \tag{3}$$

Where $\hat{s}$ is a coefficient for saturation and n is the strain rate sensitivity for s^*.

Table 1 Material properties and Statistical data of random variables.

Description	Mean value	Distribution	COV
FR4 – Young's modulus (GPa) $E_x = E_y$ E_z	 17 7.45	 Lognormal Lognormal	 5 5
FR4 – Poisson ratio ν_{xy} $\nu_{yz} = \nu_{xz}$	 0.10 0.39	 Deterministic Deterministic	 - -
FR4- Shear Modulus (GPa) G_{xy} $G_{xz} = G_{yz}$	 3 2.4	 Deterministic Deterministic	 - -
FR4 – CTE (μm/C°) $\alpha_x = \alpha_y$ α_z	 18.23 58.72	 Lognormal Lognormal	 10 10
Molding Compound – Young's modulus (GPa)	11.7	Lognormal	5
Molding Compound – Poisson ratio α	0.05	Deterministic	-
Molding Compound - Shear Modulus (GPa)	3.5	Deterministic	-
Molding Compound – CTE (μm/C°) $\alpha_x = \alpha_y$ α_z	 23 80	 Lognormal Lognormal	 10 10
Lead (Cu) – Young's modulus (GPa)	113	Lognormal	5
Lead (Cu) – Poisson ratio	0.31	Deterministic	-
Lead (Cu) - Shear Modulus (GPa)	44	Deterministic	-
Lead (Cu) - – CTE (μm/C°)	17	Lognormal	10
SnAgCu solder –Young's modulus (GPa)	51.3	Lognormal	5
SnAgCu solder – Poisson ratio	0.35	Deterministic	-
SnAgCu solder -- Shear Modulus (GPa)	18.32	Deterministic	-
SnAgCu solder – CTE (μm/C°)	20	Lognormal	10

Table 2. Material parameters of viscoplastic Anand model for SAC solder.

A (s^{-1})	Q/R (K)	ξ	m	$\hat{s}$ (MPa)	N	h_0 (MPa)	a	s_0 (MPa)
2.23E4	8900	6	0.182	73.81	0.018	3321.15	1.82	39.09

Thermal fatigue model

Solder joint fatigue life prediction involves combining finite element simulations with a thermal fatigue model. The fatigue model is generally obtained by using experimental data and accelerated testing. This model is used to determine the number of cycles that a package can sustain before failure.

The models proposed to predict fatigue life may be classified into five categories: stress-based, plastic strain-based, creep strain-based, energy-based, and damage-based. Generally the stress-based approach is used in the high cycle fatigue where it is applied to vibration, shock and stressed components. On the other hand, plastic strain-based and the creep strain-based approaches are used in low cycle fatigue. The thermal fatigue-induced strains from CTE mismatch fall under this category. The plastic strain-induced fatigue is based on plastic deformation derived from the time-independent plastic material behaviour. While, creep-strain-based approach is based on the creep deformation derived from the time dependent effects. The energy-based fatigue models are based on the calculation of the overall stress/strain hysteresis energy, where the damage-based fatigue models are based on computing the accumulated damage caused by crack propagation and fracture mechanics [4]. Since plastic strain is a dominant parameter that influences low-cycle fatigue, this study uses the Coffin–Manson type equation classified into the plastic strain-based approach. The inelastic strain is computed by nonlinear finite element simulation with unified viscoplasticity Anand model, which combines plastic and creep deformation. The Coffin-Manson fatigue model is the most widely used approach, where the number of cycles to failure N_f depend on the inelastic strain amplitude ε_p, generally given as the following equation:

$$\frac{\varepsilon_p}{2} = a\left(2N_f\right)^c \tag{4}$$

Where, a is the fatigue ductility coefficient and c the fatigue ductility exponent. A variety of strain life engineering data is available on most of the solders used in electronic packaging [5]. For SnAgCu Solder, this law is identified by [6], where a = 3.0685 and c = –0.73.

Probabilistic methodology

The probabilistic approach aims at considering the uncertainties arising from the random nature of temperature fluctuations, geometry dimension of packaging assembly, material properties and thermal expansion mismatch. The mechatronics product assembly may fail if these uncertainties are ignored. So far, probabilistic methods are used to improve design robustness and to estimate the impact of parameter uncertainties on the system response. Moreover, combining probabilistic methods to the finite element simulations does not only enable one to establish the scope and the limits of usual deterministic approaches but improves on it by providing more information and effective utilization of empirical data.

The probabilistic structural methods consist in determining the probability of failure of given structural systems. This approach is an extension of the deterministic analysis where the input parameters are not considered as deterministic value in the mechanical model but as random variables. Monte Carlo simulations (MCS) are widely used to characterise the random response and the probability density function (PDF) of the response [7].

Monte Carlo simulation

Monte Carlo simulation is a method which is widely used in the probabilistic approaches. MCS consists in generating a set of random samples. The mechanical model is run for each of these samples. The obtained results are then used to compute estimators of the response.

However, to bring accurate results MCS needs a large set of samples. In the context of thermomechanical nonlinear finite element simulation, the computational cost makes the MCS impracticable. For this reason, the solution consists in building an explicit function which can approximate the finite element response. Such an explicit function can be obtained with the response surface method (RSM). The RSM explicit function is then used in MCS [8]

Response surface method

The response surface method allows the construction of a detailed mathematical model of the response [9]. RSM surfaces are built from numerical experiments that are carried out according to a numerical design of experiments (DOE). The surface method consists in approximating the finite element response, in this work the inelastic strain of solder joint. Quadratic response surfaces are considered to approximate the inelastic strain. This approximation is the best solution because it includes a possible calculation of curvatures and avoids possible oscillations of higher order polynomials. The approximation can be written as:

$$\tilde{\varepsilon}_p = c + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} x_i x_j \qquad (5)$$

where c, b_i and a_{ij} are coefficients of this response surface to be obtained by regression, n the number of random variables and x is the realisation of the random variables.

Numerical results

The effect of uncertainties on the solder joint thermal fatigue lifetime is investigated. Material properties are given in Table 1. Geometric dimensions and temperature loading which are considered as random variables are given in Table 3 and showed in Figure 4.

Three cases are considered. The first case considers only geometric dimensions and temperature fluctuation as random variables. The second case considers only material properties and temperature cycling as random variables. The third case considers material properties, thermal loading and geometric dimensions as random variables.

Sensitivity analysis

Monte Carlo simulation combined with the response surface give a useful tool to investigate the impact of the random variables into the fatigue lifetime. The Input/output Pearson correlation coefficients measure the effect of each input variables by the correlation coefficient. The partial correlations coefficients are based on results of regressions of the model on all input variables expect one. These coefficients are useful to measure the effect of her input variable on the response variable.

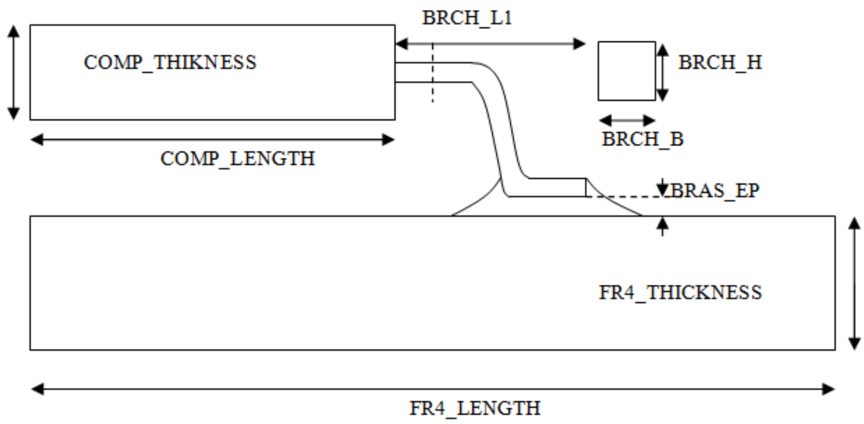

Figure 7. Geometric dimension of the packaging in the x-y plane

Table 3. Geometric dimension and thermal loading

Description	Lower value	Upper value	Distribution
TF : temperature C°	105	145	Uniform
BRCH_L 1 : Joint length (mm)	0.5	0.7	Uniform
Joint cross section BRCH_H (mm) BRCH_B (mm)	 0.22 0.17	 0.27 0.22	Uniform
BRAS_EP : solder thickness (mm)	0.1	0.15	Uniform
FR4_THICKNESS: PCB thickness (mm)	1.5	1.6	Uniform
COMP_THICKNESS: component thikness (mm)	3.1	3.3	Uniform

Figure 5 to 7 show the sensitivity analysis of the three cases, where the impact of uncertain parameters on the inelastic strain response is showed. The impact of dimension uncertainties is clearly observed. In the first case, Figure 5 shows the impact of temperature fluctuations, which is mainly the principal source of increasing inelastic strain, as well as reduces the fatigue lifetime. The scope of this analysis consists to observe that increasing the length joint plays a significant role in reducing the inelastic strain, in this way increasing the fatigue lifetime, the same remarks are observed with the component thickness and the solder thickness.

It is clear, that increasing the thermal coefficient expansion of the copper joint, of the FR4 and of the moulding compound increases the inelastic strain, because of the CTE mismatch is increased. Figure 6 shows that increasing the Young's modulus of the FR4 in the plane x-y plays a worst role on the fatigue lifetime, where it accrues the inelastic strain. This observation can be explained mechanically by the composite formulation of the FR4, where increasing the Young's modulus in the plane increases the hardness of the material leading the solder to more stress arising from the temperature deformation. However, increasing the Young's modulus in the z plane reduce the inelastic strain. Figure 7 shows that when geometric dimension uncertainties are considered with material properties and thermal loading the sensitivity of uncertain parameters changes significantly, where the influence of the temperature fluctuations is slightly reduced.

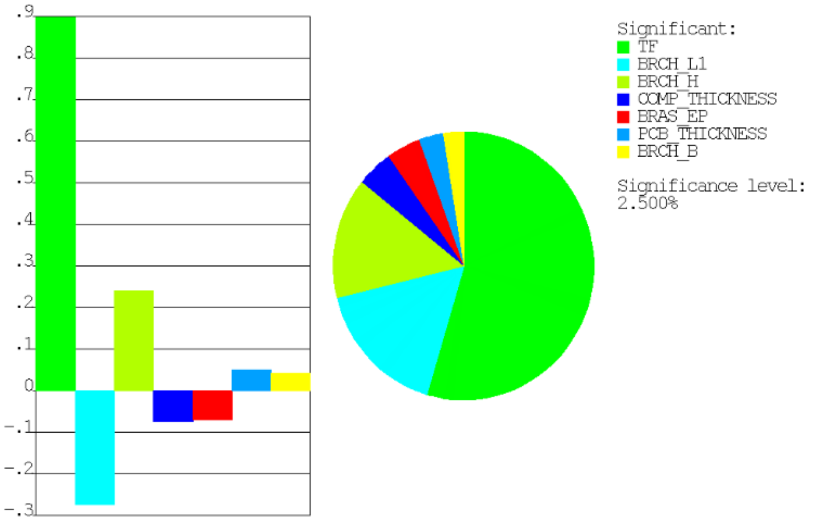

Figure 8. Sensitivity analysis of the inelastic strain in the first case

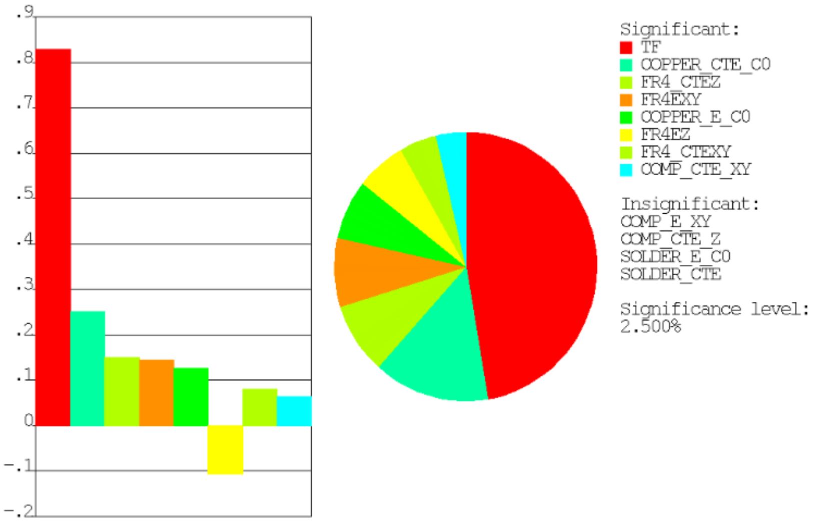

Figure 9. Sensitivity analysis of the inelastic strain in the second case

Probability distribution of the response

The inelastic strain distributions for these three cases are shown in figures 8 to 10. The inelastic strain can be fitted by normal distribution. The Chi-square goodness-of-fit test is used in order to find the best fitting probability distribution. Tables 4, 6, 8 show that the normal distribution give a good fitting to the probabilistic distribution of the inelastic strain response, where the probability that the assumption of the null hypothesis can't be rejected are 0.85, 0.82 and 0.70 respectively. The probabilistic distribution of the number of cycles before failure initiation is showed in figures 11 to 13. The mean value of the fatigue lifetime varies between 2721 (when geometric dimension only are considered as random variables) to 4093 cycles (in the case when only material properties are considered as random variables). Similar results are given experimentally by [10] for 0.4mm pitch 256 pin QFP with SnPb leaded solder and using different temperature profile, where the dwell time at maximum temperature cycling (125°C) were 20mn and the dwell time at minimum temperature (-40°C) were 4mn. Lau et al. 1996 shows that the 20 percent cumulative failure point occurred at approximately 5310 cycles. Tables 5-7-9 show that the lognormal distribution with the parameters (α and β) and the Frechet distribution known as the generalized extreme value distribution with three parameters (shape parameter κ, scale parameter σ and location parameter μ) can be used to modeling the fatigue lifetime.

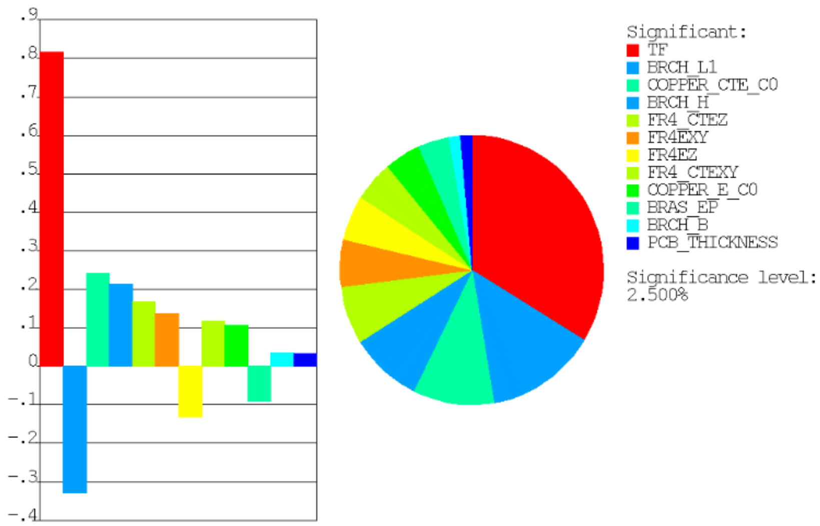

Figure 10. Sensitivity analysis of the inelastic strain in the third case

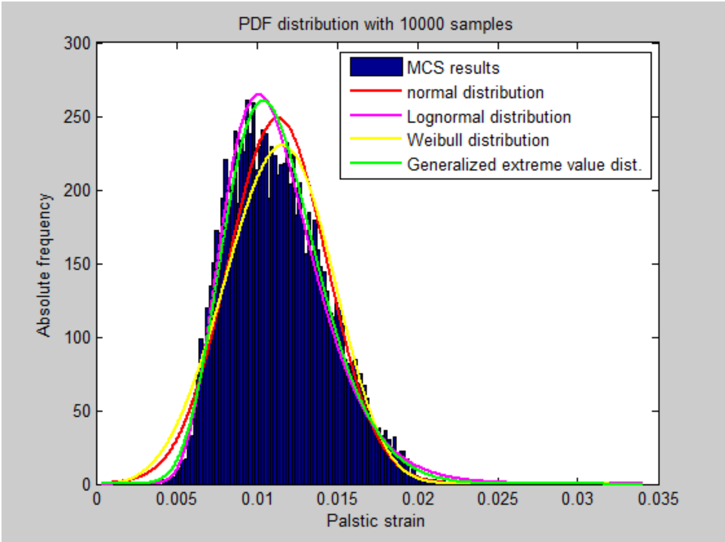

Figure 11. Inelastic strain distribution of the third case

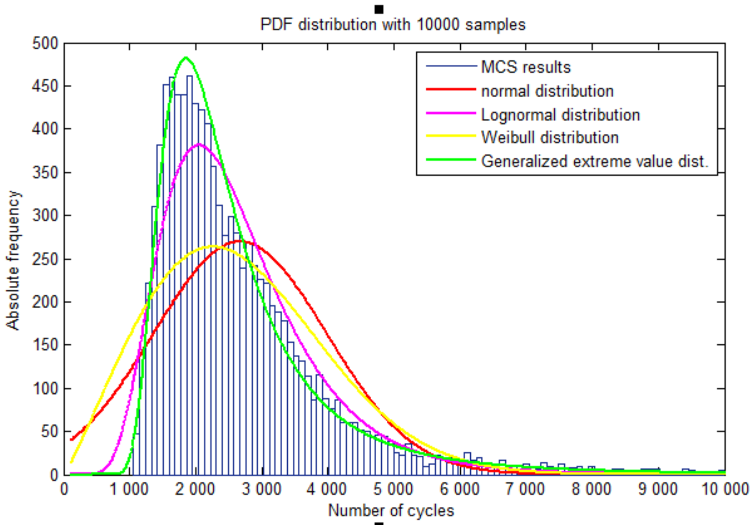

Figure 12. Number of fatigue cycles distribution in the first case

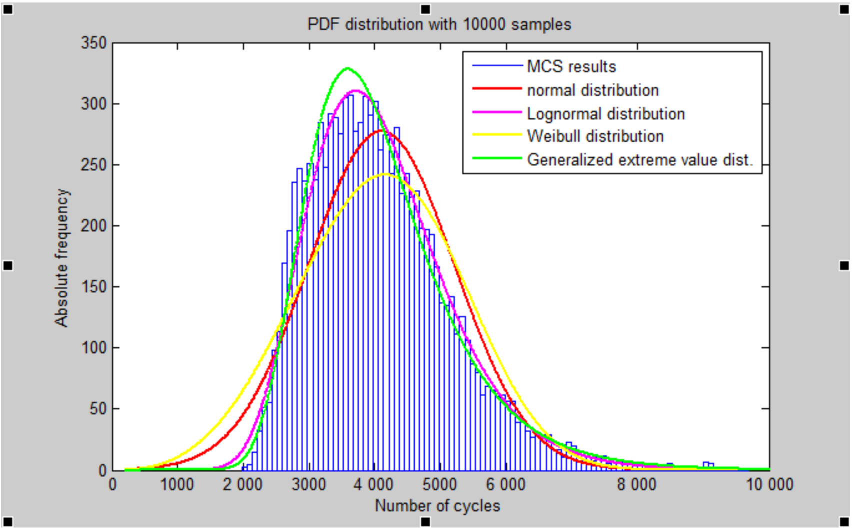

Figure 13. Number of fatigue cycles distribution in the second case

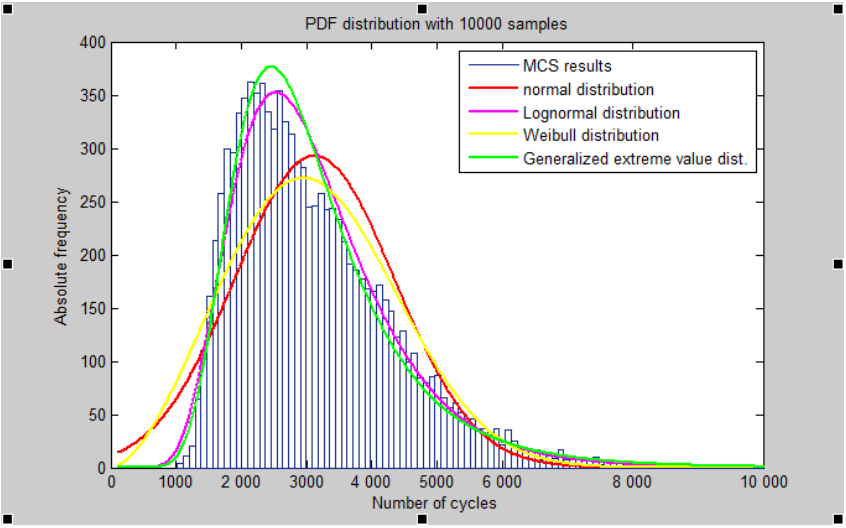

Figure 14. Number of fatigue cycles distribution in the third case

Table 4. Fitted probability distributions of the inelastic strain in the first case

	Mean	Stdv	P	Null hypothesis
Normal	1.26×10^{-2}	3.82×10^{-3}	0.85	Ok
Lognormal α= -4.42 and β = 0.339	1.27×10^{-2}	4.45×10^{-3}	0.48	Ok
Weibul a = 0.014 and b = 3.66	1.26×10^{-2}	3.84×10^{-3}	0.85	Ok
Generalized extreme value (Frechet) κ = -0.27, σ = 0.0037 and μ = 0.0112	1.26×10^{-2}	3.77×10^{-3}	0.77	Ok

Table 5. Fitted probability distributions of the fatigue lifetime

	Mean	Stdv	P	Null hypothesis
Normal	2683	1392	0	No
Lognormal α= 7.79 and β = 0.426	2657	1187	0.007	No
Weibul a = 3.042×10^3 and b = 2.053	2695	1375	0	No
Generalized extreme value (Frechet) κ = 0.32, σ = 6.97×10^2 and μ = 1.99×10^3	2721	1830	0.24	Ok

Table 6. Fitted probability distributions of the inelastic strain in the second case

Table 7. Fitted probability distributions of the inelastic strain in the second case	Mean	Stdv	P	Null hypothesis
Normal	9.11×10^{-3}	1.53×10^{-3}	0.82	Ok
Lognormal α= -4.71 and β = 0.174	9.11×10^{-3}	1.60×10^{-3}	0.70	Ok
Weibul a= 0.0097 and b = 6.71	9.10×10^{-3}	1.59×10^{-3}	0.69	Ok
Generalized extreme value (Frechet) κ = -0.35, σ = 0.0015 and μ = 0.0086	9.10×10^{-3}	1.51×10^{-3}	0.65	Ok

Table 7. Fitted probability distributions of the fatigue lifetime in the second case

	Mean	Stdv	P	Null hypothesis
Normal	4094	1099	0	No
Lognormal α= 8.28 and β = 0.255	4091	1062	0.41	Ok
Weibul a = 4.51×10^3 and b = 3.7	4072	1224	0	No
Generalized extreme value (Frechet) κ = 0.01, σ = 8.52×10^2 and μ = 3.59×10^3	4093	1108	0.23	Ok

Table 8. Fitted probability distributions of the inelastic strain response in the third

	Mean	Stdv	P	Null hypothesis
Normal	1.16×10^{-2}	3.31×10^{-3}	0.70	Ok
Lognormal α= -4.49 and β = 0.28	1.16×10^{-2}	3.42×10^{-3}	0.66	Ok
Weibul a = 0.0128 and b = 3.78	1.16×10^{-2}	3.43×10^{-3}	0.68	Ok
Generalized extreme value (Frechet) κ = -0.116, σ = 0.0029 and μ = 0.0102	1.16×10^{-2}	3.26×10^{-3}	0.64	Ok

Table 9. Fitted probability distributions of the fatigue lifetime in the third case

	Mean	Stdv	P	Null hypothesis
Normal	3060	1241	0.0001	Rejected
Lognormal α= 7.94 and β = 0.39	3061	1257	0.36	Ok
Weibul a = 3.45×10^3 and b = 2.639	3068	1250	0.01	Rejected
Generalized extreme value (Frechet) κ = 0.096, $\sigma = 8.96\times10^2$ and μ = 2.45×10^3	3062	1329	0.23	Ok

Conclusion

In this study a nonlinear thermomechanical finite element analysis is used to predict the reliability performance of the solder joint of an embedded electronic system. This approach reveals that the uncertainties related to the variability of the geometry and of the material properties such as Young's modulus, thermal expansion coefficient mismatch as well as thermal loading fluctuations have a strong effect on the lifetime of the electronic package. This efficient probabilistic approach ensures more design robustness. A possible extension of this work is to investigate the effect of solder voids and residual stresses induced in the solder joint during thermal processing due to the mismatch in thermal expansion/contraction of the constituents, which can have more impact on the lifetime of the electronic packaging. A spectral method also known as stochastic finite element method can be used in order to represent the complete randomness of the fatigue life in a more efficient way.

Acknowledgements

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Current sensor faults detection and isolation for DFGI in wind turbines

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Abstract

The objective of this paper is to detect and isolate the presence of sensor faults and in dynamical systems. Observers based on Kalman filter are used. This type of observers is then used to generate residuals based on the DOS observer architecture (Dedicated Observer Scheme). This diagnosis strategy is applied on the double-feed induction generator (DFIG) in wind turbines. The structure of a DOS is used for detection and isolation of multiple sensor faults. The approach is validated using signals obtained from a simulated DFIG system. The main contribution of this paper is the modelling of induction generator for wind turbines and the use of observers to detect faults in current sensors. The simulation model of DFIG is developed using MATLAB.

Keywords: Diagnosis, Kalman filter, Observer DOS, DFIG, Sensors faults

1. Introduction

In recent years, environmental issues play an increasingly important role in our daily lives. This is particularly due to an awareness of the renewables energy, about the consequences of some pollution on the environment and climate conditions. This work aims to improve safety, reliability and performance of wind turbines and to predict the evolution of the mode of degradation in order to improve the availability of the system [1], [2]. Our main objectives are to detect and locate faults and to determine the origin of abnormalities (i.e. failure of sensors or actuators, system malfunctions).
With the increasing size of wind turbines [3], there is a need to improve diagnostic techniques to detect the occurrence of faults. Several works have been oriented to the detection of faults and their isolation in the wind turbines. In [4] an observer was set up to detect sensor faults in the turbine hub. Reconfiguration

has been proposed in [5]. An observer with unknown inputs has been proposed [6], [7].
In this paper, we are interested in the detection and isolation of current sensor faults. For example the inside faults in the DFIG are caused by the component of the generator (rotor and stator magnetic circuits, stator windings, mechanical air gap). The generator is often exposed to perturbation as the origin of the noise from the environment of the generator, the uncertainties of measurements, sensors faults or actuators; these perturbations have adverse effects on the normal behavior of the generator and their estimation. The construction of the observer is knowledge-based for the model of the generator to observe. In this paper observers are used as well [9]. The faults are considered as unknown inputs which should be estimated. This can be done by introducing internal fault models. Other examples of observers can be found in the litterature. An unknown input observer based scheme was proposed in [3] to detect such faults in a wind turbine. The proposed technique enables to detect and isolate multiple faults of current sensors and with DOS bench observer. Stator and rotor currents are measured by using four sensors in phases *d* and *q*. The application of DOS is possible if the system is observable.

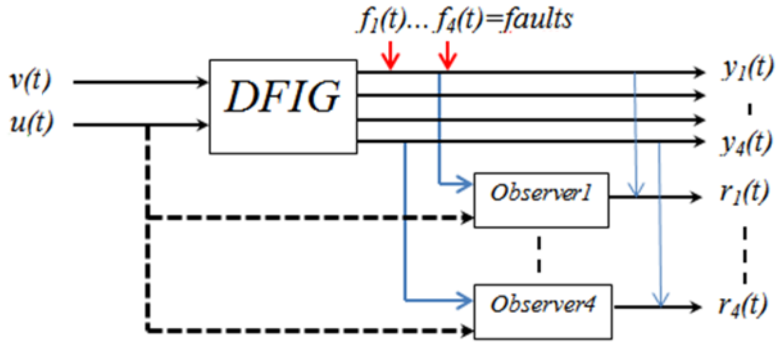

Figure 1. Structure of Observer DOS

1.1 Energy Production of the DFIG System

The double feed induction generator (DFIG) is one of the most used wind generator [8], Figure 2. Several recent papers, confirmed by industrial realizations, demonstrate the viability of this device in a wind system. The bidirectionality of the rotor converter authorizes hyper and hypo synchronization and control of power factor in the network.

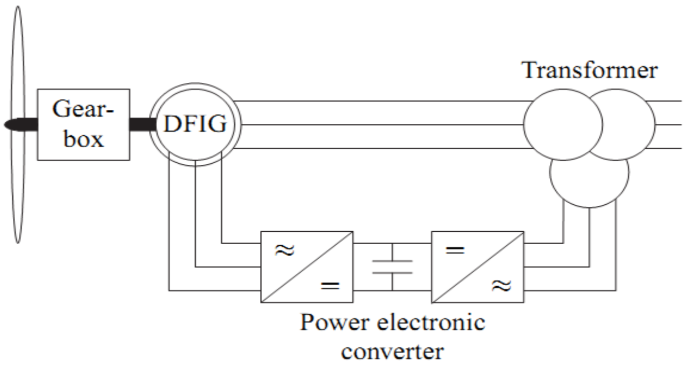

Figure 2. DFIG structure with PWM converters

The presence of a PWM converter may result in large variations of the rotor voltages with high frequencies. Rectifiers and inverters are used to solve this problem. Wind energy captured by the turbine is converted by the DFIG and is transmitted to the network by the rotor and the stator windings. The guidance system of the blades is used in order to adjust lift of the blade to the wind speed. Consequently power generated by the generator is limited. With such a system, the blade is controlled by a system called "pitch control". The blade pitch angle control system is designed for each blade. This independent regulation provides more degrees of freedom [9].

2. Model of the DFIG

2.1 Park Transformation

The Park transformation is defined by the rotation matrix of the rotating field. It consists in the projection of the three phase coordinates (*a*, *b*, *c*), in frame (*d*, *q*) [10]. In this frame, the *d*-axis is chosen to coincide with the stator axis at *t = 0* and *q* axis is lagged by 90 degrees with the *d* axis of the rotation direction. The model of the DFIG is shown in eq. (2).

$$[P(\theta)] = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta - \frac{4\pi}{3}) \\ -\sin(\theta) & -sim(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{4\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (1)$$

The model of the DFIG is described in the frame (*d*, *q*). The following equations describe the global modeling of the generator.

$$\begin{gathered} V_{ds} = R_s i_{ds} + \frac{d\emptyset_{ds}}{dt} - w_s \emptyset_{qs} \\ V_{qs} = R_s i_{qs} + \frac{d\emptyset_{qs}}{dt} - w_s \emptyset_{ds} \\ V_{dr} = R_r i_{dr} + \frac{d\emptyset_{dr}}{dt} - w_r \emptyset_{qr} \\ V_{qr} = R_r i_{qr} + \frac{d\emptyset_{ds}}{dt} - w_r \emptyset_{dr} \\ \emptyset_{ds} = L_s\, i_{ds} + M i_{dr} \\ \emptyset_{qs} = L_s\, i_{qs} + M i_{qr} \\ \emptyset_{dr} = L_r\, i_{dr} + M i_{qr} \\ \emptyset_{qr} = L_r\, i_{qr} + M i_{qs} \end{gathered} \quad (2)$$

where *V* stands for voltages (V), *I* stands for current (A), *R* stands for resistors *(*Ω*)*, $\emptyset$ stands for flux linkages (V·s). Indices *d* and *q* indicate direct and quadrature axis components respectively while s and r indicate stator and rotor quantities respectively. w_s and w_r are respectively the stator and the rotor frequency [13].

2.2 Input Observation

A state-space representation of the DFIG could be stated as follow:

$$\begin{aligned}\dot{x}(t) &= Ax(t) + Bu(t) + Ds(t)\\ y(t) &= Cx(t) + Ef(t)\end{aligned} \tag{3}$$

$$x(t) = [i_{ds}\ i_{qs}\ i_{dr}\ i_{qr}]^T$$

$$u(t) = [V_{dr}\ V_{qr}]^T$$

$$s(t) = [V_{ds}\ V_{qs}]^T$$

$$y(t) = [y_1\ y_2\ y_3\ y_4]^T$$

$$f(t)=[f_1\ f_2\ f_3\ f_4] \tag{4}$$

where $x(t)$ is the state vector, $u(t)$ is the control input, $s(t)$ is the external know input, $y(t)$ is the output vector and $f(t)$ is the vector of fault [11]. The matrices A, B and D are detailed in eq. (5) and their parameters are given in Table V, therefore $C=I_4$ is unity.

$$A = \begin{bmatrix} -\frac{Rs}{\sigma Ls} & \frac{p\omega_r L_h^2}{\sigma LsLr} & \frac{L_h Rr}{\sigma LsLr} & \frac{p\omega_r L_h}{\sigma Ls} \\ -\frac{p\omega_r L_h^2}{\sigma LsLr} & \frac{-Rs}{\sigma Ls} & -\frac{p\omega_r L_h}{\sigma Ls} & \frac{L_h Rr}{\sigma LsLr} \\ \frac{L_h Rs}{\sigma LrLs} & \frac{-p\omega_r L_h}{\sigma Ls} & -\frac{Rr}{\sigma Lr} & -\frac{p\omega_r}{\sigma} \\ \frac{p\omega_r L_h}{\sigma Lr} & \frac{RsL_h}{\sigma LsLr} & \frac{p\omega_r}{\sigma} & \frac{-Rr}{\sigma Lr} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{\sigma.Ls} & 0 \\ 0 & \frac{1}{\sigma.Ls} \\ -\frac{L_h}{\sigma.LsLr} & 0 \\ 0 & -\frac{L_h}{\sigma.LsLr} \end{bmatrix} \qquad D = \begin{bmatrix} -\frac{L_h}{\sigma.LsLr} & 0 \\ 0 & -\frac{L_h}{\sigma.LsLr} \\ \frac{1}{\sigma.Lr} & 0 \\ 0 & \frac{1}{\sigma.Lr} \end{bmatrix} \tag{5}$$

σ : is the coefficient of Blondel

$$\sigma = 1-\frac{L_h^2}{Lr\ Ls} \tag{6}$$

In our work, a discrete state-space representation of the DFIG is used (7):

$$x_{k+1} = A_d x_k + B_d u_k + D_d s_k$$
$$y_k = C_d x_k + E_d f_k \tag{7}$$

The matrices A_d, B_d, D_d, C_d and E_d depend on the sampling time (T_e= 0.001 s). For brievity, the discretization method is not detailed in this paper.

3. Diagnosis based on a kalman filter bank

3.1 Kalman Filter

The Kalman filter was proposed by Rudolf E. Kalman in 1960 [13]. The filter uses the dynamical model, the input and the output measurements to estimate the state of the system. The Kalman filter is widely used in system theory and signal processing as a mathematical technique to extract a signal from noisy measurements. It's nearly used in various applications in control [14]. The Kalman filter addresses the general problem of estimating the state $x \in R^n$, of a discrete-time controlled process that is governed by the linear stochastic difference eq.(8):

$$x_{k+1} = Ax_k + Bu_k + w_k \tag{8}$$

In addition, the relationship between the process state and the measurements is usually represented with the linear expression (9). [14]

$$z_k = Hx_k + v_k \tag{9}$$

A, B and C are matrices of appropriate dimensions, $y \in \Re^m$ is the measurement. The matrix H in the measurement equation eq. (9) relates the state to the measurement z_k. The random variables w_k and v_k represent respectively the process and measurement noise. They are assumed to be independent of each other, and with normal probability density functions:

$$P(w) \sim N(0, Q)$$
$$P(v) \sim N(0, R)$$
$$(10)$$

In practice, the process noise covariance Q and measurement noise covariance R matrices may change with time. However, here, we assume that they are constant.

We define $\hat{x}_k^- \in R^n$ as a priori state estimate at step k given knowledge of the prior process to step k, and $\hat{x}_k \in R^n$ as the a posteriori state estimate at step k given measurement y_k and prediction $H\hat{x}_k^-$.

$$\hat{x}_k = \hat{x}_k^- + K(y_k - H\hat{x}_k^-) \tag{11}$$

The implementation of Kalman filter can be divided in two steps.

- Prediction step
  - Project the state ahead

$$\hat{x}_k^- = A\,\hat{x}_{k-1} + Bu_k \tag{12}$$

  - Project the error covariance ahead

$$P_k^- = AP_{k-1}A^T + Q \tag{13}$$

P_k^- : is the a priori estimation error covariance

- Correction step
  - Compute the Kalman gain

$$K_k = P_k^- H^T (H\,P_k^- H^T + R)^{-} \tag{14}$$

  - Update estimate with measurement z_k

$$\hat{x}_k = \hat{x}_k^- + K_k (z_k - H\hat{x}_k^-) \tag{15}$$

The matrix K_k in equation (15) is the gain, which minimizes the a posteriori error covariance P_k.

$$P_k = (I - K_k H)P_k^- \tag{16}$$

The residual r_K is determined by (17):

$$r_k = z_k - H\,\hat{x}_k^- \tag{17}$$

z_k and $\hat{x}_k^-$ are respectively the measurement and the estimate priori at step k.

3.2 Filter Bank for DFIG

The state observer for fault detection and isolation is a well-known problem. To handle this problem, a filter bank can be used to estimate the dynamical behaviors of the system in order to detect them to isolate the fault. The first kind of filter bank is the Dedicated Observer Scheme (DOS) proposed by R. N. Clark in 1978 [15], [16] and [17]. The second one, is the Generalized Observer Scheme (GOS) proposed by P. M. Frank in 1987 [18]. Each filter bank is composed of a number of observers, which are supplied with all inputs and different subsets of outputs. The observer which receives a faulty measurement provides a bad estimate of the variables, while the estimation of other observers converges to the measurements of corresponding outputs, except the output error. This scheme holds even in the case of multiple simultaneous faults.

In the structure of observers GOS, the principle is to synthesize a number of observers. Each one is insensible to a special fault. If a fault appears, all estimates will be incorrect except those of the observer insensitive to this fault. This scheme offers more degrees of freedom for the design of the observer and increases robustness.

4. Simulation Results

4.1 Residual Generation

The generation of residuals, is a fundamental step in designing a diagnosis based on models. The generation of residuals is based on observers through, the reconstruction of the system outputs from the measurements and on the comparison with the signals measurements. In theory, a residual should be zero in the absence of fault and significantly different from zero in the contrary case. In practice, this condition is not exactly satisfied because signals are affected by noise. This is why it's necessary to introduce detection thresholds to avoid false alarms. These thresholds can be set by the user from a statistical analysis of residuals and taking into consideration the uncertainties of modeling. The structuring of residuals can accomplish the detecting and isolation of the faults [7]. A structuring consists of constructing residuals so that each one is sensitive to a subset of faults and insensitive to the others. One way to reach this structure is to replace the use of one observer by using a set of observers, each of them being driven by some available information. A structure of residuals, in order to detect defects in the sensor, can be done using dedicated observers following a DOS scheme [7]. In this case, the i^{th} observer is controlled by the i^{th} output of the system and all inputs. The Figure 1, shows the DOS architecture. The defects of sensors affecting measurement $y(t)$ are denoted $f_1(t)$, $f_2(t)$, $f_3(t)$ and $f_4(t)$. Observer *1* is driven by the output y_1, observer *2* by the output y_2, observer *3* by the output y_3 and observer *4* by output y_4. We note later $r_{DOSi,j}(t)$ the fault indicator signal (residual) calculated from the difference between the i^{th} system output and the i^{th} output estimated by the i^{th} observer.

The table of signatures uses binary values: "1" when the fault affects the residuals; "0" in the contrary case. The observer 1 reconstructs the model output using only the output y_1 and all inputs of the system. If the output has a defect then there is a bad estimate of the state and residual $r_{DOSi,1}$ may be affected. In this section, the detection of current sensor faults by the Kalman filter will be treated. Then, the isolation of the fault will be addressed. For this purpose, the following fault scenario will be used:

The first scenario is to introduce a fault only in $y_1(t)$. The fault was injected at t = 0.3 s and disappears time t= 0.4 s, the fault consists of a step of constant amplitude equal to 15% of the maximum amplitude of the output (Table I).

Table I: Faults Scenario I

Event Number	Fault number	Starting time (s)
1	$f_1(t)$	$0.3 \leq t \leq 0.4$

The observer *1* reconstructs the model output using only the output y_1 and all inputs of the system. This output has a fault, then there is a poor estimate of the state and residuals $r_{DOS1,1}$, $r_{DOS1,2}$ $r_{DOS1,3}$ and $r_{DOS1,4}$ are away from zero in Figure 5. The failure of y_1 is detected and isolated as shown in Figures 4 and 5.

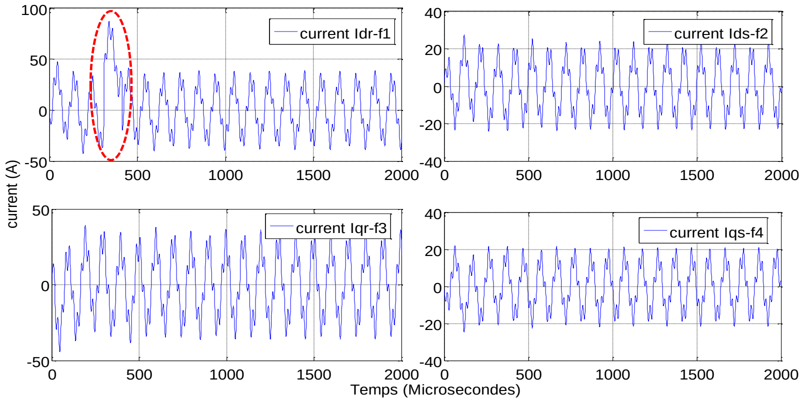

Figure 3: Rotor currents and stator current, I_{dr} presents a fault

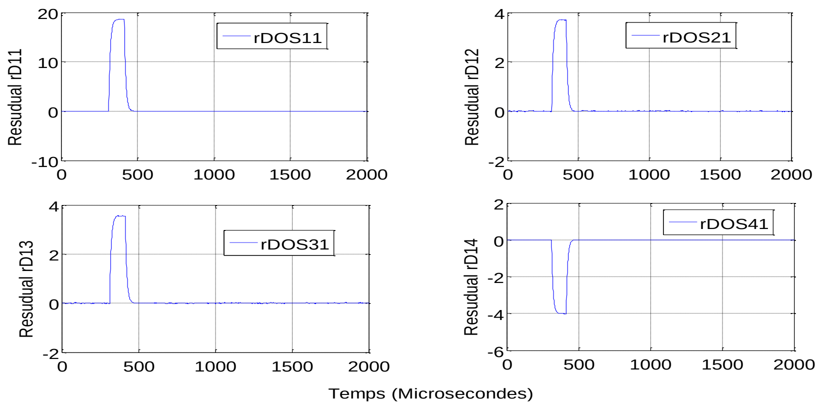

Figure 4: Detail of residuals $r_{DOSi,1}$ obtained from the for observer 1, 2, 3 and 4

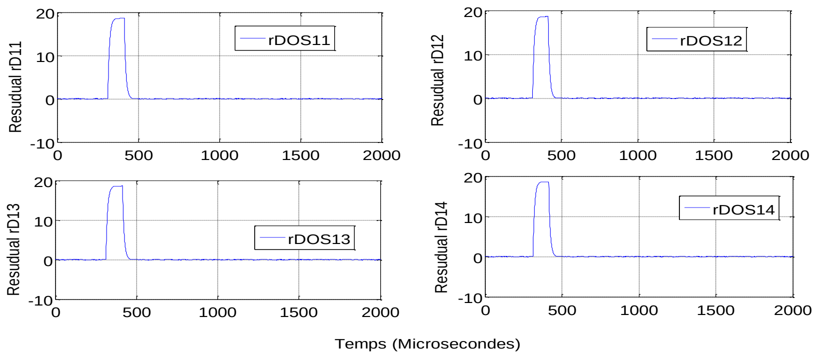

Figure 5: Detail of residuals $r_{DOS1,i}$ obtained from observer 1

The logical rules of the decision unit allow the detection and isolation of the fault. The threshold is chosen equal to 3σ (σ is the standard deviation of the signal).In this figure, we present the fault detection (*Det$_i$*) the four residuals $r_{DOS1,1}$, $r_{DOS1,2}$, $r_{DOS1,3}$ and $r_{DOS1,4}$.

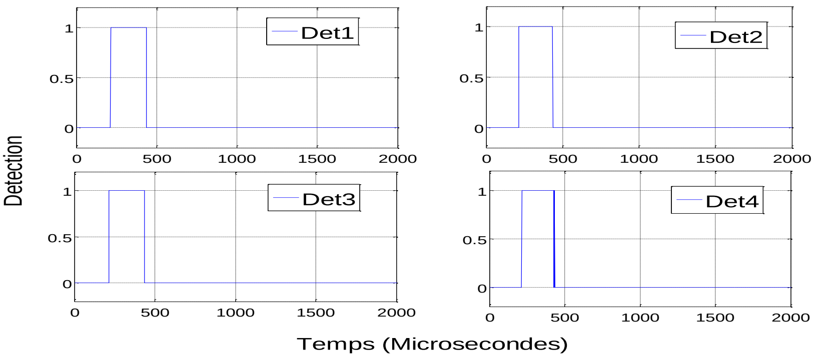

Figure 6: Single fault detection

The signature of fault f_1 is given in Table II.

Table II: Signature of fault f_1

	Obs1				Obs2			
	$r_{1,1}$	$r_{1,2}$	$r_{1,3}$	$r_{1,4}$	$r_{2,1}$	$r_{2,2}$	$r_{2,3}$	$r_{2,4}$
$f1$	1	1	1	1	1	0	0	0
	Obs3				**Obs4**			
	$r_{3,1}$	$r_{3,2}$	$r_{3,3}$	$r_{3,4}$	$r_{4,1}$	$r_{4,2}$	$r_{4,3}$	$r_{4,4}$
$f1$	1	0	0	0	1	0	0	0

According to this table, the signatures $r_{DOS1,j}$= *[1 1 1 1]* , $r_{DOS2,j}$= *[1 0 0 0]*, $r_{DOS3,j}$= *[1 0 0 0]* and $r_{DOS4,j}$= *[1 0 0 0]* correspond to the fault f_1, presented in Figures 4 and 5 and in Table I. It is possible to conclude the fault f_1 appears in y_1 .

The second scenario consists to introduce multiple faults in the outputs y_1 and y_3, the following fault scenario will be used, see Table III.

Table III: Fault scenario II

Event Number	Sensor fault	Starting time (s)
1	f_1 (t)	$0.9 \leq t \leq 1$
2	$f_3(t)$	$0.9 \leq t \leq 1$

It should be noted that in the simulation a measured noise is added to the output of the DFIG (here, a random signal with zero mean and variance equal 1). Fault detection and isolation of the sensor are made by analyzing the residuals r_{DOSi1}, $r_{DOSi,2}$, $r_{DOSi,3}$, and $r_{DOSi,4}$, according to the table of signatures (Table IV). In the absence of sensors faults, the residuals are statistically zero. This information is confirmed by other observers. It is possible to conclude that the fault f_1 appear in the output $y1$ in interval $0.9(s) \leq t \leq 1(s)$, and that the fault f_3 appear in the output y_3 in interval $0.9(s) \leq t \leq 1(s)$.

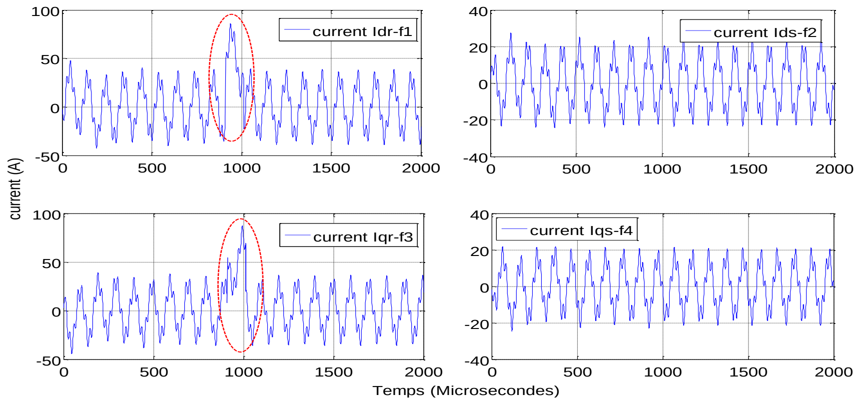

Figure 7: Rotor currents and stator current, I_{dr} and I_{qr} present a fault (second scenario)

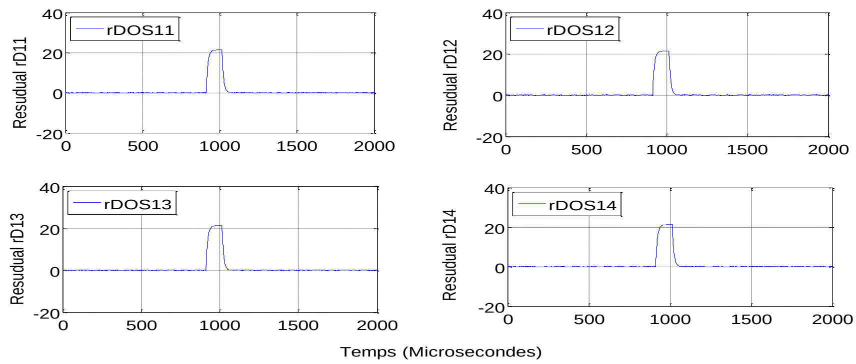

Figure 8. Multiple fault detection

The residuals $r_{DOS1,j}$ and $r_{DOS3,j}$ match the signature of faults f_1 and f_3 on the output y_1 and y_3. This information is confirmed by the residual ($r_{DOS1,2}$,$r_{DOS3,2}$) in observer 2 and observer4 ($r_{DOS1,4}$,$r_{DOS3,4}$). Applying a similar reasoning, one can conclude that the two faults occur simultaneously on the 2 outputs. Table IV presents the signatures of the different faults.

Table IV Signatures of the Faults

	Obs1				Obs2				Obs3				Obs4			
	$r_{1,1}$	$r_{1,2}$	$r_{1,3}$	$r_{1,4}$	$r_{2,1}$	$r_{2,2}$	$r_{2,3}$	$r_{2,4}$	$r_{3,1}$	$r_{3,2}$	$r_{3,3}$	$r_{3,4}$	$r_{4,1}$	$r_{4,2}$	$r_{4,3}$	$r_{4,4}$
$f1$	1	1	1	1	1	0	0	0	1	0	0	0	1	0	0	0
$f2$	0	1	0	0	1	1	1	1	0	1	0	0	0	1	0	0
$f3$	0	0	1	0	0	0	1	0	1	1	1	1	0	0	1	0
$f4$	0	0	0	1	0	0	0	1	0	0	1	0	1	1	1	1

Table.V Parameters of the DFIG 22kW Stator : 400 V 41 A, Rotor 255 V 53A [3]:

Parameters	**Values**	**Meaning**
L_h	45.8 mH	Mutual inductance
L_s	46.8 mH	Stator inductance

L_r	46.8 mH	Rotor Inductance
R_s	0.1315 Ω	Stator resistor
R_r	0.1070 Ω	Rotor resistor
P	2	Pairs of poles

5. Conclusion

In this paper, the problem of current sensor fault detection and isolation, for double-fed induction generator driven by a wind turbine application has been addressed. An observer scheme and a statistical detection algorithm have been used as residual generation and decision system, respectively. The approach has been validated using simulated signals of a double-fed induction generator for wind turbine. Through simulations, it has been demonstrated that multiple current sensor faults for rotor and stator have been correctly detected and isolated with a DOS observer scheme. The results obtained show the effectiveness of this technique, if one makes a good choice of the detection threshold. The future extension of this work is to improve the performance of observers and insensitivity on measurement noise, in a test bank in real time. We are interesting in the FDI problem for other sensors of wind turbine (voltage, wind speed). The FDI problem for time varying rotational speed of the rotor will also be studied.

Acknowledgments

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NUMERICAL INVESTIGATION OF THE DYNAMIC BEHAVIOUR OF ELECTRONIC SYSTEMS

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Abstract.
During their duty cycle, embedded mechatronic systems are subjected to vibration loading that may cause solder joint failure. The estimation of expected life for this type of systems relies heavily on a sound knowledge of the dynamic properties of involved materials. In this paper we present how to fit a probabilistic model of the mechanical behavior of a mechatronics product with experimental data obtained by laser Doppler vibrometry (LDV) measurements. Moreover, the inverse probabilistic problem allows to quantify the uncertainty on material properties for a better assessment of the random response of the numerical model

Keywords. *Mechatronic, Stochastic, Identification, Optimization.*

1 INTRODUCTION

Embedded mechatronics systems are used in industrial equipment, automobiles, medical equipment, and various portable devices. In service, these mechatronics systems are submitted to mechanical (shock, vibration) and thermal (temperature variations) loading that may cause solder joint fatigue failure. The estimation of expected life relies heavily on a good knowledge of the dynamic properties of the involved materials.

Numerical simulation is often used to describe the mechanical behavior of these systems.However, the challenge of the numerical simulation in mechatronics is the complexity introduced by the multi-physical loads applied on the mechatronics system (mechanical, thermal, electrical, magnetic, etc.). Further complexity is due to the miniaturization of the system and to the high heterogeneity of the materials involved.

In this paper we present a numerical simulation of the vibration behavior of a surface mount electronic board using ANSYS finite element code (ANSYS Guide 2011). We start with a comparison between the numerical simulations of our Finite Element Model (FEM) and the experimental results obtained by an optical non contact measurement technique. Afterwards, we determine the elastic parameters (i.e., Young's modulus, density, etc.) of the materials used for the electronic structure.

However, the knowledge of the mechanical properties is imperfect, due to inherent measurement uncertainty. Uncertainties on the geometry, material properties, border conditions or the applied load, play an important role in the validation of the finite element model. The following approach aims to assess the randomness of the response of the numerical model in order to obtain a good match between the experimental and numerical results. This approach is split into two stages.

The first stage consists in a deterministic parametric identification method in order to find the numerical values of the different material parameters. This parametric identification problem is formulated as an optimization problem in order to minimize the gap between the experimental and the simulated results. Two families of algorithms can be used to solve this type of problem:

• Exploratory algorithms, requiring only the assessment of the cost functions,

• Gradient-based algorithms, requiring the assessment of the cost functions as well as the evaluation of their gradient regarding the parameters.

In this work the genetic algorithm and the Levenberg-Marquardt algorithm are combined, in order to exploit the advantages of each method and to find a global optimal solution with a reduced calculation time.

The second stage in this work consists in a new approach for defining the confidence interval of the PCB materials parameters, based on the Inverse Reliability Strategy. This method is applied to a FEM and its performance is compared to the Monte Carlo method.

2. EXPERIMENTAL MODAL ANALYSIS

The experimental study was carried out in the C.E.V.A.A (Automotive Vibration and Acoustics Testing Centre of Rouen). The main purpose of this study was to confront experimental results to numerical ones. The experimental setup uses a Laser Doppler Vibrometer (LDV) - a non-contact velocity transducer (Pryputniewicz et all, 1989), based on the analysis of the Doppler Effect on a laser beam emerging from a solid surface. This measurement technique has the following major advantages:

- Avoids mass or stiffness loading (absence of a mechanical contact)
- Allows for remote measurement
- Measurement of moving components or structures
- Able to measure on high or low temperature surfaces

The experimental results obtained for the first ten eigen-frequency modes, are presented in Figure 4.

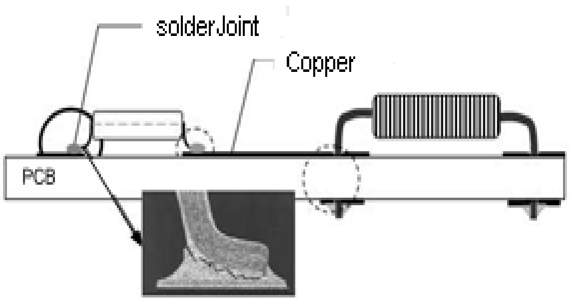


Figure 1: Example of solder joint failure (the most frequent type of failure under vibration loading).

3. VALIDATION OF THE NUMERICAL SIMULATION MODEL

Modal analysis is a method that allows determining the dynamic behavior of structures. In other words, the dynamic behavior can be represented by a number of reduced modal parameters: eigen-frequencies, damping factors and eigen-modes. The dynamic behavior of mechanical structures can be represented by the following matrix equation:

$$M\ddot{u} + C\dot{u} + Ku = f(t) \qquad (1)$$

where ***M, C, K*** are the mass, damping and stiffness matrix, respectively. $\ddot{u}$**,** $\dot{u}$**,** and u are the acceleration, velocity and displacement vectors, respectively. Eigen-modes and eigen-frequencies are calculated by solving equation (1) of the conservative system associated defined by

$$M\ddot{u} + Ku = 0 \qquad (2)$$

Numerical modal analysis was performed on a PCB of *170 mm × 130 mm × 1.6 mm*, fixed to its casing by five screws (four in each corner and a fifth central one). The simplified model of the studied structure is shown in Figure 2.

The PCB is composed of several layers of copper and composite material (FR4). A shell element type is used to modeling the PCB, where SHELL181 type is predefined in ANSYS software. The shell finite element is well suited for the modeling of composite materials. The deterministic simulation was performed by using mean values of the initial (before identification) characteristics of the PCB materials, these values are detailed in Table 1. The simulation results of the eigen-frequencies and the eigen-modes are presented in Figure 3, which are compared to the experimental results obtained by LDV. As we can see in Figures 3 and 4, we obtain a good agreement between the experimental and the numerical results. We obtain a maximum relative error of ***7%*** between the numerical and experimental eigen-frequencies.

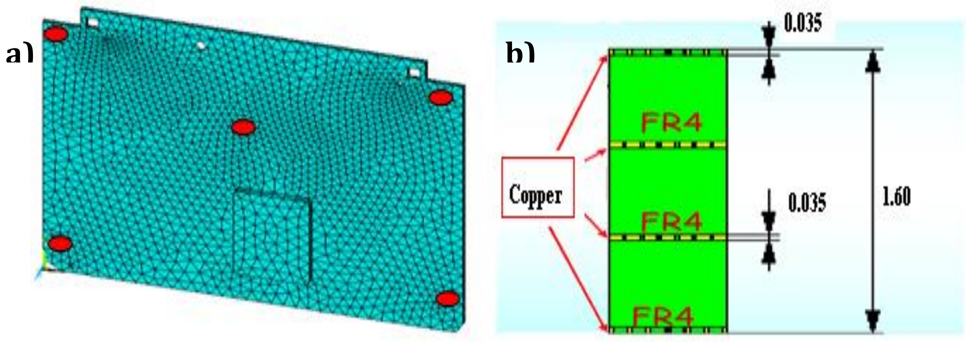
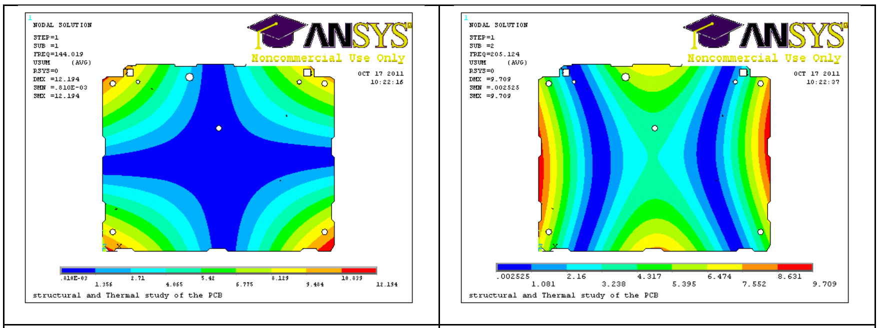


Figure 2: a) Finite element mesh of the PCB and the main component b) cross-sectional area of the PCB

Table 1: Statistical description of random variables

Description and units	Variables	Mean	Standard deviation	Distribution
Young's modulus of FR4 [Gpa]	EX_FR4	17	1,7	Log-Normal
Young's modulus of copper [Gpa]	EX_CU	110	11	Log-Normal
Shear modulus of FR4 [Gpa]	GX_FR4	3	0,3	Log-Normal
Shear modulus of copper [Gpa]	GX_CU	40	4	Log-Normal
Poisson's coefficient FR4	PRX_FR4	0,14	0,014	Uniform
Poisson's coefficient FR4	PRX_ CU	0,35	0,035	Uniform
Density of FR4 ([kg/m^3]	DENS_FR4	1900	190	Normal
Density of copper [kg/m^3]	DENS_ CU	8930	893	Normal



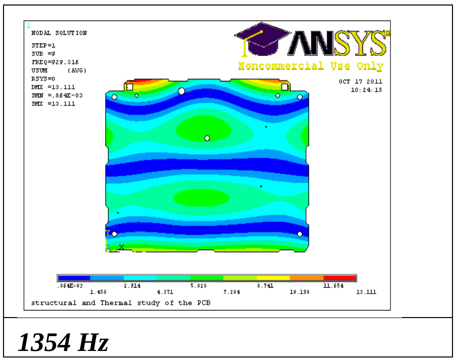


Figure 3: Simulated Eigen-modes

4. STOCHASTIC SENSITIVITY ANALYSIS

Mechanical modeling of the PCB must take into account the propagation of uncertainty by relying on probabilistic modeling of fluctuations in the input parameters. This approach is often called “mechanical-probabilistic modeling”; it aims to establish the impact of uncertainties on the mechanical response. These uncertainties are mainly composed of the inherent random input parameters (i.e. the geometrical dimensions, loading and the properties of the materials) and the uncertainties of modeling. In our study we take into account the randomness of the input parameters.

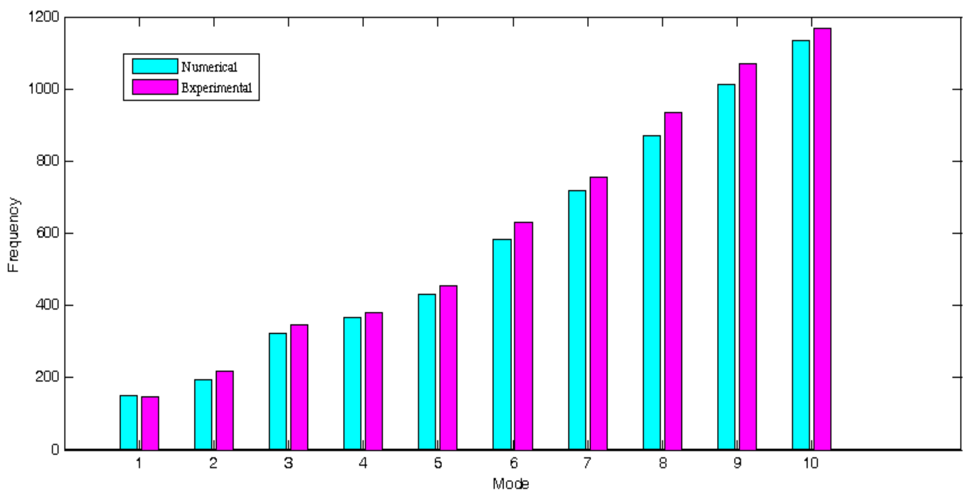


Figure 4: Experimentally and initial numerically eigen-frequencies

There are several approaches to analyze the propagation of uncertainties in the structural response (Helton and Davis, 2003). We use the Monte Carlo method to calculate the first statistical moments of the response. To do this, we assume that all the variables are random, and their probabilistic characteristics (i.e. mean, standard deviation) are given in Table 1. The statistical moments of the ten first frequencies, shown in Table 2, are estimated from 10 000 samples.

Table 2: Statistical moments of the first ten eigen-frequencies of the PCB

	experimental result	simulated result	
Mode	Frequency[Hz]	Mean[Hz]	Standard deviation [Hz]
1	146.9	147.1 (0.1 %)	6.89
2	218.8	203.8 (6.0 %)	9.34

The sensitivity analysis is carried out from the results of Monte Carlo simulations, using the Latin Hypercube sampling method based on the calculation of the coefficients of linear correlation (Nistor et al. 2003) (or Pearson's correlation coefficients). These coefficients allow classifying the model input parameters based on their importance. The results are presented in Figure 5. This sensitivity study allowed us to take into account the parameters that affect the simulation model and minimize the gap between the simulated and experimental results.

5. NUMERICAL PARAMETRIC IDENTIFICATION

The objective of this phase of the study is to estimate the numerical values to be assigned to the various parameters of the printed circuit board materials, in order to obtain a better match between the experimental and simulated results.

The parametric identification problem is formulated as an optimization problem. To do this, the reduction of the number of variables allows accelerating and ensuring convergence. This parametric identification procedure is carried out by taking into account only the most influential parameters detected by the sensitivity analysis.

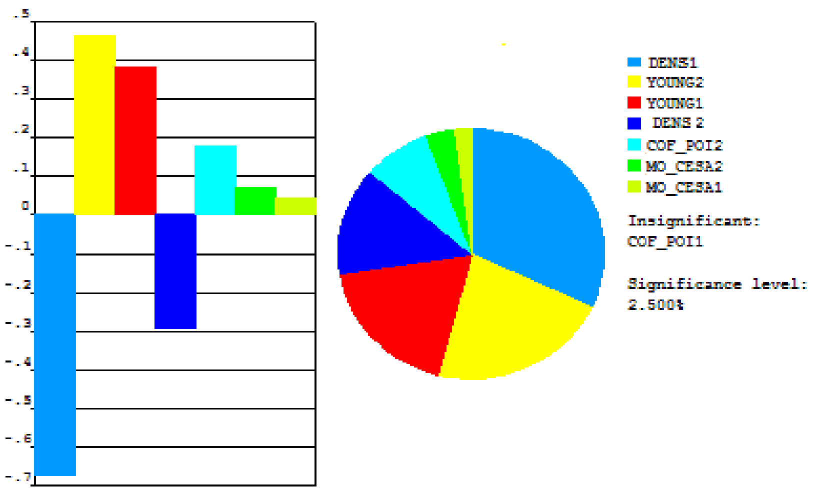


Figure 5: Sensitivity of the first eigen-frequency

The objective function of the optimization problem is expressed by the discrepancy between experiment and simulation results for each eigen-frequency mode:

$$F_{obj} = \sum_{i=1}^{nmode} \left(\frac{f_{\exp,i} - f_{num,i}}{f_{\exp,i}} \right)^2 \quad (3)$$

Where $f_{num,i}$ is the simulated frequency, $f_{exp,i}$ is the experimental frequency and x is the vector of parameters to identify. To solve the optimization problem, we have proposed to combine genetic algorithm and a gradient-based algorithm, like the Levenberg-Marquardt algorithm (Perrin 2008) in order to find a global optimal solution in a reduced calculation time. The main steps of this approach are:

1. Data initialization
2. Finding a local optimum using the genetic algorithm
3. Refining the search by Levenberg Marquardt algorithm, using the coarse solution provided by the genetic algorithm as the initial point.

Figure 6 shows the estimation of the first ten eigen-frequencies of the PCB by using identified material parameters given in Table 3.

Table 3: Identified parameters of the printed circuit board (PCB)

Description and unit	Parameters	initial value	identified value
Young's modulus of FR4 [GPa]	EX_FR4	17	17,43
Young's modulus of copper [GPa]	EX_CU	110	145,3
Density of FR4 ([kg/m^3]	DENS_FR4	1900	1881
Density of copper [kg/m^3]	DENS_ CU	8930	8939

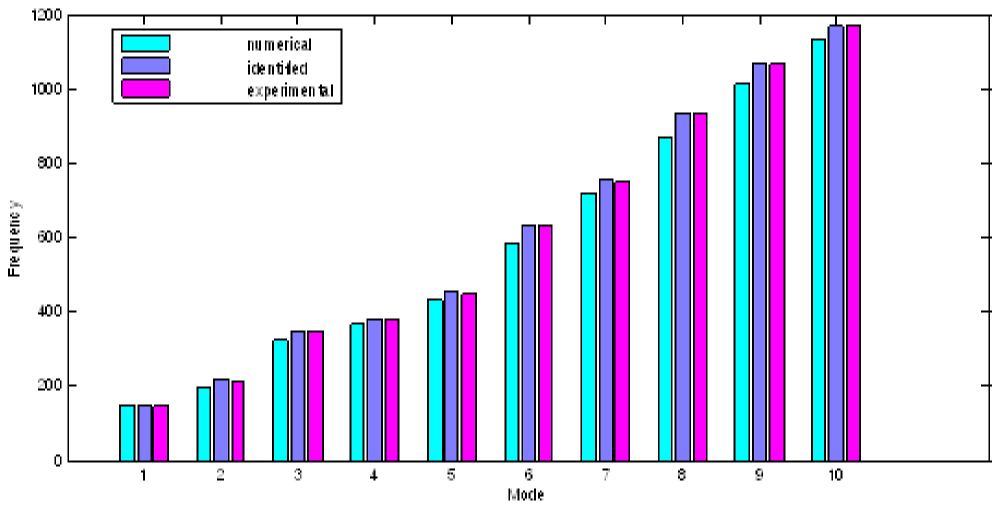


Figure 6: The first ten eigen-frequencies of the PCB before and after identification

6. MODELING THE VARIABILITY OF MATERIAL PROPERTIES

Generally, a finite element analysis program starts with a set of input data such as geometric parameters, material parameters, loads and boundary conditions. The program then generates output data for the analyzed component such as temperatures, displacements, stresses, strains, voltages and/or velocities. Almost all input parameters are subjected to scatter due to either natural variability or inaccuracies during manufacturing or operation. In a probabilistic approach, the uncertainties on the input side are described by statistical distribution functions. Therefore, it is necessary to estimate the accuracy of the statistical characteristics using confidence intervals or limits. In this section we propose a new approach for defining the confidence interval of the PCB material parameters, this method is applied to a FEM and its performances are compared to the statistical procedures obtained by Monte Carlo simulations.

6.1 Statistical procedures

This step concerns the use of statistical procedures to quantify the true statistical moments of the probability distribution that was previously determined for each of the mechanical parameters. In this discussion, a two-sided confidence interval is referred to as a confidence interval, and a one-sided confidence interval is referred to as a confidence limit. The width of confidence intervals is characterized by the probability of falling inside or outside the confidence interval. The probability of the statistical characteristic of the sampled data falling outside the confidence interval is usually denoted with the symbol $\boldsymbol{\alpha}$. Consequently, the probability of the statistical characteristic of the sampled data falling inside the confidence interval is $\boldsymbol{1-\alpha}$.

The statistical analysis of sample data is based on some assumptions. One key assumption is the independence within the samples or, in other words, the observations are independent. This means that the results of one sample do not depend in any way on the results of another sample.

Mean Value

An estimate for the mean value of a random variable $\boldsymbol{X}$ derived from a sample of size $\boldsymbol{n}$ is:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (4)$$

The estimate of the mean value is a random variable itself and it converges to the true mean value $\boldsymbol{m}$ of the random variable $\boldsymbol{X}$ if the sample size $\boldsymbol{n}$ tends to infinity. By virtue of the central limit theorem, the distribution of the estimate of the mean value can be assumed as a Gaussian distribution. Hence, the $\boldsymbol{1-\alpha}$ confidence interval is:

$$\langle\mu\rangle_{1-\alpha} = \left\lfloor \bar{x} - t(1-0.5\alpha|n-1)\frac{s}{\sqrt{n}}\,;\, \bar{x} + t(1-0.5\alpha|n-1)\frac{s}{\sqrt{n}} \right\rfloor \qquad (5)$$

where:

$t(\ldots|n-1)$: inverse cumulative distribution function of the Student's t-distribution with ***n - 1*** degrees of freedom.
s: the estimate for the standard deviation of the sample data as given by (6).
The confidence interval should be interpreted as follows: "There is a ***1 - α*** confidence that the estimated interval contains the unknown, true mean value ***m***" (5).

Standard Deviation

An estimate for the standard deviation of a random variable ***X*** derived from a sample of size ***n*** is:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (6)$$

The estimate of the standard deviation is a random variable itself and it converges to the true standard deviation ***σ*** of the random variable ***X*** if the sample size n tends to infinity. The ***1 - α*** confidence interval is:

$$\langle\sigma\rangle_{1-\alpha} = \left[s\sqrt{\frac{n-1}{\chi^{2^{-1}}(1-0.5\alpha|n-1)}} ; s\sqrt{\frac{n-1}{\chi^{2^{-1}}(0.5\alpha|n-1)}} \right] \qquad (7)$$

where:

$\chi^{2^{-1}}(\ldots|n-1)$: Inverse of the cumulative distribution function of a chi-square distribution with ***n-1*** degrees of freedom.
The confidence interval should be interpreted as follows: "There is a ***1 – α*** confidence that the estimated interval contains the unknown, true standard deviation ***σ***" (Ang and Tang 1975).
For ***n = 5000*** and the confidence interval to ***95% (α=0.05),*** we obtain the true statistical moments of the probability distribution that was previously determined for each mechanical parameters, this results are recapitulated in the Table 4. The material parameters of the Table 4 represent the equivalent parameters of the stratified PCB, for example the Young Modulus of the PCB represents the equivalent module of elasticity of the stratified PCB, where is composed on the FR4 and copper layers.

Table 4: Confidence interval of the PCB equivalent material parameters

Description and units	Mean [GPa]			Standard Deviation [MPa]		
	min	estimation	max	min	estimation	max
Young's modulus of the PCB (GPa)	27.277	27.381	27.485	2.6748	2.7462	2.8216
Shear modulus of the PCB (GPa)	3.245	3.255	3.267	0.312	0.321	0.330
Poisson's coefficient of the PCB	0.1777	0.1781	0.1785	0.01	0.0102	0.0105
Density of the PCB (kg/m^3)	1696.9	1700.1	1703.3	82.721	84.930	87.262

Minimum and Maximum Values

The minimum and the maximum values of the set of observations are:

$$y_{\min} = \min(y_1, y_2, \cdots y_n)$$

$$y_{\max} = \max(y_1, y_2, \cdots y_n)$$

This means that the minimum and the maximum of a sample of size ***n*** taken from a population ***Y*** are also random variables. For the minimum value, only an upper confidence limit can be given and for the maximum value only a lower confidence limit can be derived. Since the $Y_1, Y_2, ..., Y_n$ are statistically independent and identically distributed to ***Y***, the upper confidence limit of the minimum value and the lower confidence limit of the maximum value are:

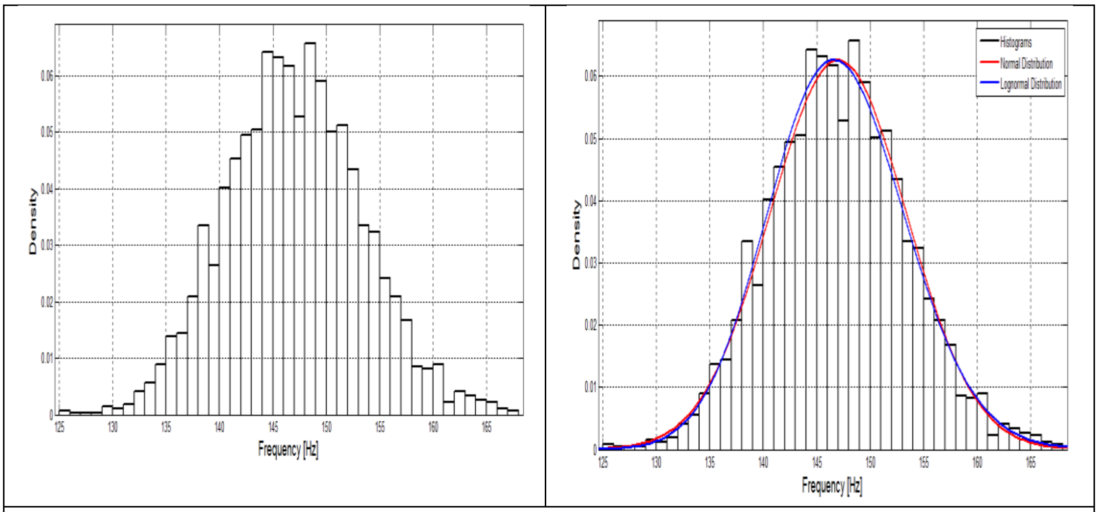
$$\langle y_{\min} \rangle_{1-\alpha} = F_Y^{-1}\left(1-\alpha^{1/n}\right) \qquad (8)$$

$$\langle y_{\max} \rangle_{1-\alpha} = F_Y^{-1}\left(\alpha^{1/n}\right) \qquad (9)$$

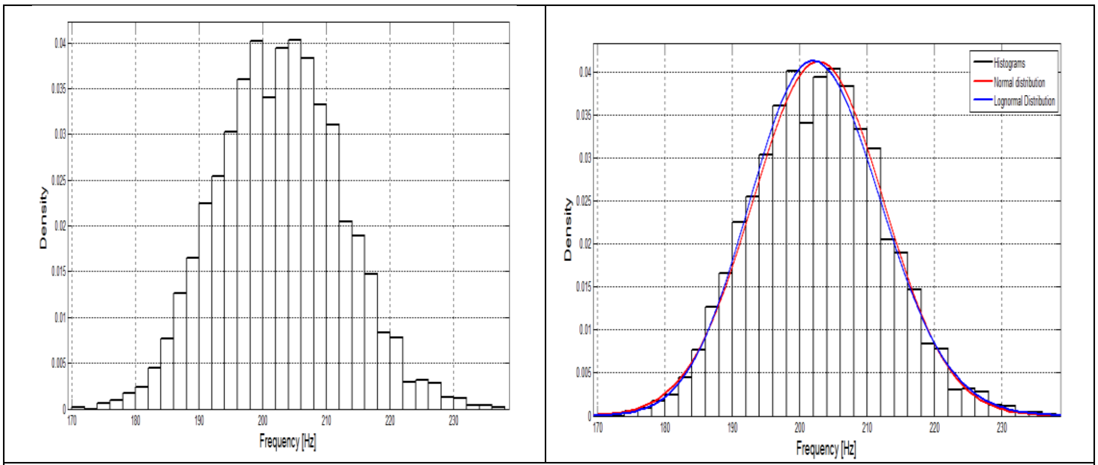
Where F_Y ***is*** *the* cumulative distribution function, y_{max} is the upper confidence interval; y_{min} is the lower confidence interval, α is a constant and $100(1-\alpha)\%$ represents the confidence interval. Obviously, the evaluation of the confidence limits requires the computation of the inverse cumulative distribution function of the random variable ***Y*** based on sampled data. This is explained in inverse cumulative distribution function, where it is assumed that the true cumulative distribution function F_Y is unknown, but can be approximated by the empirical cumulative distribution function derived from the set of observations (Figure 7).

This method is applied to the PCB for calculate the upper and lower confidence interval of the first eigen-frequency. The confidence interval was selected to be ***95%,*** the results is shown in Table 5.

The values of the confidence interval bounds depend on the probabilistic characteristics (distribution type and distribution parameters) of each parameter, the disadvantage with statistical procedure that the distribution is unknown and is approximated by the empirical cumulative distribution function derived from the set of simulation samples; this can be influenced on the credibility of the obtained results. So there is a strong motivation to develop a new technique that can overcome both drawbacks.



Mode 1



Mode 2

Figure 7: Histograms and probability density functions estimated for the first and second eigen-frequency

6.2 Inverse Reliability Strategy

In this section we propose a new approach based on the Inverse Reliability Strategy for defining the confidence interval of the PCB materials parameters. The objective is to find the upper and lower confidence interval, the evaluation of the confidence limits requires finding the mean point $\boldsymbol{y_m}$, where $\boldsymbol{y_m}$ that verifies the equality of reliability indices level relative to both sides of the confidence interval. The reliability index $\boldsymbol{\beta_c}$ is evaluated by the Inverse FORM approximation:

$$\beta_c \approx -\Phi^{-1}\left(P_f\right) \qquad (10)$$

Where Φ ( ) is the standard gaussian cumulated function and $\boldsymbol{P_f}$ is the failure probability corresponding to the confidence interval $100(1-\alpha)\%$

Implementation of the new Approach

The new algorithm case can be expressed by the three following steps (three sequential optimization steps) as shown in the flowchart of Figure 8:

- Compute the numerical values to be assigned to the various parameters y of the PCB materials, in order to obtain a better match between the experimental and simulated results. The parametric identification problem is formulated as an optimization problem. The resulting solution of this problem, as illustrated in Figure 9, is considered as a mean point $\boldsymbol{y_m}$.
- Compute the lower confidence interval bound $y_{\max}$ of the PCB materials: the objective of this phase is to minimize the eigen-frequency *corresponding to* the mean point $\bar{y}$ in order to satisfy the required

reliability levels $\boldsymbol{\beta_c}$.

$$\begin{aligned}&\min: \quad frequency\left(y_m\right)\\&subject\ to: \quad \beta_c - \beta = 0\end{aligned}$$

- Compute the upper confidence interval bound $y_{\min}$ of the PCB materials: the third optimization problem is to maximize the frequency subjected to satisfy the required reliability levels $\boldsymbol{\beta_c}$

$$\begin{aligned}&\max: \quad frequency\left(y_m\right)\\&subject\ to: \quad \beta_c - \beta = 0\end{aligned}$$

The reliability index is evaluated by:

$\beta = \sqrt{\sum_{i=1}^{n}\left(u_i\right)^2} \quad i = 1,\dots,n$; Or u_i is the normalized variable $\boldsymbol{\mu}$.

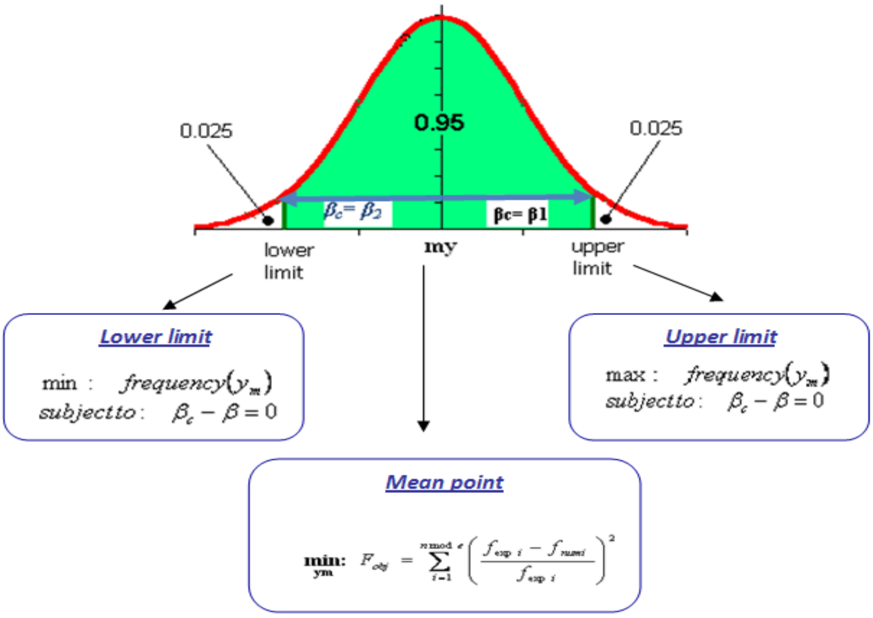


Figure 8: Implementation of the new approach

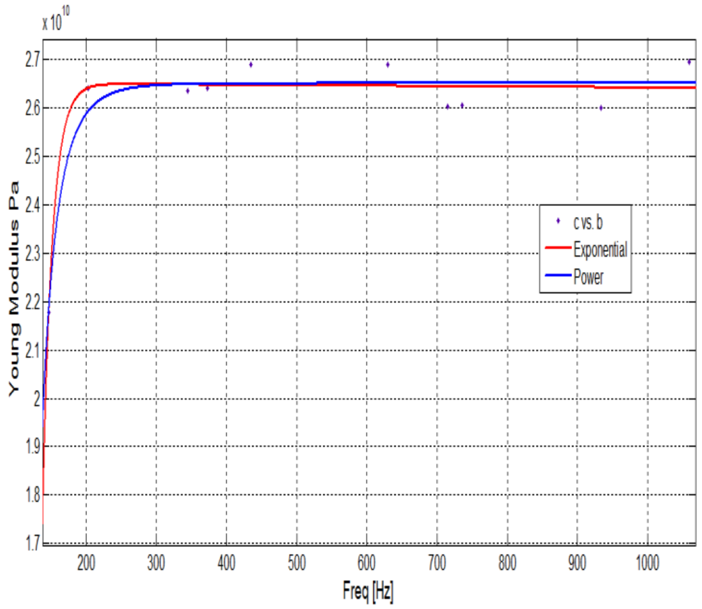


Figure 9: Results for storage modulus *Shear* (left) and storage Young modulus (right) with their frequency

Table 5 shows the results of the new approach. This method requires less computational effort than the statistical procedures; allowing also an easier way to define the confidence interval.

Table 5: Confidence interval of the PCB material parameters

Frequency mode	Statistical procedures with MCS			New Approach		
	Min [Hz]	Mean [Hz]	Max [Hz]	Min [Hz]	Mean [Hz]	Max [Hz]
1	127.50	147.01	166.52	130.59	147.01	161.20
2	173.06	202.72	232.40	179.06	202.72	224.32
3	291.80	344.34	396.88	298.57	344.34	385.27
4	319.92	372.98	426.04	324.71	372.98	422.51
5	373	434.67	495	391	434.67	443
6	528	629.74	730	539	629.74	718
7	617.12	715.44	813.17	631.12	715.44	797.17
8	629	735.78	842	648.43	735.78	823
9	787	933.69	1080	809	933.69	1067
10	902	1059	1216	925	1059	1195

7. CONCLUSIONS

In this paper we presented the identification of the elastic parameters for an embedded electronic system under vibration stress. An experimental modal analysis was performed by means of LDV. The numerical simulations of the frequencies and the eigen-modes of the electronic board were validated from the experimental results. Stochastic sensitivity analysis was used to identify the role of the uncertainties of each input parameter in the simulation of the dynamic structural response. This analysis allowed eliminating the less influential variables on the response, in order to achieve the deterministic and probabilistic parameter identification.

A new identification strategy was proposed in order to minimize the gap between simulation and experimental results; as well as to determine the best statistical moments of the law of probability associated with the settings. Finally, a new method based on the inverse reliability strategy was proposed for defining the confidence interval of the PCB materials parameters. This method is applied to a FEM for quantifying the true statistical moments of the probability distributions and its performance is compared to the statistical procedures with Monte Carlo Simulations.

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Electrothermal simulation and Reliability Analysis of Power Microelectronic Devices

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Abstract

This paper presents a methodology and tool based on electro-thermal finite elements modeling intended to analyze the sequence of the events after emergence of defects in Power Microelectronic Devices. Finite element modeling of power device and its nearby environment is detailed. Such modeling is useful to Study the effects of delamination and bonding wire lift off on device transient electro-thermal behavior, then to optimize the structure design and to guarantee a longer lifespan of the bonding were.

Keywords: Power module, Finite Element Simulation, Thermal Electric, Reliability, FORM, Fatigue.

Introduction

Power microelectronic devices have a role increasingly growing up in transport: electric and hybrid vehicles, trains and aircraft. For these applications, security and reliability are a critical point, where the reliability of the power modules should be optimized. In other words, the packaging of power microelectronic device involves a reliability challenge. Generally, power modules contain several semiconductor dies and microelectronic components soldered into Aluminium substrate. These power devices are often exposed to severe operational conditions combining thermal cycling, temperature fluctuations caused by either power transients or environmental changes, along with the resulting thermal expansion mismatch between the various package materials, results in time and temperature dependent creep deformation of solder [1-4]. This deformation accumulates with repeated cycling and ultimately causes solder joint cracking and interconnect failure[5]. To minimize development costs and maximize reliability performance, advanced analysis is a necessity during the design and development phase of a microelectronic package[6]. This requires the utilization of a life prediction methodology that is based on the damage mechanisms experienced in a field operation environment. The paper discusses the analysis methodologies as implemented in finite element simulation software tool and the corresponding results for the solder joint fatigue life. Simulated accelerated temperature cycling is performed to obtain the plastic work due to thermal expansion mismatch between the various materials. Accumulated plastic strains were incorporated to predict the fatigue life [7-10].

Finite element methods are broadly used to predict numerically the thermomechanical behaviour of power modules. However, these simulation tools are based on a deterministic approach and thus do not take into account the variability of the input parameters having an impact on the response of the model. In fact, uncertainties due to variability in design, loading, and operational conditions lead to structural stress which does not correspond to the expected one. In this paper, a probabilistic approach to the reliability prediction is proposed by considering uncertainties related to material properties, temperature fluctuations caused by power transients and Thermal environment changes, thermal expansion mismatch of the different materials of the assembly. The structural reliability theory provides an appropriate approach to take account for uncertainties. The probability of failure of a power module is estimated, where limit state function is defined by the thermal failure mode. The ANSYS Finite Element Analysis software is used to solve the heat transfer problem response [16].

The first stage of this work uses a numerical simulation to describe the electro-thermomechanical behaviour of power microelectronic module to predict the chip junction temperature of this power module. A numerical 3D finite element model of the power device is presented by taking into account material nonlinearity properties. A coupled electro-thermal finite element (FE) analysis and thermal–mechanical FE analysis is performed to analyze the mechanical behaviour of power module under steady and transient loading.
The second stage focuses on the viscoplastic finite-element simulation to predict the solder fatigue life. three different architectures of solder were evaluated. A half symmetry model of stacked flash package are generated using ANSYS APDL script. The life cycle of the resulting packages were simulated under accelerated temperature cycling conditions (-40C to +125C, 15min ramps/15min dwells). Darveaux’s methodology is used in this study to predict the solder life of the power device [10-11].

The third stage aims to describe the probabilistic coupling methods to compute the failure probability and the Finite Element model of the IGBT module and the boundaries conditions. a parametric study of the thermo- mechanical reliability of wire wedge bonds by nonlinear finite elements analysis (FEA) is conducted in order to establish a tool to optimize the thermo-mechanical performance of wire bonds for high temperature applications.

Finite element modelling

Conventionally, high power electronic packages are of stack configuration. The silicon chips are soldered onto insulating substrates typically made of a ceramic layer (Al_2O_3or AIN) sandwiched between two thin copper layers, and the entire assembly of the die and the direct copper bonded (DCB) is soldered to a copper baseplate. Aluminum wire bonds and copper busbars interconnect the die,

substrate and module terminals. Typical example of this technology is the IGBT module. Schematic drawings of the module construction are given in Figure.1.
Power device model is achieved with Ansys software using a 3D electrothermomechanical element type that has three degrees of freedom, voltage, temperature and displacement (Figure.2). This element solves the Ohm law and the heat conduction law for a static or transient analysis and takes into account the heat generated by Joule effect as well as material non linearity with temperature. Thermal conductivity and heat capacity of silicon are important parameters that can significantly influence power device cooling by increasing the thermal capacitive behavior of the silicon die with respect to the heat.

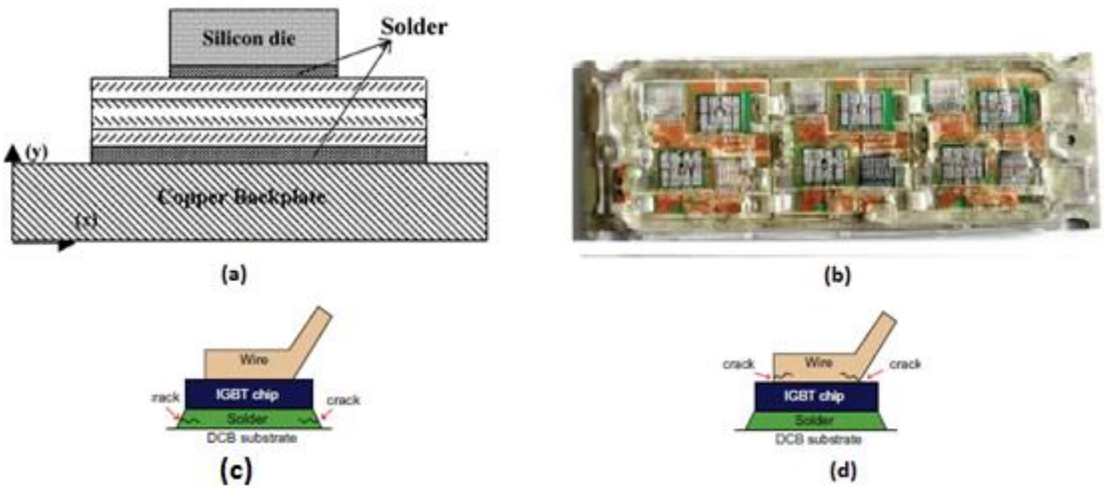


Figure 1. (a) Schematic cross section of conventional multilayer structure; (b) IGBT module; (c) Solder fatigue; (d) Bonding wire failure.

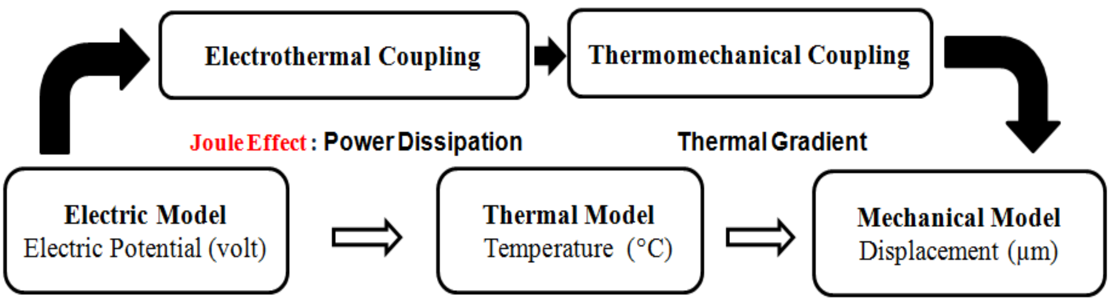


Figure 2. Schematics of electro-thermomechanical modeling with Ansys software

The purpose of the FEM analysis is to find the stress–strain distribution in the model under cyclic thermal loading. Since Pb/Sn eutectic and near eutectic solders are highly viscoplastic in nature, a nonlinear viscoplastic material is used for solder in the analysis, whereas the silicon chip, aluminum substrate and copper heat sink are considered to be elastic. Due to the CTE mismatch of laminated materials, under the cyclic thermal loading, the stress and strain development in the free edge of the solder layer will be the main concern in the design and fabrication of semiconductor device packaging [6].

The viscoplastic model used in this study is Anand's model implemented in ANSYS general purpose FEA program. Viscoplasticity is defined as unifying plasticity and creep via a set of flow and evolutionary equations where a constraint equation is used to reserve volume in the plastic region[1]. A viscoplastic model which can be incorporated into commercially available software packages is proposed by Anand [12]. This model comprises of single scalar internal state variable "s", called the deformation resistance, to measure the isotropic resistance offered by the solder to the plastic flow. In this model, it assumes no explicit yield condition and no loading/unloading criterion used. Instead, it assumes that plastic flow occurs at all non-zero stress values. Therefore, Anand's model characterized the inelastic strains with an Arrhenius term for the temperature dependency and the stress and strain rate dependency of the Garafalo form. The constitutive equation is the flow equation as prescribed in Equation1.

$$\dot{\varepsilon}_P = A\, exp\left(-\frac{Q}{RT}\right)\left[sinh\left(\xi\frac{\sigma}{s}\right)\right]^{1/m} \tag{1}$$

where $\dot{\varepsilon_p}$ is the inelastic strain rate, A is a pre-exponential factor, Q is the activation energy, R is the universal gas constant, T is the current absolute temperature, ξ is a multiplier of stress, σ is the current tensile stress, m is the strain rate sensitivity, and s is the internal state variable (deformation resistance) and the evolution equation is:

$$s^* = \hat{s}\left[\frac{\dot{\epsilon}_p}{A}\, exp\left(\frac{Q}{RT}\right)\right]^n \tag{2}$$

wheres $\hat{s}$ is a coefficient for deformation resistance saturation value, and n is the strain rate sensitivity for s saturation. Anand's model has been shown to provide reasonable results when compared to a combination of plasticity and creep model [13]. To model the material behavior of solder, nine material constants are needed which are: A, Q, ξ, m,h_0 , $\hat{s}$,n, a, plus the initial value of the deformation resistance.

Simulation begins with creating the model geometry and appropriate mesh using the pre-processor PREP7 within the Ansys FE program. Figure.3 shows the meshed structure corresponding of the entire module. Note that heat stink components are excluded. model loading condition include volumetric power dissipation of 6W/mm3 applied to the active die area.

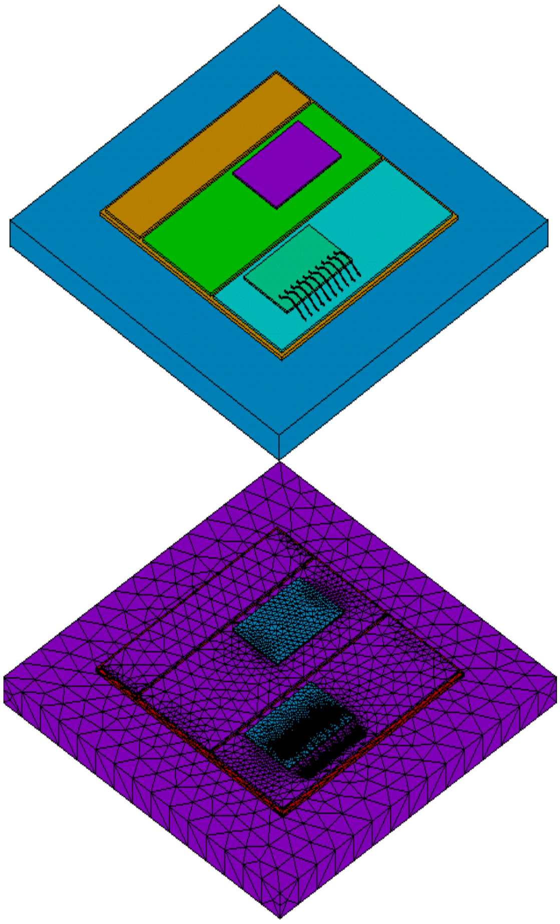


Figure 3. 3D model used in the ANSYS simulations

Figure.4 shows the temperature distribution over the chip surface and metalized of the solder layer interface. as expected the highest temperature is located at the chip centre corresponding to the highest heat flux density predicted DC thermal resistance values are derived from the model output according to the equation :

$$R_{th}(DC) = \left(T_j - T_c\right)/P_d \quad (3)$$

where T_j is the maximum temperature at the chip level, T_c is the case temperature
($25\ °C$) and P_d is the applied power dissipation.

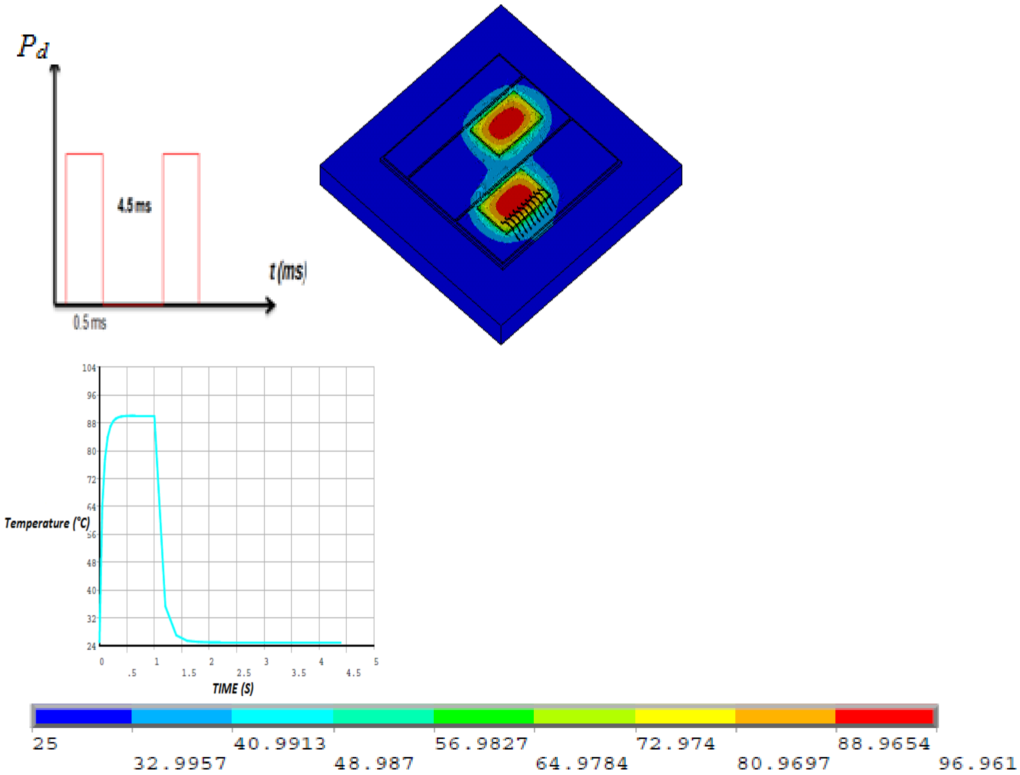


Figure 4. Temperature swing near the location of maximum value in IGBT surface.

As a result, the temperature evolution during a complete cycle for a point near the location of maximum value at the chip surface is given in Figure.4. At the end of power injection phase, temperature reaches 96 °C. At this time, we can see the temperature map within a DCB substrate in Figure.5 which shows a high coupling effect between dies. The temperature hollow at the center corresponds to the gate pad. It can be seen unequal heat flux density distribution is observed in the silicon chip area just above the region where most of the crack are concentrated. as expected the maximum temperature ($T_j = 96°C$) is reached at the lower chip and concentrated in a relatively small spot. the thermal resistance being almost double than that before cracking at that the point. this is because the heat generated by the power dissipated above the crack layer must first flow around the crack adding and additional thermal resistive path. Thus increasing the thermal resistance and so the temperature and at that location.

Thermal modeling of effects of thermal fatigue

This study focuses on viscoplastic finite-element simulation to predict the solder fatigue life of different solder configuration. Three different solder architectures were evaluated. A half symmetry model of stacked flash package are generated using ANSYS as a finite element solver. Models are simulated under accelerated temperature cycling conditions (-40C to +120°C, 15min ramps/15min dwells).

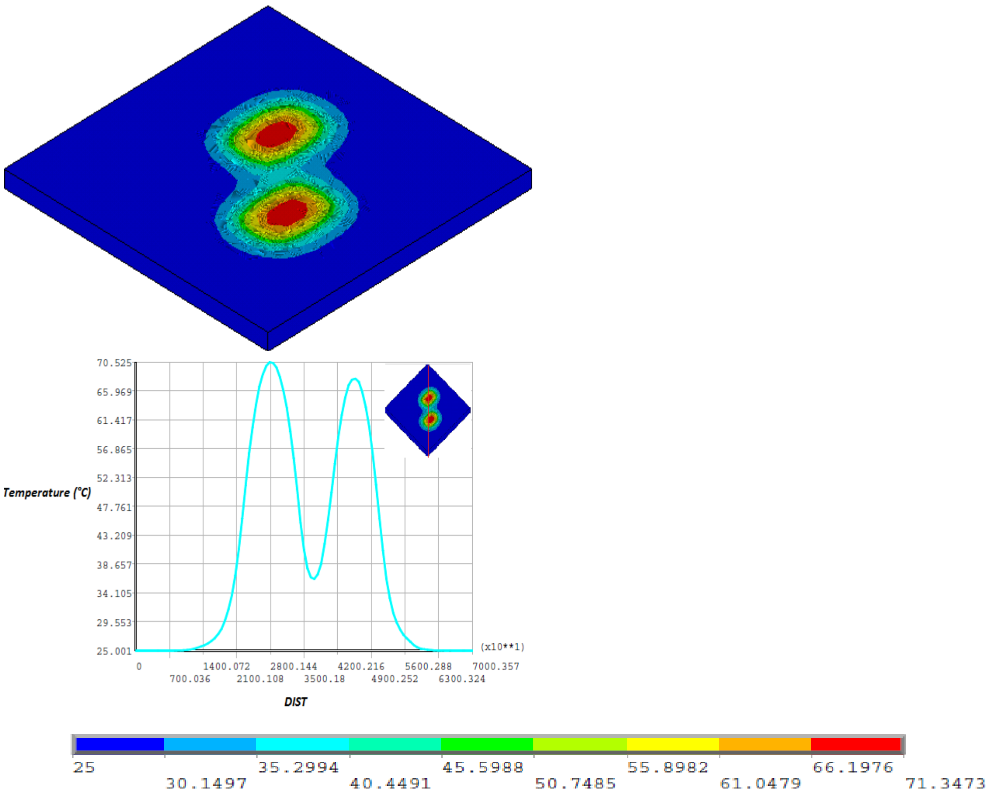


Figure 5. (a)Temperature map (°C) in DCB and IGBT dies; (b)Temperature along a central path on IGBT.

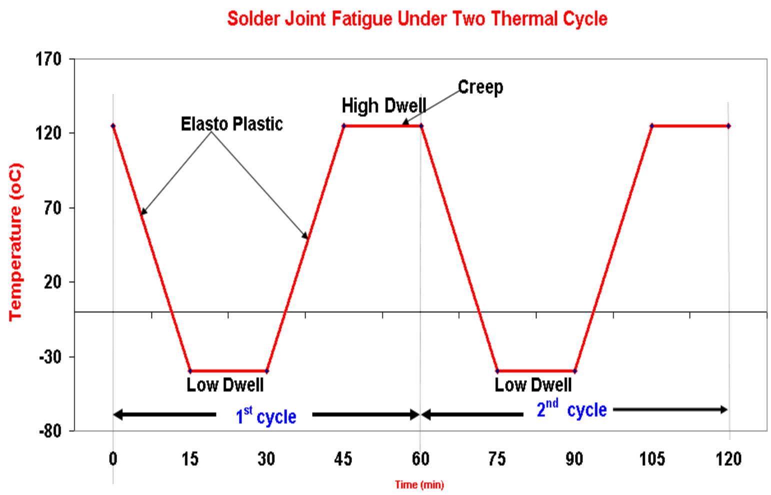


Figure 6. Thermal Cycle Profile used for Analysis

By measuring the crack growth rate of actual solder, Darveaux was able to establish four crack growth correlation constants (K_1 through K_4) along with two equations by which finite element simulation results could be used to calculate thermal cycles to crack initiation along with crack propagation rate per thermal cycle[10-11].

The layer of elements having maximum plastic work density is included in the calculation of the weighted average plastic work density, W_{ave}

$$\Delta W_{ave} = \frac{\sum_{i=1}^{element} \Delta W_i * V_i}{\sum_{i=1}^{element} V_i} \tag{4}$$

where W_i designates the plastic work density in the i[th] element and V_i is the volume of that element. A thermal cycle to crack initiation "No" is given by:

$$N_0 = K_1(\Delta W_{ave})^{K_2} \tag{5}$$

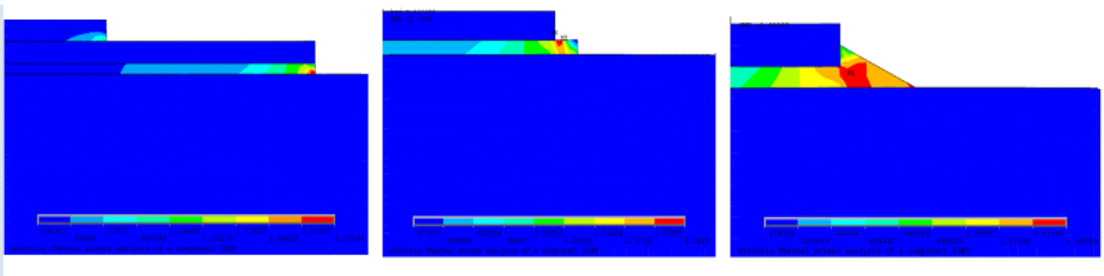
Crack propagation rate per thermal cycle "da/dN":

$$da/dN = K_3(\Delta W_{ave})^{K_4} \tag{6}$$

Here W_{ave} is the element volumetric average of the stabilized change in plastic work within the controlled eutectic solder element thickness. K_1, K_2, K_3, and K_4 are crack growth constants, which depend on geometry, loading, and the finite element analysis method. Crack growth correlation constants K_1, K_2, K_3, and K_4 are respectively 56300 cycles/psi, 1.62, 3.34E-07, 1.04. The characteristic solder joint fatigue life "α" (number of cycles to 63.2% probability of failure) can be calculated by summing the
cycles to crack initiation with the number of cycles it takes for the crack to propagate across the entire solder joint pad diameter "a". α is given by:

$$\alpha = N_0 + a \,/\, (da/dN) \tag{7}$$

It is acceptable to simplify the 3-D laminated microelectronic structure to 2-D plane strain problem. It should be pointed out that a more accurate stress analysis would require modeling the assembly with plate and 3-D interface elements. The boundary condition is that the nodes at the base are fixed in both X and Y directions. Due to the symmetry of the structure and load, we only analyzed half of the structure. The points in the symmetric plane are fixed in X direction and free in Y direction.
After successive thermal load cycles, maximum plastic work/volume information were documented along with the stress strain information for solder. Figure.7 below shows the accumulated plastic work in the solder from the finite element analysis.



Model (1) **Model (2)** **Model (3)**

Figure 7. Accumulated plastic work in the different solder configurations

Finite element analysis results indicate that the outer edge element is the critical point for delimitation initiation. It is observed that there is significant plasticity in the solder layer mainly Table.1 indicate the detailed simulation results. Fatigue life calculated and also the plastic work accumulated in the different solder configuration.

Table 1. Detailed Simulation Results

	Model 1	Model 2	Model 3
Delta Plastic Work (J/cm^3)	2.57	2.18	1.45
Crack Initiation (cycles)	85	110	213

Plastic strain accumulation and the worst solder location vary with various design configurations (figure.8). The stresses in various solder configuration also varies and the worst case found with the model (3). This means that the form geometry has an impact on solder plastic work and the fatigue life.

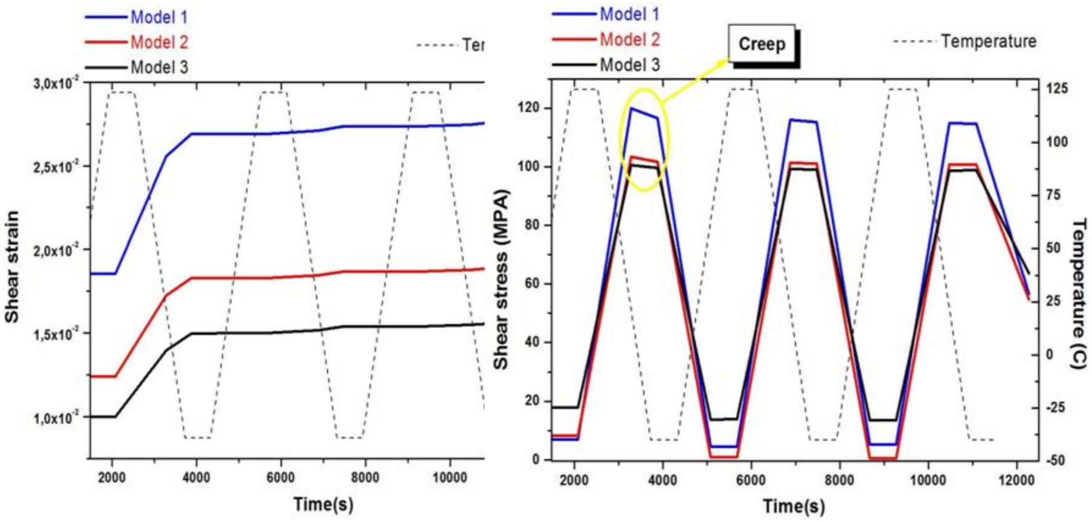


Figure 8. Temporal evolution of the shear stress and strain in the solder joint

4. Modeling of thermomechanical stresses in bonding wire

One of the most basic failure mechanisms of power device comes from bonding wire lift off. The root cause of this failure is the differences in coefficient of thermal expansion between silicon and aluminum that induces a high level of thermo-mechanical stress each time the power is undergoing a temperature variation. Such repeated thermomechanical stress generates plastic deformation between source metallization and bonding wires and leads at the end to bonding wire lift off. Therefore, it is meaningful to create a numerical tool to assess the stress levels in wirebonds of various materials and bond structures/methods in order to optimize the thermal reliability of wirebonds through minimization of the thermal stress. this tool would help us to design the geometry of the wire-span, select the bond format, select the substrate and wire materials, and stress the reliability of the optimized wire bonds. we described the probabilistic coupling methods to compute the failure probability and the Finite Element model of the IGBT module and the boundaries conditions. After that, a parametric study of the thermo- mechanical reliability of wire wedge bonds by nonlinear finite elements analysis (FEA) is conducted in order to establish a tool to optimize the thermo-mechanical performance of wire bonds for high temperature applications

FEA Model

Figure .9 shows the layered structure of the materials used in the model. This model contains a slice of the device along the wire and uses periodic boundary conditions to represent the effect of the array of wires. In order to further reduce the model size, mirror plane symmetry of the structure is taken so that only half of the model and the surrounding structure need to be included. Elastic plastic material properties are used for Cu and Al. Creep laws used for SnPb solder.

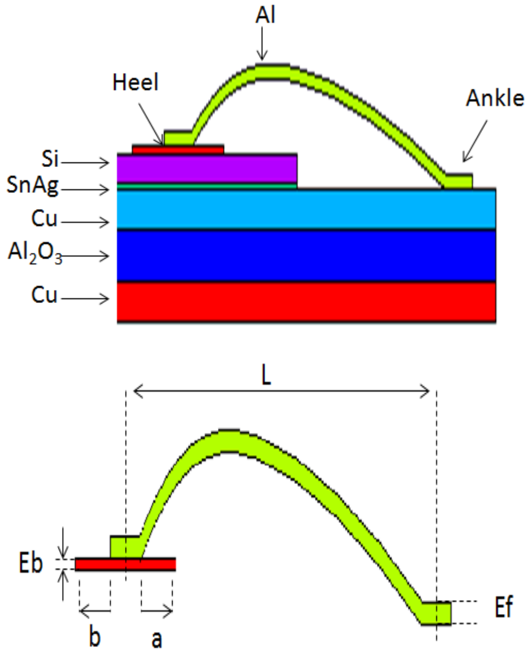


Figure 9. The layered structure of the wirebond heel

The temperature distribution and stress in model is shown in figure 10. For the Al wire, the stress concentrates at the wire die interface and at the ankle of the wire bond.

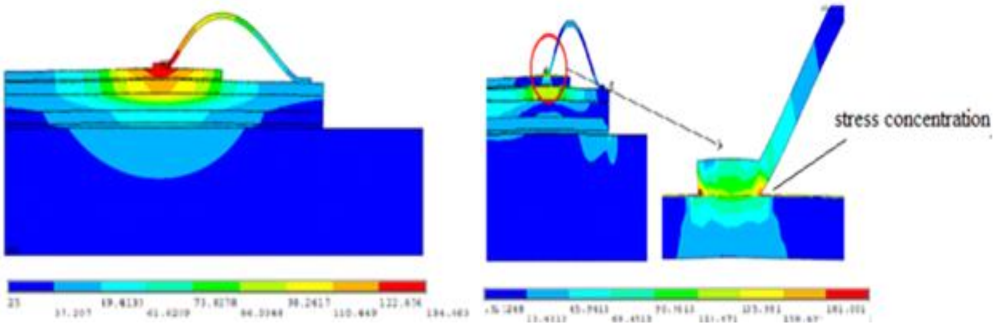


Figure 10. (a) Temperature distribution in wirebond; (b) Stress distribution in wirebond

Probabilistic design method

The probabilistic structural approach consists in determining, with a mathematical model, the probability of failure of IGBT model [14]. Indeed, when we build a traditional finite element model, all the model's input data are considered as fixed values and don't take into account the natural scatter of the parameters. The solution to consider the natural variability and uncertainties of the input parameters on the model is to treat the input data as random variables defined by a law and its associated parameters. All relevant uncertainties influencing the probability of failure are then introduced in the vector X of basic random variables. In addition, the failure of the system is modeled by a functional relation G(X), called limit state function.

Failure probability

To evaluate the failure probability with respect to a chosen failure scenario, a limit state function G(x) is defined by the condition of good functioning of the structure. In Figure.11, the limit between the state of failure G(x)<0 and the state of safety G(x)>0 is known as the limit state surface G(x)=0. The failure probability is then calculated by:

$$P_f = P_r\left[G(x) \le 0\right] = \int_{G(x)\le 0} f_X(x)dx_1 \cdots dx_n \tag{8}$$

Where P_f is the failure probability, $f_X(x)$ is the joint density function of the random variables X and P_r [.] is the probability operator. The evaluation of the integral in (8) is not easy, because it represents a very small quantity and all the necessary information for the joint density function are not available. For these reasons, the First and the Second Order Reliability Methods FORM/SORM have been developed. They are based on the reliability index concept, followed by an estimation of the failure probability [15]. Who proposed to work in the space of standard independent Gaussian variables instead of the space of physical variables.

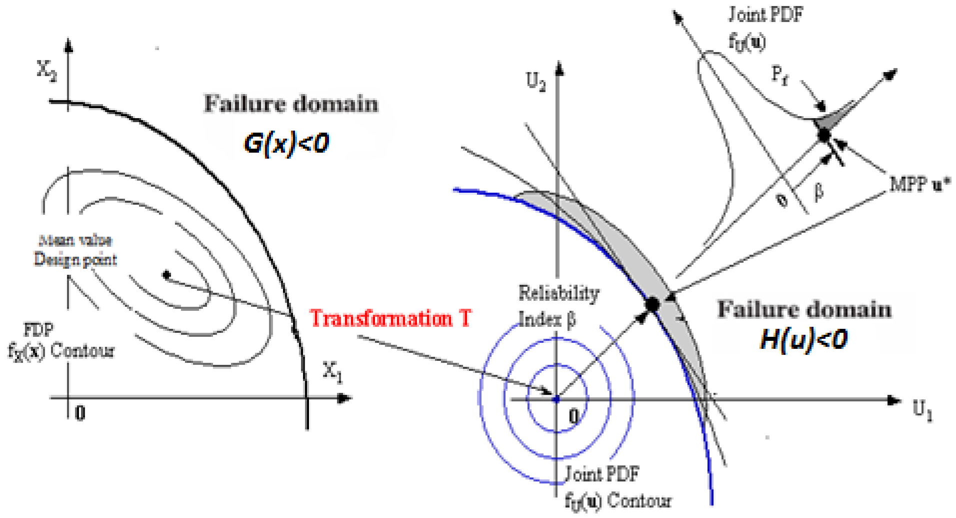


Figure 11. Physical and normalized spaces

The transformation from the physical variables y to the normalized variables u is given by:

$$u = T(x) \qquad and \qquad x = T^{-1}(u) \tag{9}$$

This operator T (.) is called the probabilistic transformation. In this standard space, the limit state function takes the form:

$$H(u) \equiv G(x) = 0 \tag{10}$$

In the FORM approximation, the failure probability is simply evaluated by:

$$P_f \approx \Phi(-\beta) \tag{11}$$

Where Φ(.) is the standard Gaussian cumulated function. For practical engineering, equation (11) gives sufficiently accurate estimation of the failure probability.

Reliability evaluation

For a given failure scenario, the reliability index β is evaluated by solving a constrained optimization problem (Figure. 11). The calculation of the reliability index can be realized by the following form:

$$\beta = \min\left(\sqrt{u^T u}\right) \qquad subject\ to \qquad H(x,u) \leq 0 \tag{12}$$

The solution of this problem is called the design point P*, as illustrated in Figure. 11. When the mechanical model is defined by numerical methods, such as the finite element method, the evaluation of the reliability implies a special coupling procedure between both reliability and mechanical models.

Random variable and limit state function

From the mechanical failure, we consider as random five variables defined with their density function. The parameters distribution type and value are listed in Table. 2.

Table 2. Variable and law type

Random variables	Distribution	mean	Standard deviation
a(µm)	Normal	100	10
b(µm)	Normal	100	10
L(µm)	Normal	14000	1400
Ef(µm)	Normal	100	10
Eb(µm)	Normal	20	2

The limit state function, relating the thermo-mechanical failure of the wirebonds , is written to consider that the system falls into the failure field if the equivalent stress von mises at a potential failure does not reach a target value (equation 13).

$$G(X) = \sigma_{targ} - \sigma_{calc}$$
(13)

σ_{alc} and σ_{targ} are respectively the number of the equivalent stress von mises computed by the finite element code and the objective stress that the system does not have to reach. In this initial configuration, the reliability index is equal to *4.09* (which is equivalent to a probability of failure $P_f = 0.9591$) with the fixed upper temperature $T_{max} = 100°C$.

For ameliorate the reliability level a wirebond interconnection, we used an optimization procedure minimizing the stresses at potential failure locations. The optimization problem of the wire bond interconnection can be formulated as:
minimize the stress: $\sigma(x) = f(x_1, x_2, x_3, x_4, x_5)$
subject to the constraints of upper and lower limits:

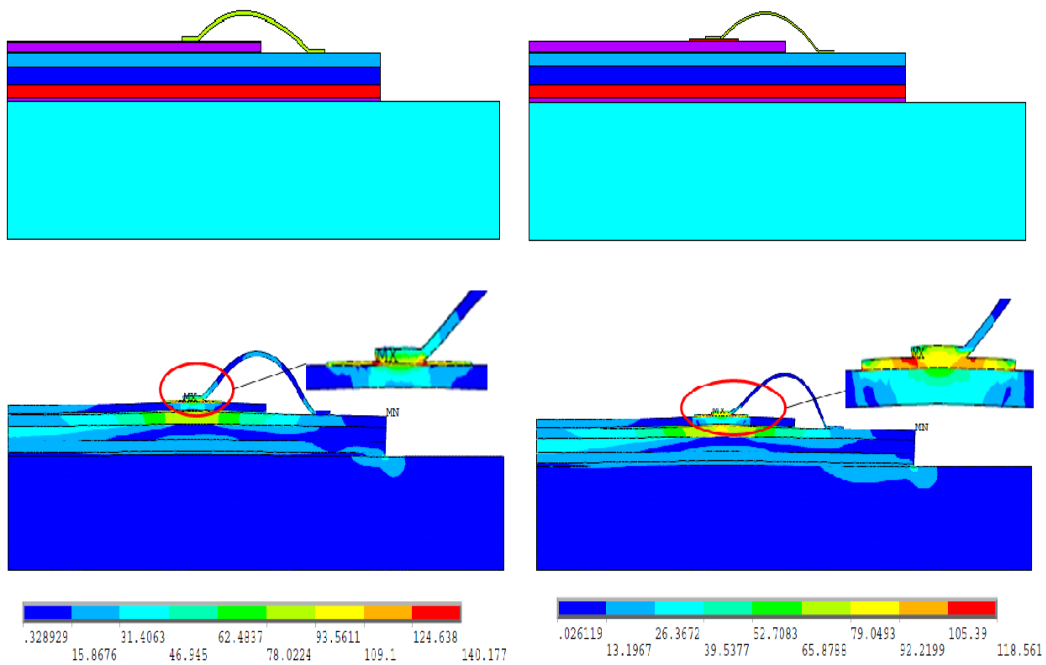
$$x_i^l \leq x_i \leq x_i^u . \quad (14)$$

where x_1, x_2, x_3, x_4, x_5 are the design variables as defined in Figure. 9.

Table 3. Optimization results

design variables	initial value	optimum value
a(µm) /10²	94	95.00
b(µm)/10²	111	110.2
L(µm)/10²	140	135.3
Ef(µm)	100	50.00
Eb(µm)	20	49.72

The table 3 shows the optimization results, the wire bending stress is minimized For ameliorate the reliability level of the model. the figure.12 presents the initial and optimized design of the wire bond system.



(a) Initial Design **(b)** Optimum Design

Figure 12. Stress distribution in initial and optimum design of the wire bond

5. Conclusion

The F.E. model studied in this paper is used to investigate electro-thermal coupling effects within a power chip and its environment. Thus, all dissipated powers are considered (wires, metallization,and chip). Two kinds of model are used: a ‘‘3D model” that only takes into account the The bonding wires, this model is developed in order to understand the solder degradation in IGBT modules, and a ‘‘simplifed model” that takes into account the material nonlinearity properties of the chip and the viscoplastic behavior of the solder, this last is used to predict the solder fatigue life and to estimate the reliability level of the bonding wire. Such modeling is useful for a parametric study of the thermo- mechanical reliability of wire wedge bonds, also conduct to establish a tool to optimize the thermo-mechanical performance of wire bonds for high temperature applications .

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Land-Use planning in the vicinity of energy and other hazardous installations: How safe is safe-enough for our backyards?

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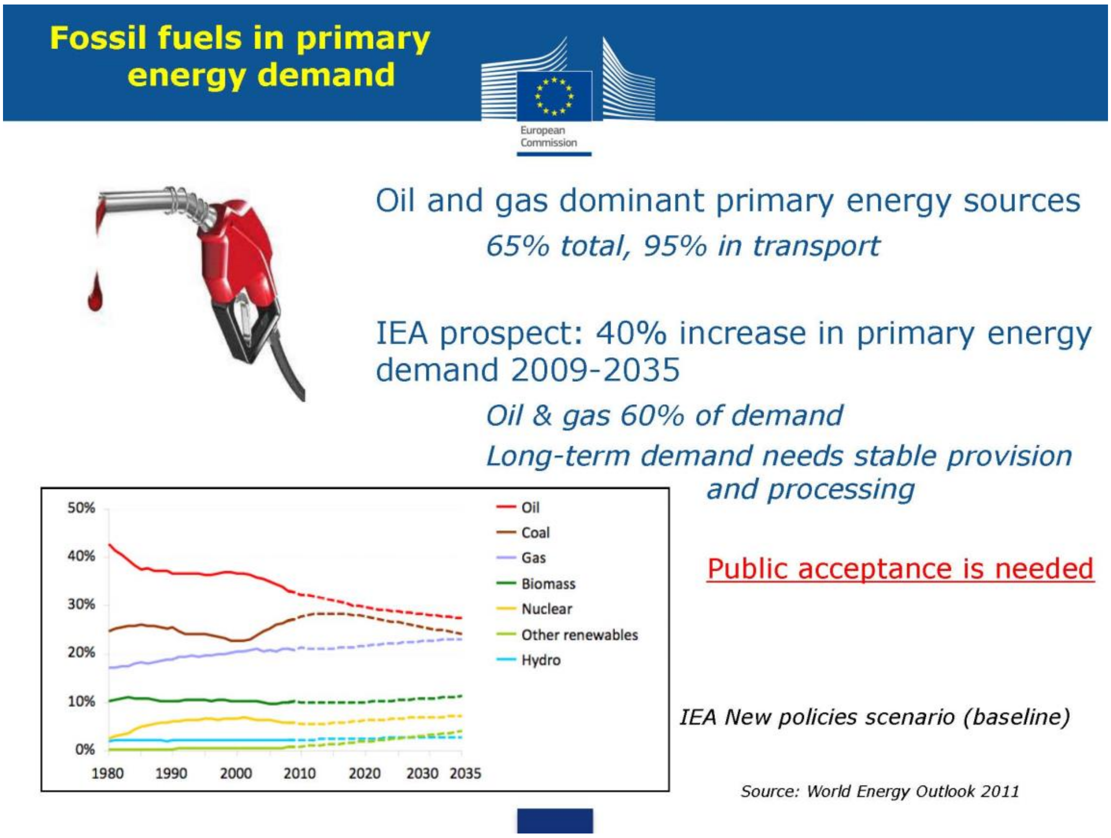
Overview

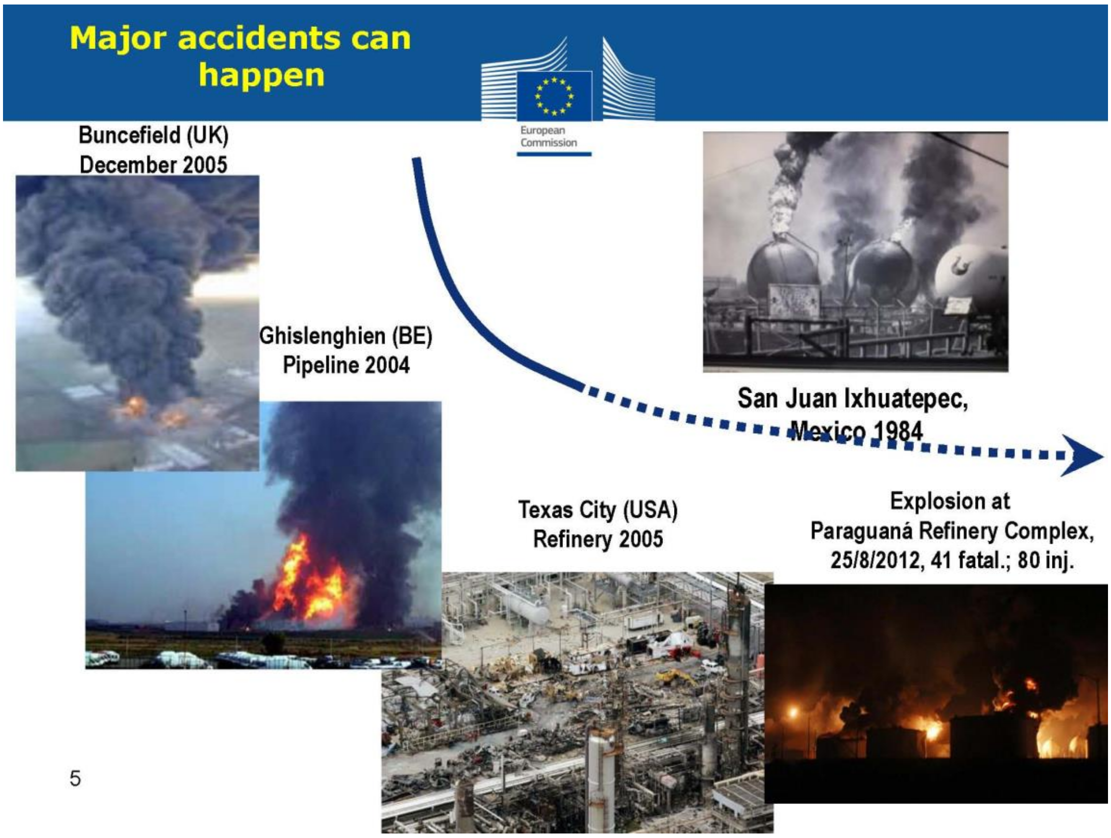
- Energy sector – Oil & gas installations
- Land-use planning around hazardous installations
- Criteria & methodologies
- EU initiatives: EWGLUP
- Principles for sustainable LUP
- New Seveso III - Challenges

Land-use in energy installations

Often specific regulatory framework exists ...

... or decisions are based on pollution or noise.


Fossil fuels in primary energy demand
European Commission
Oil and gas dominant primary energy sources
65% total, 95% in transport
IEA prospect: 40% increase in primary energy demand 2009-2035
Oil & gas 60% of demand
Long-term demand needs stable provision and processing
Public acceptance is needed
50%
40%
30%
20%
10%
0%
1980 1990 2000 2010 2020 2030 2035
Oil
Coal
Gas
Biomass
Nuclear
Other renewables
Hydro
IEA New policies scenario (baseline)
Source: World Energy Outlook 2011


Major accidents can happen
European Commission
Buncefield (UK) December 2005
Ghislenghien (BE) Pipeline 2004
San Juan Ixhuatepec, Mexico 1984
Texas City (USA) Refinery 2005
Explosion at Paraguaná Refinery Complex, 25/8/2012, 41 fatal.; 80 inj.
5

How safe is safe-enough?

Risk Assessment methodologies in support to LUP decisions

- Deterministic
  - ✓ Based on scientific/ engineering judgment
- Semi-quantitative
  - ✓ General descriptors of risk
  - ✓ Risk Matrix
- Quantitative
  - ✓ Numeric description of risk:
    - consequence-based
    - Risk-based (probabilistic or "full QRA")
- "Generic" safety distances, for standardised installations.

7

Approaches for LUPdecisions (1)

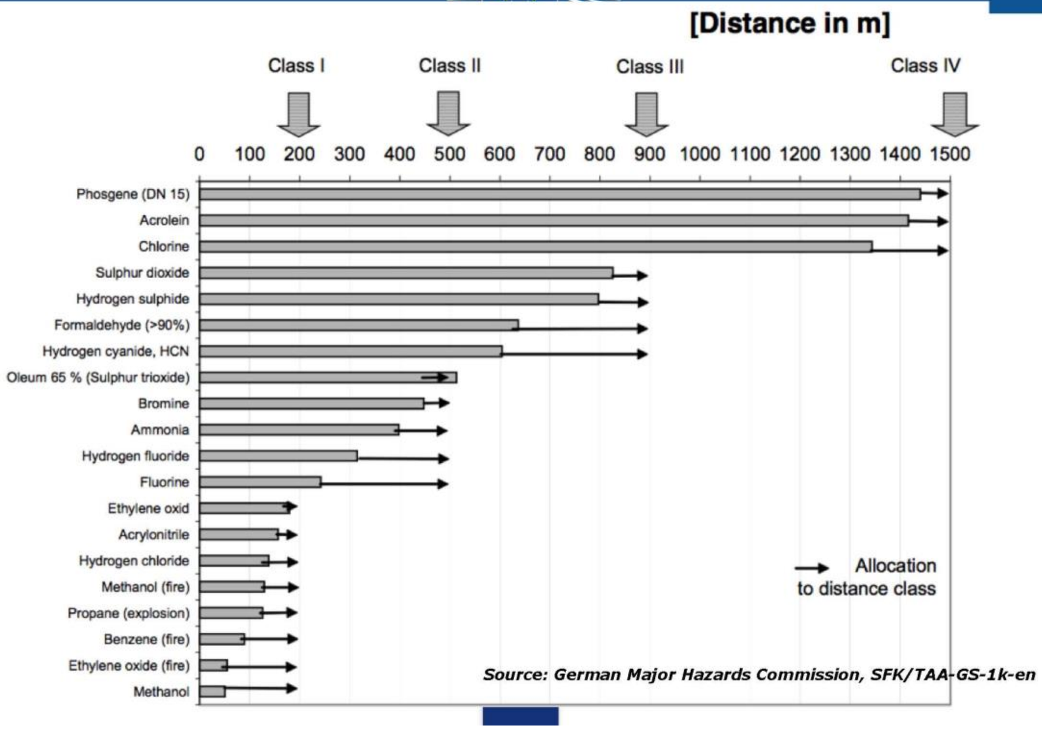
European Commission

Deterministic approach with implicit judgment of risk - "state-of-the-art"

- Target to operate without imposing any risk to the population outside the fence.
- Apply state-of-the-art technology and take additional safety measures on the source in order to restrict the consequences within the fence.
- Likelihood is taken implicitly into account in the definition of the "state-of-the-art".
- For LUP, use of zones derived from the consequences of representative scenarios.

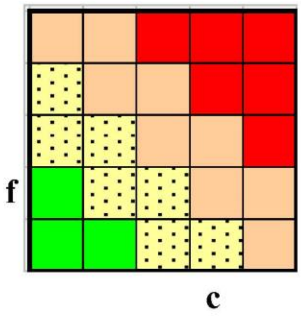
8

Example: Germany



"Semi-quantitative" approaches

European Commission



Multi-dimensional or multi-layer representation of

- **Likelihood of accident scenarios**
- **Conditions (rapid phenomena or not)**
- **Severity**
- **Vulnerability**

*Some of the parameters may be semi-quantitative (expressed by **Ranges or Classes**) or qualitative*

*➢ **Composition** is done with logical rules*

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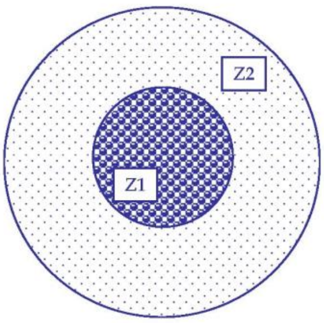
"Consequence-based" approach

European Commission



*Based on **Reference scenarios***

*Two **endpoints** (thresholds) are calculated:*

- **"lethal" effects**
- **"irreversible" effects**

Some examples of threshold values for different effects:

- **LC1% and IDLH, ERPG or AETL (or equivalent dose, for shorter exposure times), for toxic releases**
- **the thermal radiation corresponding - for a given exposure period - to 3rd and 1st degree burns respectively, for thermal effects**
- **the overpressure corresponding to eardrum rupture, for explosions**

*The **outer zone** usually serves for separation from densely populated areas or buildings with sensitive population*

1

"Risk-based" approach (full QRA)

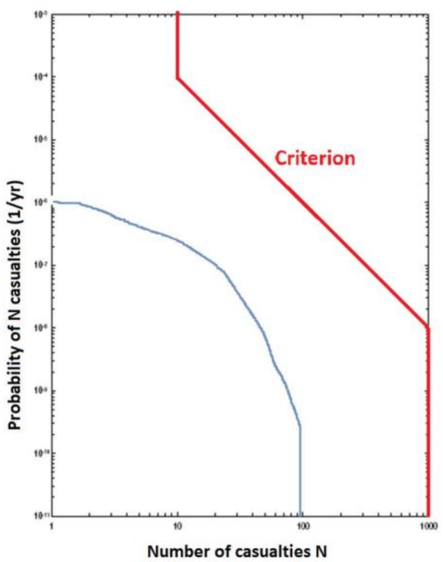
12

Example: Flanders – Individual and Societal Risk Criteria

Individual risk criterion

Risk Acceptability	IRC
Border of the establishment	10^{-5}/y
Border of residential area	10^{-6}/y
Border of area containing vulnerable location	10^{-7}/y

Societal risk criterion



Source: LNE, Belgium

Example: UK

- Decisions are taken by the Local Planning Authorities; advice is produced by HSE (Health and Safety Executive)
- Zones define areas of particular concern
- Consultation Zone is limit of HSE interest
- Within CD there are:
  - Inner Zone: (10 cpm) 10^{-5}; 1800 TDU; 600 mbar
  - Middle Zone: (1 cpm) 10^{-6}; 1000 TDU; 140 mbar
  - Outer Zone: (0.3 cpm) $3x10^{-7}$; 500 TDU; 70 mbar
- Chances per million (cpm) per year of receiving a Dangerous Dose
- Consequence based zones (mainly for flammables)

14 Source: Health and Safety Executive, UK

UK: Decision Matrix

Sensitivity Level	Development in Inner Zone	Development in Middle Zone	Development in Outer Zone
1 (e.g. factory)	DAA	DAA	DAA
2 (e.g. houses)	AA	DAA	DAA
3 (schools, elderly)	AA	AA	DAA
4 (stadium, hospital)	AA	AA	AA

15 **PADHI+ (Planning Advice for Developments near Hazardous Installations) is the software used by Planning Authorities to generate the advice themselves.**

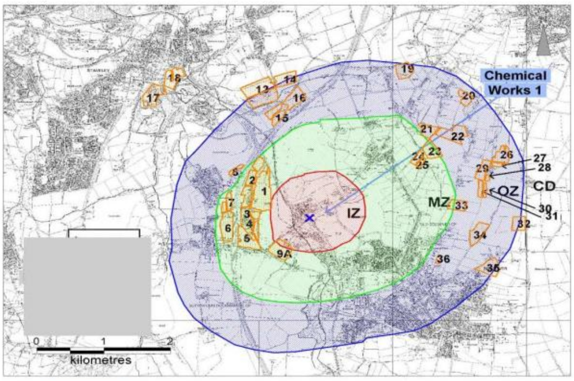
Follow-up to Buncefield accident LUP around large-scale petrol storage sites

European Commission

Development Proximity Zone – *Within the Inner Zone, with only limited access to workforce (e.g. warehousing – no offices)*

Consultation Distance – *To change size informed by risk (based on observed effects)*

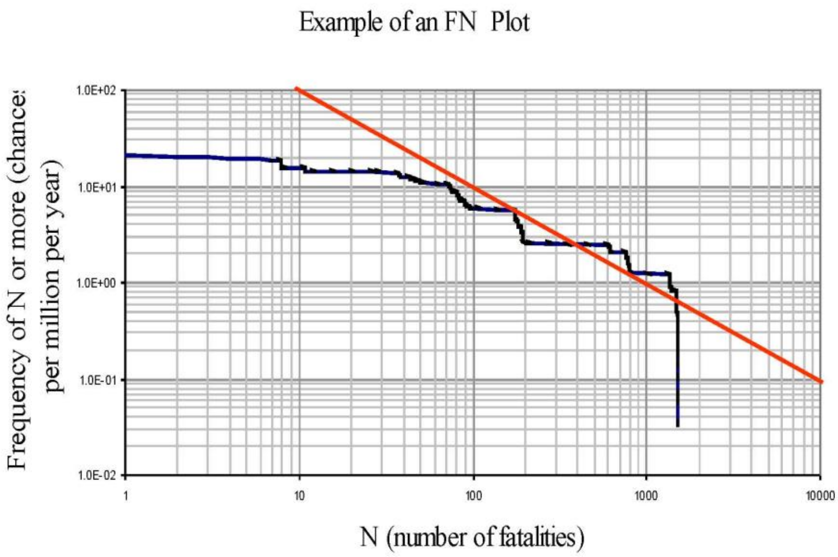
Societal Risk



16

UK: "Quick F-N" screening tool

European Commission



European Commission

How safe is safe-enough?

What is Europe doing for that?

Lille Conference, Feb. 2002

European Commission

Conclusions:

- LUP is a decision-making process that needs to take into account many parameters, **safety being only one** of them.

However:

- Need to ensure **consistency** in taking technical advice into consideration in LUP policies.
- Need for the LUP policy to be **defendable** and with **reproducible** results/decisions.
- Need to arrive at **transparent** decisions, understandable by all involved parties.
- No need to base decisions on common methodologies, but there is benefit from the use of **consistent scientific data** (e.g. scenarios, frequencies, thresholds of health effects)

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European Working Group on Land-Use Planning

European Commission

EWGLUP:

- About 90 experts contributed to the work of the Group (2003-2010)
- Both Seveso (risk management) and Planning Authorities
- Industry
- Research organisations

- **Guidelines**: Adopted by CCA; Accepted by COM Decision C(2007)2371
- **Roadmaps** of Good Practice in LUP
- **Handbook** of Scenarios for LUP (under preparation)

- **Improvement of understanding of different approaches**
- **Challenge: Bridge the gap**

20

Some key considerations in LUP decisions

European Commission

- Safety distance vs. quantity: There should be a link between safety distances and quantity of dangerous substances on site.
- Safety investments should have an impact on the land use policy
- More stringent LUP if the accident has a higher probability to happen
- LUP less stringent if public concerned can be moved to a safe place before the accident happens (for slow kinetics; link with emergency response)
- LUP is a medium- to long-term procedure (5-10 years horizon); basic community needs must be covered in the meanwhile
- Be brave enough to investigate solutions out of the box; change may be profitable to everyone

21

Frankfurt airport's new runway – Ticona plant

Seveso III – Land Use Planning   Art 13 Dir. 2012/18/EU

What? MS to take into account Seveso principles (prevent accidents and limit consequences to human and environment) in their LUP by controlling

- Siting of new establishments
- Modifications to existing establishments
- New developments (transport routes, locations of public use, residential areas)

How? LUP should take account of

- appropriate **safety (new!)** distances
- for areas of particular natural sensitivity or interest : **other relevant measures (new!)** can be taken
- for existing establishments, additional technical measures so as not to increase the risks

Seveso III – Land Use Planning

Consultation of the public concerned

- ✓ ***NEW!*** Detailed procedural guarantees for participation in specific individual LUP projects (Article 15) – similar guarantees for participation in general plans and programmes
- ✓ ***NEW!*** Access to justice if inadequate consultation on individual projects
- ✓ ***NEW!*** Operators to provide sufficient information, including scenarios & risks (for LT, on request)
- ✓ ***NEW!*** Coordination possible with consultation procedures under EIA and SEA Directives

Current Challenges

1. *Do we all (safety authorities – planners – public) speak the same **language**?*
2. *Do we consider and provide protection from **all relevant hazards**?*
3. *Does our Risk Assessment provide **robust results** to support risk management decisions?*
4. *What is the **quality** of our Risk Assessments (Frequency data, models, expression of uncertainties)?*
5. *Can we make the results of complex assessment **understandable** to lay-people?*

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Buncefield, UK, 11 December 2005

- Do we consider UVCE of liquid hydrocarbon vapors in our LUP plans?

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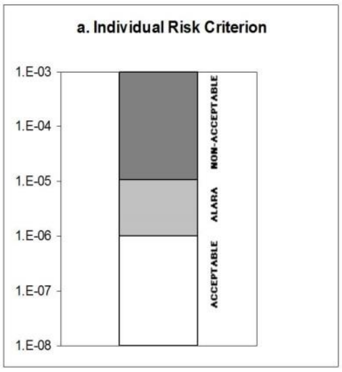
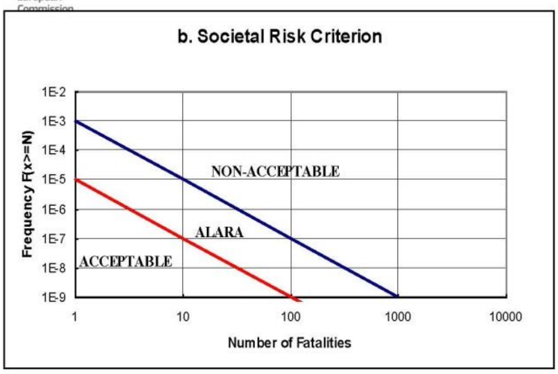
Risk-based criteria



Principle of Equity



Aversion to increased casualties

- <u>In the Netherlands:</u>
  Agreed methodology
  Agreed assumptions
  Agreed tool

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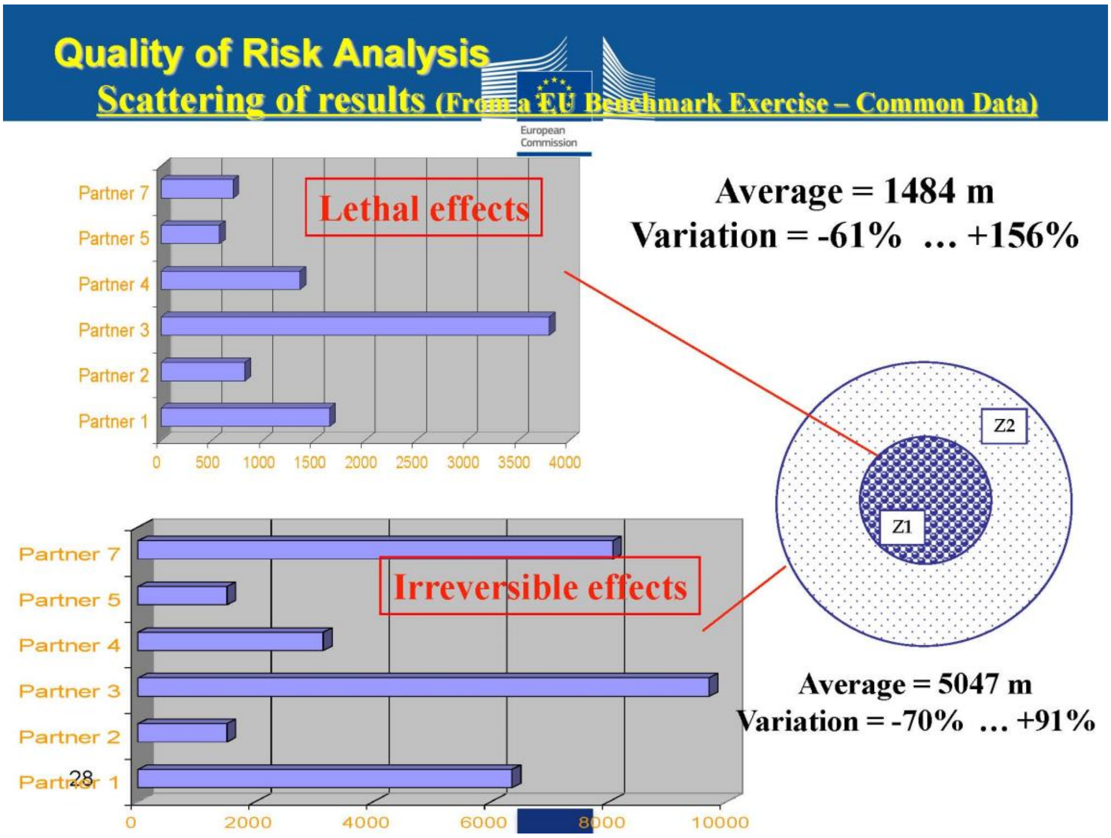
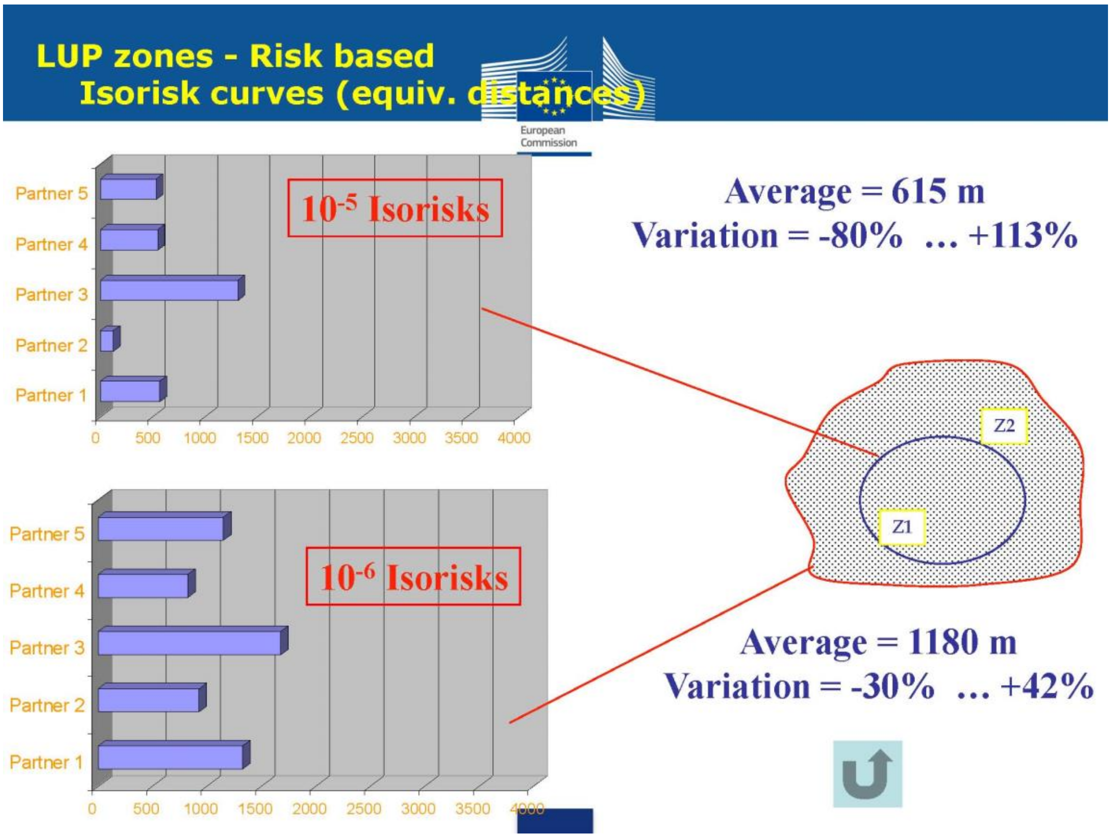

Quality of Risk Analysis
Scattering of results (From a EU Benchmark Exercise – Common Data)
European Commission
Lethal effects
Partner 7
Partner 5
Partner 4
Partner 3
Partner 2
Partner 1
0 500 1000 1500 2000 2500 3000 3500 4000
Average = 1484 m
Variation = -61% … +156%
Z2
Z1
Irreversible effects
0 2000 4000 6000 8000 10000
Average = 5047 m
Variation = -70% … +91%
28


LUP zones - Risk based
Isorisk curves (equiv. distances)
European Commission
10^{-5} Isorisks
Partner 5
Partner 4
Partner 3
Partner 2
Partner 1
0 500 1000 1500 2000 2500 3000 3500 4000
Average = 615 m
Variation = -80% … +113%
Z2
Z1
10^{-6} Isorisks
Average = 1180 m
Variation = -30% … +42%

Public participation

➢ Involvement of all stakeholders
- Early involvement
- Design of appropriate procedures

➢ Need for appropriate risk assessment and management
- Transparency
- Input: High quality risk calculations but clear and understandable information

Concluding remarks

➢ A unique answer to the question "how safe is safe-enough?" does not exist

➢ However, addressing this question requires
- Transparency
- Robust methodology
- Repeatable and defendable solutions

➢ LUP is a dynamic process; linked with SEA.

➢ Consultation of the public is an opportunity
- Recognizes to the citizen ownership of the problems
- Democratic debate
- Input: High quality risk calculations but clear and understandable information

➢ Safe plants, perceived to be safe.

Thank you for your attention!

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For more information...

DG ENV website
http://ec.europa.eu/environment/seveso/index.htm

EWGLUP website at JRC/MAHB:
http://mahb.jrc.ec.europa.eu/landuseplanning

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The risk of the hazardous freight transportation chain

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Summary

The transportation of hazardous freight is a significant part of Latvian economy. The potential risk presented by the operation of many facilities within the hazardous freight transit infrastructure is comparable to the danger presented by the SEVESO II objects; however, the legislation of the European Union does not currently stipulate any demands regarding the endorsement and control over the operation of such facilities that would be adequate to the danger represented by these objects.
The legislative acts of the European Union effective to date do regulate the operation of every single object within the hazardous freight transport chain separately, with no regard to the integrated operation of such facilities within a common risk chain. The new objects are approved for construction, despite the resulting increase in risks within the realm of their integrated operation.
The approach to applying the results obtained during the risk evaluation in land use planning varies greatly in different major European countries. Currently, there are no common documents effective in the European Union that would regulate the issues of applying the results obtained during risk evaluation in land use planning.

Keywords: risk assessment, dangerous freight, acceptance criteria, land-use planning

The flow of hazardous freight within the territory of Latvia

There are a total of about 50 high-risk objects in operation throughout the Latvian territory that are subjects to the provision of the SEVESO II directive. Most of them are port terminals located within the three major Latvian seaports – in Riga, Ventspils and Liepaja. These mostly manage the transfer of hazardous materials en route from Russia and other CIS countries to the Western Europe. The intensity of the hazardous freight transit flow through the Latvian territory is very high. Approximately 50 million tons of various freights are being shipped yearly through Latvian territory, from east to west. Most of this volume consists of the freight that is classified as hazardous. The largest share of its nomenclature is oil products, ammonia, acrylonitril, LPG and ammonium nitrate.
In accordance with the data displayed in Table I, most of the hazardous freight is transported to Latvian ports by rail. Earlier transmission pipelines were used to handle a significant portion of hazardous freight transit. However, after the crude oil supply pipeline was shut down in 2006, the volume of hazardous freight being piped within the territory of Latvia has decreased drastically. At the

moment, there is one oil product supply pipeline what operates in Latvia, which is used to pump diesel fuel from Belarus to Ventspils. There is situated 4 million. m^3 large underground gas storage at Incukalns, where the natural gas supplied from Russia is being stored. Latvian transmission pipeline system is linked into a common Baltic network, which handles the supply of natural gas from the underground storage at Incukalns to Estonia and Lithuania.

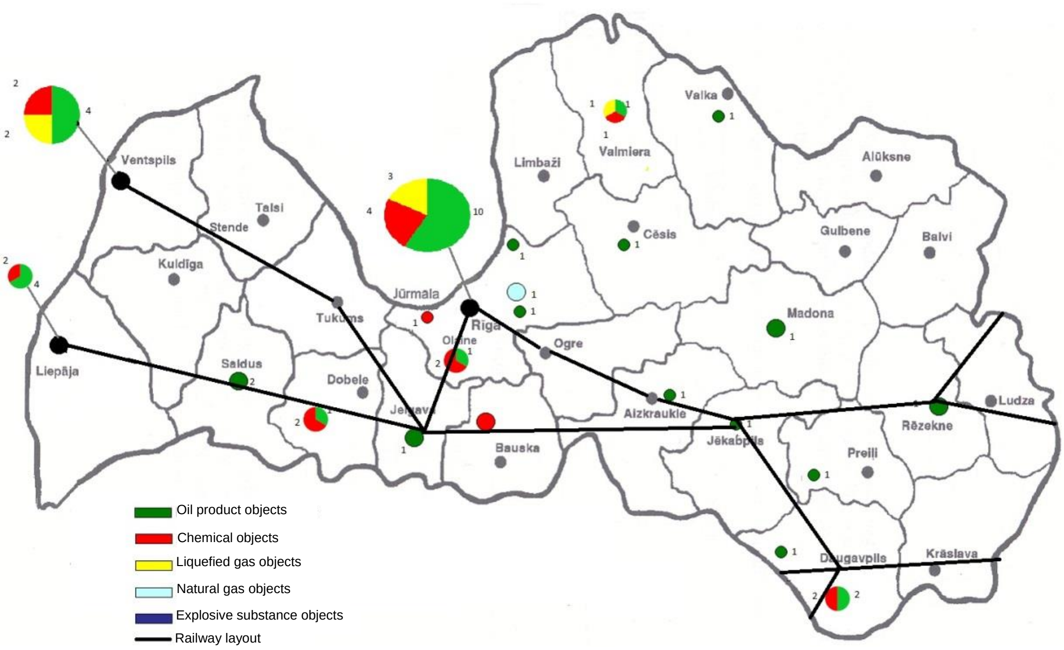


Figure 1. The map of SEVESO II objects and railroad infrastructure.

Table I: Freight flow, thousand tons, adapted from [1].

Year	Transported by rail	Piped
2004	51058	19409
2005	54861	20259
2006	48731	14543
2007	52164	6497
2008	56164	5033
2009	53679	3771
2010	49164	5635

The hazardous freight business is a considerable part of Latvian economy, but it also represents a potential risk, what has to be taken seriously. The Latvian risk matrix for risks of state importance, displayed in Figure 2, assigns the position of the highest industrial risk in Latvia to the transportation of hazardous freight by rail. This is due both to the large amount of hazardous freight being transported and to the railroad accidents involving spillage of hazardous substances that have happened within the last 20 years. The Latvian risk matrix for risks of state importance was developed in 2011 on the initiative of the State Fire and Rescue Service of Latvia with the participation of the representatives of ministries responsible. The development of this risk matrix was methodically supported by the experts from PSI „Risks un audits" LTd.

Probability		**Insignificant risk**	**Significant risk**	**Average risk**	**High risk**	**Extremely high risk**
Very high	Once a year and more frequently	Forest fires	Drowning	Fires Grave traffic accidents Homicide Suicide	Death caused by malignant tumours	Death caused by heart and circulatory system diseases
High	Once in 1-15 years	Accidents at SEVESO objects. Small hydropower plants	River pollution Sea pollution Transportation of hazardous freight by car	Transportation of hazardous freight by rail Flood Storms		
Average	Once in 16-50 years	Epizootics Terrorism	Risk potential of SEVESO objects Main gas pipelines		Powerful storms	
Low	Once in 51-100 years					
Very low	Rarer than once in 100 years			Risk potential of airport "Riga"	1% floods	Risk potential of the Daugava hydropower plant cascade
	Injured / aggrieved	10 to 100	101 to 1000	1001 to 5000	5001 to 10000	Over 10000
	Fatalities	1 to 10	11 to 100	101 to 500	501 to 1000	Over 1000
	Material losses	50K to 100K.	100K to 1M.	1M to 10M.	10M to 100M.	Over 100M.
		Insignificant	***Significant***	***Average***	***Severe***	***Catastrophic***

Consequences

Figure 2. The risk matrix in Latvia for risks of state importance.

Elements of the hazardous freight transit risk chain

The diagram shown below displays a hazardous freight transit risk chain which is typical for Latvia and includes railroads, railroad junctions, and stationary dangerous objects, ports and sea shipping lines. The dotted line in the diagram separates those elements of the risk chain which are usually operated within urban areas and thus may be subjects to additional safety requirements.

One of the objectives of this study is to characterize and demonstrate the importance of complex risk evaluation being applied to the system of such facilities in general rather than confining oneself to evaluating the danger presented by separate facilities taking the Latvian case as an example.

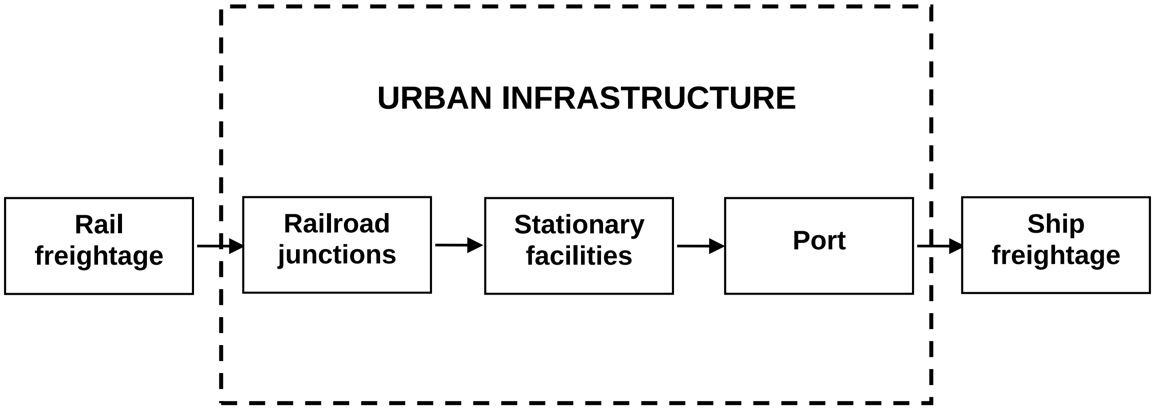


Figure 3. Hazardous freight transit risk chain

Safest elements of the hazardous freight transit risk chain in Latvia are the stationary dangerous objects. This is due to the adequately arranged legislation in effect and the effective control. The SEVESO II directive has been implemented in Latvia since 2001. Companies what have applied this directive are obliged to assess the risk of their operations and to reduce it, if necessary. During the implementation of this directive, lots of companies that manage hazardous substances have upgraded their technical equipment and improved the process control.

In order to describe the improvement of risk situation, the table shown below sums up the information on the decrease in the probability of serious accidents in the largest oil product terminal in Latvia „Ventspils nafta" terminal", Ltd. which operates within the port of Ventspils. The oil products are delivered here both by rail and through a pipeline. The current capacity of the terminal reservoirs is 1 M m^3. The terminal operates 3 railway tank unloading facilities and 9 pump stations. The data is acquired from the regular risk assessments gathered during the company's modernization process. The upgrade itself was generally aimed at the replacement of the old technological equipment left from the Soviet times and at the automation of the process control and the safety system.

Due to the provision of the SEVESO II directive, the stationary object control system in Latvia is also improved and currently ensures the operation of these facilities in compliance with the safety requirements. The control is maintained by both state and municipal authorities. At the state level, it is maintained by the Environmental State Bureau, which assesses the Safety reports and Risk reduction policies submitted by the companies. The State Environmental Service curries out complex inspections with the participation of the representatives of the State Fire and Rescue Service of Latvia and the Consumer Rights Protection Centre, what controls the operation of hazardous machinery. The hazardous facilities are subjects of control by municipalities exercised through the relevant environmental departments.

Table 2: The probabilities of the worst accident scenarios at the „Ventspils nafta „terminal", Ltd. adapted from [2].

Risk objects	Assessment of 1996	Assessment of 2001	Assessment of 2006
Unloading facility	1.1×10^{-3}	3×10^{-5}	1.8×10^{-5}
Pump station	3.5×10^{-3}	6.2×10^{-5}	1.3×10^{-5}
Valve unit	6.6×10^{-4}	3.5×10^{-5}	3.3×10^{-7}
Tank park	2.3×10^{-5}	1.4×10^{-6}	5.7×10^{-7}

Despite the number of railroad accidents in Latvia what have decreased over the past 7 years (see Table 3), the rail transport can surely be referred as to the weakest link of the hazardous freight transit chain in Latvia. There have been 4 serious railroad accidents in Latvia where hazardous substances were involved in past fifteen years. The first was in 1998 near Vecumnieki. The wheel axle box on one of the railroad tanks got overheated, which caused the axle box and the axle to weld together. It resulted in the derailment of 14 tanks loaded with diesel fuel. 810 tons of diesel fuel were spilled out and ignite. The photos below show the rescue operations initiated in the aftermath of the accident.

Figure 4. Photos from the site of the Vecumnieki railroad accident.

In two years, the second accident of similar scale occurred near the Livberze station. This one was caused by a collision of a car with the train. The resulting derailment of 10 railroad tanks caused 770 tons of diesel fuel spilled out and ignites. The third accident occurred in 2008 at the Ventspils 2 railway station, when the engine driver drove through a red light and crashed into another train standing at the station. As a result, 13 tanks were ruptured and the spilt petrol ignited. The fourth accident, in 2012, was caused by a rail defect. 17 tanks were derailed, but the oil products that spilled out did not ignite this time.

The load of the railroad in the Latvian transit corridor is so intensive that it might be compared with "a pipeline on wheels". When tankers can not be loaded in ports due to the wind, the ever-incoming trains carrying hazardous freight are parked to stand by not only at the large railway junctions, but also at small stations throughout the whole transit corridor. Large amounts of hazardous freight may be stationed at such small stations for days, in spite of the fact that these stations have neither the specialists, nor the technical equipment required to deal with the consequences of a possible leak of hazardous materials. Even the amount of hazardous freight carried by a medium-sized train loaded with petrol exceeds the lowest qualifying limit set by the SEVESO II directive.

Table 3: Statistics of railroad accidents in Latvia, adapted from [3].

	Number of railroad accidents						
Year	2004	2005	2006	2008	2009	2010	2011
Total	70	70	63	61	30	41	35
collisions (except for the collisions at the railway crossings)	0	0	0	1	1	1	0
derailment	1	1	1	0	0	0	1
accidents at the railway crossings	12	12	10	10	8	10	8
accidents involving people and the rolling stock on the move	57	57	52	45	19	27	26
fire in the rolling stock	0	0	0	0	0	0	0
Of the total number of railroad traffic accidents – those, which involved the transportation of hazardous freight	0	0	0	1	2	2	2
Of which – accidents that involved the spillage of hazardous freight	0	0	0	1	0	2	2

The accident that occurred at the Ventspils 2 station is a fine example of risk potential that such seemingly minor railroad infrastructure objects may present. In the morning of December 20th, 2008, the train carrying petrol tanks crashed into another petrol-loaded train which stood at the 2nd track of Ventspils 2 station. As it is shown in the scheme of the accident in Figure 4 at the moment of the incident, four of the five tracks within the territory of the station were occupied by trains carrying hazardous substances. The direct collision damaged the locomotive and 8 tanks of both trains, and the spilt petrol ignited. Three burning tanks with petrol were pushed off the track and the large territory was on fire. The heat radiated by burning railroad tanks of the 2nd track, soon caused another 6 railroad tanks located on the 3rd track catch the fire. Thanks to the efficient action of the rescue teams, the escalation of the accident was stopped. They towed away tanks loaded with heavy oil products standing on the 4th track and acrylonitril tanks standing on the 5th track. The petrol fumes exploded twice while the fire was being extinguished, throwing the flame up to the height of 60 metres.

One of the weak points within the Latvian railroad infrastructure is the abundance of railroad lines only consisting of a single track. Of the overall length of the railroad lines, which is about 2000 km, only 320 km have two or more tracks. The fact that an intensive traffic is being organized in both ways on a single track proves that the safety of railroad transport in Latvia heavily depends on the traffic control.

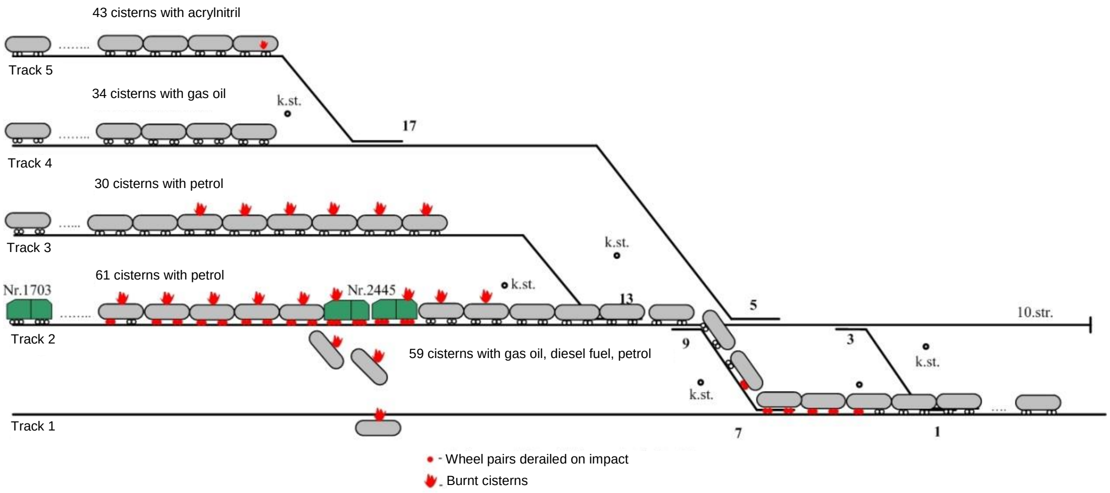


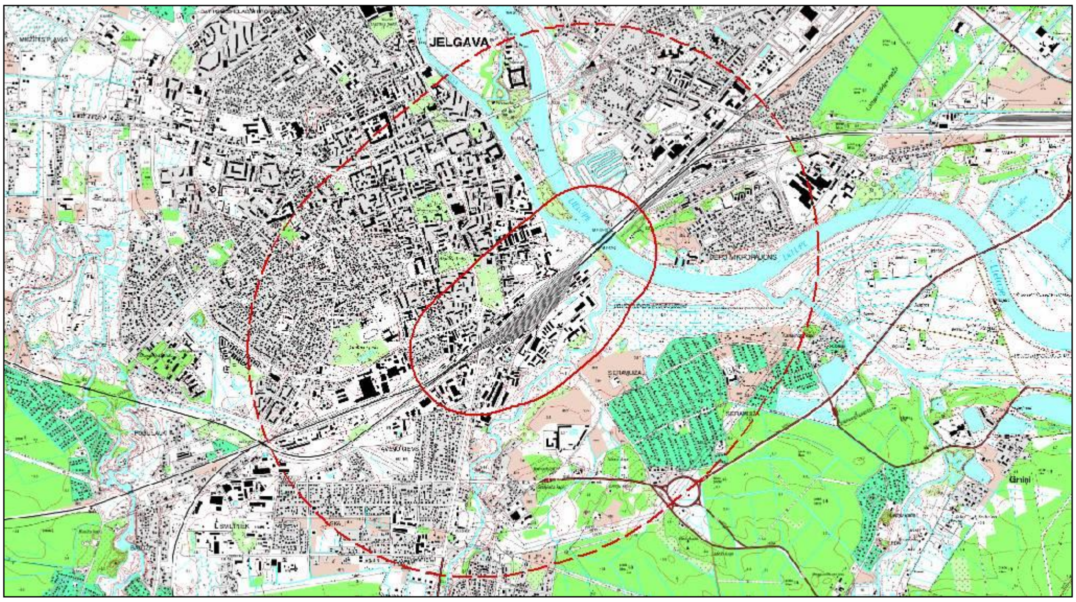
Figure 4. Scheme of the train crash in Ventspils 2 railway station, adapted from [4].

Figure 5 shows the photos of the train engulfed in flames and the blaze of fire caused by the explosion.

Figure 5. Photos of the accident at the Ventspils 2 railway station

Trains carrying hazardous freights are being marshalled and serviced at two marshalling yards, in Riga and Rezekne, and at four railroad depots in the cities of Jelgava, Ventspils, Daugavpils and Liepaja. All these railroad junctions are situated within the territory of large cities and surrounded by densely populated urban areas with multi-storey buildings. An examination of the Jelgava railroad junction can contribute to the better understanding of risk potential presented by such facilities. The Jelgava railroad junction is located in the very centre of the city with a population of about 65 000. There are over 30 tracks at the station, where there may be trains loaded with oil products, ammonia, acrylonitril and LPG may be stationed. The amount of hazardous substances that might be within the territory of the Jelgava railway station at a given moment is 3 times bigger than the upper level qualifying amount of hazardous substances are stated by the SEVESO II directive. In the SEVESO ll directive context such big stationary objects as Jelgava railroad junction needs to have the Safety report prepared, risk assessment made and adequate risk management system implemented. Regretfully the SEVESO II directive does not apply to dangerous goods transportation.

The risk assessment of the Jelgava Railroad junction was the initiative of the Jelgava Municipality. The results of this risk assessment [5] have shown that the probability of accidents in Jelgava railroad junction is quite high. Probabilities of ammonia and petrol accidents is with the rank 10^{-4} [5]. That is due to the immense flow of hazardous freight. The zones affected by the probable consequences of such accidents are quite large, too. A complete destruction of just one tank loaded with ammonia may cause the substance in lethal concentrations to spread over a distance of 450 meters (see Figure 6.), covering an urban area with multi-storey buildings and numerous commercial centres. One of Jelgava's hospitals was also situated within this area just a short time ago. To make things worse, the overall risk situation at the Jelgava railroad station is greatly affected by the intense passenger traffic at the station, which greatly increases the social risk at this object.



5000ppm spreading area
IDLH spreading area

Figure 6. The area what would be affected by the toxic influence of ammonia fumes in case of a railway tanks being destroyed at the station, adapted from [5].

Despite the results obtained by the risk assessment, the Jelgava Municipality does not have any legal instruments that could limit the operation of the Jelgava railroad junction. On the other hand, according to the Civil Defence Law of the Republic of Latvia, the municipality of Jelgava is responsible for rescuing the inhabitants within its territory in case of an emergency, railroad disasters including. The situation is pretty much the same with the other cities in Latvia where the marshalling and servicing of trains carrying hazardous freight takes place.

The operation of the ports themselves as the elements of sea transport infrastructure is one of the elements within the risk chain of hazardous freight transit, and its safety must be looked at both separately and within the general flow of hazardous freight.

The operation of Latvian ports in the last 20 years might be considerate as quite safe. Several chemical leaks are registered each year at the major Latvian ports, but these usually are insignificant and have not been of any considerable risk to date. So far just one serious accident has been registered. It occurred in the Ventspils port in 1967, when a tanker loaded with oil products exploded near a pier and its debris were thrown all over at a distance of over 500 metres. But we can say it was a long time ago.

The most recent accident was chemical leak that occurred in July 2009 at the Baltic Container terminal of the Riga Port. There were five 20-ton containers in the port, loaded with acetone cyanohydrins, which is a highly flammable and an extremely toxic substance. The pressure started to grow inside of one the containers, which caused its safety valve to open, releasing a small amount of toxic fumes into the atmosphere. The rescue team of the State Fire and Rescue Service, which was summoned at the site, has first tried to cool the container down, but then it was decided to evacuate the residents from the vicinity. There was a significant risk of an explosion. As estimated by the State Fire and Rescue Service, in case of an explosion the lives of people within the area of 300 m would be threatened. The investigation showed that the reason of the emergency was the transportation of hazardous substance in a container which was not cleaned properly beforehand. This has caused a chemical reaction, due to which the temperature and the pressure inside the container started to increase. The accident at the Baltic Container terminal has revealed yet another fault in the control over the facilities handling hazardous substances. In accordance with the license it had received, the Baltic Container terminal is not considered a dangerous object. Thus, it has neither the adequate safety systems implemented, nor the trained staff who could react properly in case of a chemical leak.

The hazardous materials from the Latvian ports are then shipped across the Baltic Sea. According to the HELCOM data [6], the frequency of accidents involving ships in the Baltic Sea is comparatively high. Over the period of 2004-2010, there was an average of 116 ship-related accidents happening yearly, 8% of which involved environmental pollution. The typical types of accidents and incidents involve ships collision and grounding. Even though the shipping conditions near the shores of Latvia are complicated enough and the maritime traffic is quite intense, the accidents involving ships quite rarely occur within the Latvian territorial waters. According to the data provided by the Maritime Administration of Latvia (see Table 4), there is an average of 14 maritime accidents and incidents per year happening within the territorial waters of Latvia, 3% of which cause environmental pollution. The most significant sea pollution of the past few years was in 2007, when a dry cargo ship „Golden Sky" ran aground not far from the Ventspils Port. The volume of the resulting spillage into the Baltic Sea was about 13 tons of oil products and 1500 tons of potassium chloride.

Table 4: The statistics of maritime accidents and incidents within the territorial waters of Latvia, adapted from [7].

Year	2004	2005	2006	2007	2008	2009	2010
Number of accidents/incidents	11	25	14	15	14	13	10

Applying the results obtained during risk assessment in land use planning.

Despite the numerous attempts to amend the relevant legislation of Latvia with the acceptable risk standards, no legislative act that would stipulate the conditions of territory usage according to the acceptable hazard levels to the inhabitants has yet been confirmed at the state level. The common argument behind this is the assertion that Latvia can not simply adopt the relevant legislation of some certain country, and a directive of the European Union is awaited instead. As a remedy for the absence of such regulation, several municipalities of Latvia have developed or is currently working on their own regulatory acts regarding the land use planning.

The greatest experience with risk management is accumulated in Ventspils, which is the most significant hazardous freight transit port in Latvia. The City Council of Ventspils has had the standards for individual and social risk and the environmental licensing procedure introduced by the Council Resolution dating as far back as the year 1994. The Dutch legislation within the realm of risk management effective during that period was used as a legislative basis. One of the objectives of environmental licensing was to reduce the risk presented by existing facilities and to prevent the founding of any new business within the city that might exceed the acceptable risk levels.

The interest of the Ventspils Municipality regarding the risk assessment was caused by the concern expressed by the scientists and the society in regard to the operational safety of the liquid ammonia transfer terminal. The facility in the Ventspils Port was built in the 1970-s in accordance with all the construction standards effective at that time. The technology includes the railway tanks unloading facility, two isothermal ammonia reservoirs, each with a capacity of 30,000 m^3, a compressor shop, a ship loading berth and the technological pipelines. Due to the fact that the ammonia reservoirs are situated virtually in the very centre of the city, the failure of one reservoir would cause the lethal concentrations of ammonia to cover almost one third of the urban territory, where 40,000 people dwell, in just a few minutes. The risk assessment for this liquid ammonia transfer terminal was done with the participation of Dutch risk management experts, who did the first quantitative risk assessment in Latvia in 1991. The individual risk isolines in Fig. 8 show the true danger to the residents of Ventspils during that time. Ever since the environmental licensing procedure has been established, Ventspils has made essential achievements in risk reduction.

The municipalities of the cities of Jelgava and Jekabpils, which are located within the hazardous freight rail transit corridor, have raised the issue of protecting their residents against such threats with the state authorities for several times over the last 20 years, though with no progress to date. The risk

calculations done on behalf of these cities show that the danger that the inhabitants of areas near the railroad infrastructural objects are exposed to is very high. Such course of action would never be allowed in most European countries. Regretfully, the extent of these municipalities' influence on rail freightage and the operation of railroad infrastructural facilities, which are considered as objects of national importance in Latvia, are very limited.
In turn, the Development Department of the Riga Municipality was pushed to amend the rules regulating the usage of the city's territory with acceptable risk criteria by the resolutions of several state and municipal authorities, which were only based on safety requirements stipulated within the construction standards.

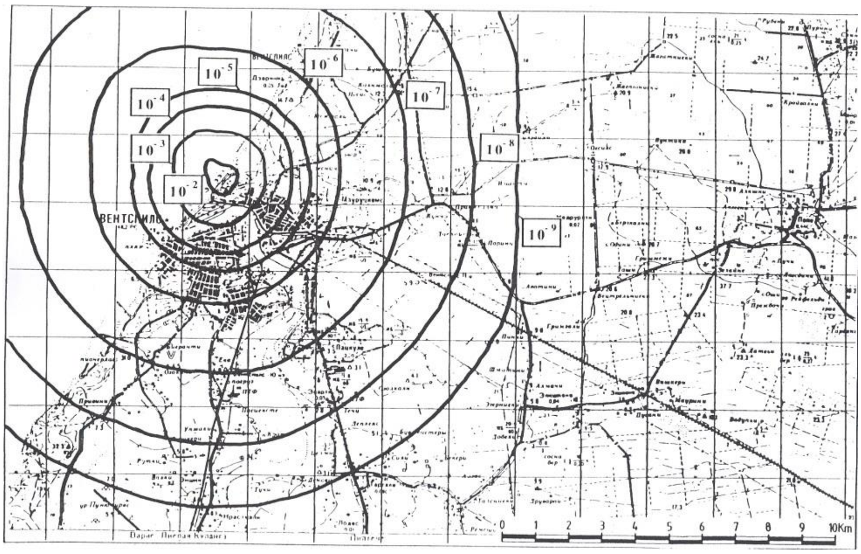


Figure 7. The individual risk isolines for Ventspils ammonia terminal in 1991, adapted from [2].

As an example, it is worth to mention the decision to allow an intense harbour activity in the immediate vicinity of a large LPG terminal. The Riga LPG terminal, operated by „Latvijas propana gaze", Ltd. was built during the 1960-s and its technological equipment remains virtually the same ever since. It is used for transfer of liquefied petroleum gas exported by Russia and other CIS countries to Western Europe. LPG is delivered by rail and then forwarded to the next destination by sea. The facility houses 53 over ground tanks for the storage of LPG, each one with a capacity of 175 m^3.
Considering its location, the risk potential of this facility was ascertained well back in the Soviet times. It was built on the outskirts, near the mouth of river Daugava. The nearest inhabited area was located at a distance of more than 500 meters from the facility. After the implementation of SEVESO II directive, the risk assessment for this facility showed, that there was a high probability of a large-scale accident at this object. And the potential hazardous consequences of such accident would affect the lives of people within the range of 800 meters [8]. Despite the risk assessment results that clearly indicated both the high probability of an accident and the very large areas exposed to the subsequent damage, the responsible state and municipal authorities allow actions in the immediate vicinity of the objects that can increase its already high risk level. In that case the timber terminal was built near the LPG object. The situation that

has developed is best illustrated by the photos shown below. One of the pictures shows stockpiles of wood along the fence of the facility, just tens of meters away from the LPG reservoirs. In the other picture, there is a pipeline flyover for loading ships, which has been already obviously hit by loaded timber lorries for several times.

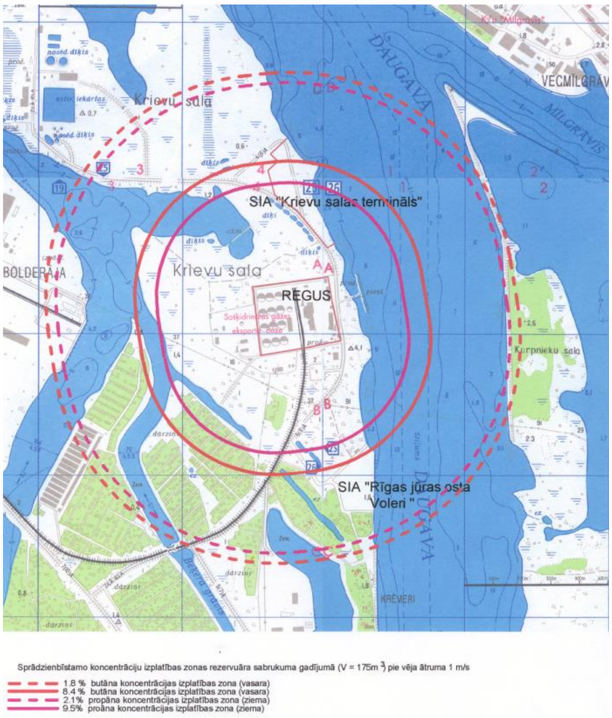


Figure 8. The areas exposed to the explosive concentrations, adapted from [8].

Figure 9. Photos from the vicinity of the Riga LPG terminal operated by „Latvijas propana gaze", Ltd.

Another argument that motivated the Development Department of Riga Municipality to develop the rules of using the city's territory is the ambiguous information on the danger presented by the other SEVESO II objects obtained from the state control authorities.

The current limitations for usage of the territory around the SEVESO II objects in Riga and several other cities of Latvia rely on the information about the danger of such objects provided by the Environment State Bureau. The Environment State Bureau of Latvia is a competent authority that organizes the evaluation of Safety reports and the Risk reduction policies for the SEVESO II objects and passes a resolution on the operation of the object. As long as there are no unified methods and no unified acceptable risk criteria in Latvia, the risk assessments for the SEVESO II objects contain a great deal of variations regarding the accident probability assessment, the extent of harmful influence of such accidents and the calculations of the areas impacted by such.

By request of the Riga Municipality, the experts of PSI „Risks un audits” Ltd. have assessed the statement for usage limitations concerning the areas around the dangerous objects situated in Riga. The main conclusions of this assessment are as follows:

- Similar limitations for usage of territory are set for different areas with different exposure to the harmful consequences of various accidents,
- The probability of an accident has not been taken into consideration while setting the limitations for usage of territory

Developing the advice on the mandatory rules for usage of territory in Riga, one has to state that there are no unified criteria in the European Union for applying the results of risk assessment in land use planning [9], [10]. The research on the approach implemented within this realm by the leading countries of the European Union reveals the essential differences in the acceptable risk levels and in the conditions for usage of territory, depending on the extent of danger [11], [12].

The absence of unified understanding for the application of risk criteria in land use planning in the European Union prevents smaller countries from adopting such standards into the national legislation and commencing the modern practice of planning the territorial development.

The activity of Latvian municipalities that develop their own mandatory rules for the usage of territory, on one hand, indicates that such standards are necessary. On the other hand, if this initiative remains at the municipal level, other problems are to be expected. If every municipality shall apply their own mandatory rules, using different acceptable risk criteria, then for Latvia this would mean that the rail freight operators would have to apply different safety requirements for the same service at different points of Latvia.

Conclusions

The analysis of hazardous freight transit chains done herein indicates that the safety limits of the carrying capacity of Latvian railroads are by far exceeded, however, more and more new hazardous freight transfer terminals are being built in Latvia. Seven new SEVESO II objects have been built in Latvia over the past 10 years, with even more similar facilities waiting for approval at the moment. These new stationary facilities are going to benefit from the modern technological equipment and the implementation of modern safety solutions.

Thus, these objects themselves are safe enough and the state regulatory authorities have no legal reason to object to the construction of such facilities. The example of Latvia shows the reason of including certain restrictions in relevant legislation concerning the associated risks caused by new facilities.
The European Union should legally pass a bill stipulating the minimal acceptable risk criteria that every EU member state would have to meet, with each state reserving the right to apply more strict criteria within its boundaries. The absence of such regulations leaves the inhabitants of some EU member states exposed to an unacceptable high risk.

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Analytic Network Process (ANP) approach to support the decision-making process related to rockfall risk management

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Abstract

Many kilometers of roads have adjacent rock slopes that are prone to rockfall. This rapid mass movement can be dangerous for human infrastructure and property, sometimes with dramatic consequences. The fulfillment of safety requirements for roads in mountainside areas is a multidimensional concept that includes socio-economical and technical perspectives, thus leads to issues that are simultaneously characterized by a high degree of conflict, complexity and uncertainty. Multicriteria Analysis (MCA) is an effective approach that can deal with these kind of issues. Three different rockfall protection devices are compared through the Analytic Network Process technique, in a specific geo-environment, to show the feasibility of the method and how it can be a valuable tool for public and private decision maker.

Keywords: Road management, Rockfall protection devices, Multicriteria Analysis, ANP, Decision making process.

1. Introduction

Transportation corridors in mountainous regions are often susceptible to major hazards, namely shallow landslides such as rockfalls. The analysis of risks associated with these types of instability is a complex operation requiring the precise assessment of hazard and vulnerability. The effects of rockfall events on a road can include damage to vehicles, injury or death of passengers and pedestrians, as well as economic losses. Engineering design of protection devices should aim to minimize risk, taking advantage of the most advanced technologies. Public and private decision makers (DMs) should be equipped with the instruments which allow them to choose the best solutions.
The fulfillment of road safety is a multidimensional concept and thus it is characterized by a high degree of complexity and uncertainty. Multicriteria

Analysis (MCA) is a very efficient approach to deal with these kinds of issues. It is a family that includes a series of evaluation techniques that are able to consider simultaneously several criteria, in order to support the Decision Maker in making comparative assessments through a rational approach of alternative projects and solutions.

This paper presents the application of MCA to rockfall risk management through the development of an Analytic Network Process (ANP) model. Three different protection devices, usually used for rockfall road protection (embankment, shelter and tunnel) were taken into account. A focus group with experts in geo-engineering was organized in order to identify and weigh the elements of the model. The ANP technique was applied using the Super Decisions software. An examples of application is proposed and discussed. The approach was applied to a test site located in the north-western Italian region of Piedmont.

It is important to emphasize that the model framework was developed to be applied in a standard way, while the sub-criteria and the respective weights were calibrated for the case study under analysis.

2. Research objectives and description of the case study

The process of making the best decision in the evaluation and management of a rockfall event encounters many obstacles due to the lack of information on the specific natural phenomena and to the heterogeneity of the available information sources. Therefore it is important that decision-makers, as well as public administrations and designers are able to evaluate different rockfall hazard scenarios and possible protection devices using specifically designed tools. The evaluation tool must take into account the different aspects involved in the interaction between rockfall and road, considering both tangible aspects (such as economy or design) and intangible aspects (social or ethical aspects). Moreover, the technique must allow an objective, transparent and traceable decision-making process.

In order to tackle this delicate problem, an application of Multicriteria Analysis model (specifically an ANP approach) for the comparison of different rockfall protection devices was proposed with the aim of choosing the most suitable one to ensure road safety.

The model developed was applied to a real case: a stretch of the SP165, in Vintebbio (Sesia Valley, Piedmont region, Italy) (Figure 1). The SP165 is an important part of the road network of the Sesia Valley, because it connects the cities at the top of the valley with the highway at the bottom

The road layout is very tortuous following the contour of the rockside. The road is characterized by a variable width that in some stretches doesn’t allow the simultaneous passage of vehicles travelling in opposite directions. Considering that alternative routes to support mobility are limited, it can be argued that the SP165 is a strategic road due to the high movement of vehicles throughout the year.

Part of the rockside was made safety in the past using wire mesh in adherence and a precast shelter (Figure 2), while the remaining part is still prone to rockfall hazard.

The territory crossed by the SP165 road is characterized by rocky outcrops of Permian volcanic rock, lavas and pyroclastic rocks formed during a series of volcanic episodes occurred 270 million years ago. Sometimes they are interrupted by fragments ripped from the crystalline basement metamorphic rocks (schists of the Lakes) and merged during an eruption in the pyroclastic flow.

Several on site surveys have been performed together with an analysis of the historical catalogue in order to identify rock block size (this has been found to be 0,5 - 2m^3).

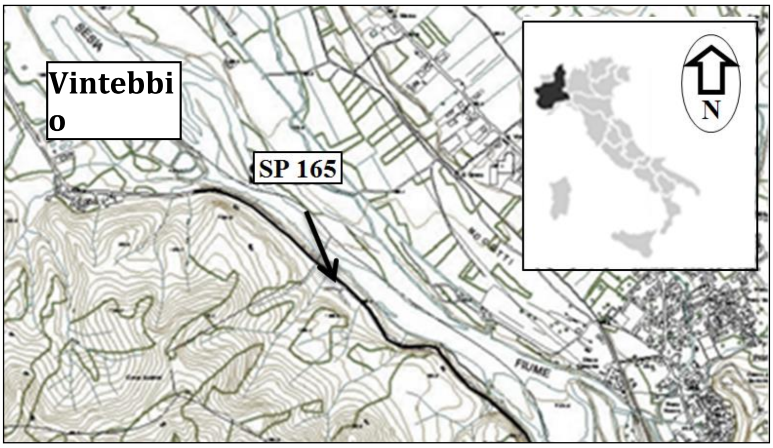


Figure 1: Map of the studied territories, the arrow indicates the SP165.

Figure 2: On the left an example of road path; on the right the rockfall protection shelter.

The rock block energy is high and the falling process is widespread along the road. Taking into account the geotechnical characteristics of the rock face it is possible to assume that the road is not under imminent threat, therefore urgent interventions are not required.

3. Rockfall risk and protection devices

Rockfall phenomena is one of the most dangerous phenomena affecting roads in mountainside area, from the phenomenological point of view, this rapid movement is induced by the detachment of a rock block from a rock slope and down slope movement. Although the typical size is small in comparison to other landslide, rockfall is among the most destructive mass movements because the falling blocks move at high speed (Corominas et al. 2005; Bunce et al. 1997; Evans and Hungr 1993, Varnes 1984).

In order to minimize the rockfall hazard on a road, different types of technological solutions have been developed.The main factors that influence protection device design as well as construction techniques are: site morphology and topography; geological and geotechnical condition; surface water and groundwater conditions; surface constraints; environmental constraints; safety aspects during the construction phase; work site location and construction times.
Protection interventions against rockfall can be classified as active or passive: the aim of an active system is to prevent instability from occurring, whereas passive system is design to mitigate the effects of a previous movement by intercepting and stopping falling rock blocks. The alternatives (shelter, embankment and natural tunnel) took into account in the development of the model, are the passive type.
Shelter is a precasted concrete structures, covered by an absorbing layer made up of ground in order to dissipate the energy resulting from the rock blocks impact, the structure is often topped by net fences (Montani et al., 2004; Chiaves, 2004).
When blocks have volumes or speeds, great enough to break through the maximum resistance of traditional net fences, ground embankments are the best technical solution.An embankment is a massive artificial ground barrier and it is steady with different kinds of reinforcements, such as geotextiles or geogrills, metallic wire stripes or nets (Peila at al., 2007; Peila and Mignelli, 2010).
At least natural tunnel avoid the risk of falling rocks in the prone road, but it is also necessary adequately design the entrances, where the problem of falling rocks persists (Peila and Pelizza, 2002; Montani et al., 1996).

4. Methodological approach

4.1 The Analytic Network Process

The Analytic Network Process (ANP) is a decision support tool, belonging to the Multicriteria Analysis family, that has recently gained popularity. Developed by T.L. Saaty (2005) as the generalization of dependences and feedbacks of the more well-known Analytic Hierarchy Process (AHP) (Saaty, 1980), the ANP represents a theory of relative measurement on absolute scale of both tangible and intangible criteria based both on the judgement of experts and on existing measurements and statistics needed to make a decision (Saaty, 2005; Saaty and Vargas, 2006). By freeing us from
the burden of ordering the components in the form of a directed chain as in the AHP
hierarchy, the ANP represents any decision as a network and allows the structure to develop more naturally. The ANP therefore represents a better way to faithfully describe what can happen in the real world and is gaining merit as a useful tool to help technicians make their decision processes traceable and reliable. By including dependences and feedbacks and by cycling their influence by means of the supermatrix approach, the ANP is more objective and more likely to capture what happens in the real world, thus providing effective support for the kind of decisions needed to cope with the future (Zoffer et al., 2008).
From the methodological point of view the ANP is based on five fundamental steps (Saaty, 2005): (i) structuring of the decision-making problem; (ii) clusters

and nodes weighting by means of pairwise comparisons; (iii) supermatrices formation; (iv) elicitation of final priorities and (v) sensitivity analysis.
A very large amount of well-established literature concerning the ANP exists in different fields. Mention can be made of applications in the sphere of waste management (Aragonés-Beltrán et al., 2010; Bottero and Ferretti, 2011), strategic policy planning (Ulutas, 2005), environmental impact assessment of territorial transformations (Bottero and Mondini, 2008; Liu and Lai, 2009), market and logistics (Liang and Li, 2008), economics and finance (Niemura and Saaty, 2004) and civil engineering (Neaupane and Piantanakulchai, 2006). For a detailed and comprehensive overview of the various applications in the environmental field, in which this methodology has attracted increasing attention, it is possible to refer to the classification of literature proposed by Huang (2011).

5. Model development

5.1 Construction of the network

As far as the problem structuring phase is concerned, the ANP approach involves identifying groups or clusters constituted by various elements (nodes) that influence the decision. All the elements in the network can be related in different ways since the network can incorporate feedbacks and complex inter-relationships within and between clusters, thus providing a more accurate modelling of complex settings. The network construction represents an important and very creative phase in the problem-solving process.
In the present application the model has been developed according to the simple network structure illustrated in Figure 3. It also possible to structure the decision problem according to the complex network structure (Saaty, 2005) which is usually based on four sub-networks: Benefits, Costs, Opportunities and Risks. These sub-networks allow all dimensions of the decision problem to be considered.
In particular, the problem has been divided into five clusters (namely: economic aspects, environmental aspects, social aspects, transport aspects and urban planning aspects) that have been organized according to the network model. With reference to the alternative options previously described (section 3), the general objective of the analysis is to rank the alternative scenarios according to their overall performance. Table I provides a description of the elements which constitute the clusters established in the network.

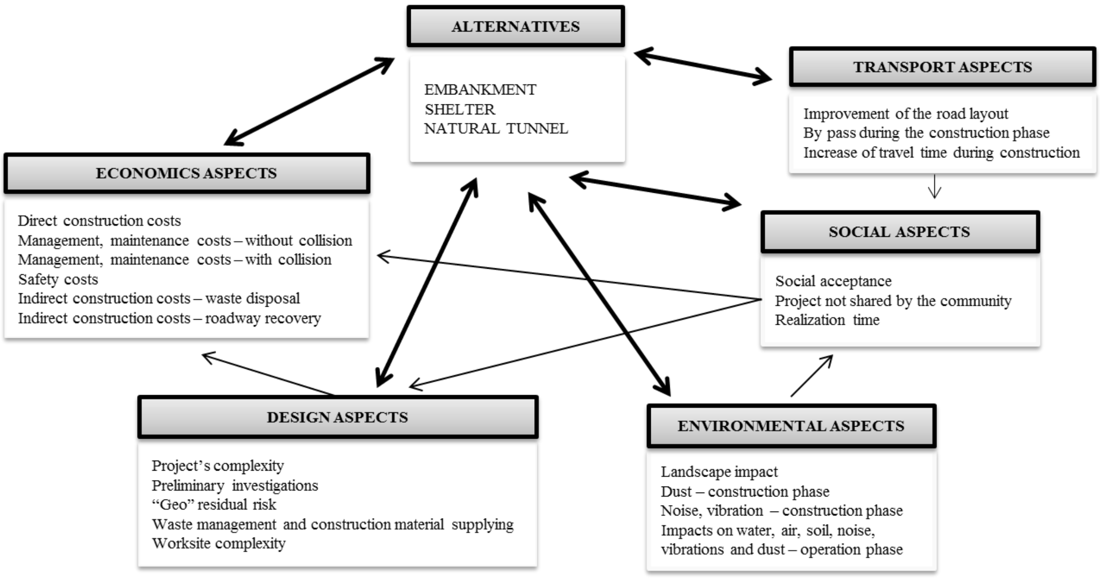


Figure 3. Decision network of the problem.

5.2 Weighting of the elements

With reference to ANP methodology, the next step of the analysis consists of pairwise comparisons in order to establish the relative importance of the different elements, with respect to a certain component of the network.

The comparison and evaluation phase is divided into two distinct levels: the cluster level, which is more strategic, and the node level, which is more specific and detailed. In pairwise comparisons, a ratio scale of 1-9, namely the Saaty fundamental scale, is used to compare any two elements. The numerical judgments established at each level of the network make up pair matrixes. The priority of each element is determined by the normalized eigenvector of the pairwise comparison matrix.

With the objective of establishing the importance of the criteria of the analysis, a focus group was organized with experts in the field of geo-engineering in order to discuss the general aspects of the problem and to weight the decision elements.

At the cluster level, the result of this phase is represented by the so-called cluster matrix. At the node level, once all the pairwise comparison matrices were compiled, all the related vectors together formed the unweighted supermatrix. Finally, according to ANP methodology, the cluster matrix was applied to the unweighted supermatrix as a cluster weight. The result was the weighted supermatrix, which was raised to a limiting power to obtain the limit supermatrix, where all columns were identical and each column gave the global priority vector. This phase represents the progressive formation of the three supermatrices, the initial or unweigthed, the weighted and the limit matrix. As an example that illustrates this phase, Table II shows the pairwise comparison matrix at the cluster level with the alternatives as parent node for the comparisons. Table III represents the cluster matrix showing the priorities of the elements previously compared in Table II.

Table I: Brief description of the considered elements of the network.

Environmental aspects	
Landscape impact	The negative impact generated by the protection device on the ‘‘urban and territorial values’’ of the area, caused by the construction site and the final building
Impacts due the construction phases – dust	The dusts emitted into the atmosphere by the building site involved possible disturbances for the inhabitants of the area with reference to worsening of air quality
Impacts due the construction phases – noise, vibration	Noise and vibration produced by the construction site, by the transport, by the excavation, by the handling loads, etc,
Impacts on water, air, soil, due to noise vibration and dust during the life time	Impact of the constructed protection device on the natural environment during the operating phase (lifetime of the building).
Economic aspects	
Direct construction costs	Cost of the material for the project execution, labor cost, design cost, transport costs, equipment cost, etc.t
Management and maintenance cost, without rock block collision	Routine maintenance and routine management of the device
Management and maintenance cost, with rock block collision	Extraordinary maintenance works if the device is damaged by rock block collapse (i.e. partial recovery of the embankments, maintenance of soil above the artificial tunnel)
Costs of safety during the operating phase	Cost associated with the realization of security tools in the operational phase (i.e. emergency lights, speed detectors)
Indirect construction cost – waste disposal	The possible cost of waste disposal
Indirect construction cost –roadway recovery and traffic variations cost	The indirect costs are the expenses for materials, machinery and works not directly related to the construction phase (i.e. recovery cost of the roadway cost of traffic variation)
Design aspects	
Project's complexity, skills of design staff, safety management	The selection of excavation techniques, the management of job site space, the design time, the skills and abilities of design staff,
Preliminary investigations (number, quality, type, accessibility to the site)	Difficulty in the realization and interpretation of preliminary geotechnical investigations, taking into account the access to the site, number and type
Geo-residual risks related to excavation and work site	Residual risks in the execution phase and construction phase
Waste management and construction material supplying	Landfill disposal, storage and handling of excavated material (technical and legal problems)
Worksite complexity	Worksite organization, work site design and worksite spaces management
Transport aspects	
Improvement of the road layout	Decrease in average travel times, improving the road layout
By pass during the construction phase	Partial or complete closure of the road during execution phase, and consequential deviation of traffic flow on alternative routes
Increase of travel time during construction	Increase of the average travel times and volume of traffic on alternative roads
Social aspects	
Social acceptance	Impact of the device on the local community opinion
Project not shared by the community	The local community, does not approve the work
Times of realization	The discomfort due to the traffic bypass, the social cost of the work and the exposure time to the hazard increases on proportional way to the increasing of the realization time

This example at the cluster level represents a step of the evaluation process less based on technical expertise but more political decision-making. These assessments are arbitrary and different choices can therefore be made. In this application, the evaluation was performed giving great relevance to the economic and design aspects which characterized the problem under analysis.

Table II: Pairwise comparison matrix at the cluster level.

ALTERNATIVES	Design aspects	Economic aspects	Environ. aspects	Social aspects	Transport aspects	Priorities
Design aspects	1	1/3	5	3	5	0.260
Economic aspects	3	1	7	7	5	0.519
Environmental aspects	1/5	1/7	1	1	3	0.086
Social aspects	1/3	1/7	1	1	2	0.082
Transport aspects	1/5	1/5	1/3	1/2	1	0.053

Table III: Cluster matrix.

	Alternat.	Design aspects	Economic aspects	Environ. aspects	Social aspects	Transport aspects
Alternatives	0.000	0.500	1.000	0.500	0.500	0.500
Design aspects	0.260	0.000	0.000	0.000	0.000	0.000
Economic aspects	0.519	0.500	0.000	0.000	0.500	0.000
Environmental aspects	0.086	0.000	0.000	0.000	0.000	0.000
Social aspects	0.082	0.000	0.000	0.500	0.000	0.500
Transport aspects	0.053	0.000	0.000	0.000	0.000	0.000

6. Results of the model

6.1 Priority list of the alternatives

As previously mentioned (section 5.2), in the last phase of the elicitation of the final priorities, the weighted supermatrix is raised to a limiting power in order to converge and to obtain a long-term stable set of weights. Each column of the limit supermatrix provides the final priority vector of all the elements being considered (Table IV).

Table IV shows the final ranking of alternatives according to the judgments established during the pairwise comparisons. Analysing the results normalized by cluster, it appears that the embankment is the most suitable rockfall protection device

with 60% of importance, followed by the natural tunnel, with 24% of importance and the shelter, with 16% of importance.

In rapid analysis, the embankment is the preferable solution because the building costs are cheap, the design stage is fairly simple and the device has less social impact. However, it could be a natural barrier for wildlife and for water flows. Moreover it does not produce any improvement for traffic. The results of the ANP model highlight that the most important elements in the decision problem are: i) direct construction costs for the economic aspects (0.480); ii) the social acceptance for the social aspects (0.477); iii) the geo-residual risk for the design aspects (0.448); iv) the landscape impact for the environmental aspects (0.470) and v) the improvement of road layout for the transport aspects (0.747).

Table IV: Final priorities of the elements of the model.

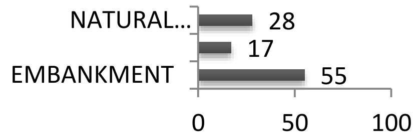
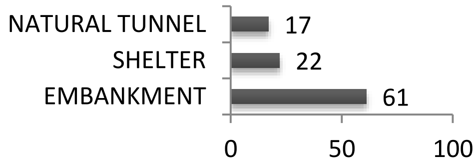
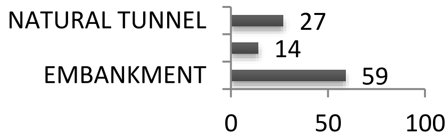
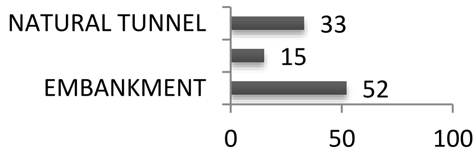
Element	**Normaliz-ed by cluster**	**Limiting**	**Element**	**Normaliz-ed by cluster**	**Limiting**
EMBANKMENT	0.60247	0.28804	Geo-residual risk	0.44847	0.05576
SHELTER	0.15856	0.07581	Project's complexity	0.17648	0.02194
NATURAL TUNNEL	0.23896	0.11425	Worksite complexity	0.09051	0.01125
Direct construction costs	0.47980	0.13095	Preliminary investigations	0.11595	0.01441
Indirect construction costs – roadway recovery	0.06420	0.01752	Waste management	0.16860	0.02096
Indirect construction costs – waste disposal	0.14485	0.03953	Dust-construction phase	0.13071	0.00535
Management, maintenance costs – with collision	0.15455	0.04218	Noise, vibration-construction phase	0.11024	0.00451
Management, maintenance costs – without collision	0.04705	0.01284	Impacts on water, air, soil, noise, vibrations due to operation phase	0.28863	0.01183
Safety costs	0.10954	0.02989	Landscape impact	0.47042	0.019284
Project not shared by the community	0.41095	0.02400	By pass during the construction phase	0.11937	0.00301
Realization time	0.11208	0.00654	Improvement of the road layout	0.74706	0.01883
Social acceptance	0.47698	0.02786	Increase of travel time	0.13357	0.00336

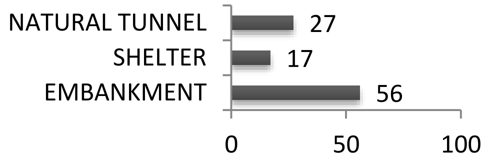
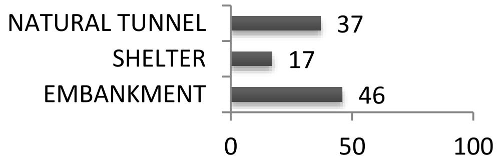
6.2 Sensitivity analysis

After obtaining a ranking of the alternatives, a sensitivity analysis was performed on the final outcome of the model in order to test its robustness and verify the stability of the final results based on variations in the input by changing the criteria weights. A sensitivity analysis is concerned with a "what if" kind of question to see whether the final answer is stable when the inputs (judgments or priorities), have been changed. It is of particular interest to see whether these changes modify the order of the alternatives.

In this application several scenarios were simulated varying the cluster weights which represent the fundamental aspects involved in the decision-making process. First of all, the five clusters were considered as having the same importance. Then, the weights were changed and one cluster at a time was given a weight of 60%, thus considered as being much more relevant than the other clusters which were attributed the same importance. Table V shows the sensitivity analysis results. The left-hand column shows the cluster weights established in the different scenarios, and the right-hand column shows the final priority of the three alternatives for each scenario. The analysis performed shows that the model can be considered stable because the embankment is the most preferable alternative in each scenario.

Table V: Sensitivity analysis.

Cluster weights			Alternative ranking
Scenario 1	Design aspects	0.200	
	Economic aspects	0.200	
	Environmental aspects	0.200	
	Social aspects	0.200	
	Transport aspects	0.200	
Scenario 2	**Design aspects**	**0.600**	
	Economic aspects	0.100	
	Environmental aspects	0.100	
	Social aspects	0.100	
	Transport aspects	0.100	
Scenario 3	Design aspects	0.100	
	Economic aspects	**0.600**	
	Environmental aspects	0.100	
	Social aspects	0.100	
	Transport aspects	0.100	
Scenario 4	Design aspects	0.100	
	Economic aspects	0.100	
	Environmental aspects	**0.600**	
	Social aspects	0.100	
	Transport aspects	0.100	

Scenario 5	Design aspects	0.100	
	Economic aspects	0.100	
	Environmental aspects	0.100	
	Social aspects	**0.600**	
	Transport aspects	0.100	
Scenario 6	Design aspects	0.100	
	Economic aspects	0.100	
	Environmental aspects	0.100	
	Social aspects	0.100	
	Transport aspects	**0.600**	

7. Conclusions

This paper illustrates the application of the complex ANP method to support the choice among different rockfall protection devices. The parameters of the model were set for a very busy mountain road, and embankment, natural tunnel and shelter cover by rockfall barrier were the analyzed protection devices (alternatives of the model).

The ANP technique allows the most important elements of the decision problem to be highlighted through a transparent and traceable decision-making process thus facilitating deliberation. Moreover, the technique supports communication with the DMs and grants a mutual understanding. The results of the analysis performed show that the ANP model is suitable to represents a real world problem. The technique in fact provides the means of performing complex trade-offs on multiple evaluation criteria, while taking the DM's preferences into account.

The main disadvantage in the practical application of the ANP is a consequence of the complexity of the decision making problem that to be analysed. To this end, the ANP prescribes a high number of comparisons that occasionally become too complex to understand for DMs who are not familiar with the method. Hence, a great deal of attention should be devoted to the elaboration of the questionnaires and the comparison process must be helped by a facilitator (Aragonés-Beltrán *et al.*, 2010; Bottero et al., 2011).

For expanding the analysis and validating the obtained results it would be of scientific interest to apply this conceptual model to a different real case study in order to test and assess the usefulness of this tool and to implement and improve the model.

In conclusion, the methodology adopted was successful in structuring the complex decision context related the interaction between rockfall events and road protection device decision.

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On correlation between availability, technology and land use in container terminal

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1. Introduction

Container freight transport has grown over the last two decades, about 9-12% per year (Crainic and Kim, 2007). This trend confirms that the multi-modality feature of container transport is an important factor, among others, that contributes to its growth (any container has a standardized load unit that is suitable also for truck and train transportation). In this framework, container terminals are crucial connections between modes: a bottleneck in terminal operations may affect both inbound and outbound traffic.

Increasing number of intermodal operators make that competitiveness becomes crucial issue to survive in the market. New objectives and performance measures need to be identified and employed to evaluate the performance of a container terminal. Clearly defined measures allow adopting decision support systems that optimize objective functions based on such indicators. There can be distinguished at least two main classes of factors (Vacca , Bierlaire and Salani M, 2007):

1. Service-oriented: they measure the service levels provided to clients and are usually expressed by the turn-around time of both ship liners and outside trucks. This class of indicators needs to be developed in order to take into account competitiveness. It includes berth service time (i.e. vessel turn-around time in hours; vessels time to berth; vessels berthed on time; etc.) and gate service time (i.e. truck turn-around time at the gates; trucks still on terminal over 1 hour; etc.).
2. Productivity-oriented: they measure the volume of containers’ traffic managed by the terminal, such as TEU volume growth (TEUs per year), crane utilization per crane), crane productivity (moves per crane, per hour), berth utilization (vessels per year, per berth), land utilization (TEUs per year, per gross acre), storage productivity (TEUs per storage acre) and gate throughput (containers per hour, per lane).

In both types it is require understanding logistics chain (even simple operation) to know factors background. Dependability issues are also important in context of service optimization. Container terminal operations and their optimization have received increasing interest in the scientific literature over the last years. For an overview of terminal operations, it can be mainly refer to Vis and de

Koster (2003) and Steenken et al. (2004). Vis and de Koster (2003) illustrate the main logistics processes which take place in container terminals (arrival of the ship, loading and unloading operations, transfer and stacking of containers) and provide a review of relevant literature. Steenken et al. (2004) provide an exhaustive overview of methods for the optimization of container terminal operations.

Many of the contributions are mainly dedicated to sophisticated models for single decision problems at container terminals. Some authors (Moccia, 2006; Sammarra, 2007) are specializing the quay crane scheduling problem Moccia. Imai, Nishimura, Hattori and Papadimitriou (2007) investigate the berth allocation problem under different scenarios.

Kim and Bae (1998), Kim and Kim (1999), Kim and Kim (2002), Kim and Park (2003), Kim and Hong (2006), Kim and Lee (2006), Watanabe I. (2009) present and describe yard operations presenting optimizations of selected operation.

Gambardella et al. (1998) presents the container terminal as a whole system and optimize the flow of containers.

Many of papers concerning on preparing and monitoring container terminal points. However there is lack of information about correlation between availability, productivity and land use in context of chosen transshipment technology. The aim of article is to compare two the most important machines used in inland terminal taking into account its availability, productivity and required land use.

2. Base information on container terminal technologies and surface

There are different methods of assesig container terminal surface. Most of them is based on designer experience. There is applied method in Poland, which was used in 70'-80', when intermodal transport was introduced in Poland.

The rules are quite simple, but take into account only one type of transshipment machine – gantry crane. Nowadays very often reachstrackers can be seen on inland terminal (figure 1). Total surface of container terminal is linked with storage place: 75% of total surface is storage yard. There is role taken from experience, that at least 1/3 of yard should be out of storage (due to operational needs). In addition container field capacity is described by TEU, not number of containers.

However key point of terminal land use is transshipment technology. As it was mentioned before, there are two main types of machines: gantry cranes and reachstrackers.

Gantry crane is meant as machine used in older of greater terminals. Example of gantry crane on figure 2 is presented. Typical crane based on two pillars on width of 4 meters can operate over 30 - 35 containers per hour, modern machines digitally controlled even more. What is really important container cranes use reliable and efficient electric motors, wheatear condition proofed. However the price for medium size machine is 3-5 Meuro, depending on motors, weight, operating line.

About 10 time cheaper solution is reachstracer. Although transshipment ability is little lower than crane (25 container per hour), the machines are very sensitive on whether conditions. During the winter availability decrease from summer 0.99 to even 0.8. Main problem is oil in lifting pistons. Another difference is land reservation. Crane needs only space for its pillars and gap to first row of containers (in Polnad at least 1.65m). Reachstracer need usually 20m to operate safe.

Reachstraces are meant as modern and cheap solution for container transshipment. However the problem is not stable level of availability, in consequences not stable value of productivity.

Figure 1. Reachstracker under operating

Figure 2. View of ganty crane

3. The case.

This section will show difference in space required for container terminal depending on availability and type of machine.
Calculation assumptions are as follows:

- total terminal capacity is 2000 TEU (50% of 20' and 50% of 40'),
- total capacity in number of containers is 1500,
- required operational capacity is 2/3 of storage yard, means 1000 containers,
- turnover daily is ¼ of operational capacity, 250 boxes,
- terminal operate 10/24h,
- transit path for lories under the crane takes 4m.

Two different machines will be taken to calculation: gantry crane and reachstracer. In comparison we have different values of availability, especially for winter and summer seasons.
Let's assume, that crane can operate 35 containers per hour and 25 for reachstracker in excellent conditions (availability equal to 1).
Table 1. presents results of computations. Rb and Rc machines are reachstrackers respectively in the summer and winter. Ra column presents values for perfect reachstracer.

Table 1. Results of calculating

	Ra	Rb	Rc	Crane
Availability (season)	1	0.99	0.8	0.99
Theoretical hour productivity [cont]	25	24.75	20	34.65
Practical hour productivity [cont]	25	24	20	34
Practical day productivity [cont]	250	240	200	340
No. of required machines	1	1.04	1.25	0.73
SURFACE				
Storage height [cont]	3	3	3	3
Number of rows [cont]	6	6	6	6
Number of slots in line [cont]	55	55	55	55
Number of transits ways	2	2	2	1
Transit way widht [m]	20	20	20	4
Storage surface [m^2]	26 928	26 928	26 928	9 108
Total surface [m^2]	36 352.8	36 352.8	36 352.8	12 295.8

As it is visible there are huge differences between winter and summer season in reachstracker operation ability. When availability is close to 1 practically there is no point to be aware of productivity. In case of crane stable value of availability gives excellent results. Buffer of productivity gives possibility to operate even more that 350 container per day.

Terminal land use is clearly visible when compare different transshipment technologies. Container warehouse can be three times smaller that serviced by reachstrackers. Investment in crane results smaller expenses on container yard. However during founding new terminal usually it is not clear if the business promises profitable future or is not worth crane installation.

4. Conclusion

Many of papers concerning on preparing and monitoring container terminal points. However there is lack of information about correlation between availability, productivity and land use in context of chosen transshipment technology.
Like it was presented in section 3, reachstraceks, meant as modern and cheap operating terminal lifting machines, are not as productive as traditional gantry cranes. Additionally reachstracers are sensitive on whether conditions, what makes availability values different for different seasons. The problem is in operating cycle and maintenance problem with frozen oil in lifting pistons. Electric motors in cranes give leading point.
Cranes are know from expenses associated to buying and installation. On the other hand are more reliable, have longer life time and are cheaper in operating. Land use requirements are much lower in case of cranes.
However the managing problem is to estimate what more profitable: unstable work conditions and cheaper machine, or long term investment and cheap and effective transshipment.

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Risk assessment of the road transportation concerning dangerous goods.

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Abstract

Urbanization is seen as a rapid process covering new areas and suburbs. Industrial areas are usually placed not far from cities to provide fast transportation of workers and goods. Urbanisation spreads over these areas and the space between factories, logistic centres, and warehouses is often taken for residential estates, parks or shopping centres. Inhabitants may face very often to the problem of vehicles transporting goods and even dangerous goods through the area of high dense population or protected natural environment. The aim of the paper is to propose a model of risk assessment concerning road transportation of dangerous goods through the areas of various objects exposed to hazard brought about the transportation process. Vehicle transporting dangerous goods produces moving risk due to dangerous loads moving through areas of different exposures what gives at any point of the road changeable value of the risk. Model is based on the concept of road risk profile which takes into account road segments of various population densities, natural environment and engineering installations.

Paper provides an example of calculation of proposed risk profile for a given road segment and a tanker.

Introduction

Daily observed hazard dealing with a moving mass (kinetic energy) is nowadays fully accepted as hundreds of vehicles are around visible. 40 tons truck, moving about 40 km/h has a kinetic energy equivalent to explosion of 0,5 kg of TNT (trotyl). Much more dangerous is a vehicle with dangerous goods. Heavy track carrying dangerous material, like a tank of 30 tons capacity of petrol, carries considerably more undesired events not only due to mechanical energy but also chemical or thermal ones. Energy stored in 30 tons of petrol is equivalent to 300 t of TNT. We are familiar with large number of tankers passing through residential or park area going from refineries or stores to gas stations. There are also other dangerous goods (poisonous, corrosive, etc.) transported every day to chemical companies. All land transportation tasks dealing with procedure, documentation, permissions, technical and law requirements should be fulfilled according to international agreements described precisely in ADR, RID or ADN, but despite of it, we still observe accidents and less or more severe consequences due to transportation of hazardous materials. The idea presented in the paper is based on observation of landscape through the car window and assessment of possible losses due to release of dangerous goods carrying by the truck. Paper concerns a method of risk assessment due to transportation of dangerous goods through the areas of different exposure to hazards arisen from releasing flammable liquids, poisoning gases etc. It is assumed that risk is evaluated according to route segments, so that finally one may get a road risk profile at the transportation route [Cassini]. The problem stated above was previously analysed and some data in specific cases is available [3, 5, 8].

Analysis of transportation system

Risk analysis in technical system is based on general algorithm [6] and starts with description and identification of all factors influencing safe operation. Looking at goods transportation, it is distinguished transportation system and process. Transportation process describes changes of elements' states in time and takes place in the specific infrastructure. Transportation system is a set of elements which consists of: means of transport with operator, surroundings like technical infrastructure and natural environment. One of the most important roles in transportation process takes a human being operating and managing process. To identify hazards in goods transportation it is necessary to identify sources of hazards and potential objects exposed to hazards since consequences depends on relation hazard – exposure [3]. From the safety point of view transportation system should be divided in two sets of objects containing: sources of hazard (hazardous active) and objects being exposed to hazard (hazardous passive):
One may also distinguish in the transportation system roughly static and dynamic elements. Change of descriptive parameters of static elements is very slow regarding time of vehicle movement (road dimension, distances among buildings, population density, etc.). Dynamic elements are represented for instance by parameters characterizing: vehicle movement, traffic, walking people, animals, wind, rain/snow, etc. Static elements describe surroundings potentially affected by active elements, though static elements can also be active in the sense of hazard (slippery or rough road, curved or sloped road, broken tree branch close to the road, etc.).
Road is divided in segments [5] taking into account possible exposed objects like: people, natural environment, technical infrastructure. In general, road as main static element is described by:

- road parameters (dimensions, structure, surface, conditions,…),
- road infrastructure parameters (pavements, roadside, bus/tram stops, bridges, crossroads, railway crossings,…),
- road neighbourhood parameters:
    - inhabited area (type of houses, density of buildings, barriers/traffic lights, population density,…),

- uninhabited area (flora, fauna,…).

Model assumptions

Transportation is defined as a set of transportation system and process: $TR = \langle TRS, TRP \rangle$. Transportation system represents material objects while process describes distribution of object's state in time. Adopting system definition from system theory [2, 10, 12] it is assumed that transportation system create set of elements, it attributes and relations linking attributes to elements:

$$TS = \langle E, W(E), R_{EW} \rangle$$

where: $E = \{e_i\},\ i = 1,2,\dots,n$ – set of elements,
$W(E) = \{w_{is}\},\ i = 1,2,\dots,n,\ s = 1,2,\dots,m_i$ – set of attributes,
R_{EW} – set o relations.
It is assumed that any undesired event originates from basic event of some system element. In the system there are defined sets of elements called active *EA* and passive elements *EP*: $TS = \{EA, EP\}$.
EA and *EP* are defined respectively as:
$EA = \langle EA, W(EA), R_{AW} \rangle$,
$EP = \langle EP, W(EP), R_{PW} \rangle$.
Attributes *W*(*EA*) describe such features of elements that can possibly fail and therefore start chain of undesired events. Attributes *W*(*EP*) characterize attributes describing failure modes or losses due to given dysfunction of finally affected elements.
An event during operation making abnormal, undesired state of *EA* elements initiates a chain of events resulting finally in losses of *EP*.
Hazard is defined as an event which may potentially transform into undesired event i.e. event causing losses. Amount of losses depends on development scenarios which is a process of change of element attributes.
Source of hazard is concentrated in dangerous goods and since it is moving, also hazard moves, making at given road segments various risk.
Let us assume for simplicity that road regarding neighbourhood safety has three types of segments $S = \langle s_1, s_2, s_3 \rangle$: segment passing uninhabited field S_1, segment passing uninhabited forest or park S_2, segment passing inhabited area S_3. Deeper analysis may show more types of segments if necessary data is provides.
Having defined types of road segments entire route of length *L* may be divided in *m* segments described by its length and type: $D_L = \{d_k(l_k, s_j)\}$, where d_k is *k*-th route segment of length l_k, of type s_j and $L = \sum_{k=1}^{m} l_k$.

Hazard identification

Regarding transportation process of carrying dangerous goods by heavy truck we should include into analysis: vehicle (tanker), operator (driver), fright, road, roadside, road and neighbourhood infrastructure, traffic, type of land development (compact/dispersed settlement, uninhabited, recreation ground, forest, park, field, river, lake, etc.), flora and fauna, weather conditions and process like accelerating, breaking, turning, driving up or down etc. In the system and process having such differentiated elements and states it is difficult to find out all or the most possible hazards. It is proposed systems approach to identify hazards.

Transportation system is described by attributes. Any undesired state of attributes may cause an accident having losses observed at various objects and various modes. That analytical part of hazard identification is supported by inventive methods like HAZOP, FMECA, Cause-Consequence Analysis and the other [6, 9].

Hazard identification is done by the analysis of matrix of relations between distinguished attributes. Let's denote hazard as a source event (failure, mishap, mishandle, external failure, etc.) consisting in causing losses. Losses are considered as excessive costs or undesired states of the system not included in ordinary repair. Active object initiates a chain of events and finally, passive object suffers losses. All relations among active and passive attributes are elements of Cartesian product $W(EA) \times W(EP)$. If analysis of such relations reveals losses of passive element than the basic event is identified as hazard in transportation system.

Denote couple of attributes according to cause – consequence relation:
$\omega_{ij} = w(ea_i) \rightarrow w(ep_j)$, what means, that ea_i acts "dangerously" on ep_i.

$$W(EA) \times W(EP) = \begin{bmatrix} \omega_{11} & \cdots & \omega_{1n} \\ \vdots & \ddots & \vdots \\ \omega_{n1} & \cdots & \omega_{nn} \end{bmatrix}$$

Using techniques appropriate for peculiar character of couples ω_{ij} and available in risk analysis [60300] we select meaningful and important relation having at the end losses to the system. Each couple in the matrix $W(EA) \times W(EP)$ is valued 0 or 1 if an influence of active object on passive one exists:

$$v\left(w(ea_i) \rightarrow w(ep_j)\right) = v(\omega_{ij}) = \begin{cases} 1 \text{ if } EA \text{ acts on } EP \\ 0 \text{ otherwise} \end{cases}$$

Then we get matrix directing couples important for hazard identification:

$$v(W(EA) \times W(EP)) = \begin{bmatrix} v(\omega_{11}) & \cdots & v(\omega_{1n}) \\ \vdots & \ddots & \vdots \\ v(\omega_{n1}) & \cdots & v(\omega_{nn}) \end{bmatrix}$$

Hazards correspond to all events connected to attributes of *EA* where:

$$H\big(W(EA)\big) = \{W(EA): v(\omega_{ij}) = 1\}.$$

Result of this step is a set of attributes of all active elements of transportation which may generate losses due to passive element.

Risk evaluation requires estimation likelihood and consequence magnitude due to each hazard. Likelihood corresponds to active objects *EA*, while consequences to passive ones *EP*.

Each active element is described by vector of failure likelihood:

$$l(ea_i) = [l(ea_{i1}) \ \dots \ \ l(ea_{ii}) \ \dots \ \ l(ea_{in})]$$

and for all $v(\omega_{ij}) = 1$, likelihood of the failure is: $l(ea_{ij}) > 0$. For all active elements we get the likelihood matrix with regard to passive elements:

$$\mathrm{L}(EA) = [l(ea_{ij})]$$

In similar way we should determine vector of consequences corresponding to passive elements as a result of failure of active element.

$$c(ep_i) = [c(ep_{1i}) \ \dots \ \ c(ep_{ii}) \ \dots \ \ c(ep_{ni})]^T$$

For all passive elements we get the consequences matrix regarding active elements as basic cause:

$$\mathrm{C}(EP) = [c(ep_{ij})]$$

Each single hazard caused by active element produces risk as:

$$r(e_{ij}) = l(ea_{ij}) \cdot c(ep_{ij}).$$

Finally we get for entire system a risk matrix as a Hadamard product:

$$\mathrm{RS} = \mathrm{L}(EA) \circ \mathrm{C}(EP) = \left[\left(l(ea_{ij}) \cdot c(ep_{ij})\right)\right] = [r(e_{ij})],$$

where $r(e_{ij})$ is risk associated with *i*-th element with consequences sustained by *j*-th element,

In fact in some cases it may be *i*=*j*, what means that the failure of *i*-th element has serious consequence for itself.

Having matrix RS we may observe value of risk originated from failure modes of each element directed to other objects RS(*E*). Assuming independence of all such relations it allows for summation of risks and obtaining risk vector for all elements.

$$\mathrm{RS}(E) = [r(e_{ij})] = \left[\sum_j r(e_{ij})\right]^T = [r(e_i)]^T$$

Risk profile

In order to describe a risk profile of the road segment $d_k(l_k, s_j)$ we have to select system elements corresponding to the given road segment d_k:

$$\wedge_{e_i} \left(\left(W(e_i) \in W(d_k) \right) \Rightarrow r(e_i) \right).$$

Details of the analysis depend on knowledge about the system and data. Available data usually doesn't concern specific problem and only rough assessment is possible. Valuation of possibilities and consequences depends on scenarios of events development. The main variables influencing valuation derives from: parameters of exposure to hazards caused by dangerous materials, propagation of flame or poisonous cloud due to material density, wind speed, humidity, instant or postpone effect for passive element. For detailed analysis some data is available for instance in [8]. For preliminary analysis it may be applied PHA requiring relative data and giving provisional assessment of risk [9, 11].

Illustrative example

It is assed route of transportation of petrol from general store to gas station. The route takes place through five various road segments (Fig. 1).

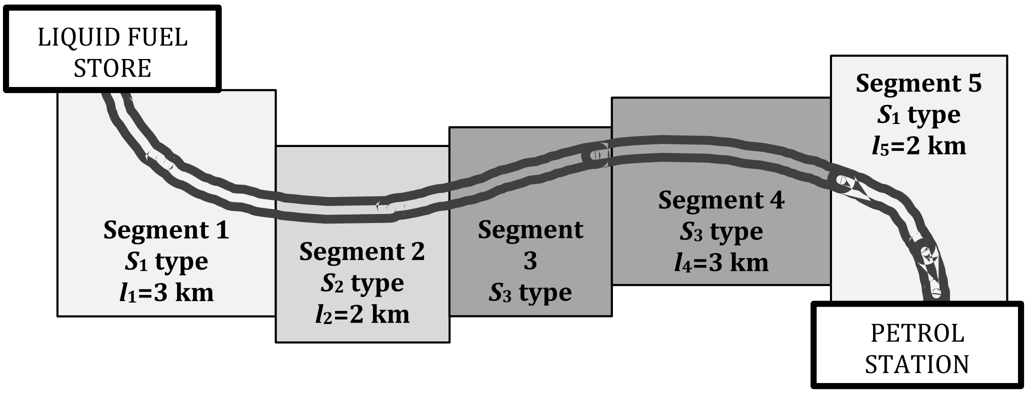

Fig. 1. Layout of the route divided in 5 segments

There are identified six elements of the transportation system: vehicle, driver, road shoulder, tree, pedestrian, residential house. Cause consequences analysis is omitted here since it is another extensive work. Only example relations among active and passive element are shown in Table 1. As exemplification of these relations it is given for instance: tanker due to brakes failure may cause an accident and set vehicle in fire, death, house destruction or break a tree. Another relation: tree at the road shoulder may be broken by stormy wind, fall down and cause an accident involving other vehicle or pedestrians. In the example, tanker failure, leakage, driver mishap and collision with other vehicle may take place at each segment, while collision with pedestrian only in segments 3 and 4.

Tab. 1. Cause-consequence relation matrix among active and passive elements

No.	Object Passive Active	Tanker	Driver	Other vehicle	Pedestrian
1	Tanker failure	1	1	1	1
2	Tank leakage	1	1	1	0
3	Driver mishap	1	1	1	1
4	Other vehicle collision	1	1	1	0
5	Pedestrian stormed into	1	0	0	1

	road				

Assume a scale of likelihood and consequences [1, 11].

Tab.1b . Five grade likelihood scale

very unlikely	remote	occasional	probable	frequent
1	2	3	4	5

Tab.1c. Four grade scale of consequences

minor	major	critical	catastrophic
1	2	3	4

Then there are formulated matrices of likelihood and consequences as it is shown in one combined Table 2. Final result i.e. risk calculated for each hazard and for elements is placed in Table 3.

Tab. 2. Likelihood (*L*)/Consequences (*C*) matrix

Object Passive Active	Tanker		Driver		Other vehicle		Pedestrian	
	L	*C*	*L*	*C*	*L*	*C*	*L*	*C*
Tanker failure	4	2	2	2	2	3	3	4
Tank leakage	3	3	1	2	1	2	0	0
Driver mishap	3	3	2	2	1	3	1	3
Other vehicle collision	2	1	1	1	2	3	0	0
Pedestrian stormed into road	2	1	1	1	0	0	3	4

Tab. 3. Risk matrix for identified hazards

Object Passive Active	Tanker	Driver	Other vehicle	Pedestrian	Total risk for element
Tanker failure	8	4	6	12	30
Tank leakage	9	2	2	0	13
Driver mishap	9	4	3	3	19
Other vehicle collision	2	1	6	0	9
Pedestrian stormed into road	2	1	0	12	15

Risk assessment for the exemplary transportation system is done in two phases: individually for each identified hazard and as a whole for each element of the system.

PHA risk matrix 4x5 (Table 5) shows that hazards assessed as more than 6 and 4 (high consequences) are the most severe and should be unaccepted.

Tab. 5. PHA risk matrix

Likelihood Consequences	1	2	3	4	5
1	**1**	**2**	**3**	**4**	**5**
2	**2**	**4**	**6**	**8**	**10**

3	**3**	**6**	**9**	**12**	**15**
4	**4**	**8**	**12**	**16**	**20**

The list of these unaccepted hazards is as follows:
Cause: Tanker failure → Consequence: Truck damage; (Risk: 8),
Cause: Tanker failure → Consequence: Bodily harm of pedestrian; (Risk: 12),
Cause: Tank leakage → Consequence: Truck damage; (Risk: 9),
Cause: Driver mishap → Consequence: Truck damage; (Risk: 9),
Cause: Pedestrian stormed into road → Consequence: Bodily harm of pedestrian; (Risk: 12),
Other risk assessment, referred to elements shows just rank of primary causes invoking largest hazard. Here there are no acceptation criteria but the order of events attracting attention to be analysed in first turn. The rank is:
1. Tanker failure (Risk: 30),
2. Driver mishap (Risk: 19),
3. Pedestrian stormed into road (Risk: 15),
4. Tank leakage (Risk: 13),
5. Other vehicle collision (Risk: 9).

Tab.6. Assessment concerning road segments shows risk in segments:

Risk: 71	Risk: 71	Risk: 86	Risk: 86	Risk: 71
Segment S_1	Segment S_2	Segment S_3	Segment S_4	Segment S_5

Conclusions

The developed model shows the frames of systemic approach to the risk analysis. It is shown system decomposition with respect to elements causing hazard and elements being exposed to consequences. That split analysis allows for precise selection of basic hazardous events and finally their assessment in entire system. In transportation system method clearly divides causes and consequences. Respectively to available data analysis may be done quantitatively or qualitatively applying for instance PHA method.

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How can you protect yourself against chemical risk?

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Abstract

The goal of this work was to develop a pragmatic analysis to evaluate risk and propose suitable protection gear for pharmaceutical industries, thanks to a computer tool.
In an attempt to comply with legislations and ergonomics, we took into account the process, the industrial tasks and the properties of the Active Pharmaceutical Ingredient (API) and solvents.
Protection must be defined according to body parts concerned by the chemical risk. Consequently, five qualitative and quantitative approaches are put forward. Collective protection is determined by the type of ventilation according to the confinement of the process. Eye protection is based on a logical tree. Respiratory system protection and hand protection approaches are explained thanks to a logical and mathematical reasoning. Finally, body protection approach enables to match a class of risk with labcoats and overalls.

Keywords: Collective protection, Hand protection, Eye protection, Respiratory system protection, Body protection.

1. General Methodology and collective protections

1.1 Introduction

In front of a chemical risk, means of protection must be implemented. Although collective protection equipment (CPE) is privileged, it is also necessary to implement Personal Protection Equipment (PPE). It is therefore necessary to identify at first, the risks an operator can be exposed to. Following a risk assessment, the type of CPE and PPE will be determined. Depending on the type of PPE, the methodology developed will be different.

The following flowchart illustrates the general methodology.

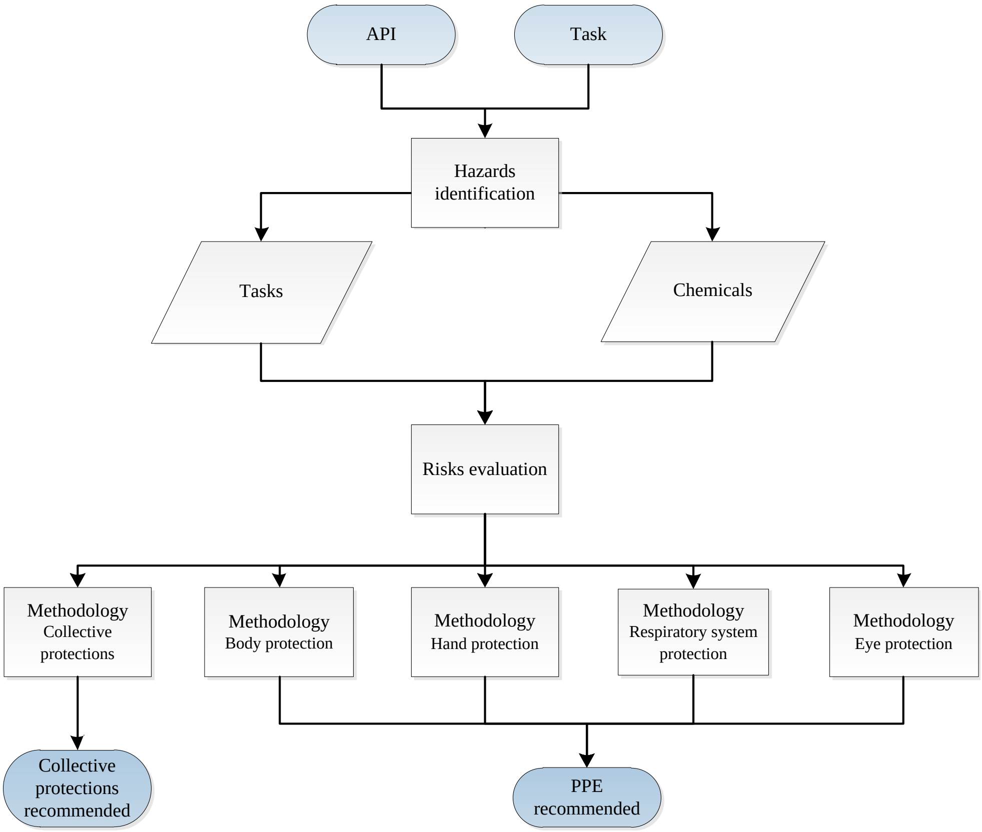

Figure 1. General flowchart of the methodology

1.2 Hazards identification

The first step is to set up two comprehensive inventories of used products and operating conditions in order to identify hazards in which the operator may face.

- Tasks: this inventory lists the utilization conditions in which an operator of the company faces (e.g.: the process and its confinement, the involved chemicals, the duration, the frequency of the task...).

- Products: this inventory lists all the used chemicals in the company and their physicochemical properties (e.g.: the name, the references of the products, the references, the risk phrases, the pictograms…).

1.3 Risks evaluation

1.3.1 Determination of collective protections.

The aim of CPE is to protect employees against risks that may threaten their health or safety. The collective protections permit to limit risk or confine it and

they are always implemented primarily to PPE. The methodology focuses only on ventilation systems since it seems to be the only collective protection applicable to chemical hazards.
In a company, different types of ventilation can be set up like surrounding catchment, effective local ventilation, general ventilation.
To choose the most suitable collective protections, it is necessary to look at the containment of the process. Thus, a relation between containment and recommended collective protections is made.
The use of the collective protections will allow the employees to reduce the strain on the respiratory protection. Indeed, when surrounding catchment or use a capture effective local ventilation (e.g.: hood), the level of respiratory protection will be reduced immediately below the protection level of efficiency.

1.3.2 Determination of individual protections.

The methodology determines the protective equipment that an operator must wear to protect themselves from chemical hazards (collective protections but also PPE).
Taking into account exclusively the chemical risk, only the following protections are analyzed: Eye protection, face protection, respiratory protection, hand protection and protection of the body.

2. Body protection

2.1 Introduction

In pharmaceutical industry, wearing a body protection like protective clothing is an obligation. This methodology is made to help the Safety and Security Manager to choose the rightful equipment.
The objective of this methodology is the determination of a protection level an operator has to be submitted according to the conditions of use (like product, quantity, task…). This methodology is based on an already-existing method from INRS (National Institute of Research and Safety) [1]
A type and a category of protective clothing will be associated to the protection level.

2.2 Method

2.2.1 Exposition class.

The determination of quantity class is made on a daily basis and considers the consumed quantity of Active Pharmaceutical Ingredient (API) compared with the most consumed API in the whole plant. The frequency class enables to differentiate the products that are used occasionally in comparison with the most often used product.
A matrix combining the quantity class with the frequency class determines the exposition class.

2.2.1 Hazard class.

This class permits the consideration of the intrinsic properties of the API. Hazards class can be determined either by the risk phrases on the MSDS, or by the Observable Effect Level (equivalent to French's VLEP). The chosen hazard class is the one obtained with the highest level of class.

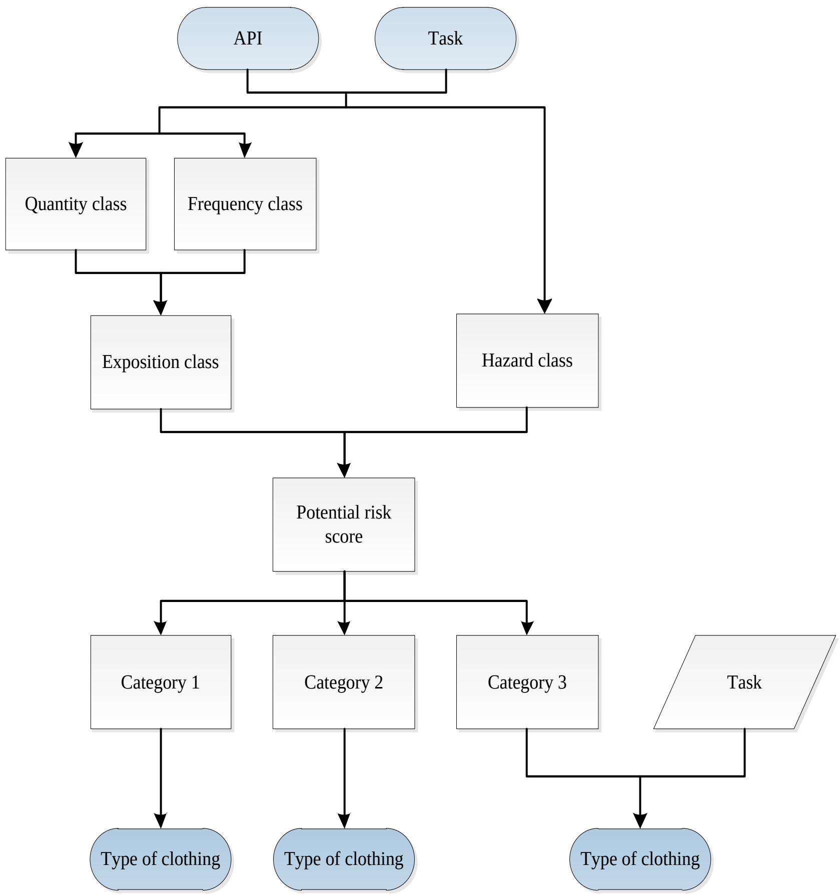

Figure 2. General flowchart for the body protection

2.2.3 Potential risk score.

This score allows the determination of the products requiring a priority and detailed the chemical risk evaluation.

The objective of this part is to determine three risk levels, each one corresponding to a clothing category as recommended by regulation.
The combination of the hazard class and the potential exposition class gives the potential risk. It allows the risk to be organized into a hierarchy of three levels.
After having ranked the risk and made a category of protective clothing correspond to this risk, a type of protective clothing is determined. This type is defined by European standards according to the risks of exposition dependent on the nature of the chemical and on the type of contact with this one (spatter, suspension, jet, fog).

For a major risk (Category 3), different types of protection clothing are determined by European standards. Six types of protection's clothes of category 3 are determined according to the following table (Table I).
For an intermediate risk (Category 2), Type 6 protection is preconized. This enables the operator to be protected against the spatter.
For a minor risk (Category 1), a basic clothing protection is preconized. No type is defined.

Table I [2]

Type 6	Protective clothing against liquid chemicals (Limited protective performance)	NF EN 13034
Type 5	Protective clothing for use against solid particulates (aerosol).	NF EN 13982
Type 4	Protective clothing against liquid chemicals (Pulverization protection)	NF EN 14605
Type 3	Protective clothing against liquid chemicals (Liquid protection and limited gas protection)	NF EN 14605
Type 2	**Protective clothing against liquid and gaseous chemicals, including liquid aerosols and solid particles (non-gas tight)** Equipment assuring a partial protection against gas. Breathable air's alimentation.	NF EN 943-1
Type 1	**Protective clothing against liquid and gaseous chemicals, including liquid aerosols and solid particles** (gas tight) Equipment assuring a complete protection against gas. Breathable air alimentation.	NF EN 943-1 NF 943-2

2.2.4 Case of a major risk (Category 3).

The objective is to correlate each task with a type of cloth (Table II).
Each task is assigned to an installation. That is why it is useful to understand the functioning of each installation to determine the elements enabling us to determine which type of clothing to use.

- The physical state of dangerous chemicals;
- The kind of contact (spatter, suspension, jet, fog);

Table II

Task	**Possible physical state**	**Kind of contact**	**Type of clothe preconized**
Grinding	Solid particle	Suspension	T5
Calibration	Solid particle	Suspension	T5
Compaction	Solid particle	Suspension	T5
Covering	Solid particle Liquid	Jet	T3
Granulation	Solid particle	Jet	T3
Assembly	Solid particle Liquid	Jet	T3
Weighing	Solid particle	Suspension	T5
Sieving	Solid particle	Suspension	T5
Mixing	Solid particle	Jet	T3

	Liquid		
Loading/Unloading	Solid particle Liquid	Jet	T3

2.3 Results

Opposite to the others, this methodology cannot be tested. In fact, determining a category and a type of protective clothing needs to introduce data concerning the quantity of product and frequency of the task. Consequently, it is impossible to compare the result obtained with the recommendation issued by the supplier's data.

3. Hand protection

3.1 Introduction

An operator does not always have to wear protection gloves. It depends on the task which is carried out and the used chemical. First, a preliminary step is to know if the use of gloves is compulsory. Then, the type of gloves, that's to say the material of the gloves, is determined by means of matrix calculations according to the chemical families present in the API. The following chart indicates the global method of determination of hand protection:

3.2. Method

<u>3.2.1 Are gloves compulsory?</u>
The protection gloves are more or less convenient for the operators. To determine if gloves are compulsory, many steps must be followed for the chemicals (API and solvent if necessary):

- Check of risk phrases:

Wearing protection gloves is compulsory if at least one risk phrases' dealing with skin contamination is present in the Material Safety Data Sheet (MSDS) of the chemicals. Those are H300, H301, H302, H304, H310, H311, H312, H314, H315, H317, H340, H341, H350, H351 (lethal, toxic, harmful if swallowed, in contact with skin, risk of cancer…). If the data of the used products does not include those phrases, gloves are not compulsory.

- Accessibility of chemicals:

If the chemicals bring a skin contamination, it is useful to know if the operator is exposed to dangerous products during a task. If the chemicals are accessible during a task, hand protection is highly recommended.

- Body part exposure during the task:

If the API and the solvent are accessible and if the hands are exposed to hazardous substances, it is necessary to wear chemical protection gloves.

<u>3.2.2 Which type of gloves wear?</u>
Before having the result of the choice of gloves types, various stages and calculations must be done:

- Chemical families and gloves materials:

To determine the material of the gloves to wear, it is proposed to use the composition of the chemical mix (or the API alone) according to a list of the chemical families.
The chemical families and their number i (line) are the following:
1: aromatic, 2: ketone, 3: halogenated group, 4: ether, 5: acid, 6: amino group, 7: alcohol, 8: heterocyclic group, 9: sulphur, 10: ester, 11: amide, 12: sulfoxide, 13: nitro, 14: alkene, 15: sulfonamide, 16: aldehyde, 17: nitrogenous group.
following:
1: rubber, 2: nitrile, 3: neoprene, 4: PVC, 5: butyl.

- Resistance matrix (A):

A resistance matrix of gloves types against the chemical families named A has been established thanks to literature. Let A(i,j) represent its coefficients.

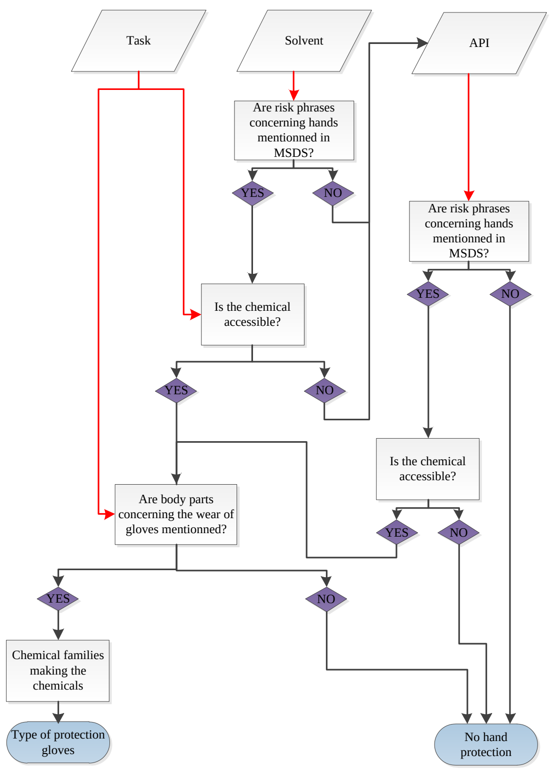

Figure 3. General flowchart of hand protections

The most used gloves in pharmaceutical activities and their number j (column) are the
The signification of their value is the following:
A(i,j)=0 : prohibited, A(i,j)=1 : lowly advised, A(i,j)=2: advised, A(i,j)=3: highly advised.
The resistance matrix is the following:

- Composition column vector (X):

Let X represent the composition vector of the mix in column, X(i) its coefficients, with i the number of the chemical family.
If one family i is present in one chemical (API or solvent), then X(i)=1; if it is present in both of the two chemicals, then X(i)=2; X(i)=0 if not.

- Compatibility matrix (S):

Let S represent the compatibility matrix and S(i,j) its coefficients. The matrix corresponds to the product of A by X. Indeed, with this multiplication, some type of gloves could be eliminated because of the chemical composition of the mix or the API when S(i,j)=0.

$$A = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 2 & 0 & 2 & 0 & 3 \\ 2 & 3 & 3 & 0 & 1 \\ 0 & 2 & 0 & 2 & 0 \\ 2 & 2 & 2 & 2 & 3 \\ 0 & 2 & 0 & 0 & 0 \\ 0 & 2 & 2 & 2 & 3 \\ 1 & 1 & 1 & 0 & 0 \\ 0 & 2 & 0 & 3 & 2 \\ 0 & 2 & 2 & 0 & 2 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 2 & 2 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 & 1 \end{pmatrix}$$

- Transfer matrix (T):

Let T represent the transfer matrix, and T(i,j) the matching coefficients as following:

$$\begin{cases} i \in [1;17], j \in [1;5] \\ T(i,j) = 1 \text{ if } \sum_{j=1}^{5} S(i,j) = 0 \\ T(i,j) = S(i,j) \text{ else} \end{cases}$$

3.3. Results

<u>3.3.1 Multiplication scores.</u>

At this point, a vector R of multiplication scores is calculated, R(j) corresponds to the multiplication score of the type of gloves number j:

$$R(j) = \prod_{i=1}^{17} T(i,j)\,, j \in [1;5]$$

Eventually, the gloves which obtained the best score are preconized. However, for some API, it appears that all R(j)=0. In this case, this score is given up and the method proceeds to the calculation of addition scores.

3.3.2 Addition scores.

If all R(j)=0, then a vector R' of addition scores is determined:

$$R'(j) = \sum_{i=1}^{17} S(i,j)\,,\, j \in [1;5]$$

As before, the gloves which obtained the best score are preconized. However, this vector of addition scores is only used if multiplication scores are not picked.

3.3.3 Choice of protection gloves.

The types of gloves protection to wear are classify by decreasing scores, R(j) or R'(j) according the case: the higher is the score, the better is the rank of the type of gloves. If a score is null, then the type of glove is not recommended.

3.3.4 Validation by comparative results.

This part of the methodology is validated by comparing the results of the methodology on APIs used in Ethypharm with the MSDS. If the type of gloves recommended in the MSDS of a chemical product match with the results obtained by the method, the method is valid for this API. This method reached of coherence.

At the end, 95.45 % of tests are in accordance with the recommendations of the MSDS. Therefore, the method is valid.

4. Respiratory System Protection

4.1 Introduction

Using a respiratory system protection is necessary when an operator is facing the risk of affecting his or her health by inhalation of air loaded with polluting gas, toxic vapour, dust or spray. Consequently, the use of a respiratory system is not systematic and it is useful to develop a method in order to help the choice of the type of respiratory system.

Before developing the method, it is important to define what a respiratory system protection is. It exists two categories of respiratory system:

- Filtering face mask;
- Heavy breathing protection or self-contained breathing apparatus.

In our case, we need to make three cases according to the mixture used to determine the respiratory system protection:

- Solid mixture;
- Liquid mixture without ethanol as solvent;
- Liquid mixture with ethanol as solvent.

4.2 Method

4.2.1 Solid mixture.

First, it is necessary to study risk phrases linked with the API selected by the user. Indeed, if none of the following sentences is mentioned in the API's MSDS, the user will not need to wear a respiratory system protection. The risk phrases concerned are : H330 / H331 / H332 / H334 / H335 / H336 / H340 / H341 / H350i / H351 / H360 / H360FD / H361 / H361FD / H362 / H371 / H373.

If the test on risk phrases is positive, the methodology keeps to be followed. Then, each filter is associated to one or more chemical families. A matrix is created in order to match the compatibility of each filter (K, E, P) with the chemical families spotting in the list of API present in Ethypharm. The filters compatible with the API are obtained by multiplying the matrix by the composition vector (explained in 3. Hand protection). After determining the type of filters, their efficiency must be chosen. The toxicity of the chemicals defined by pictograms enables to specify the efficiency on a scale going from 1 to 3. To finish, the type of system (filtering or insulating) is specified thanks to the containment of the process used. The correspondence is writing in Table III

Table III

Containment of the process	Pictograms	Efficiency	Respiratory system
Dispersive	Without	1	Filtering
Open	Without	1	Filtering
Closed but open regularly	Without	1	Filtering
Always closed	Without	1	Filtering
Dispersive	SGH 07 SGH 08	3	Filtering
Open	SGH 07 SGH 08	3	Filtering
Closed but open regularly	SGH 07 SGH 08	2	Filtering
Always closed	SGH 07 SGH 08	2	Filtering
Dispersive	SGH 09	/	Insulating
Open	SGH 09	3	Filtering
Closed but open regularly	SGH 09	3	Filtering
Always closed	SGH 09	3	Filtering

4.2.2 Liquid mixture without ethanol as solvent.

As for the solid mixture, a first test is realised on the risk phrases of the solvent and API.

Then the toxicity of the solvent and API is looked after. Indeed, if the mixture is not toxic, this is no need to wear a respiratory system protection.

At this point, the wear of a respiratory system is aborted if the saturation vapour pressure is higher than the used pressure.

After this step of tests, the type of filter (A, Ax, B) the user must wear is determined. That’s why the organic characteristic of the solution is studied. If the solution is organic, the type of filter preconized is A or Ax. Otherwise, B filter is advised. According to the boiling temperature, a A type filter is choose if it is higher than 65 degrees. Otherwise, the Ax filter is kept.

To finish, the efficiency and the type of system are determined thanks to the containment of the process (Table IV).

Table IV

Containment of the process	Efficiency	Respiratory system
Dispersive	3	Filtering or insulating
Open	3	Filtering or insulating
Closed but open regularly	2	Filtering
Always closed	1	Filtering

4.2.3 Liquid mixture with ethanol as solvent.

When ethanol is used, the user needs to wear a respiratory system with a filter A such as the recommendations of the MSDS of the ethanol. The efficiency and the type of system are determined like the liquid mixture without ethanol, i.e. with the containment of the process (Table IV).

4.2.4 Reduction with the use of efficient collective protection.

If the operator use a collective protection like a local efficient ventilation or a surrounding catchment, the efficiency of the respiratory system is reduced by one (Table V).

Table V

Efficiency and system without collective protection		Efficiency and system with collective protection	
System	Efficiency	System	Efficiency
Insulating		Filtering	3
Filtering	3	Filtering	2
Filtering	2	Filtering	1
Filtering	1	Nothing	

4.3 Results

In order to confirm the methodology, tests are realized. They consist in checking that the respiratory system mentioned in the MSDS of the API is the same that what we have obtained with our method (help of the computerized tool).
At the end, 95 % of tests are in accordance with the recommendations of the MSDS.
Therefore, the method is accepted.

5. Eye protection

5.1 Introduction

In the pharmaceutical industry, safety glasses are obligatory during all the tasks in which the operator can be exposed to API.

5.2 Method

This method is based on a flowchart. The first step is to check if an insulating respiratory system protection is used. If yes, safety glasses are no used because this kind of respiratory protection already protects the eyes. If not, safety glasses should be advised.

In this aim, the second step is to check if the risk phrases H314, H318 or H319 are mentioned in the MSDS of the API (Table VI).

Table VI: Risk phrases relative to eye protection.

Risk phrases number	Risk phrases description
H314	Causes severe skin burns and eye damage
H318	Causes serious eye damage
H319	Causes serious eye irritation

If one or more of those risk phrases are mentioned, safety goggles or a full face mask is advised to protect efficiently the operator. If not, safety glasses are advised by default.

5.4 Results

Thanks to this method, the operator can determine the most suitable eye protection according to the API used and the industrial task done.

6. Conclusion and Limits

Each chemical and pharmaceutical plant needs a method of chemical risk analysis to determine the most suitable protection equipment which is essential to ensure operators' safety.

Taking into account the API, its physical and chemical properties and the industrial task, this method is a global way to determine the adequate protection equipment in chemical activities. These factors are essential in the choice of the equipment since a collective or an individual protection has to be adapted to the risk.

However, it should be stress that this method does not take into account the accidental case. Furthermore, the user has to take other considerations, such as the equipment's costs or the operator's comfort.

Moreover, it has to be pointed out that this method only enables to give indications about which kind of protection equipment wear. Indeed, the employees' protection is linked to their behaviour and only a risk awareness campaign could reduce accidents at its root. To conclude, the final decision has to be taken by the person in charge of safety of the firm.

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The emergence of a Zone Health Risk Assessment approach in France

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Abstract

This paper is based on the involvement of its author in a French Haut Conseil de la Santé Publique (HCSP) working group whose aim was to write recommendations for realising Zone Risk Assessments (Z-HRA) inside areas polluted by local industries. Although this new approach appears for sure as a better one than the mono-sites impact studies, which at present are compulsory in France, this paper shows a series of difficulties to set it up, which originate from three different categories, a scientific one, a pragmatic one, and a political one. The each time first question for example, of fixing the boundaries of the polluted zone inside which a Z-HRA should be launched, is simultaneously linked to these three categories of difficulties and to their entanglement. Other similar questions which rose inside the working group are related in this paper and demonstrate both the usefulness and the complexity of Z-HRA approach, as a new risk assessment and risk management tool.

Keywords: Health Risk Assessment, public debate, decision making process

Introduction

Health Risk Assessment (HRA) is a regulatory procedure which has become mandatory in France since the 1996 Air Act. It was required since 1979 from industrial entities that they provide “impact studies” to the administration when they ask authorisation to operate a new facility, introduce new equipments, or a new industrial process. But the 1996 Air Act added the obligation for industrials to take into account possible effects of their activities on the surrounding population health and for this purpose to conduct risk assessments on the model codified by the American National Research Council (1983) [1]. Thus, when examining each HRA study, the French environmental administration will check in particular that the pollutants generated by the project do not produce an “excessive” health risk for the surrounding populations or will impose that the concerned industrial entity set up additional equipment in order to abate or suppress these risks.

Although this procedure, - the “site” HRA regulatory approach -, has been implemented since 15 years, it is increasingly criticized for two reasons. The first one could be summed up as following. As companies are often located near each other and also near other activities, one must recognize that the pollutants and nuisances generated by industrial plants and by other sources (such as vehicles for instance) tend to accumulate within “zones” which would include several polluting sources. Furthermore, even if each individual company complies with its regulatory requirements, - each emitted pollutant of each industrial plant staying under and admissible level-, it cannot be excluded that the local populations be subjected to above regulatory threshold concentrations of one pollutant or the other, or to harmful combinations of them. Hence the idea, according to which it would be sanitary and scientifically better to implement “zone” assessments, rather than “sites” ones, began to come through since the beginnings of the 2000s.

The second critique addressed towards the “site” HRA regulatory approach and the implementation of 1996 Air Act concerns the decision making process and its lack of transparency. Number of problems had occurred in France during the phase of results communication to the population, after conducted HRAs in the framework of the setting up of new facilities (refuse incinerators for instance). In some cases, concerned populations had demonstrated their refusal to new polluting facilities, although these new facilities had been authorized by environmental administration and public authorities. These problems slowly lead to the idea, largely advocated in the international literature, of a substantial and early involvement of the concerned populations and representatives of environmental associations, in procedures that needed to be invented.

Meanwhile, a few experiences that could be gathered under the name “Zone Health Risk Assessments” (Z-HRA) had been conducted in France, on an experimental and pragmatic basis. They were initiated for diverse reasons, and gave rise to process and results that were themselves contrasted, but generally positively judged.

According to this general background, the French ministries in charge of health and the environment requested the Haut Conseil de la Santé Publique (HCSP) to draft a report on the interest and the conditions for conducting risk assessments studies in the context of activity basins. More precisely the HCSP was mandated to report on two linked subjects: “the development of a methodology regarding health risks in the context of zone studies”, and “helping interpret the results of risk assessments conducted in the framework of impact studies”. In order to fulfil this mission, the HSCP established a multidisciplinary working group made up of (French) experts of various institutions. The group met from September 2009 to October 2010, held about ten meetings, hearings or work sessions, and at the end produced a recommendation report that was accepted by HSCP in January 2011, and published on its website. I was one of the participants of this working group, as one of the two social sciences representatives inside it, the other members of this group mostly being representatives of health and environmental "harder" scientists (epidemiologists, toxicologists), some of them ([8]) having taken part to previous experimental Z-HRAs.

The purpose of this paper is to report some of the difficulties we met, and some of the controversies we had when discussing and writing our recommendations. The difficulties we met were of different origins. Some of them were related to scientific problems or uncertainties; I will not lie down on those first ones, because I am not the most qualified one to do so. But some of them were technical or pragmatic difficulties; and some of them were linked to political considerations. As a social scientist, I will mainly report on these pragmatic and political problems.
Last point to say before entering into these questions: inside the HSCP working group, everybody was at once convinced that the recourse to Z-HRA should anyway be a better solution than the existing one. Taking into account health risks inside "zones" was for each of us on one hand a much better way of assessing the "real" risks for the concerned populations and on the other hand a powerful tool for opening debates and imagining diverse solutions for reducing risks inside each "zone". Succeeded examples of this second advantage had been reported to us: for instance we learnt that, in some cases, the setting of a new plant by a new industrial entity, inside an industrial zone, had lead to discussions between the different industrial-polluters of the zone, and to a lowering of the emissions of certain pollutants (benzene for instance) by the "older" polluting industrials entities, so that globally, the level of the given pollutant staid below the authorized thresholds, inside the zone. In such cases, diverse stakeholders, this time mainly the concerned industrial entities and the State environmental inspectors, succeeded when revisiting their respective contributions in a pollutant emissions, so as the global level of these emissions would be acceptable for the surrounding population.
Thus, we were in favour of Z-HRA, for sanitary and democratic reasons and we wanted to emphasize both aspects with our recommendations. But problems were going to rise, when coming to details and trying to imagine and write the good recipes for conducting Z-HRA.

What is a zone?

The first problem we met was unexpected. Although all of us were theoretically putting forwards the advantages of a zone approach in place of (multiple) mono-site HRA(s), we realised that we did not know how to define the concept of "zone", in a generic way, so this definition could be helpful for future and various stakeholders. In fact, the zone concept was blurry due to the large range of activities that had to be considered: industrial plants of course, but also farming, road transport, wastelands… all these activities are possible contributors of cumulative pollution and then of risks for the population health; additionally, the zone concept was not so clear according to its possible perimeter: as we were aware of the fact that emissions into the atmosphere or

[8] Those ones mainly were Civil Servants originating from the Cellules InterRégionales en Epidémiologie (CIRE); the CIRE used to be part of the Directions Régionales des Affaires Sanitaires et Sociales, and are now part of the Agences Régionales de Santé (ARS). CIREs also gather in a network driven by the Institut National de Veille Sanitaire (INVS).

into water environment barely have any limits, should we engage our work when considering a zone as a vast territory, that would include a large series of activities and also a big amount of inhabitants and other stakeholders?
For pragmatic but rather non scientific reasons, we quickly decided, as a first step, that a "zone" should not be too big. In order to go further towards a definition of the zone, we reviewed different facets it should take into account. The first of them could be called the triggering factor which in our view could be threefold: a zone approach, and then the delimitation of a zone, has to be considered when either particular environmental problems have been detected inside a given area, or when specific heath risks inside a given population seem to be detected (and *a fortiori* if this population, or local environmental associations are claiming on this subject), or, third possible triggering factor, when a new polluting plant or a new polluting process is about to increase polluting emissions in a given and already polluted area. So the zone should be drawn around the geographical origin of one or the other of theses diverse warning "signals" or points of entry in the process. In order then to draw the boundaries of a zone, we added several intertwined other facets, an economic one, a political one, a population one, and an environmental one. The three first of these ones were rather pragmatic and political: a zone should be a kind of "solidarity area" where people work and (or) live, and anyway are interested in its economic development, and a zone should concern only a few major polluting sources and a few local authorities territories, so as collective decisions could be discussed. Of course, the last facet stayed the more important one: a zone should also be delimited by environmental considerations, that is to say significant spatial differences between polluting emissions concentrations, between the inside and the offside.
At the end, we proposed the following definition of a zone, in the Z-HRA framework. It is "a solidarity area, in terms of economics, physical attributes and population, where a range of economic activities (industries, transportation of people or goods, agriculture…) took place, are taking place or will take place, contributing significantly to the emission of potential hazardous agents in the environment, that may, alone or when combined, affect health in the short or long term, given the way that the diverse populations occupy the area" [2, p 14].

Involving stakeholders

The second issue we had to face was the setting up of an organizational framework which could allow the involvement of the diverse concerned stakeholders, in the Z-HRA process. The international literature which had been examined on this question [3] is almost unanimous. Although the involvement of stakeholders in HRAs or quasi equivalent of Z-HRAs, all over the industrial world, brings new complexities and may at once appear as a waste of time for deciders, this involvement appears in the long run as a source of multiple benefits. The process of the assessment is generally at the end of a better quality, the results are at least better understood by the concerned populations, and the decisions stemming from the analysis are most of the time better accepted in this case. Furthermore, most of the recent academic articles on this subject stress that these results are better achieved when stakeholders are invited to participate in the process as early as possible [4].

We had a lot of discussions in our HCSP working group on the best organizational way of involving stakeholders in Z-HRA. On this point as on others, we mainly agreed on and shared the above opinion: diverse stakeholders, and if possible, all the concerned stakeholders of a given zone, should be invited, as soon as possible, that is to say even before boundaries of the zone were to be drawn up, to take part in the Z-HRA process that would treat of “their” zone. But, in the details, the problem was also a pragmatic one.

To put it schematically, we first worked on the setting up of a local and democratic organization which would be in charge of the “political” conduct of a given Z-HRA, once this action had been locally decided, and once the zone had been precisely defined. In this view, we advocated for the establishment of a Steering and Monitoring Committee (COS ([9])), that would be in charge of the choice of a research department which would lead scientific investigations on cumulative pollutants emission inside the zone, and of organizing discussions between the stakeholders, mainly on the basis of these scientific investigations. We imagined that stakeholders would belong to 6 different colleges, in order to cover the different gathered interests. So, we recommended that one would find inside a COS representatives from local (political) authorities such as mayors of the concerned communes or districts, from the State, government agencies and institutions, from employers of companies or facilities located in the concerned territory, from employees of the same companies or facilities, from the civil society (environmental associations, neighbourhood committees), and from qualified individuals. The president of the COS should be as independent as possible and be appointed by the Committee members, his main task being to conduct open debates, and the secretariat should, to be pragmatic, be held by state representatives.

More accurately, the COS’ missions could be split into three phases:

- the starting one would be to induce a shared vision of the problem between stakeholders, to decide whether a Z-HRA is needed, and to precise the boundaries of the relevant zone.

- The second phase, once a Z-HRA has been decided, would be to write draft specifications for its conduct, with the help of a chosen service provider (research firm or any other competent body); then the COS should choose, after a call for applications, another research firm or competent body for conducting the scientific part of the Z-HRA

- During the third phase, the COS would accompany the scientific work, analyse its results and disseminate them; it also may formulate recommendations pertaining to risk management measures. Once arbitration has been made by the competent authorities, and once the decided risk management measures should be enacted, the COS would follow this implementation and assess its impacts.

We had a lot of discussions, inside our HCSP working group, on the functioning of this COST, on its composition, and on its supposed role inside the decision

[9] COS (Comité d’Orientation et de Suivi) in French.

making process. We did not always agree but had to make some compromises. For instance, on the question “are all the stakeholders, inside a given COS, equal?” the response is inevitably complex. A pure democratic vision would suggest that the 6 above mentioned colleges representatives should be equal in the COS discussions, but *de facto*, some stakeholders have a different status than others: the State representatives may impose at any time existing regulations, the companies’ employers or owners will be asked by the States representatives to pay at least for the scientific work done during the conduct of Z-HRAs and eventually to participate to consequential risk management measures, although other colleges’ representatives would not have these prerogatives or duties ([10]). Hence, the involvement of the diverse COST stakeholders in the decision process, after the Z-HRA had been achieved, is a problem I will come back later. But let us go back for a while, in the implementation of the whole process. What is above related refers to a constituted COS, with its proper difficulties as its appointed members meet, discuss, exchange. When relating deliberately on the propositions we made and on their difficulties, I skipped another and anterior problem, which is the constitution of the COS itself. Yet, a COS cannot rise from nowhere and it need itself to be settled. This is why we had to distinguish a preliminary phase, before the COS three here above described ones. Once an environmental, sanitary, or regulatory problem linked to the implantation of a new polluting plant has been detected in an area, we proposed that the State representatives engage a preliminary assessment of this problem, inside a preliminary delimitation of the concerned area. This first assessment, which in our view should need a light scientific assistance, should be engaged through State funds. If this preliminary exam seems to lead to further needed ones, that is to say the constitution of a COS and the conducting of an Z-HRA, the State representatives would just have in charge the previous impulse. Once a COS is on the way, States representatives should withdraw of their *de facto* first leading position in the process.

The decision making phase

Another subject of discussion, inside our HCSP working group, has been about decision making, once Z-HRA has been finished, and specifically on the role of the COS with regards of this last phase. To be schematic, two positions opposed each other. Some of us would defend, as a way of pushing as far as possible democratic procedures, the idea that the COS should be empowered in the decision making phase. Stating that there is a general tendency, in industrial countries so that stakeholders whose advices are not taken into account exit more and more local and democratic procedures, some of us would tend to say that, if the COS could propose risk management propositions in response to the Z-HRA, then, those propositions would have to be considered as legitimate by the competent authorities. Others had a very different position and maintained the COS in a strict role of a proponent and of an adviser; risk management decisions would only rely in the competent authorities’ hands, - that is to say mainly in

[10] Stating that stakeholders are in fact different, we proposed that one of the first task a constituted COST should be to write a (local and appropriated) « code of conduct » of the diverse stakeholders themselves.

France the State local representatives-, which may take into account, or not, the COS propositions. In the report, we cut the discussion, rather in favour of this second position; but we proposed a way between these two positions in an article we wrote afterwards ([11]).

Imposing Z-HRA as a new regulation?

The last discussion we had I would like to relate is linked to the previous point. As already said, if we did not always agreed on the details, all of us believed in the general superiority of Z-HRAs with regards of mono-sites HRAs, which are at this date compulsory inside French law. Thus, the question whether we should recommend that Z-HRAs be compulsory, beside mono-sites HRAs or instead of them, stemmed naturally. Two series of arguments were facing on that point. On one hand, some of us were stressing the fact that, till now at least, the most interesting cases of Z-HRAs that had been achieved were conducted on a voluntary basis: these ones had been successfully led because some stakeholders, mainly facility owners, inside a given area, had realised that an experimental zone procedure should be a better solution for everybody than a series of regulatory site ones; so, these stakeholders decided themselves, with the public authorities approval, to experiment locally a kind of Z-HRA. Thus, for some of us in our working group, imposing the Z-HRA procedure as a new regulation could appear as a paradox and at the end be counterproductive ([12]); that is why those ones inside our working group would prefer not to impose Z-HRA as a regulation, but to leave local actors make their choice. On another hand, some others of us stressed the idea that Z-HRA, notwithstanding the fact it was obviously a better procedure than mono sites HRA, was indeed a long, difficult, and time consuming procedure, at least for its main leaders. This is why, -some of us said-, if this complex procedure were not made compulsory, local actors would generally choose to avoid it, and rely on old mono sites approaches, which now is a routine procedure, comparatively easy to implement. In this matter as in others, we had to cut our discussions and to write a compromise: we globally pronounced in favour of promoting the use of Z-HRA inside a regulatory framework, but which had to be, " at the very least, both prescriptive and flexible, adaptable to various local situations,…" [2, p 17].

Conclusion

In this communication, I have tried to report on some of the difficulties we met, as a multidisciplinary working group in charge of formulating recommendations for the implementation of Z-HRAs in France. I reported mainly on what I have called pragmatic, technical or political problems, and I have left aside more

[11] This multidisciplinary article is not yet published. To be short on that point, we argue that there were two hypotheses: if the competent authorities agree with the COS propositions, there is not any problem; if they disagree, competent authorities have to argue and explain the reasons of this divergence with the COST, before imposing their will. See Fourniau JM [5], who advocates, in the general French context, that public decisions must respond to the lessons drawn by public debate.

[12] How to involve for instance, on a voluntary way, the various colleges of stakeholders in the COS, if the process itself is compulsory?

scientific (“hard science”) ones. Yet, some of those ones are as acute as the others I mentioned. Pollution inside a “zone” for instance is mainly due to local industrial pollutant emissions, but also to a “back ground noise” composed of car traffic emissions and also of a global pollution generated at a larger level than the concerned zone but affecting it. The COS and the stakeholders of the zone have to and may only work on the lowering of the locally generated pollution but not on its background noise. But scientific apparatus would measure the whole, although a distinction between both is needed if one wishes to appreciate everybody’s contribution and responsibility in the pollution. Another scientific problem is to appreciate pollutants combinations inside a zone and their possible effects on health for the inhabitants.

Scientific problems are not only difficult by themselves because of uncertainty or lack of measures; in this case, some of their difficulties become entangled with political or pragmatic problems. For example, if we go back to one of the initial question I spoke on in the Z-HRA framework, -delimiting the zone-, one can say that a zone is simultaneously but sometimes with contradictions defined through scientific considerations (a quick exam of the effect of a chosen tracer, for a first delimitation), but also administrative or geographical ones, and also political ones.

The bunch of difficulties we met is not specific to our task. As far as I know, all over the industrialized world, nobody has found the “good” solution to solve all the problems raised by the implementation of Z-HRAs or equivalent. Even in the USA, the “old” risk assessment model is criticised ([13]) but not easily replaced by an as strong one as the Red Book’s model which could solve all the dilemmas of our complex world.

These considerations lead to the general feeling I personally have now, after a while, about the work we made in this working group. On one hand, I still have no doubt on our aims and approach: the Z-HRA procedure we tried to shape and recommend is for sure a better way for dealing with local industrial pollution than the mono site HRA approach for a series of already developed reasons. But on the other hand, I have to recognize the procedures we imagined and recommended, for dealing with these both scientific and political problems, have a global tendency to be time, - and sometimes money-, consuming for stakeholders, and that the pursuit of our multiple objectives (better health for the concerned populations, better scientific knowledge in that purpose, incorporating local democracy inside decision making processes) inevitably brings or increases complexity all along the processes. This is maybe the reason why the recommendations we officially made one year and a half ago have not yet been namely been operated: as far as I know, not any Z-HRA in France has been conducted, with reference to our report, since this report was published on the HCSP website; and I have not heard either that public French authorities would have impose as a new regulatory tool the Z-HRA procedures we described. But I will not be too pessimistic with this statement. Nevertheless, new ideas or new ways of dealing with public problems need some time, and a lot of adjustments

[13] See recent official comments on the initial model: « The committee recommends an important extension of the Red Book model to meet today’s challenges better – that risk assessment should be viewed as a method for evaluating the relative merits of various options for managing risk rather than as an end in itself », [6].

with theoretical considerations, to be implemented. So that we, as social scientists, have to go on paying attention to those fascinating problems, processes, an locally imagined solutions to treat them, these solutions be called Z-HRAs or not.

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Building a Capability Platform for Safety during a Change Process

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Abstract

In this paper the changes when introducing Integrated Operations in a drilling company is analyzed. The changes include the establishment of a support center for drilling in 2004/05 and also the use of video conference equipment. In this study data from this establishment and also from a follow-up in 2012 is used to analyze the development in the company. The theoretical framework has been based on a capability platform where stacks of the capabilities technological solutions, people, processes and organization/governance are used for enhancing safety. The capability theory emphasizes customers and that changes are initiated from the outside of the company in contradiction to the socio-technical approach most commonly used in the field of safety management. Important findings are that changes implemented to be competitive advantages were developed internally and changing the internal processes in the company. The result is an iterative process where improvements are implemented throughout the company and as such improving the safety in an ongoing process.

Keywords: Safety, Capability Platform, Integrated Operations, Management of Change, Petroleum Industry.

Introduction

"Integrated Operations" is a term for a change process that has been taking place and still is taking place in the oil and gas industry, commonly Integrated Operations (IO) are defined as *"The vision of the Digital Oil Field is one where operators, partners, and service companies seek to take advantage of improved data and knowledge management, enhanced analytical tools, real-time systems,* *and more efficient business processes."* (Edwards et al., 2010) As we can see from this definition, the emphasis is on technology and progress has primarily been technology-driven; a stepwise development from remote support, via remote monitoring to remote control of certain operations. The final step is to remote control of all operations (Johnsen et al., 2005) where more of the control of offshore installations is transferred from offshore installations to onshore operation centers. Edwards et al. (2010) describe three items that are central to recognizing operations as IO:

1. A move to a real-time or near real-time way of working.
2. The linking up of one or more remote sites or teams to work together.
3. A move to more multidisciplinary ways of working.

Traditional work processes and organizational structures are challenged by more efficient and integrated approaches to offshore operations. As a contribution to the development of IO in the petroleum industry, we introduce the following definition of IO: "*Integrated Operations (IO) is an organizational form in the petroleum industry that facilitates the interaction between organization, leadership, technology and work processes at all levels and functions, between land, sea and partners, to develop resources and logistical chains adapted to the organization's intention"* (Steiro & Torgersen, 2012). These new approaches are taken into use to overcome traditional obstacles – whether they are geographical, organizational or professional – to efficient decision making (Skjerve & Basio, 2012).

Table 1. IO and new ways of working in petroleum companies (Skjerve & Basio, 2012).

Traditional way of working	Integrated Operations way of working
Serial	Parallel
Single discipline	Multi discipline
Dependence of physical location	Independence of physical location
Decisions made based in historical data	Decisions are made based on real- time data
Reactive	Proactive
Continuous relationships with team mates	More fragmented relationships with team mates
The collaboration activity will have a higher degree of informal exchange	The collaborative activity will be more formal
Lower degree of technology-mediated teamwork and use of groupware technology	Higher degree of technology-mediated teamwork and use of groupware technology
Static work processes	Dynamic work processes

This study is a case study in a drilling company that has implemented collaboration tools and established support centers for their rigs in their onshore offices. The aim of establishing these centers is to transfer some of the offshore functions to these support centers – making them operational centers. They have implemented many of the IO ways of working as listed in Table 1 and moved from the more traditional ways of working.

Safety is crucial in this process as sources of information might be lost when functions and ultimately people are moved from their proximity to the hazards where they are able to observe, perceive and sense early warning signals (Leveson, 2004), the land centers must be organized in a manner ensuring utilization of all the relevant competence, experience and knowledge present.

Moving of functions can cause different interaction patterns. Distances may create negative interaction patterns as seen from the Longford accident in Melbourne in 1998 where engineers were moved away from the plant and daily interaction with operators disappeared (Hopkins, 2000). Also prior to the Deepwater Horizon accident in 2010 there had been organizational changes where roles and responsibilities had been changed and failure to adequately delineate roles and responsibilities for key decisions were found (The Bureau of Ocean Energy Management, Regulation and Enforcement, 2011).
The capability platform theory enables us to analyze the relevant factors for safety in terms of the interaction between technology, people, process and governance as well as the interactions between them. Capability logic flows from outside to in, never inside out because business value is always defined in the eyes of an ultimate costumer. This way of thinking is different from other approaches in the field of safety management where a socio-technical system approach is more used (Hollnagel & Woods, 2005; Rasmussen, 1997; Perrow, 1984). This approach emphasizes the increasing complexity of these systems and the interactions and implications on actors from other actors and systems, the actors being authorities, companies, the employees and other stakeholders. The capability platform approach focuses on the customers and is closely related to offering services that customers are willing to pay for. The difference in these approaches has led us to wanting to use the capability platform approach to discover if the result from such analysis would give highly different results than more traditional analyses in the field of safety management. The aim of this paper is to utilize the capability platform approach related to safety and to identify which capabilities are essential in maintaining or increasing the safety level during an organizational change process.

We have collected data in the drilling company in two different time periods. The first period was as they started the establishment of support centers in 2004 and 2005. At this time, they had huge centers covering all the support personnel at an office location (Ose and Steiro, 2012). The analysis was performed by doing observations in the support center, in depth interviews and examination of documentation. Over time, they have tried different solutions and the second period for our data collection was in the spring of 2012. At this point, the drilling company had much smaller support centers at their different office locations. The center we visited, were supporting two rigs, but it was possible to use glass doors to separate both the different rigs and the different disciplines in a flexible manner.

In Section 2 we describe the theoretical basis for our analysis where the capability platform theory is directed into the field of safety. Section 3 gives the material and methods that have been used in this study. In Section 4 the case is described in more detail and in Section 5 the results from the observations and interviews are summarized and also discussed. In Section 6 the conclusions are given in terms of the case company that is studied in this paper, directions to further work in using the capability platform theory related to safety and some concluding comments as to differences between the capability platform approach and the more traditional socio-technical system approach in safety.

Theoretical basis

A capability platform is described as a stack, in which technology solutions form the base of the platform with people, process and organizational elements making the upper layers (Teece et al., 1997). Organizations exist in a networked setting with heterogeneous resources. One key characteristic of the platform concept is that innovation and change occur from outside to inside (Henderson et al., 2012). Dynamic capabilities can be defined as; *"The firm´s ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments"* (Teece et al., 1997: 516). Leonard- Barton (1992) writes that dynamic capabilities reflect an organization´s ability to achieve new and innovative forms in order to gain a competitive advantage. This definition has two key elements. First, the value of a capability is defined in a manner that explicitly impacts a business outcome. While internal costumers may be involved, business value is always defined in the eyes of an ultimate customer. Secondly, a capability is the synthesis of people, process, technology and governance. No single dimension is more important than another. Values arise from the synergy of the four dimensions. Each dimension must be understood in the context of the transformation effort. Capability thinking requires a continuous iteration among the four dimensions to be sure that the true complexity and conditions for success of the process are understood (Henderson et al., 2012).
In order to build a capability platform for safety, we can address the safety issues at all the levels in the stack:

1. Technology Solutions
2. People
3. Process
4. Organization/Governance

Technology is an enabling device for people, processes and governance (Henderson et al., 2012). In a safety perspective, technology solutions act as an enabler for creating safety values for the customer in the sense that it both capture experience in terms of safety critical information and that it serves as a foundation for people, process and organization/governance to ensure safety.
People are the center of value creation for most organizations. The concept of core competencies is a testament to the value embedded in culture, knowledge and creativity of people (Henderson et al., 2012). For safety, this means that the competences in safety as well as the actions are important and that safety has to be prioritized in the organization. A consequence of the capability platform theory's emphasize on customer value, is that safety must be prioritized in a degree that demonstrates the prioritization in the customer organization in the sense that is reflecting how much they are willing to pay for safety.

Processes create both the efficiency and reliability that is vital to grow (Henderson et al., 2012). For the safety aspect, this means that the processes as described by the organization must reflect safe processes. In order for the processes to be vital for growth, they must apply through the organization and reflect best practice and as such be easily implemented if the organization gain new and similar tasks.

Governance brings both the tension between local and global goals and the issue of ownership. Local versus global goals is a traditional tension between the corporate interest and the edge of the organization where performance demands may conflict with global goals (Henderson et al., 2012). For safety, the governance capability brings the aspect of safety being a local goal as well as a global goal in the sense that the actual performance reflects the global safety goals of the organization.

A capability perspective focuses on the transformation of core competences that truly define value in the eyes of the customer. It uses this focus to find ways to deal with increased complexity. It also requires an iterative approach. There are many ways to implement this iterative approach but the key is to make sure that the process is driven by customer value. The process also involves strategic learning in terms of a platform that allows for rapid development and deployment of new products and services. This platform will evolve and serve as an efficient engine for execution of the capability while also allowing for continuous innovation from outside – in. Generativity is a key feature that must be taken into this process (Henderson et al., 2012).

Materials and Method

Data collection was done in two different periods of time; in 2004/05 and in 2012. In the first period, a project group of four researchers studied the Support Center and the company. Written material and oral presentations from the drilling company were used as background information before the interviews. Thirteen interviews were held with the 34 employees in the Support Center; each lasted for approximately an hour. At least three researchers were present at each interview, and it was decided that reports checked by the researchers involved were an adequate record of the data collected. The interviewees were selected from different disciplines in the Center. A longer interview was held with the manager responsible for implementing the Center, and finally a videoconference with the manager, his own immediate manager and an ICT manager.
In the second period of data collection, two researchers did the observations and interviews. In this phase, 9 persons of the total 13 persons working with the support of the two rigs were interviewed using a pre-developed interview guide. In addition, we observed how the work was done in the Center for two days and also had some informal conversations with the employees.

The interviews were conducted as open-ended interviews with an interview guide (Yin, 2004, Kvale, 1996). The areas covered centered on changes in the employees' personal work situation concerning cooperation, their experiences of the change process and any advantages and disadvantages they experienced, and possible scenarios for the future development of the Center. Additional questions to produce more concrete answers and make situations more specific were asked when possible.

After both periods of data collection, memos were written summarizing the most important findings from the data collection. The summary memos distributed to the company also gave the drilling company the opportunity to correct eventual misunderstandings and wrong assumptions made by the researchers.

Dijkstra (2006) questioned the notion that information on safety should be gathered only from safety personnel, and our data were gathered from all disciplines and could thus contribute to a wider perspective on safety and risk. This is important since we see safety as a multidisciplinary phenomenon. The data collected were also discussed amongst the researchers as recommended by Yin (2004), for instance, in order to limit the individual researcher's interpretations of the data.

Description of case – changes in the Center from 2004/05 to 2012

The case used in this paper is a drilling company that established a Support Center based on the onshore support teams assigned to supporting its drilling rigs and floaters in 2004/05. Before the Support Center was set up, the location of the onshore offices was somewhat arbitrary and not closely matched to ether the rig or the discipline of the employee. All rig support personnel were located on the same floor but in separate offices in the same area. After the establishment of the Support Center, the various disciplines were brought together in an open landscape in which all the support personnel were located. The relevant disciplines comprised operations, maintenance, drilling support, economy, quality, health, safety and environment (QHSE), and human resources (HR). Typically six persons are involved in the support of one installation, some of whom are assigned to two rigs or floaters
This area designated to the Support Center in 2004/05 was about 600 square meters and is the prime working area for 34 employees. In addition to standard office facilities, the area included a room for videoconferences, two rooms with large screens for displaying data in real time. One of the rooms was also the emergency preparedness room. There were also two silent rooms in which staff can hold sensitive or private phone calls or meetings. The most significant change in working conditions in the Support Center did not concern technological changes, but rather changes in office arrangements. In total, 8 drilling rigs and floaters were supported from the Center.

The personnel in the Center said in 2004/05 that they had a lot to do and that they worked long hours and also took tasks home at night. Especially tasks where concentration was needed, was done at home after the working hours because they did not find that it was quiet enough to do these jobs in the Center. There was also a constant focus on how the establishment of the Center could lead to increased efficiency and lead to reducing the number of personnel working to support each rig. They also found the Center to be a stressful environment with a lot of noise and unnecessary interruptions during the day. Many of the persons in the Center also found that they did not have the time to update themselves on all the main activities for all the rigs that were supported from the Center; they had more than enough to do just doing their own job.

The Center that we visited in 2012 was much smaller in size than the Center in 2004/05 and only 2 rigs were supported from the Center. Also, the personnel categories were different; Operation Manager, Operational Advisor, Maintenance Manager and Operational Planner have their primary work space in the Center. Health, Safety and Environment Advisor, HR, Economy and Procurement are located in offices close to the Center. The video conference equipment is integrated in the Operational Advisor's primary work space and glass doors are used to separate the personnel supporting the different rigs and also the Operational Advisors from the Operational Planner that is supporting both rigs and the Operation Managers. There are extra work places in the Operational Advisors' offices that are used by the other staff when they are participating in video conferences. The Maintenance personnel are located in another room separated by a door that is mostly kept open. Video conferences are held with both the rig and the Operator Company and internal meetings in the drilling company across rigs and office locations. These arrangements enable them to both cooperate in the Center as a whole and to cooperate in smaller groups.

In the Center a new way of working has been established where they use the video conferences actively and often. The personnel working directly in the support of the offshore rigs usually start their work day at 7 AM in the morning and use the time prior to the morning meetings at 8 to update themselves on the activities that have taken place since they went home the day before, provided there have been no major incidents, then they would have been informed and on duty when needed. On normal days, there are different video meetings with different participants from different locations and organizations in the time before lunch at 11. The participants on the video meetings are the customer, internal meetings in the drilling company both for the different disciplines and for the personnel supporting a rig and also there are meetings with suppliers when needed. The drilling company has the responsibility to plan and execute maintenance related to drilling and wells. After lunch it is quiet in the Center allowing the personnel to have local discussions, phone calls and work separately on their own tasks. Usually, when there is not something critical that is going on related to the rigs, the personnel in the Center are finished with their tasks and can go home around 3 PM. We observed and did the interviews in a period the informants termed normal and quiet.

Results and discussion

Our case company is very customer-focused and willing to adapt to customer requirements, and this is also an important aspect of the capability platform, where capabilities are described as being developed in ecology as a virtual, increasingly global and network-based model. In 2004/05 we found that the drilling company was developing capabilities with its customers rather than internally in their own company. For instance when it was adapting its technological systems, their processes and organization to individual customers, its own platform as a company was weakened and fragmented. The establishment of the Support Center was a step towards closer internal collaboration, but as we found, it needed to be followed by internal processes. In 2012 the company has developed internal processes and uses the technologies that were implemented for competitive purposes to improve the internal processes in their own company.

Regarding Technology Solutions the drilling company was implementing new solutions such as equipment for video conferencing in 2004/05 as a competitive advantage. They had some difficulties regarding this equipment due to fire walls and some problems related to starting to use the equipment. In 2012 the use of this equipment is integrated in the normal operations and there is no threshold for starting video conferences. They use the equipment several times a day and in addition to using as the customer requires, they also use it to have internal meetings for personnel assigned to the same rig and located in the support center, offshore and with the customer. In addition, they use the equipment to have internal meetings in the different disciplines at different office locations. The drilling company has also decided to have their own Information and Communication Technology (ICT)-system in addition to the system they are obligated by the customer to have in order to gather experience internally.

The people are through the interviews reported the most important asset of the drilling company as it also was in 2004/05. They have a lot of experience in drilling. In 2004/05 little effort was put into developing the internal drilling competence and little time was used on this. In 2012 the emphasis on developing internal teams and sharing experience is regarded as important in the company. Effort and time is put into having arenas for internal discussions. There are planned video conferences three times a week for each rig with the personnel that are located at different locations. In addition, there are bi-weekly meetings in the different disciplines that are located at different office locations. An internal identity is built in the drilling company.
In 2004/05 there were different contracts both for the different customers and also for the same customer. This made it difficult to collaborate internally in the drilling company. In addition, the support center was so large that it was not possible to get an easily overview of all the activities related to all the different rigs that were supported there. In 2012, only two rigs were supported from the center and all the personnel were informed about all the main activities for both the rigs. From a safety perspective, this enables them to be able to support one another if something critical was to happen.

Regarding governance, in 2004/05 there was agreement on all the levels in the organization that the objective of establishing the center was cost savings and reducing the number of employees. In 2012 the emphasis was put on that this was a good way to work and on important leanings and experience. They received positive feedback from their customer regarding safety and were encouraged to have a safety focus and to utilize the customer's systems and also the internal meetings for safety discussions.

Table 2. Summary of important findings related to the capabilities from both 2004/05 and 2012.

Capability	Findings in 2004/05	Findings in 2012
Technology Solutions	Different technology solutions such as video conference equipment were being implemented. There were some difficulties due to fire walls. The implementation of new	The uses of technologies such as video conferences are a natural part of the work and being used several times a day. The equipment is used both to improve cooperation with the customer and to improve cooperation internally in own company.

	technology is done to get a competitive advantage.	The drilling company uses their own program in addition to the program used by the customer to gather experience internally. There are plans to increase the use of the costumer's ICT-system.
People	There was a lot of drilling experience in the company. A lot of the persons in the support center have offshore experience. Little effort to develop the drilling competence internally in the drilling company, focus is on the customers.	The use of technology such as video conferencing to develop the competence internally in own company. They have a drilling engineer with the customer permanently. Effort is put on building the internal identity both for the personnel located offshore, in the center and with the customer. Internal meetings three times a week that are not required by the customer.
Processes	Different contracts with different customers and also with the same customer. Too large support center for the personnel to get an overview of all the activities.	One customer and one standard contract enable the drilling company to develop unified processes in the company. Two rigs supported from the center and the personnel were informed of all the main activities. They were also able to support one another.
Organizati on/Govern ance	The drilling company was surprisingly unified on the different levels where they all said that savings and reducing the number of personnel were the objectives of the establishment of the support center. Safety was mostly as the customers decided.	At this time the emphasis was reported not on cost savings but more on learning and changing. The center represented a good way of working. The drilling company received good feedback from the customer regarding their safety focus.

As an overall finding from the case company, they have moved from the customer focus into utilizing the technological solutions and possibilities firs as a competitive advantage and into also using them for internal purposes. This may very well be a competitive advantage that they will profit from in the next round – being more proactive, valuing learning and sharing experience and building internal arenas for these purposes. The drilling company has proved to be able to conduct an iterative process where improvements and changes are developed and used on improving the processes throughout the company.

Conclusion

This analysis shows how a drilling company has developed its capabilities over a period of time. It shows how they used the changes brought about by the introduction of Integrated Operations first as a competitive advantage and later as an iterative process to improve the internal processes in the company. They used what was learned in relation to their customer to also build an internal identity and internal arenas for sharing experiences. This enables them to develop their processes further and in the next round that will represent a competitive advantage. This shows that capabilities can be of value to the customer even though they are not specified in the contracts and they do not get directly paid for it. It is, however, not identified if this is being valued by the personnel handling the contracts.

How this drilling company is able to take the changes that are initiated from the outside and incorporate them in their own processes, are being shed light on by using the capability platform theory. It is, however, internal processes in the

drilling company that manage to decide to be proactive regarding the implementation of the changes initiated by Integrated Operations and also deciding and nurturing a company where safety is regarded important and where the personnel give one another positive feedback when they do their jobs well.
Utilizing the capability platform theory, gives the analysis a very strong customer focus. This may create a vulnerable company with a too strong customer focus and too few internal processes and strategies. For instance, adapting the capabilities of one customer makes the company dependent of this customer and if this customer decides to use another supplier, the company will find it difficult to adapt to the capabilities of another customer. The drilling industry may serve as a good example of this as this industry is characterized by relatively short-term contracts and the presence of harsh competition. It may, however, be profitable for the company in the long run to have some strategic processes initiated from within own company in terms of specifying what their core competences and also values should be emphasized and developed in the company and not leave the entire development to the customers.

Further work on capability platforms on safety should be to detail the safety aspects of the capabilities further and analyze how they can be developed. It would be of great interest to look at the capabilities both from the drilling company's and from their customer's points of views. Utilizing the theory of capability platforms, however, may make it possible to compare different studies in different companies that have use the same theoretical framework.
The customer focus that the capability platform approach gives is different than the socio-technical system approach most commonly used in safety management. The results from an analysis where customers are the only stakeholders that are valued because they are ultimately giving value to the company, is different and narrower than the socio-technical system approach. Implicitly in the capability platform approach, there is also a view that "the customer is always right" because a company's strategy should evolve around requirements from customers. What is normally the view of safety management is that customers are giving both positive and negative implications for safety and also in the last round; authorities are securing a minimum of safety through legislation. Hence, authorities and legislation should be included in the capabilities for safety. This is also essential because the legislation vary in different parts of the world even with the same customer showing that they do not want to pay for more safety than they have to.

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Deriving Major Accident Failure Frequencies with a Storybuilder Analysis of Reportable Accidents

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Abstract

Quantitative Risk Assessment (QRA) is used in the Netherlands and the UK for site permitting and land-use planning around industries with dangerous substances. For example, individual risk contours resulting from a QRA determine where houses and other types of constructions may exist. Both industry and regulators ask for models and data that are up to date. Key components are failure scenarios and frequencies. In the past, one-time investigations were carried out that were time-consuming and costly. The current paper describes a systematic approach for the derivation of failure scenarios and frequencies that was initiated by HSE and RIVM. All accidents in the UK and the Netherlands that must be reported to the Labour Inspectorate are analyzed with the Storybuilder method. In this way, underlying failure causes at operational and management levels can be investigated and stored in a structured database. For the derivation of frequencies, various paths to obtain information on the size of the equipment population were explored. The ambition is to continue the project for a long period, making the inputs for the QRA more reliable.

Keywords: Major hazard accidents, Storybuilder accident investigation, failure frequency, risk calculation, equipment population.

1. Introduction

The Seveso II Directive is aimed at the control of major-accident hazards [i]. It was adopted after the accident releasing a toxic cloud of dioxins at a chemical plant in Seveso, Italy, in 1976. The directive states land-use planning implications of major accidents should be taken into account in the regulatory process.

In the Netherlands, the Seveso directive has been implemented in the "Major Accidents Risks Decree" [ii]. This regulation (amongst others) states that the risks for third parties should be calculated using Quantitative Risk Analysis (QRA). The "External Safety Decree on Establishments" defines how the QRA must be performed and how outcomes for individual risk and societal risk should be used for land-use planning and site permitting processes. For instance, no housing is allowed at locations where the individual risk exceeds 1 x 10^{-6} yr^{-1}. The software package Safeti-NL is used to perform the risk calculation, while a manual gives guidelines for the input data [i]. Safeti-NL uses several input parameters, amongst which the failure frequencies of scenarios are prominent.

As the risk calculations have significant consequences for land-use planning and site permitting, industry asks that models and data are updated to the latest insights. An example is the fairly recent development of legislation for natural gas production sites. For this, RIVM has been asked to derive failure frequencies and scenarios for aboveground gas pipelines [iii].A new project had to be started to investigate what information is available in international literature and public or proprietary databases. If there is a lack of data for the equipment under investigation, analogies to equivalent equipment must be sought. In the example of the natural gas pipelines an analogy was sought between buried pipelines and above-ground pipelines, while scenarios and frequencies for flanges were based on data from the Dutch gas industry. Investigations like these are costly, time-consuming, and deliver a one-time set of answers to questions studied.

RIVM and the UK Health and Safety Executive (HSE) joined in a project to investigate if it is possible to update failure scenarios and frequencies in a more systematic and continuous way [iii] HSE further desired to see if Storybuilder could be used to update information on underlying failure causes (as was requested by the industry after the Buncefield accident in the UK in 2005). The Storybuilder software package was developed to analyze occupational accidents (in order to calculate occupational risks) and is a versatile instrument. It is also used by the Dutch Labor Inspectorate to analyze the major hazard accidents of the past few years. This is part of an ongoing project at the Labor Inspectorate to draw lessons from major hazard accidents and direct the inspection program toward relevant hazards, barriers and underlying causes.

2. Collection of data

To derive new failure frequencies, two sources of information are needed: the number of failures (accidents) per selected scenario and the total number of experience years for the equipment at stake. As a feasibility study, we restricted the information gathering to equipment populations for pressure vessels and pipe work. The accident analysis with Storybuilder served multiple purposes and was not restricted to specific equipment types.
The scope of the analysis was limited to top tier Seveso II companies. Accidents of relevant size occurring at these companies are reported to the Labor Inspectorate, which then investigates and reports the details of the accidents. These reports were used for the accident analysis in Storybuilder. Seveso II companies are also required to produce a Safety Report and carry out a Quantitative Risk Analysis. These sources of information were – among others – used for the analysis of the equipment population.

2.1 Accident Investigations: the Storybuilder Method

Storybuilder was developed in a project to quantify occupational risks [iii, iv]. It is a software program that combines a database with a graphic user interface that can be used to input and depict accident paths. Accidents are analyzed by answering the questions what, where, how and why the accidents have happened. By answering these questions for many accidents, a bow-tie structure gradually arises that shows common causation mechanisms for the distinguished types of accidents. Examples of accident types for occupational risk are “fall from ladder” and “hit by flying object”.

The Loss of Control event forms the centre of the bow-tie. The left-hand side of the bow-tie contains various levels of prevention barriers and the right-hand side includes levels of mitigation barriers. Each barrier is associated with a Safety Barrier Task and each task is connected to the Management Delivery System. For each accident, the status of these barriers is analyzed along with the status of the barrier tasks and the management delivery system. This information is stored in a structured and flexible database where extra information on influencing factors associated with barrier failures can be added. Furthermore, new accident scenario paths can be added at all times.

If many accidents of the same type are analyzed, common accident routes (or paths) can be identified. Moreover, the database also shows why the relevant barriers failed, both at an operational level and from a management perspective. An example of the graphical interface of Storybuilder is given in figure 2.

For the current project we used two data sets from the Netherlands and the UK. In the Netherlands, major hazard accidents must be reported to the Major Hazard Control (MHC) unit of the Labor Inspectorate. Major hazard accidents are those where an uncontrolled development leads to a release of specified dangerous substances and causes serious risk to human health or the environment. The 63 accidents that occurred in 2008-2010 (and were investigated and finalized with a report) were analyzed with Storybuilder for the Labor Inspectorate [v].. With this analysis the Labor Inspectorate wishes to determine trends in causes and effects that can help direct future inspection programs.

For the current project we used two data sets from the Netherlands and the UK. In the UK, the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR, 1995) ensures that incidents resulting in injuries (or workplace related diseases) are reported to the HSE. HSE investigates these incidents and reports to the MARS database those incidents that meet the Seveso criteria (or COMAH, Control Of Major Accident Hazards in the UK). In the UK, there are about 1000 COMAH sites and the HSE has analyzed accidents that occurred at COMAH sites since 1991 with Storybuilder as well [v].
Both datasets were used to assemble information related to pressure vessels and pipe work.

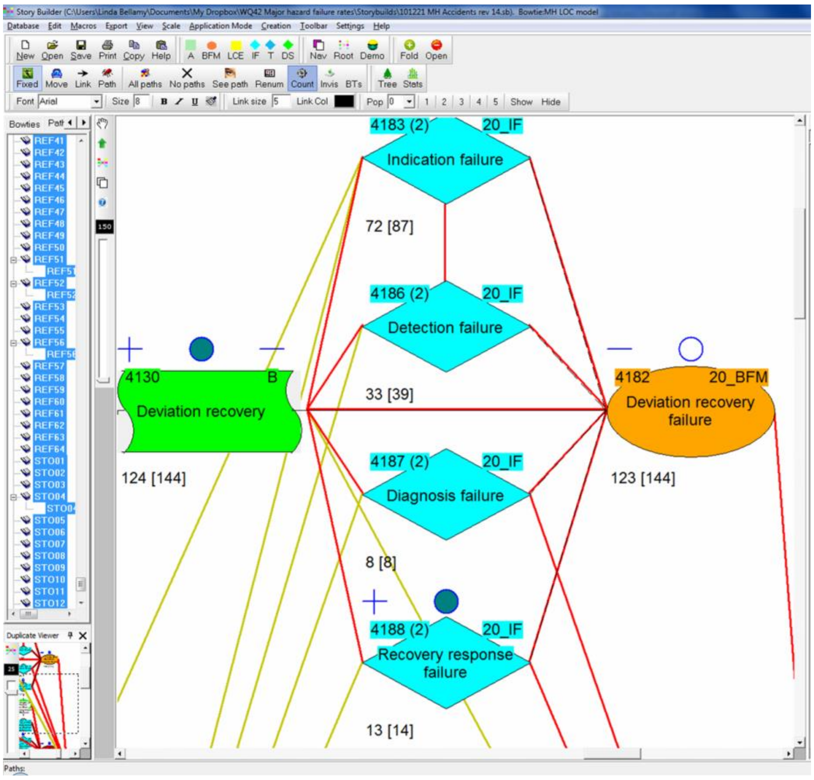

Figure 1. Screen Capture of Storybuilder with an Example of Paths Going through IDDR (Indicate, Detect, Diagnose, Respond) Barriers

2.2 Equipment Population in the Netherlands

In order to determine failure rates both the number of accidents and the total number of equipment experience years (equipment population) must be known. This section focuses on the equipment population in the Netherlands.
Various routes for determining the size of the equipment population can be imagined. A list of the data sources used is given in table 1. Other data sources were investigated, but were considered not useful at the time:

- Queries to be sent by the Dutch chemical industry branch organisation (not feasible within the time constraints of the project)

- Lloyd's Register – Stoomwezen (in charge of testing pressure vessels in NL) (not the data needed)
- Engineering Design Companies (not the data needed)
- Dutch Labor Inspectorate (not feasible within the time constraints of the project)
- Permits (not the data needed)

Eventually five sources were used to gather information on (pressure) vessels and pipe work. With these sources, the size of the equipment population at 20 top-tier Seveso companies was estimated:

- One LPG bulk storage facility
- One steel manufacturing company
- Two companies producing industrial gases
- Two refineries (with associated bulk storage of fuel)
- Seven companies storing bulk liquids (four fuel and three fuel and toxic chemicals)
- Seven chemical manufacturing companies

Table 1. List of Data Sources for Estimating the Size of the Equipment Population

Source	Comment
Safety Reports/ Notifications/QRA	A substantial amount of information was retrieved from Safety Reports and Notifications. Note: Notifications are documents in which companies inform the competent authorities that the amounts of substances at the site exceed the thresholds for Seveso II. These documents therefore contain detailed information on the amounts of substances present at the site. In the Safety Reports companies report the identified hazards and the measures taken to reduce these hazards. These reports contain more detailed information on the type of equipment used and some further technical data.
Google Earth	This source was used to count the larger equipment types and visible pipelines. Indoor equipment and equipment within congested plants obviously can not be identified with Google Earth.
Direct contact with companies through existing contacts with employees	Some information was collected through existing contacts at industries. These data were used to determine the reliability of the data retrieved from other sources.

Source	Comment
RRGS (Dutch Risk Register Dangerous Substances) [iii]	RRGS is a data source that contains information on various types of companies that handle, manufacture and transport dangerous substances. It is used to inform the general public and (therefore) does not contain detailed equipment data. This information source was mainly used to determine the risk contours and site boundaries and check other sources.
Internet	Additional general information was gathered through internet, in particular, the age of installations and the number of employees.

An important issue is that there must be a match between the equipment for which accidents are reported and the equipment for which the size of the population is investigated. If, for example, releases from pipelines with a diameter smaller than two inches will never result in a reportable accident, such pipelines should not be included in the equipment population count either.

3. Results and Discussion

3.1 Accident Analysis

Analysis of the UK incident data (975 incidents) is described in detail in an article by Lisbona et al. [9].Some general conclusions that bear the most relevance to this project are given below:

- Among containment related barrier failures, containment condition/material failure (259 incidents), isolation failures (170) and equipment connection failures (83) are the most frequent barrier failures.
- The 259 incidents regarding containment condition/material failure can be further characterized by influencing factors. These factors were mainly related to mechanically damaged equipment (68 %), design errors (14%) and the use of inadequate/wrong equipment (10%)
- The mechanically damaged equipment (68%) was influenced mainly by corrosion/erosion, which accounted for half of the incidents in this subset.
- Underlying causes in the management system can be discerned with Storybuilder; each of the barrier failures is a result of task failures (failure to provide, use etc.) and these, in turn, fail due to a management delivery system failure (failure in plans/procedures, communication, ergonomics etc.). For the incidents regarding containment condition/material failure, the failure to provide (e.g. no plans, no equipment or no availability of operators) was the most important factor. "Plans and procedures" was the most common management system delivery failure.
- Storybuilder can provide a lot of information on incidents that can be used by companies and competent authorities to focus their attention on the right factors to improve safety performance and develop inspection plans.

For the pressure vessels and pipe work category, the following findings were reported:

- A total of 44 pipe work/vessel failures were identified in the data, of which 23 were associated with mechanical failure. The 23 mechanically-related failures could be broken down into four failures of pressure vessels and 19 pipe work failures.

- The HSE has also reported 23 incidents to the MARS database and from these no pressure vessel failures were found, but six pipe work failures were identified. Of the six pipe work failures, three were related to corrosion/erosion failures.

The analysis of the Dutch incident data (63 incidents in 2008-2010) is described in detail by Mud et al. [8]and a later survey on 118 incidents from 2006-2010 in an article by Bellamy et al [xi]. The conclusions from many incidents:

- Most importantly, there was a general failure to recover from process deviations. If these are detected and acted upon in an early phase, many incidents could have been prevented.
- In many incidents, incorrect materials were used for installation parts.
- There was a general inadequate control of process streams.
- Proper preparation of plant items prior to maintenance (Lock-Out/Tag Out, LOTO) was inadequate.
- Many errors occurred in assembly of components (i.e. there were loose connections).
- Many incidents were related to opening of containment with direct links to the atmosphere (containment is by-passed but does not fail structurally).
- Regarding the barrier tasks, maintenance was the most important factor, in about 50% of the incidents. Inadequate delivery of equipment was the most common management system delivery failure. This is different from the UK data and is discussed in possibly UK inspectors are more focused on plans and procedures, while the Dutch focus more on management system deliveries for equipment.

For the pressure vessels and pipe work category, the following findings were reported:

- There were no recorded pressure vessel body failures in the incidents 2008-2010.
- There were six recorded pipe body failures: one was a full bore rupture, two were ruptures over 1/3 of the diameter, one was a small hole of 5-25 mm and two were of unknown size. A distinction into full bore rupture versus leaks (relevant for failure frequencies) can thus be made as 1/6 versus 5/6 (with more data this can be substantiated further).
- For the six pipe work failures, three were associated with corrosion, one with fatigue, and two with high temperature and high pressure deviations in operating conditions. For this group, it could be concluded that corrosion causes 50% of the failures.

The above conclusions, from the different accident analyses, show that Storybuilder can deliver information on incidents that can be used for focusing attention to frequent failure modes and subsequent improvement plans. It can discern what management tasks and delivery systems are most likely to fail for different barriers so that inspection plans can act upon this information. Information on different failure scenarios and direct causes can be used to calculate failure frequencies and to discern the most important contributing factors.

3.2 Equipment Population in the Netherlands

The results of the data collection are presented in table 2. Apart from these data, site characteristics such as area size, mass of substances, number of employees and age of installation were collected as well in order to investigate possible correlations.

Taking the experiences with both pipe work and pressure vessels into account, the following can be concluded on the routes to gather information:

- *Safety Reports* do give a reasonable amount of data. They mainly focus on information for determining risks to employees or third parties and thus will likely give more information on larger types of equipment. Thus, it is not surprising that a thorough investigation of process descriptions revealed a large amount of process pressure vessels that were not visible in plant overview diagrams. As a result, if the desire is to derive failure frequencies for many different types of equipment, Safety Reports are still not sufficient as the only source of information.

Table 2. List of Data Assembled on 20 Top-Tier Seveso Sites

	Chem. manuf.	**Chem. manuf.**	**Prod. of ind. gas**	**Refining**	**Bulk fuel storage**
Meters pipework					
Google Earth	ND (DTD)	ND (DTD)	6,000	72,000	35,000
QRA of Safety Report	NISR	2,890	1,000	NISR	NISR
Direct info from companies					
Nr of press. vessels & press. storage tanks					
Google Earth	6	0	1	9	0
QRA of Safety Report	NISR	2	5	68	0
	Bulk fuel storage	**Chem. manuf.**	**Steel making**	**Chem. manuf.**	**Chem. manuf.**
Meters pipework					
Google Earth	36,000	650	ND (SBU)	ND (DTD)	ND (DTD)
QRA of Safety Report	NISR	NISR	NISR	SRI	NISR
Direct info from companies		500			
Nr of press. vessels & press. storage tanks					
Google Earth	6	0	SBU	14	5
QRA of Safety Report	6	4	7	SRI	5
Direct info from companies		10		29	
	Chem. manuf.	**Prod. of ind. gases**	**Bulk fuel & tox. storage**	**Bulk fuel storage**	**Chem. manuf.**
Meters pipework					
Google Earth	ND	ND (SBU)	7,000	30,000	5,500
QRA of Safety Report	NISR	NISR	2,700	NISR	NISR
Direct info from companies					
Nr of press. vessels & press. storage tanks					
Google Earth	0	SBU	0	0	0
QRA of Safety Report	NISR	NISR	3	0	5
	Refining	**Bulk fuel & tox. storage**	**Bulk fuel storage**	**Bulk fuel & tox. storage**	**LPG bulk storage**
Meters pipework					
Google Earth	30,000 (PSA)	40,000	2,500	ND	ND
QRA of Safety Report	5,360	1,000	NISR	NISR	15,500
Direct info from companies					
Nr of press. vessels & press. storage tanks					
Google Earth	17	3	0	0	6
QRA of Safety Report	17	1	0	0	6

DTD = Difficult To Determine (large sites), ND = Not Determined, NISR = No Information in Safety Report, PSA = Part of Storage Area, SBU = Site Boundary Unclear, SRI = safety Report Incomplete

- *Google Earth*: At a first glance, Google Earth can deliver quite reasonable information for large equipment types situated outside. These data correlate reasonably with information given in Safety Reports and by contact from companies. For pipe work, quite some more guesswork is involved - but for the larger pipes situated outside, the information is at least useful for a rough estimate. However, failure scenarios for pipe work are generally split up into diameter ranges, and thus more work needs to be done to obtain information on diameters. Another disadvantage for using Google Earth is that it is not possible to discriminate between equipment containing hazardous substances and equipment that does not contain hazardous substances (for example substances used for utilities, such as fire fighting water or cooling water). Furthermore, it is not possible to determine if equipment is in use or out of commission. Lastly, specific details about the instrumentation and safeguards present in equipment cannot be derived with Google Earth. Therefore, Google Earth is only useful to obtain a rough estimate for large equipment types, but cannot be used for detailed analyses.

- *Direct contact* with representatives of the companies involved will likely give information with the highest quality. However, if the desired level of detail of the information is high, the amount of effort required to supply the data is correspondingly high. In addition, the outcomes of the work are uncertain. It will supply better insight in failure mechanisms (which is in everyone's interest) but the updated frequencies might have undesirable consequences for site permitting. It is, therefore, not expected that industries will put a large amount of effort into filling a public database. The data could be used on a collection of companies to "calibrate" other data sources however.

3.3 Failure Rate Calculation

The small number of companies in table 2 does not allow making any statistically sound estimations of failure rates at present. However, an example calculation will be given to illustrate the method and determine how much data is needed to develop statistically sound failure rates. For an example calculation, it is assumed that the 20 companies are representative for the Seveso companies in the Netherlands. As there are currently around 420 Seveso companies in the Netherlands, the size of the equipment population determined for the 20 companies would have to be multiplied accordingly. In these examples, for now, we overlook the fact that the accumulated accident data was derived for all Seveso sites while the equipment population data was gathered for top tier sites only. Once the feasibility is demonstrated, a further distinction of accident data into top- or lower-tier sites can be made.

In this paper we define the failure frequency as the 50% percentile value of a Poisson interval, derived from the number of accidents that occurred and the number of equipment experience years. This approach is slightly more conservative than taking the mean value, but it has the advantage that frequencies can be derived even if zero accidents occurred. Another advantage is that the 50% percentile value does not fluctuate as much as the mean value, which is an important advantage if the impact of failure frequencies for land-use planning and site permitting is considered.

<u>Pipe Work Example</u>

If we take the highest number of pipe work found, either by Google Earth, Safety Reports, or direct contacts in table 2, we have an average of 22 km of pipe work per company. This leads to 420 * 22 km ≈ 9,000 km of pipe work and 27,000 km-years for three years of accident investigations. With six recorded pipe body failures in three years a failure rate (50% percentile) of $2.5*10^{-7}$ m^{-1} yr^{-1} then results. The current failure rates used in the Netherlands for pipelines with a diameter of over 150 mm are $1*10^{-7}$ m^{-1} yr^{-1} for a full bore rupture and $5*10^{-7}$ m^{-1} yr^{-1} for a leak at 10% of the pipe diameter. Thus, the calculated value is in the region of what is used already. As discussed in the results of the accident analysis of the Dutch incidents, one out of six incidents resulted in a full bore rupture. This can be used to make further distinctions into the failure frequencies. Also, the causes for these failures can be divided into 50% for corrosion-related failures versus others as shown in the incident data. As this is only an example, we cannot draw any further conclusions on failure rate calculations. We think it is apparent that the approach (so far) is feasible, and that more accurate values can be obtained in time when more accident data and more accurate equipment population information become available.

4. Conclusions

Storybuilder is a useful and versatile tool for analyzing accidents in the process industry. It can identify common accident scenario paths and deliver quantified information. This includes the most frequent barrier failures and the management delivery causes underlying these failures.

The equipment population size cannot be estimated to the desired level of detail with simple methods and will, therefore, be a challenge. Different information sources must be used and combined, and only parts of the desired data can reasonably be gathered each year. Key conclusions of the work:

1. Safety Reports generally do not have the level of detail needed for an accurate estimation of population data. Safety Reports focus on the larger installations and, therefore, details about smaller equipment are not available.

2. Google Earth gives an accurate estimation of large pressurized storage vessels and only roughly gives an estimate of the amount of pipe work between storage tanks and process plants. More information from companies might reveal the exact accuracy of these estimations.

3. Information obtained directly from companies is most reliable but requires a substantial effort from these companies if all information must be delivered on short notice.

By combining the data described above, updated failure frequencies can be derived for different types of equipment that take into account underlying causes, barrier failures and safety management system delivery failures.

5. Prospects

In order to come to a reliable database of failure scenarios and frequencies for use in a quantitative risk analysis, it is decided to continue the data gathering in a follow-up project. Storybuilder has proven to be a useful and versatile tool for analyzing accidents in the process industry. In the follow-up, Storybuilder will be used to analyse accidents over a larger period of time, thus increasing the number of incidents in the database over time. To get a better estimation of the equipment population size, it is shown that simple methods such as the use of Safety Reports or Google Earth don't provide all the information required, and therefore, detailed information obtained directly from chemical industries is needed. To limit the amount of work, the following approach is adopted to survey the total equipment population size in the UK and the Netherlands:

1. Chemical plants are classified in a limited number of categories (plant types), such as LPG bulk storage, refinery, or storage facility of bulk liquids.

2. For each plant type, two or three companies will be selected for a detailed analysis of the size of the equipment population. This analysis is carried out in a collaboration between the project team and the industry involved. Along with the equipment count, a limited set of plant characteristics is recorded, e.g. the substance contained.

3. Modifying factors for the number of equipment per plant type can be defined, e.g. based on process type or annual throughput.

4. The equipment count per plant type may be verified with independent institutions such as certifying bodies and plant designers.

5. Seveso sites in the UK and the Netherlands are divided in separate plants using the Safety Reports. For each plant, the plant type is determined.

6. The total number of the equipment population size is now calculated by multiplying the typical number of equipment for each plant type with the number of plants assigned to this plant type.

The result of the survey will give the total number of equipment within the population of Seveso sites in the UK and the Netherlands.

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Flood resilient city design: a review of existing methods and tools

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Abstract

Floods are part of nature and they may affect all aspects of our lives. Recent changes to the urban system and its environment caused by rapid urbanization and climate change increase both the flood probability and the impact of flooding. Consequently there is a need for all cities to adapt to climate and socio-economic changes by developing new strategies of flood risk management. Following the paradigm shift from traditional to more integrated approaches, and considering the uncertainties of future development, one of the main emerging tasks of flood managers become the development of resilient cities. Urban resilience is a concept from which it is possible to reduce the consequences of urban system disturbances, and even consider these disturbances as an opportunity for urban development in a more sustainable way. This paper describes different methods, tools, and methodologies, existing today in the context of our research. We then discuss and analyze the usefulness of these methods and tools according to the main objectives of our research.

Keywords: urban system, flood risk, resilience, methodology, urban design

Introduction

Urban floods are increasing worldwide and are likely to become even more damaging in the future [34]. This is particularly the case for cities which are the most vulnerable because of the concentration in these areas of people, their possessions and their economics activities which are all subject to floods. Recent changes in urban systems and their environments caused by rapid urbanization and climate change increase both the probability and the impact of flooding. About 75% of flood damages would be identified in urban areas [10]. Moreover, there exist a high number of interdependencies between the individual components of the urban system that make cities even more vulnerable to floods. During the last decade extremely damaging floods have occurred all over the world: New Orleans 2005, Central Europe 2009, Chine 2010, Thailand 2011, etc. Increasingly it is recognized that the use of large infrastructures alone to tackle these kinds of disasters has the risk for technological failures and is likely to be less effective than integrated approaches to manage flood risks [16]. Consequently, it highlights the necessity for a new and a different approach to urban design, planning and building to cope with urban flood risk. To make it happen, flood risk management needs to be better integrated into planning, urban retrofitting and development processes [15]. However, there are many barriers to integrate flood risk in urban planning and design because urban planning and design set out to integrate different needs and requirements at a range of spatial and temporal scales. In this, flood risk management is not normally considered to be the most important of the various utility and service needs and opportunities [49]. Thus, there is a need for all cities to adapt to climate and socio-economic changes by incorporating urban resilience strategies into overall city planning.

We focus our research on how flood risk can be integrated in urban development by means of the concept of resilience. Indeed, urban development and regeneration present windows of opportunity to increase flood resilience that are still not taken advantage of. Urban resilience is a concept from which it seems possible to reduce the consequence of urban system disturbances, and even consider these disturbances as an opportunity for urban development in a more sustainable way [41]. Thus, in our research we accept the non-equilibrium view of uncertainty and unexpected change among the fundamental characteristics of the urban system, and then disturbances become accepted. Urban resilience is based upon a systemic approach and an understanding of multiple spatial and temporal levels of the urban system and the interactions within and between the different levels. The main goal of our research is to provide guidance for urban planning and design in order to improve flood resilience of cities in a more systemic and integrated manner.

This paper describes different methods, tools, process and methodologies, existing today in the context of our research. We then discuss and analyze the usefulness of these methods and tools according to the main objectives of our research. Finally, we present and justify which of them seem suitable to use or to adapt for our ongoing research.

Research goals

1.1. Urban growth, climate change and flood risk

Floods are part of nature and they may affect all aspects of our lives. Today, there are several causes making urban flood risk management really complicated. Since 2007, half of the world population lives in cities [45]. Moreover, the total urban population is expected to double from two to four billion over the next 30 to 35 years [46]. This rapid urban development is usually accompanied by an important urban sprawl generating risk itself. On the one hand, this leads to build the city in areas where hazards are stronger; on the other hand, the urban networks are no longer adapted and under dimensioned for the collection and evacuation of the stormwater [21].

Furthermore, climate change is avowed and it generates a number of uncertainties according to the scenarios of temperature rise proposed by the experts of the IPCC. But whatever the scenario chosen, impacts on the frequency and severity of rainfalls are expected. Similarly, more intense periods of drought will alternate with these higher rainfalls [28]. Droughts will have a direct effect on soil sealing. Thus, more intense rainfalls on impermeable soils will increase the risk of flooding. Moreover, other sources of flooding coming from the sea level rise can be expected. Also, other uncertainties related to the reliability of data, their acquisition and then their exploitation complicates the management of flood risk [2]. It is on the basis of these uncertain, incomplete and imprecise data that the flood forecasting models are produced as well as the design of protective systems.

Thus climate change, combined with the concentration of people and properties in urban areas, suggests terrible events for the coming years. Flood risk is expected to increase significantly: the economic cost of flood risk is expected to reach around the world the value of 100 billion euros per year at the end of the century [14].

Therefore, in this context where the world becomes increasingly uncertain, there is a need for all cities to develop new strategies of flood risk management to anticipate flood scenarios that probabilistic models consider them as extreme or rare [55]. These strategies should incorporate this multitude of exacerbating factors such as urban development, climate change and the different sources of flooding in the city [5], which complicates the management of flood risk. Currently, some strategies are evolving but they are still often reactive rather than proactive, and they are generally isolated. They generally emphasize structural measures (dikes, dams…) and adopt a sectoral approach to cities. Yet other strategies may exist, among them resilience which provides a systemic approach. Rebuild our modes of managing risk by means of the concept of urban resilience requires creative thinking and innovations that profoundly modify existing strategies to anchor in a dynamic and integrated approach that considers all dimensions of the urban system and its interactions, in an organized manner and across the different spatial and temporal levels.

1.2. Resilience concept

Several researches have led to the development of the resilience definitions, general as well as specific to particular fields. The following table (Tab. I) summarizes the literature review of [18].

Recently, resilience has increasingly been applied to linked social-ecological systems [20]. The reason for extending the use of resilience to socio-ecological systems is that any delineation between social and ecological systems is seen as artificial and arbitrary [4]. Social-ecological resilience has been defined as: “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity” [19]. According to this approach, resilience is not only about being persistent to disturbance. It is also about the opportunities that disturbances open up in terms of recombination of evolved structures and processes, renewal of the system and emergence of new trajectories [18]. Thus, the concept of resilience in relation to social-ecological systems incorporates the idea of adaptation, learning and self-organization in addition to the general ability to persist disturbance [18].

Table VIII : Major definitions of resilience [18]

Definitions	Characteristics	Focus on	Context
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological/ ecosystem resilience, social resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibria, stability landscapes
Social-ecological resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability, learning, innovation	Integrated system feedback, cross-scale dynamic interactions

Indeed, it appears in this approach that resilient systems are systems that can adapt to disturbances [13, 17, 23]. Resilience is not a concept just related to the time of crisis and post crisis (as suggested by some other definitions [30]), but a concept derived from a learning process [6, 11, 23], where the disturbance is the developer of underlying capabilities of the system.

1.3. Holistic and systemic approach of the research

A city or more generally, the urban issue, can be conceived as a complex system. According to the problem studied, the urban system considered will not be necessarily the same. There is not only one possible urban system, but as many systems as problems exist [7].

Urban flooding cannot be managed in isolation, so it is essential to any approach to address the different spatial levels of the urban system. Indeed, an understanding of the interactions and relationships across different levels of the urban system and the impact they have on the resilience of the city, is very important. However, anybody does not know too much about these interactions and relationships, and how they may affect the resilience of cities [54], which makes the task very difficult.

A challenge for our research is to define a flood resilient urban system, identifying furthermore the goals or purposes of the system, the components of

the system and their functions and the interactions between its different spatial and temporal levels. The use of a systemic approach will allow us to design our complex problem as a whole, a set of elements making system.
In this system, humans are an important component that will have to be considered. Indeed, to understand and to design for resilience, the role of the humans needs to be understood. Whereas humans may be a major source of accidents, designers of most modern systems recognize that the adaptability of humans makes them an essential component for resilience.
In short, it comes to understanding the urban system complexity by means of systemic analyzes in order to succeed the design of flood resilient cities.

1.4. Urban resilience and sustainable urban development

The resilience approach from social-ecological studies is applied in this research with respect to the urban system. Resilience concept applied to the urban system is known as urban resilience.

Urban resilience is a concept from which it is possible to reduce the effects of disturbances that can affect the urban system, and even considering the disturbances as an opportunity for a more sustainable urban development [41]. According to this characteristic, the disturbance is not necessarily a negative event but rather an important part in the urban system operation. In this perspective, risk management will not consist to resist, based on the idea that there is only one equilibrium situation for the system, but rather, to create other viable situations which allow the urban system to continue operating. Indeed, the idea is not to create an optimal state for the urban system but rather the selection of solutions that are more likely to succeed under an increasingly uncertain future.

Nowadays, the application of flood urban resilience concept is basically translated into the design of buildings, constructed in order to suffer the least damage as possible. But in the same way, we can also identify other important urban components in a city. Thus, it comes to understanding the urban system complexity by means of systemic analyzes in order to succeed the design of flood resilient cities. Indeed, the urban system is made up of a set of elements interacting with each other and optimizing the behavior of each individual component does not guarantee that the global system is itself optimum.

To the extent that the existing physical/built form of a city is limiting or problematic, urban planning and design can articulate policy and physical/spatial solutions to address the problems. More innovative urban planning and design is possible in large-scale ecocity projects where ambitious goals for multiple aspects of sustainability can be adopted to guide and focus the design process, including: a sustainable urban hydrology model, zero net energy use, a mix of urban uses, inclusion of biodiversity, and providing a healthy environment for people [35]. Thus, several aspects of sustainable development are concerned by these objectives. However, to date there have been no references on urban resilience to floods guiding the process of urban planning and design in order to contribute to sustainable development of cities.

Urban resilience is a new way of thinking about sustainable urban development, rather than specific set of guidelines, instructions, or checklists. Urban resilience is more strategic than normative, because, to be effective, resilience must be explicitly based on, and informed by, the environmental, ecological, social, and economic drivers and dynamics of any particular place, and it must be integrated across a range of linked scales [39].

Cooperation between urban resilience to floods and urban planning and design does not yet exist, from both a theoretical and a practical aspect. There is no systemic and efficient theory or urban planning and design strategy that takes urban resilience to flood into account. Otherwise, urban planning and design is inherently a strategic process in that it attempts to understand and proactively manage the elements and forces that are the cause of change, rather than employing tactics to respond to the change themselves [1, 42]. For urban planning and design to be strategic, it requires integration of interdisciplinary knowledge to define strategic goals consistent with political expectations, economic factors, and the reality of the existing landscape condition [35].

1.5. Research goals

The purpose of this research is to formalize useful knowledge for decision support in order to design flood resilient cities. Indeed, we focus our research on the integration of the flood risk in the urban planning and design by means of a resilient approach. The main goal is to provide guidance on urban planning and design in order to improve the flood resilience of cities. We expect to define under what urban, technical, morphological, programmatic and social configurations a resilient urban system to flood is possible to be designed. As a result, an urban design strategy that holistically considers all areas of the urban water cycle as well as its linkages to other components of the urban system should be determined for a particular urban area. The idea is not to create an optimal state for the urban system but rather the selection of solutions that are likely succeed under an increasingly uncertain future. Applying the strategy, urban planners, architects, engineers, as well as project managers should be able to propose appropriate urban design actions improving the overall resilience of the city.

Finally this research does not aims to offer an overall assessment of resilience but it seeks to define the actions to be implemented to achieve, by the evolution of urban components, a desired level of flood resilience of the urban system.

Review of the existing methodologies, methods and tools…

To achieve our research goal and given the context previously developed, an indispensable prerequisite is to develop a multidisciplinary methodology allowing to integrate flood resilience in urban planning and design. This objective can be achieved if we are able to measure objectively the level of service provided by the urban system as a whole. Furthermore this assessment will have to be used to provide an effective decision support process to different stakeholders in order to determine the best urban planning and design strategy to

improve the level of urban system resilience to flood. Thus, our research aims to be a part of a participative decision process in urban planning and design.
Based on these needs, we conducted a literature study on the methodologies, methods and tools that ongoing researches on natural hazards and resilience have developed. Because our research is also in the context of sustainable urban development, we then also investigated in other urban fields on methods and tools developed which could be interesting.

1.6. Concerning researches on natural hazards and resilience

During the recent years, a growing interest for resilience has been expressed in the natural disaster mitigation and especially in the flood related events. The European Union, under the Seventh Framework Programme (FP7), has initiated several research initiatives in order to explore this concept especially for the urban environments. Among them, we investigate projects about vulnerability (MOVE (www.move-fp7.eu), ENSURE (www.ensureproject.eu)), floods (IMPRINTS (www.imprints-fp7.eu), CORFU (www.corfu7.eu)), storms (MICORE (www.micore.eu)), landslides (SafeLand (www.safeland-fp7.eu)), droughts (Xerochore (www.feem-project.net/xerochore), DEWFORA (www.dewfora.net), DROUGHT-R&SPI (www.eu-drought.org)), social sciences (CapHaz-Net (www.caphaz-net.org), ConHaz (www.conhaz.org), emBRACE (www.embrace-eu.org)), earthquakes (SHARE (www.share-eu.org), REAKT (www.reaktproject.eu)), volcanoes (MIAVITA (www.miavita.brgm.fr), VUELCO (www.vuelco.net)), forest fires (FUME (www.fumeproject.eu)), multi-risk/risk prevention (KULTURisk (www.kulturisk.eu), MATRIX (www.matrix.gpi.kit.edu), CATALYST (www.catalyst-project.eu)), and others (SMARTeST (www.floodresilience.eu), FIRESENSE (www.firesense.eu), NIKER (www.niker.eu), PERPETUATE (www.perpetuate.eu)).
We identified several projects with the very similar purpose and goal, the same methodology or means to achieve it and similar final outcomes. So we classified and described all projects according to these criteria.

Thus, some of the projects intend to develop tools in order to predict possible impacts of the negative event or just to provide information on it. The main objective of them is to provide guidance for the stakeholders which will have to propose possible future scenarios. Then, we define another group of projects whose purpose is to create frameworks, methods or tools in order to asses and quantify vulnerability or risk. They use existing methodologies as basis of their work and the goal is to develop a handbook which will outline the different frameworks, methods and tools most appropriate for vulnerability or risk assessment and qualification. Other projects are working not to create knowledge about the specific hazard or disaster, but rather to identify and share information about best practices, identify gaps, and strengthened and extend existing networks. The goal that most of them achieve is to provide some guidelines for the best practices of the specific hazard or disaster, both before and after such disaster occurs. Another set of projects intend to develop frameworks or methods for the provision of early warning and response in order to increase the event preparedness and, identify and implement appropriate risk reduction measures. The goal achieve is to provide guidance of preparedness and adaptation to risk and elaborate strategies and recommendations for activities. The last group of projects defined intends to develop tools to mitigate risks from various hazards in order to the real time risk mitigation methods. The means to achieve their purpose is developing conceptual framework, indicators and models which will allow the projects to finally provide guidance in the definition and implementation of strategic options for risk mitigation management and governance.

Among all these analyzed projects, nine of them introduce the concept of resilience. Concretely, the concept appears in the projects related to vulnerability, floods, droughts and social sciences. Within them, a central idea of resilience can be retained which is “recovery”. Indeed, resilience is often considered as the opposite of vulnerability in such a way that reducing vulnerability is the means to increase resilience. Thus, for most of the projects, the level of resilience depends on post-event recovery options. It will be the result of the effectiveness of event mitigation measures; those mitigation measures aimed to reduce vulnerability.

Particularly, projects related to vulnerability and droughts, define resilience as the capacity to recover effectively after a disturbance in such a manner that pre-event vulnerability will be reduced. Nevertheless, they don’t consider resilience only as the opposite of vulnerability. Resilience enters in these projects also as a dynamic concept that it addresses the capacities to innovate and the ability to strategically orient complex process. For these projects, resilience is a concept related to time of crisis and post crisis, it is a process during and following a disturbance. Then, the projects related to floods consider resilience as a new approach to urban flood management. It will be the means to guide strategies in order to improve the quality of urban flood management and reduce flood risk. A new idea of resilience is introduced by the projects related to social sciences where resilience is considered as a long-term process. Particularly, it is defined as a concept underling the need to live with change and uncertainty, and to permanently learn. So it is a resilience which takes the learning and the adaptation against risk into account.

In Europe there are several urban development practices exsting today that sought to integrate flood risk. Concretely, projects which we deeply investigated are the FloodResilienceCity (www.floodresiliencity.eu), FloodProBE (www.floodprobe.eu) and LifE (www.lifeproject.ino) projects. The FloodResilienceCity project is an EU-funded project which enables responsible public authorities in eight cities in North West Europe to better cope with floods in urban areas. This will be done through a combination of transnational cooperation and regional investments. In this project the concept of resilience is introduced in a general framework which is based on four sets of thematic activities, each one with detailed action programs, based on “4-A approach” (Awareness, Avoidance, Alleviation, Assistance). Otherwise, the FloodProBE is a European research project with the objective of providing cost-effective solutions for flood risk reduction in urban areas. It aims to develop technologies, methods and tools for flood risk assessment and for the practical adaptation of new and existing buildings, infrastructures and flood defences leading to a better understanding of vulnerability, flood resilience and defence performance. The

issue of the protection systems performance against floods is integrated in the assessment of the urban resilience assessment, resilience evaluated in terms of resistance, recovery and absorption ability [30].
The LifE project aims at identifying ways in which the means of managing flood risk can be integrated within development sites to meet objectives for zero carbon, high quality, and sustainable developments at minimum cost. Thus, LifE is a holistic approach to design that integrates sustainability, flood management and development. It is based on social and environmental longevity, maintaining functionality during flooding and finding economic efficiencies through and integrated approach to design. The LifE Principles are: provide space for the river, provide space for rain, create space for amenity, integrate with community needs, design to be adaptable, reduce car dependency, provide space for energy and provide backups.

In order to implement strategies which are based on mixed approaches between protection (levees) and adaptation of the city (urban technical networks) to design the resilient city to flood, some researches have been yet developed with the purpose of defining methods to assess urban resilience . Among them, [30] developed methods to assess the resilience of the urban networks. He defined three essential abilities to study and assess resilience: resistance ability, absorption ability and recovery ability. Operational safety methods, graph theory methods and the Geographic Information Science were used respectively to analyze theses different abilities. Moreover, specific indicators were developed to assess the absorption and the recovery ability.

Another research ongoing is focused on the design of support decision tools in order to improve the urban resilience. [50] developed a decision support system spatially referenced for the resistance of levees. His goal is to establish a research on the assessment of levee performance to improve the process of urban resilience based on the protection. Otherwise, in the same area of research [44] developed a diagnostic with the purpose of raising awareness about the consideration of the disruptions and interdependencies between the urban networks. This diagnostic will be the base for the support of discussions about the interrelationships between the urban networks managers. A second step in her research to improve the resilience of a city will be to design a tool to support the governance of the urban networks. This tool will be based on systems of information spatially referenced. Thus, managers of urban networks will be provided with the necessary data to design resilience at the level of their networks, coordinating their actions with the whole of the network managers [41].

Other researches are ongoing about resilience and climate change adaptation. Many methods and tools for assessing climate change impacts, vulnerability and adaptation options, focusing on the water sector, have been developed [32]. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) [8], a number of approaches for climate impact and adaptation assessment are available to succeed the (quasi-)stationary approach. It distinguishes (at least) four approaches: cause-base (or: impact); effect-based (or: vulnerability); top-down; and bottom-up (or: adaptation). Cause-based versus effect-base describes weather the climate impact and adaptation assessment looks forward or backwards, respectively, in time from a given reference time. This influences the direction in which the cause and effect chain is followed in the reasoning [20]. In the area of climate change research and policy a top-down approach is usually followed. This classical approach has been called the “predict-optimize-act” approach, thus the methods and tools within this approach take climate change scenarios as their starting point. From a different perspective, a bottom-up approach may address the reality of decision-making at local, regional and sectorial levels more directly than the climate-centered top-down approach [32]. This approach doesn’t depend on the ability to project climate change and its impacts into the future.

[32] makes a further distinction between the static and the dynamic approach for climate impact and adaptation assessment. In his work, the dynamic approach is termed the resilience approach which is founded on the understanding that the state of a system is subject to change. Any one approach (or combination of approaches) can accommodate a variety of different methods as to how it is delivered [32]. Following his specific understanding of resilience, [32] conducted a literature study on the methods that can be used within the resilience approach. He examined four methods in detail: Adaptive Policy Making (APM), Real-In-Options (RIO), Adaptation Tipping Point (ATP) and Adaptation Tipping Point-Adaptation Mainstreaming Opportunity (ATP-AMO). Actually, a larger range of methods can be applied within the resilience approach, but these were selected in order to cover a range of different approaches in combination with resilience approach [32]. As an example, Table II presents some recent case study experience with the above methods, including the reason for selecting the method.

Table IX : Recent experiences with the methods in practical cases [32]

Case study description	**Method selected**	**Reason for selecting the method**	**Source**
Water management in the Netherlands	ATP	It identifies the most urgent effects of climate change and accelerating sea level rise and when these effects will occur	Kwadijk et al. (2010)
Coastal management in the Netherlands	APM	It embeds the analysis process in an institutional framework; it considers different types of uncertainty	Rahman et al. (2008)
Defence raising for the Thamesmead area in the Thames Estuary	RIO	It identifies the "optimal" set of static adaptive strategies in response to advances in knowledge about climate and socio-economic change	Woodward et al. (2011)
Defence raisinf for the Rotterdam area in the Rhine-Meuse Estuary	ATP-AMO	It identifies where and when to incorporate defence raising with "normal" investment projects, such as for urban regeneration and renewal	Boer (2012)

1.7. Concerning sustainable urban development

In the context of urban water management, several decision-support tools have been developed with the purpose to achieve a sustainable urban water management.

A decision process usually consists of different steps. This process requires that the decision is not limited to a simple choice but it is built progressively. The decision process basically consists of two phases: the problem setting (phase of intelligence, i.e. the problem formulation and the construction of the motivations) and the problem solving (phases of comparison of decision alternatives, choice and retrospective analysis)

[22] identified eight major projects on urban water management which developed a decision support process using several methods and tools: DAYWATER, Triple bottom line, SWITCH, SUDS-BMP-LID, SWARD, RERAU and INDIGAU, ECOPLUIES, CARE-S. Among them, he distinguished two important types of decision support tools: those at the structure level which doesn't have a holistic vision of the system, and the tools at the urban water system level. Within this last kind of decision support tools, it is found the SWITCH project (www.switchurbanwater.eu), which we explored in detail.
SWITCH project (2006 to 2011) involved innovation in the area of sustainable urban water management often also referred to as integrated urban water management (IUWM). It looked towards water management in the 'city of the future'. The main goal of SWITCH was finding new solutions to increase the efficiency of urban water systems. To achieve this goal, SWITCH developed strategies for particular places, based on visioning and scenario building. In this context, the main aims of strategy development are to [3]:

- develop robust adaptable strategy that has the potential to achieve a shared vision under a whole range of different scenarios;
- encourage stakeholders to take the leading role in an IUWM strategy development process.

Strategy development based on visioning and scenario building is also consistent with a project cycle management (PCM) approach to IUWM and, more specifically, to the emphasis that PCM puts on social and institutional learning.
Project Cycle Management (PCM) was introduced by the European Commission in the early 1990's to improve the quality of project design and management and thereby to improve aid effectiveness [25]. The PCM principles can be summarized as: structured and informed decision-making; involvement of stakeholders in decision-making; incorporation of aspects of sustainability; use of the logical framework approach; and an integrated approach [3] defined for the SWITCH project, a set of generic steps that can be used to develop an overall strategy that are based on visioning and scenario building. They highlight that the exact sequence of steps, number of iterations and the tile that might be needed will depend on the context.

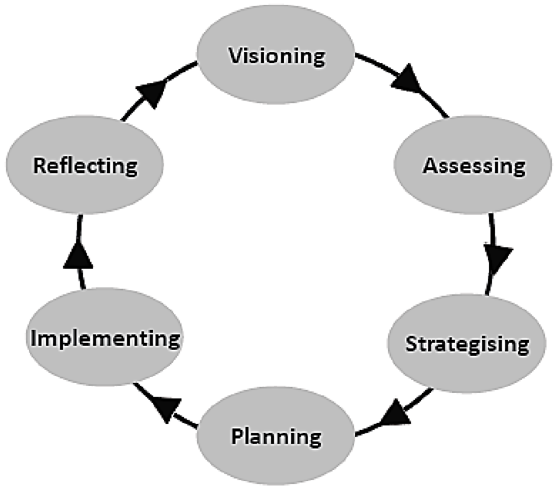

Figure 15. An example of an IUWM project management cycle [3]

.
The 9 steps are the following:

1. Identify components of an overall strategy;
2. Evaluate each strategy component;
3. Identify specific risks and constraints;
4. Link strategy components to relevant parts of the vision;
5. Evaluate the utility of strategy components against the disaggregated vision under all scenarios;
6. Refine strategy components;
7. Combine strategy elements to produce versions of an overall strategy;
8. Select and refine and overall strategy;
9. Start the planning process.

Finally, the methodology of the strategic planning process for IUWM with a long-term strategy developed for the SWITCH project was the one shown in the following figure (Fig. 2).

Otherwise, in other researches, a social learning framework is also proposed to integrate urban planning and flood risk management: Learning & Action Alliance (LAA) [20, 49. 3] defined a Learning Alliance as "a group of individuals or organizations with a shared interest in innovation and the scaling-up of innovation, in a topic of mutual interest", and add the word Action to highlight both its learning and also its delivery aspects. [49], described and evaluated a new framework to organize social learning to support collaborative planning, drawing on theories on social learning, development planning [48] and decision making [26, 43]. In the context of [49] research, Action refers to the integration of flood risk management in urban development planning projects. The main output of LAAs is knowledge [52]. Complex decision making – as integrated planning – requires applicable knowledge [31]. Knowledge needs to feed into planning and land-use decisions and is the basis of any flood resilient city [53]. Thus, the organization of a LAA should enable the development, exchange and application of knowledge [49].

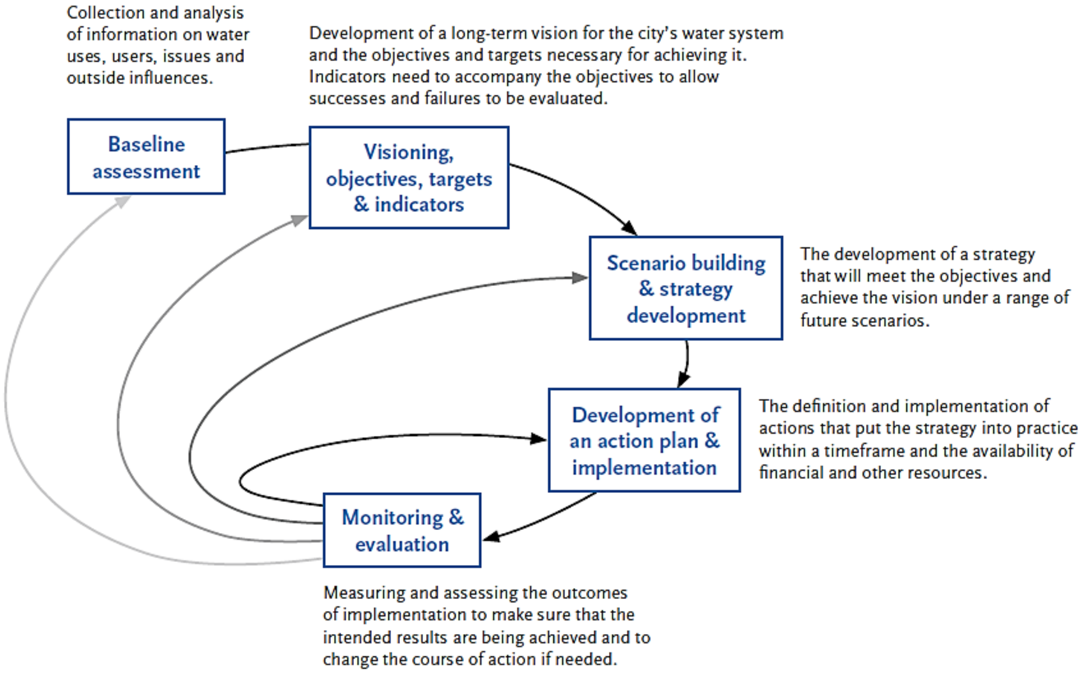

Figure 16. Methodology of the strategic planning process for IUWM (SWITCH project)

Anyway, in a decision support process, before defining the strategy, i.e. solve the problems, it is really important to properly formulate the problems to solve. Indeed, in a decision-support process the problems are not given a priori but they are built progressively [29]. Thus, the identification and formulation of the problems is one of the most important phases, especially when the problems to be considered are multiples and complex and perceived differently by the stakeholders involved in the decision [12].

With this purpose, we analyzed two methods which have been used to well understand the operation of the urban system and the problems that might be caused during a flood. Among them, the Functional Analysis (FA) [30] and the Source-Pathway-Receptor (SPR) model [16].

The Functional Analysis (FA) is an operational safety method analysis for complex system modeling. It is a systemic method to understand and to describe how a system works. It provides with a complete analysis of the system's components and their interactions with each other and the outside world and consequently the functions they provide. Indeed, it is based on the functions of a system to understand its operation. Indeed, the functional analysis is an approach consisting in to identify, classify, characterize, prioritize and/or enhance the functions of a system. This analysis has been applied in different fields such as construction products of buildings [27], dams [38], roads [47], water facilities inside buildings [9], and levees to protect against flooding [40]. More recently, the Functional Analysis has been applied for urban networks modeling [30]. [30] determined the functions performed by the components of the different urban networks in the particular case of flood risk (ensure continuity of service, resist hydraulic flows, provide with water flows, resist mechanical pressures, allow the proper functioning of other system components).

The Source-Pathway-Receptor (SPR) model is used to characterize flood risks in terms of the Source-Pathway-Receptor [16]. The sources are weather events or sequences of events – such as heavy or sustained rainfall and marine storms – that may lead to flooding. Pathways are the mechanisms that convey flood waters that originate as extreme weather events to places where they may affect receptors. Pathways, therefore, include fluvial flows in or out of the river channels, overland urban water flows, coastal processes and the failure of fluvial and sea defences or urban drainage systems. Finally, receptors are the people, properties, industries and built and natural environments that flooding may affect. This model is useful to understand and characterize the flood risk and it can be applied at different urban system levels. At the more detailed scale of individual urban areas, a different set of flood mechanism and issues should be considered [16]. For example, intra-urban flooding could be caused by intense rainfall which could overwhelm the urban drainage system. The model is used to propose responses to flood risk which aim often to modify the pathways or receptors of flooding [16].

Discussion

Following the desired shift in urban flood management from traditional to integrated approaches, and considering the uncertainties of future development due to drivers such as climate change, one of the main emerging tasks of flood managers become the development of flood resilient cities. Our research aims at providing guidance on urban planning and design in order to improve flood resilience of cities.
To achieve our research goal and given the context previously developed, an indispensable prerequisite is to develop a multidisciplinary methodology based in a support decision process, allowing to integrate flood resilience in urban planning and design. After reviewing several studies ongoing or already finished on urban resilience, we verified that cooperation between urban resilience to flood and urban planning and design does not yet exist, from both a theorical and a practical aspect. Indeed, no methodology framework has been developed allowing the design of flood resilient cities.

The main outcomes of the studies on urban resilience carried out so far are methods and tools to assess urban resilience. However, some of these tools such as indicators [30] can be applied in one of the phases of a support decision process. The LifE project is the only one who gives some ideas of how flood management could be integrated in urban design. Even if some interesting urban design principles were defined in the project, they were not identified with the purpose to improve urban resilience to flood.

Concerning researches on other urban fields, we have seen in the SWITCH project that the development of a strategy based on visioning and scenario building is also consistent with a project cycle management approach to IUWM. This is an interesting result because a strategy was defined developing a methodology where urban water management was integrated. Thus, applied to our research, urban resilience to flood could be integrated. Moreover, that the methodology is also consistent with a project cycle management is an important point because urban planning and design strategies, that we aim to develop to improve flood resilience, will be transformed at some time in actions on urban areas, i.e. urban projects. Two stages of this methodology previous to the definition of the strategy are the visioning and the scenario building. First, visioning is the process of developing a vision of a desired future state. We could thus reflect the priority issues and then turning them into a desired state. To achieve this purpose the Functional Analysis and the Source-Pathway-Receptor model could be adapted. Even if there are many tools of urban flood modeling which exist today, they have to be applied in a particular urban area to identify issues under flooding conditions. On the contrary the FA and de SPR model allow a conceptual modeling of the problem.

Scenario building is a plausible and internally-consistent description of a possible future situation. We are not agree with this stage of the methodology because even if it is possible to develop several scenarios trying to represent all possible futures, the uncertainty will never be zero so the system could be wrong dimensioned. Furthermore, scenarios are often developed by means of experiences of the past even if today the urban system is evolved of that of the past and it is evolving every day. Scenarios are developed in order to develop strategies based on these scenarios and then assessing if the vision defined is achieved or not. Thus, some methods and tools could be applies in this stage to substitute scenarios. For example, the methods examined by [20], which can be used within a resilience approach for climate impact and adaptation assessment. Among them, the ATM-AMO (Adaptation Tipping Point – Adaptation Mainstreaming Opportunity) is likely the best to adapt in our research because it is within a resilience approach and at the same time within a bottom-up approach allowing to cope with the uncertainty of the future. Indeed, ATM-AMO method does not depend on the future situations, but rather it examine whether and for how long, current strategies will continue to be effective under different negative events. So, the starting point of the method is the current situation of the system. However, this method has never been applied to the whole urban system and it should to be analyzed if it is possible.

Finally, for the development of the strategy a Learning and Alliance Action approach could be applied. In the same way that it was proposed to integrate urban planning and flood risk management, it could also be applied to integrate urban planning and design and flood resilience. It could provide us with the necessary knowledge for our complex decision support process. Indeed, knowledge needs to feed into planning and design decisions and is the basis of any flood resilient city. Nevertheless, in this stage the collaboration of a multidisciplinary group of stakeholders will be necessary.

Conclusions

Flooding is a major natural hazard affecting millions of people every year, claiming the lives and causing global economic losses annually. As result, it is essential that all urban areas seek to manage the risk flooding in an effective and appropriate way. Nowadays, considering the uncertainties of future development due to drivers such as climate change, one of the main emerging tasks of flood managers become the development of flood resilient cities. Urban resilience is a concept from which it is possible to reduce the consequences of urban system disturbances [33, 37] and even consider this disturbance as an opportunity for urban development.

The first stage of our work consisted of defining the main goal of our research, which is to formalize useful knowledge for decision support in order to design flood resilient cities. We then demonstrated that to achieve it and given the context previously developed, an indispensable prerequisite is to develop a multidisciplinary methodology based in a support decision process, allowing to integrate flood resilience in urban planning and design.

According to this purpose, the next stage consisted of a literature study on the methodologies, methods and tools that ongoing researches on natural hazards and resilience have developed. In terms of results, based on this study, we have determined that no methodologies, methods or tools have been developed so far in order to introduce flood resilience in urban planning and design. The main outcomes are methods and tools which focus on the assessment of urban resilience. Consequently, we also explored other urban fields such urban water management. In this context we identified several decision-support tools which have been already developed with the purpose to achieve a sustainable urban water management. Specifically, we were interested on the methodology used by SWITCH project, which is based on visioning and scenario building in order to define a strategy. We then identified different the Functional Analysis and de Source-Pathway-Receptor model as adapted tools to develop the vision. Instead of the scenario building we proposed to use other methods and tools used within a resilience approach for climate impact and adaptation assessment [20]. Especially, we considered the ATM-AMO (Adaptation Tipping Point – Adaptation Mainstreaming Opportunity) the best adapted for our research because it is a method which does not depend on the future situations.

Finally, a perspective of our research is to continue the literature study in order to well define the particular methodology that we are going to use for our research and to determine all its stages and the methods and tools that will be developed within each one.

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Criteria for Sustainable Land Use Planning – analogies from the fields of regional water resources and flood risk management

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Abstract

In order to make land use planning sustainable, new planning and decision-making procedures need to be developed. In this presentation a set of useable normative criteria for the assessment and development of such procedures is proposed. The criteria are concerned with integration of knowledge and values into the planning process, and with the generation of commitment, legitimacy or acceptance for the resulting plan. The criteria were originally derived as a response to the lack of deductive approaches in the evaluation of planning procedures used in the fields of regional water and flood risk management, making it possible to highlight their potential for sustainable development. The assumption made here is that the deductive criteria can be a valuable contribution also to the broader and related field of land use planning. The ESReDA seminar has provided a good starting point for an extended discussion of the use of the criteria as a tool for operationalizing the concept of sustainable development in the field of land use planning.

Keywords: Land use planning, planning procedures, assessment, participatory planning, sustainable development

1. Background

In order to make land use planning sustainable, new planning and decision-making procedures need to be developed. Here, a set of useable normative criteria for the assessment and development of such procedures is proposed. The criteria were originally derived as a response to the lack of deductive approaches for the evaluation of participatory planning procedures used in the fields of regional water and flood risk management, making it possible to highlight their potential for sustainable development. The assumption made here is that the deductive criteria can be a valuable contribution also to the broader and related field of land use planning. This assumption is based on the fact that the character of the criteria is very general, and that the criteria are based on the twin concepts of *participation* and *integration*, which function as well-established dimensions of sustainable development in relation to water and flood risk management as well as in relation to land use planning.

Defining the meaning of the concepts of integration and participation in relation to planning procedures require a multidisciplinary approach, which makes use of knowledge from a wide range of scientific disciplines and fields, e.g. several fields of natural sciences, political science, psychology, organizational theory, planning theory and political economy. Having recognized this, the criteria were derived through a very broad literature review and synthesis. The work was inspired by thoughts of grounded theory, not because there was a lack of theories *within* the broad spectrum of scientific fields, but because there was a lack of theoretical frameworks that *combined* the huge amounts of theoretic and empiric knowledge of relevance for the studied issue.

The criteria were first intended for application to regional water resources management, where they have been used for assessing planning practices and a legal framework that steers planning practice (the EU Water Framework Directive, WFD). The assessments made showed that the criteria have great practical potential, as they could provide important and practicable recommendations for making both planning procedures and their legal contexts better in relation to sustainable development. Recently, a study has been conducted to transfer the criteria framework to the field of natural risk management, with a focus on floods. Twelve key researchers were interviewed, collectively capturing the broad spectrum of knowledge concerned (Hedelin, forthcoming)The results indicate that the criteria are transferrable to the adjacent field, and that no changes are in fact needed for applying the criteria to the new field. The main reason given was that the criteria are sufficiently general in character. A natural question stemming from that result is then to what *other* fields of research and practice are the criteria valid? The ESReDA seminar provides an opportunity to present to and propose the use of the criteria in the field of land use planning, which in many ways is closely related to, and partly overlapping with, the fields of water resources and natural risk management.

2. Proposed criteria for sustainable land use planning

The criteria cover issues of integration of knowledge and values into the planning process and with the generation of commitment, legitimacy or acceptance for the resulting plan. See Table 1 for an outline. In this section, the proposed criteria are presented very shortly. See Hedelin (2007) for a thorough presentation of the criteria and of how they were derived.

The deductive criteria were derived through a review and synthesis of the theoretical and empirical literatures on issues of integration and participation in relation to planning. Criteria A to E stem from the concept of integration.

Table 1: The table outlines the criteria framework. The twelve criteria are derived from the concepts of integration or participation. For proper use of the criteria, a broad understanding of the meaning of its components and connections is vital. (The table was first published by Hedelin 2007.)

Sustainability dimension	**Structural component**	**Criteria** Planning processes for sustainable river basin management must include, support, or promote:	
Integration	…across disciplines	A	integration of knowledge from all relevant disciplines.
		B	handling of different views of knowledge (e.g., positivist, relativist).
		C	handling of different kinds of uncertainty.
	… across values	D	identification of the most relevant values in relation to the current issue.
		E	rational argumentation based on the identified values, by relating them to alternative choices in the planning process.
Participation	… contributing to the process	F	inclusion of knowledge owned by relevant actors.
		G	inclusion of the ideological orientations represented by relevant actors.
		H	participation in the most critical phase(s) of the process.
	… generating commitment, legitimacy or acceptance	I	a procedure for defining the actors that should be involved.
		J	handling of power asymmetries.
		K	procedures that ensure that ideological orientations are not suppressed (for consensus-based approaches).
		L	learning.

They are structured based on the idea that integration can be obtained across disciplines (A–C) and across values (D and E) (Jepson 2001). Criteria A say that disciplinary knowledge must be integrated in the process. For doing so, the issue of interaction between persons and knowledge fields that have different knowledge views is vital (B). It also says that in relation to this, the issue of uncertainty needs to be handled in a systematic way (C). Criteria D and E say that values need to be integrated in the process. The first step then is to identify the most relevant values (D) so that these can be explicitly related to during the course of the planning process (E).

Criteria F to L are closely linked to participation, and much influenced by current thoughts on deliberative democracy. The criteria are structured according to the main aims related to participation – increasing the quality of decisions, and generating the necessary commitment, legitimacy or acceptance (Hemmati 2002). Criteria F and G are mainly derived through looking at the first aim while criteria H to L mainly relate to the last one. Criteria F to G say that the knowledge owned, and ideological orientations represented, by the concerned actors need to be included in the process (F and G respectively). Value systems or ethics are other terms used in similar meaning as ideological orientation. Criteria H to L say that the participatory efforts in the process should be connected to the most critical phase or phases of the process (H). In general, concerned actors (other than those directly responsible for the carrying out of the formal process) come in too late in the process, making it difficult for them to influence the fundamental direction of the decision rather than its details. These criteria also say that one must have a systematic approach for identifying which actors that should be involved (I). They further states that issues of power asymmetries are vital for establishing a democratic process (J, K). Also learning

(L) is a key aspect in relation to democracy, since those involved need to have a good deal of understanding of the complex issue at hand.

Stemming from a synthesis, the criteria are linked in various ways; e.g. the integration of knowledge and values (A to E) is of cause dependent on the involvement of concerned actor´s knowledge and values (F and G), and in order to meet criterion L, almost all of the other criteria have to be fulfilled. Furthermore, arguments behind one criterion also support other criteria, and accordingly several of the criteria are often needed to fulfil such an underlying argument. Some examples are as follows. Criteria A to C, F and G are highly relevant in providing high quality information for the process. Criteria E to L are necessary for participants to effectively influence the planning process. Criteria H to K (and perhaps also E) are central to the issue of accountability and legitimacy. Criteria F, G and J to L concern the development of shared visions and goals among the participants.

3. Examples of earlier use of the criteria

The criteria have been used by the current author for assessing planning practices in Sweden, which are a response of the implementation of the WFD (for a full presentation of the study, see Hedelin and Lindh 2008). Here, interviews with responsible water directors and planners showed important deviations between the planning practices and the normative criteria, and the assessment made it possible to formulate practicable recommendations. One example is that the interviews reviled that important information on uncertainties in baseline data were in fact systematically hidden by the way the data was being handled. In the cases where lack of data made it uncertain if a water body should be classified as having “good” or “moderate” status, some planners decided to classify the water body as having good status. In that way one would not place any demands for environmental measures in relation to that water. The argument provided was that the WFD would result in regulatory demands for taking so many measures that the following costs would be unreasonable from a societal perspective. Here, the planners (consciously?) prioritized measures on waters with higher rates of degradation over waters with lower rates of degradation. Whether that is a good priority is an interesting question in itself. In relation to the criteria however, the main issue is that in order to encourage rational discourse and democratic and participatory planning processes, issues concerning the level of resources and the strategies for water conservation (the key issue for the planning processes) should be handled in the open, making it possible to explicitly define possibilities and drawbacks, and to discuss ways of prioritizing. Planners should thus not focus on how to spend the taxpayer’s money, but rather on the issue of how prioritizing should be handled methodologically. Based on this, the recommendation made was to raise the awareness among planners, of their role in the political process that water planning actually is.

Another example comes from a case where the criteria were used to assess the WFD (see Hedelin 2008b for a full presentation of the study). Here, a barrier for attaining sustainable management practices were actually identified, since the main occasion for making value trade-offs prescribed by the directive is connected to the making of exceptions from the directive's general objective (generally defined as good status). Instead of being about prioritizing between the main values involved, the defining of objectives is prescribed as a purely natural scientific procedure, which according to my own experience colours much of the work with related to the WFD. Admitting that water management is political however, makes it illogical to connect the value trade-offs to the making of exceptions. The recommendation made was to adjust the WFD so that the meaning of the term environmental objective would include the granting of exceptions. This change also would require that the main aim of the WFD is changed from preservation and protection of water to sustainable use of water (which would certainly imply protection and preservation of many waters).

4. Possible future outcomes

The examples provided show that the criteria can be useful for identifying shortcomings and to formulate practicable recommendations for how (water) planning can become more sustainable. In regard of future outcomes, besides of the possible growing of scope to include land use planning as an area of application, the criteria are also intended to be used as a basis for direct development of planning practices. Using the criteria as a basis for shaping a specific planning process probably requires larger efforts than using them for assessment, since the necessary level of detail becomes higher. Making proper decisions on forms for involvement of concerned actors, on tools for handling of data, and on methods for structuring a rational discourse that explicitly relates to the main values involved, requires a good understanding of the specific planning context, in addition to the theoretical knowledge represented by the criteria. Here, participatory or action based research approaches could be promising, since they seriously engage in the task of creating solutions that are based on both academic (more general) and practical (more context specific) knowledge. A basic assumption made is that both kinds of knowledge are vital for making long term effective changes in practice. See van Herk et al. (2011) and Ribarova et al. (2011) for recent examples of participatory research within the fields of flood risk and water resources management.

Another possible way to use the criteria for development of planning practice could be to transform the framework into a tool that could be used directly by practitioners themselves. As the criteria currently are formulated and presented, with academic and sometimes quite abstract terms, many respondents pointed out that it might be difficult to grasp the fundamental meaning of the criteria for someone not knowledgeable within the academic fields that the criteria cover. One way of transforming the framework to a practitioner's version could be to simply suggest a revised version, and then to assess the result of its use. Another way, perhaps more effective, could be to develop the framework in collaboration with practitioners.

5. Application of the criteria to the field of land use planning

As mentioned in the background section, the recently completed study that aimed at transferring the criteria framework to the area of natural risk management showed that the criteria are sufficiently general to be transferred to the adjacent planning field even without making any changes (Hedelin, forthcoming). One respondent expressed the general character of the criteria as: “It [the criteria framework] is general. … It is almost like when you read the Bible. The Golden Rule of life … the Ten Commandments …”. Another respondent pointed to another reason for the criteria being transferrable: “They are context independent since they concern the procedure”. The conversations held pointed to the fact that the level of generality of the criteria framework might in fact make it applicable to a range of adjacent physical (and non-physical?) planning fields.

To propose that the normative criteria might be just as valid for processes of land use planning as for processes of water planning or natural risk management is by no means meant to claim that there are no fundamental differences between the fields that must be considered when shaping planning practices. For example, during the interviews of the study on the transfer to the natural risk field, two differences between the fields of water and of natural risks were discussed – one related to the character of the (bio)geophysical processes involved, and the other related to the engagement and organizational structure of the concerned actors. Without going in to these differences, the point here is that even if such differences do not call for changes within the criteria framework, knowledge on such differences in planning contexts is vital for successfully turning the criteria into practice.

One important difference between the fields of water and land use planning that comes to my own mind is that the main professionals engaged have different educational backgrounds, which is an important determinant for world-views and professional culture (e.g. see Hedelin and Lindh (2008) for a discussion of the world-views of the water planners in Sweden). Issues of water are often handled by persons with various natural scientific backgrounds (mainly biologists and chemists). The group of professionals involved in land use planning mainly consist of architects and physical planners. To my experience this difference (as one among other reasons) very roughly makes water planners to focus on nature preservation, while land use planners focus more on development. Much simplified, amongst water and environmental planners the value of preserving nature is elevated in priority, while amongst land use planners, nature preservation is seen as one out of many values, and their job is to find an acceptable balance between these values. When using the criteria framework for developing planning practice or for analysing assessment results, the world-views, attitudes and cultures of the practitioners is indeed important to consider. To make the criteria framework a better tool for handling these issues, an on-going study is currently engaged with widening the scope of the criteria to include organizational and institutional aspects. This forthcoming extension of the framework might be possible to make with regard to all the three fields – land use planning, water planning and natural risk management.

The ESReDA seminar has provided an opportunity to present to and propose the use of the criteria in the field of land use planning, which in many ways is closely related to, and partly overlapping with, the fields of water planning and natural risk management. In that way, the seminar has been a good starting point for an extended discussion of the use of the criteria as a tool for operationalizing the concept of sustainable development in the field of land use planning.

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Quantitative Assessment of Domino Effect in the Framework of Land-Use Planning

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Abstract

Land-use planning with respect to major accident hazards needs to deal with high-consequence low-probability (HILP) events. Consolidated methodologies, usually based on bow-tie analysis, exist to identify accident scenarios deriving from activities involving the use or the storage of hazardous substances. However, conventional approaches usually are not able to capture escalation scenarios. In the present study a methodology developed for the quantitative assessment of risk due to domino effect is applied to the analysis of an extended industrial area. A set of models for the calculation of equipment damage probability were developed and combined to improved criteria for the calculation of threshold values for equipment damage. A specific effort was dedicated to the improvement of models for the calculation of equipment damage probability due to jet and pool fires. The results evidence that quantitative risk assessment of escalation hazard is of fundamental importance in order to identify critical equipment and to address prevention and protection actions.

Keywords: Land-use planning, escalation, domino effect, quantitative risk assessment, major accident hazard.

1. Introduction

Land-use planning with respect to major accident hazards needs to deal with high-consequence low-probability (HILP) events. Consolidated methodologies, usually based on bow-tie analysis, exist to identify accident scenarios deriving from activities involving the use or the storage of hazardous substances. However, domino effect was responsible of several catastrophic accidents that took place in the chemical and process industry (CCPS (2000), Khan and Abbasi (1999), Lees (1996)). Escalation of primary accidental scenarios triggering a

"domino effect" have caused extremely severe accidental events in the chemical and process industry. As a matter of facts, severe accidents may arise from the escalation of primary events to trigger secondary scenarios, as documented in the technical literature and in accident reports. Hence, the identification of possible escalation events is required in the safety assessment of sites where relevant quantities of hazardous substances are stored or handled. In the European Union, "Seveso-II" Directive (96/82/EC) requires the assessment of on-site and off-site possible escalation scenarios in sites falling under the obligations of the Directive. Particular concern is posed to the identification of domino scenarios involving secondary units outside the site where the primary event takes place. Consolidated approaches to this issue are still lacking. Several methods were proposed to assess the possibility of domino effect (Bagster and Pitblado (1991), Latha et al. (1993), Delvosalle (1998), Gledhill and Lines (1998), Khan and Abbasi (1998), Cozzani et al. (2005), Reniers et al. (2005)), but the identification and quantitative assessment of domino scenarios is still an open issue.
In the present study a methodology developed for the quantitative assessment of risk due to domino effect is presented. A set of models for the calculation of equipment damage probability were developed and combined to improved criteria for the calculation of threshold values for equipment damage. A specific effort was dedicated to the improvement of models for the calculation of equipment damage probability due to jet and pool fires. Exclusion criteria were also developed to identify primary scenarios not likely to result in escalation. The “domino package” of the Aripar-GIS software was upgraded to allow its use for risk recomposition accounting for the contribution of domino effect. The set of tools developed allows the quantitative assessment of domino effect in complex lay-outs and extended industrial areas. A case-study was explored, evidencing that quantitative risk assessment of escalation hazard is of fundamental importance in order to identify critical equipment and to address prevention and protection actions.

2. Methodology

2.1 General features

The main features of the methodology are outlined in the following, while further details may be found in the literature (Cozzani et al., 2005). Figure 1 summarizes the main steps the procedure.
The starting point of the methodology is the assumption that a full characterization of all the primary risk sources present in the lay-out of concern is available, as usual when the assessment of domino effect in a quantitative risk assessment (QRA) or quantitative area risk assessment (QARA) study is undertaken. If the site falls under the obligations of the EC "Seveso-II" Directive, such data may be easily gathered from the safety report of the plant.
According to Figure 1, the starting point of the methodology is the analysis of the facility considered, aimed at evidencing the reference equipment which may lead to a Loss Of Containment events (LOC) able to generate primary fire events. This preliminary screening is based on a limited set of input data, such as the inventory of hazardous materials, the type of equipment and the operative conditions combined with the analysis of the facility layout.

After the reference equipment identification, the analysis is then focused (steps 2,3 and 4) on the characterization of the primary event, both in terms of expected frequency and consequences assessment. In particular, the approach suggested by the "Purple Book" (Uijt de Haag and Ale (1999)) is used to determine the standard LOCs associated to the equipment considered, to which the release frequencies, also reported in "Purple Book", are associated.

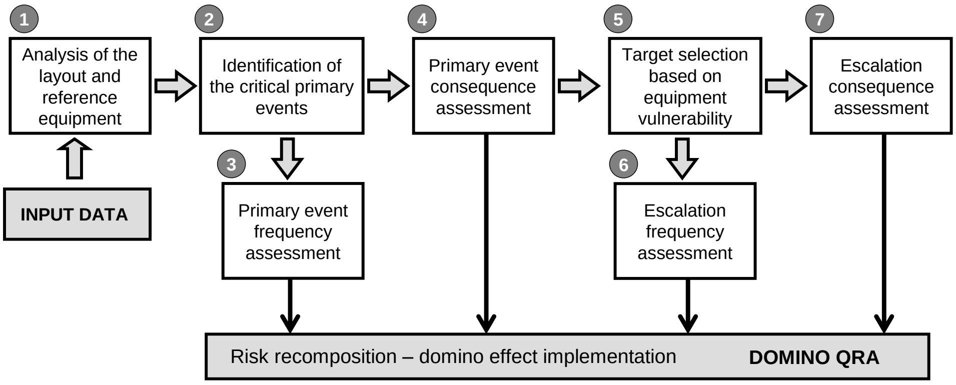

Figure 1. Flowchart of the reference methodology developed for the quantitative assessment of domino effect.

The consequences of the primary LOCs may be assessed with standard models for consequence analysis (Van Den Bosh et al. (1989), Van Den Bosh and Waterings (2005)). On the basis of these results, the secondary targets affected, involved by the primary events, are identified (step 5), applying a screening criterion based damage thresholds.

The frequency calculation should be performed in three steps. First the damage probability of each escalation target, $P_{d,i}$, should be calculated. Simplified equipment damage models will be discussed in the followings. In the second step, the overall frequencies of escalation scenarios that result from a primary event and several secondary events taking place simultaneously should be calculated. It is reasonable to consider independent, from a probabilistic point of view, each escalation event causing the damage of a secondary unit. Thus, the damage probability of a unit due to a given primary event may be considered independent from the possible contemporary damage of other units. If n possible escalation targets are present, a single primary event may trigger up to n different secondary events. Each of the secondary events has an overall probability to take place due to the primary event considered equal to $P_{d,i}$. However, each secondary event may take place simultaneously to other secondary events. A single escalation scenario may thus be defined as an event involving the contemporary damage of k of n units resulting in k final outcomes, with k comprised between 1 and n. The number of escalation scenarios involving k different final outcomes may be calculated by the binomial coefficient:

$$N_k = \binom{k}{n} = \frac{n!}{(n-k)!k!} \tag{1}$$

The total number of different overall escalation scenarios that may be generated by a single primary event, N_d, may be calculated as follows:

$$N_d = \sum_{k=1}^{n} \binom{n}{k} = 2^n - 1 \tag{2}$$

If a numerical index (1 to n) is assigned to each of the n secondary events that may be triggered, a single overall escalation scenario may thus be identified as a vector ($\mathbf{J}^k{}_m = [\gamma_1, \gamma_k]$), whose elements ($\gamma_j$ (j = 1, …, k)) are the indexes of the k secondary events that take place during the overall escalation scenario. The subscript m of vector J indicates that the overall escalation scenario is the m-th (m = 1,…,N_k) combination of k secondary events.

The probability of a single overall escalation scenario involving the contemporary damage of k units resulting in k secondary events, identified by the vector Jkm, may be evaluated as follows:

$$P_d^{(k,m)} = \prod_{i=1}^{n} \left[1 - P_{d,i} + \delta(i, \mathbf{J}^k{}_m)\left(2 \cdot P_{d,i} - 1\right) \right] \tag{3}$$

where the function $\delta(i,\mathbf{J}^k{}_m)$ equals 1 if the i-th secondary event belongs to the vector $\mathbf{J}^k{}_m$, 0 if not. Eq.(3) is the algebraic expression obtained from the union of the probabilities of the k events belonging to the m-th combination, calculated considering as independent the secondary events.

The expected frequency of the m-th overall escalation scenario involving k simultaneous secondary events, $f_d^{(k,m)}$, may thus be calculated as:

$$f_d^{(k,m)} = f_p \cdot P_d^{(k,m)} \tag{4}$$

where f_p is the expected frequency of the primary event that triggers the escalation. It must be remarked that the frequency f_p is the overall expected frequency of the primary event. The total probability that a primary scenario may trigger an escalation may be calculated as follows:

$$P_e = \sum_{m=1}^{n} \sum_{k=1}^{\binom{n}{k}} P_d^{(k,m)} \tag{5}$$

Thus, the overall escalation frequency of the primary event may be calculated straightforwardly from the following expression:

$$f_e = f_p \, P_e \tag{6}$$

Thus, the expected frequency of the primary event taking place without triggering an escalation, $f_{p,nd}$, may be calculated as follows:

$$f_{p,nd} = f_p \cdot \left(1 - \sum_{k=1}^{n} \sum_{m=1}^{N_k} P_d^{(k,m)} \right) \tag{7}$$

The procedure outlined above allows the identification and the calculation of the expected frequencies of overall escalation scenarios involving the contemporary damage of more than one secondary unit. This makes an important difference with respect to previous methodologies, that only consider the possible damage of a single secondary unit at time in a 1 to 1 sequence (the so-called "domino chains": a first scenario damaging a single equipment item and starting a

secondary scenario; the secondary scenario damaging a third unit and starting a tertiary scenario and so on). The possibility to consider simultaneously more than one secondary scenarios deriving from the damage of several equipment items due to the primary event of the domino sequence allows taking into account more realistic secondary scenarios, since the analysis of past domino accidents evidences that simultaneous secondary events usually take place during severe domino accidents (Reniers and Dullaert (2007), Reniers et al. (2008)).
The probabilistic assessment combined with the frequency evaluation of step 3 (see Figure 1) allows determining the expected frequency of escalation. Since the conventional models used for consequence assessment in a QRA framework are not able to consider the effects of multiple scenarios, a simplified approach needs to be used for the representation of the actual consequences of the domino scenarios. The overall consequences of the overall scenario, expressed as the probability of death of an unprotected individual, are assumed to be the sum of the death probabilities due to all the scenarios involved in the domino event, with an upper limit of 1. This approach, tough simplified, was found to be acceptable and not over-conservative in the framework of a QRA (Cozzani et al. (2005)).

Risk recomposition may be carried out with a specific software. In particular the Aripar-GIS software package may be used, combining all the outcomes of the different steps of the methodology as shown in Figure 1 (Cozzani et al. (2006), Antonioni et al. (2009)). It should be remarked that the above methodology, due to the generation and vulnerability calculation of the overall domino scenarios also allows the calculation of societal risk if information is available on the distribution of the population.

2.2 Threshold values for escalation assessment

In order to apply the above methodology, some simplifications need to be applied in order to limit the computational effort required for risk calculation. In particular, the equipment items that may be damaged by a primary scenario need to be identified. In order to approach the problem, threshold values for radiation and overpressure damage are usually applied (Khan and Abbasi (1998), Gledhill and Lines (1998)). Since escalation is influenced both by the severity and the duration of the primary scenario (in particular in the case of fires), the derivation of specific threshold values should take into account these aspects.

In the case of fire scenarios, two elements are necessary to describe the escalation vector on a given target: a reference value of the radiation intensity and a reference time for the duration of the scenario. The vulnerability of process equipment to fire radiation was explored in a previous study (Cozzani et al. (2006a)), on the basis of the estimated time to failure (ttf) of atmospheric and pressurized storage vessels. The analysis of a representative set of unprotected vessels showed that time to failure is always higher than 30min for radiation intensities lower than $10kW/m^2$ in the case of atmospheric vessels, and lower than $40kW/m^2$ for pressurized vessels. These results allowed the definition of the threshold criteria summarized in table 2 for atmospheric vessels and in table 3 for pressurized vessels.

In the case of primary scenarios in which the escalation vector is a blast wave, the damage of process vessels is mainly related to the maximum peak overpressure on the equipment item of concern, although the damage extension is actually related also to other complicating factors (Cozzani and Salzano (2004a)). Damage thresholds may be obtained from probabilistic damage models (Cozzani and Salzano (2004b)). However, in the framework of domino effect assessment, it must be remarked that the structural damage threshold may not be correspondent to the threshold values related to the escalation of accidental scenarios. The possibility of escalation following the damage is dependent also on other factors, the more important being the damage extension and the characteristics of the released substance. This may lead to an apparent paradox of lower escalation thresholds for pressurized vessels than for atmospheric ones, due to the wider escalation potential of pressurized vessels event in the presence of minor structural damage. A specific assessment of these aspects was carried out in a previous study (Salzano and Cozzani (2006)).

With respect to fragment impact, the very high projection distances experienced in past accidents (more than 800m) make the threshold approach useless, since the threshold distances would be high enough to extend far outside the plant boundaries. The introduction of probabilistic criteria may allow the estimation of more useful figures to estimate fragment impact probability (Gubinelli et al. (2004)).

Escalation thresholds applied in the present study are reported in tables I and II. Further values of escalation thresholds for other equipment categories are reported elsewhere (Cozzani et al. (2006)).

Table I: Threshold criteria for atmospheric vessels.

Scenario	Escalation vector	Modality	Escalation criteria
flash fire	heat radiation	fire impingement	unlikely
fireball	heat radiation	flame engulfment	$I > 100 kW/m^2$
		stationary radiation	$I > 100 kW/m^2$
jet-fire	heat radiation	fire impingement	always possible
		stationary radiation	$I > 10 kW/m^2$
pool fire	heat radiation	flame engulfment	always possible
		stationary radiation	$I > 10 kW/m^2$
VCE	overpressure	MEM $F \geq 6$; $M_f \geq 0.35$	$P > 22 kPa$
confined explosion	overpressure	blast wave interaction	$P > 22 kPa$
mechanical explosion	overpressure	blast wave interaction	$P > 22 kPa$
		fragment projection	fragment impact
BLEVE	overpressure	blast wave interaction	$P > 22 kPa$
		fragment	fragment impact
point-source explosion			$P > 22 kPa$

Table II: Threshold criteria for pressurized vessels.

Scenario	Escalation vector	Impact mode	Escalation criteria
• flash fire	heat radiation	fire impingement	unlikely
fireball	heat radiation	flame engulfment	unlikely
jet-fire	heat radiation	fire impingement	always possible
		stationary radiation	$I > 40 kW/m^2$

pool fire	heat radiation	flame engulfment	always possible
		stationary radiation	$I > 40kW/m^2$
VCE	overpressure	MEM $F \geq 6$; $M_f \geq 0.35$	$P > 16kPa$
confined explosion	overpressure	blast wave interaction	$P > 16kPa$
mechanical explosion	overpressure	blast wave interaction	$P > 16kPa$
		fragment projection	fragment impact
BLEVE	overpressure	blast wave interaction	$P > 16kPa$
		fragment	fragment impact
point-source explosion	overpressure	blast wave interaction	$P > 16kPa$

2.3 Models for equipment vulnerability

The QRA framework calls for the development of simplified probabilistic models for equipment vulnerability. The conventional procedures used for accident frequency estimation, as well as the methods proposed for domino probability assessment (Cozzani et al. (2005)) require the availability of models that yield the damage probability of process equipment given the value of the physical effect that impacts on the equipment item of interest. The use of simplified models, based on a limited number of parameters, is required to contain the calculation time of QRA procedures for escalation assessment, since they involve the analysis of a high number of accidental scenarios (Cozzani et al. (2006a)). Thus, equipment vulnerability models were based on probit functions to relate a “dose” of physical effects to the escalation or damage probability of an equipment item.

In the case of fires, in general radiation is the escalation vector, and equipment damage is caused by the temperature increase due to flame radiation and/or engulfment. Since this is a rather slow process (time to failure of a vessel is usually of the order of minutes or higher), a time lapse exists between the start of the primary event and the start of the secondary events triggered by the escalation. Thus, the “time to failure” (ttf) of target units, where the secondary events are likely to start, is a fundamental parameter in the analysis of escalation events triggered by fire. A longer ttf is likely to results in a less credible escalation, since the probability that mitigation actions by protection systems or emergency teams are successful increases. The ttf may be then compared to a characteristic time for an effective mitigation (tte). The analysis of protection systems (dumping aimed to depressurization, water curtains by automatic systems, additional water protection by emergency teams) can be performed by LOPA techniques, and specific damage probability functions may be obtained for the plant under examination. In the present study, specific models were used for the assessment of vessel “time to failure”, based on the results of detailed simulation (Landucci et al. (2009)).

In the case of blast wave impact, probit functions may be defined correlating the peak overpressure to the probability of equipment damage (Cozzani and Salzano (2004a)). he maximum peak overpressure was assumed as the “dose” in the probit correlation since this parameter allows a conservative estimate of blast wave effects on structures (Salzano and Cozzani (2005)). In a previous study, a specific analysis based on fuzzy sets was carried out to discern the probability of

"limited" and of "extended" damage given the vessel failure caused by different values of peak overpressure (Salzano and Cozzani (2006)).
Tables III, IV and V show the probit functions used in the present study to analyze the case-studies discussed in the following. As evident from the tables, no criteria is proposed for domino effects triggered by fragments, Actually, a complex probabilistic assessment is required to assess the probability and the possibility of vessel rupture (Gubinelli et al. (2004), Gubinelli and Cozzani (2009a), Gubinelli and Cozzani (2009b)).

Table III: Equipment vulnerability models for atmospheric vessels. ttf: time to failure (s); V: vessel volume (m^3); I: radiation (kW/m^2); Ps: maximum peak static overpressure (Pa).

Escalation vector	Type of vulnerability model	Vulnerability model
radiation	Probit model based on ttf and model for ttf vs. radiation	$Y = 12.54 – 1.847 \cdot \ln(ttf)$ $\ln(ttf)=-1.13 \cdot \ln(I)–2.67 \cdot 10^{-5}\ V+9.9$
overpressure	Probit model based on peak static overpressure	$Y = -18.96 + 2.44\ \ln(P_s)$ atmosp.
		$Y = -28.07 + 3.16\ \ln(P_s)$ elongated
		$Y = -17.79 + 2.18\ \ln(P_s)$ auxiliary

Table IV: Equipment vulnerability models for pressurized vessels. ttf: time to failure (s); V: vessel volume (m^3); I: radiation (kW/m^2); Ps: maximum peak static overpressure (Pa).

Escalation vector	Type of vulnerability model	Vulnerability model
radiation	Probit model based on ttf and ttf vs. radiation	$Y = 12.54 – 1.847 \cdot \ln(ttf)$ $\ln(ttf) = -0.95 \cdot \ln(I) + 8.845\ V^{0.032}$
overpressure	Probit model based on peak static overpressure	$Y = -42.44 + 4.33\ \ln(P_s)$

Table V: Probabilities of limited (P_{LOC1}) and severe (P_{LOC2}) loss of containment following equipment damage due to blast waves. All pressures in kPa.

atmospheric	P_{LOCI1}	P_{LOCI2}
$\Delta P < 15$	1	0
$15 \leq \Delta P \leq 20$	$1 - 0.2 \cdot (\Delta P - 15)$	$0.2 \cdot (\Delta P - 15)$
$\Delta P > 20$	0	1
pressurized		
$\Delta P < 40$	1	0
$40 \leq \Delta P \leq 50$	$1 - 0.1 \cdot (\Delta P - 40)$	$0.1 \cdot (\Delta P - 40)$
$\Delta P > 50$	0	1

3. Definition of Case-Studies

3.1 Selection of Case-Studies

In order to exemplify the methodology two case studies are presented and discussed. The first case-study selected is a "hot-spot", consisting in a limited area where a high escalation hazard is present, requiring a detailed analysis. The second case-study concerns the analysis of an extended industrial area and is aimed at understanding the actual effect that the inclusion of domino effect may have on individual risk figures used in land-use planning.

3.2 Case-Study 1

The layout considered for the case study is reported in Figure 2: a small area of large industrial facility is considered. The necessary input data for the analysis are summarized in Table VI. A hydrogen manifold is located close to an ammonia storage facility. The ammonia storage consists in 10 pressurized vessels (S101-S110) located at a distance of about 20m from the hydrogen pipeline. A leak from hydrogen pipeline is supposed to generate a strong jet fire able to impinge one or more pressurized vessels, thus leading to escalation. In order to simplify the case study, only one release position and orientation are considered in the analysis.

3.3 Case-Study 2

In Figure 3 a map of the industrial area considered is reported. As shown in the figure, several plants falling under the "Seveso-II" Directive are present in the area: 12 process and chemical plants, 6 storage plants and 1 waste treatment plant. Table VII reports a list of the hazardous substances handled or stored in the area and the final outcomes associated to these substances in the safety reports. A cooperation with the competent authorities for the application of "Seveso-II" Directive made available all the relevant data concerning primary events and possible escalation targets present in the safety reports issued for the industrial sites present in the area. These data were the basis for the case-study, although some changes were introduced to avoid the use of confidential data. It should be remarked that safety reports did not include detailed information on possible escalation scenarios, in spite of the requirements present in the legislation. Thus, the final outcomes of secondary events following target equipment damage due to escalation had to be defined in the present study.

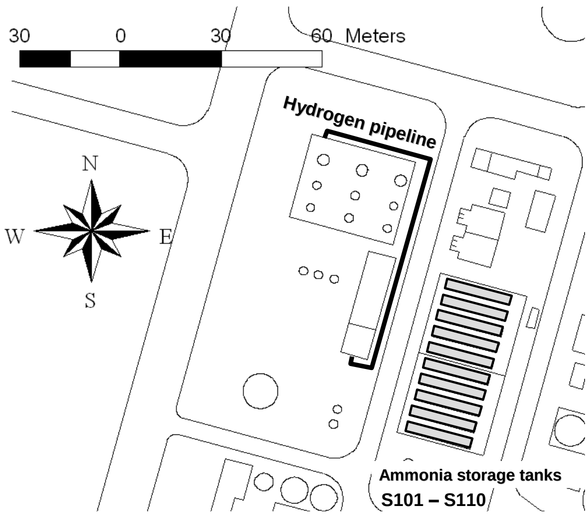

Figure 2. Lay-out considered for case-study 1.

Table VI: Equipment characteristics and input data used for the analysis of case-study 1.

Parameter	Primary source: hydrogen pipeline	Secondary sources: ammonia storage vessels (S101 – S110)
Diameter (mm)	100	3000
Length (m)	110	18
Volume (m^3)	0.86	127 (nominal 100 m^3)
Elevation	1 m	Ground level
Total inventory (kg)	0.5	56000
Operative temperature (K)	293	293
Operative pressure (barg)	6	9
Design temperature (K)	n.r.	323
Design pressure (barg)	n.r.	19.26

4. Results and Discussion

4.1 Results of case-study 1

Following the approach reported in Figure 1, primary event characterization was carried out applying a standard LOC assessment for the primary source. In particular, according to "Purple book", two reference LOCs are associated to pressurized pipelines. The LOCs are described in Table VIII, that also reports the correspondent standard frequencies. LOC1 is a catastrophic failure supposing the full bore rupture of the pipeline while LOC2 consists in a minor leak (10% nominal diameter rupture).

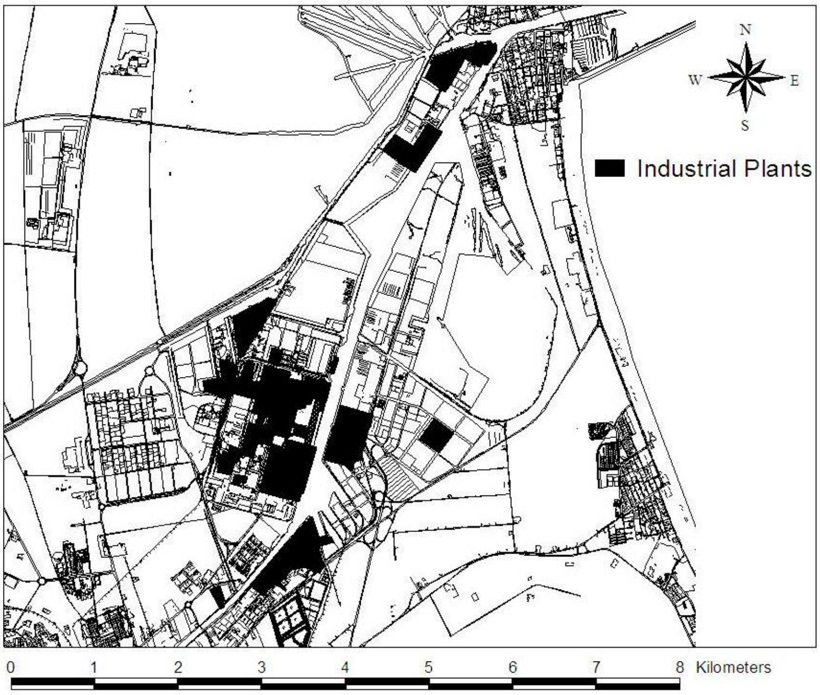

Figure 3. Lay-out considered for case-study 2.

Table VII: Hazardous substances and final outcomes for primary scenarios considered in case-study 2.

Name	*CAS No*	*Scenarios in Safety Reports*
1,1,2,2-tetrachloroethane	79-34-5	Toxic dispersions
Acetone	67-64-1	Fires
acrylamide	79-06-1	Toxic dispersions, Fires
acrylonitrile	107-13-1	Toxic dispersions, Fires
allyl alcohol	107-18-6	Toxic dispersions, Fires
ammonia	7664-41-7	Toxic dispersions[1]
1,3-butadiene	106-99-0	Fires, Explosions
but-1-ene; and isomers/mixtures	106-98-9	Fires, Explosions
chlorine	7782-50-5	Toxic dispersions
cyclohexane	110-82-7	Fires
ethylene dichloride	75-34-3	Toxic dispersions[2], Fires
n-hexane	110-54-3	Fires
heptane and isomers	142-82-5	Fires
hydrogen	1333-74-0	Fires
hydrogen chloride	7647-01-0	Toxic dispersions
hydrogen fluoride	7664-39-3	Toxic dispersions
LPG	68476-85-7	Fires and explosions
methane	74-82-8	Fires
methanol	67-56-1	Toxic dispersions, Fires
methyl bromide	74-83-9	Toxic dispersions
nitrogen oxides	10102-44-0	Toxic dispersions
propylene	115-07-1	Fires
styrene	100-42-5	Toxic dispersions[3], Fires
vinyl acetate	108-05-4	Fires
vinyl chloride	75-01-4	Fires

(1) Flammability scenarios for ammonia neglected in safety reports due to its narrow flammability range (15-28%). (2) Considered even if substance is only harmful (Xn)

The jet release following LOC1 leads to limited consequences (not likely to trigger an escalation in the lay-out considered). On the contrary, the severe release following LOC2 is able to generate a strong jet fire affecting the ammonia storage. No other fire scenarios associated to the release were considered in the study, since a limited duration was assumed for the release due to the action of mitigation systems. The quantification of the heat flows following the LOC2 primary jet fire is presented in Figure 4. As shown in the figure, four equipment items are affected by the primary jet-fire: the first tank (S101) is directly impinged by the flame, while other three tanks are exposed to distant source heat radiation (S102, S103, S104). Table VIII summarizes the impact vector, e.g. the heat load received by each target in the considered fire scenario and the time to failure estimated by applying the correlations reported in Table IX, selected on the basis of the type of fire exposure of each vessel. For each of the target vessels, the escalation scenario was the release of the entire inventory of the ammonia storage tank leading to a toxic dispersion. An instantaneous heavy gas release (transitioning to neutral or buoyant during dispersion) with the source located on the ground level was modelled considering a wind speed 2m/s and stability class F.

On the basis of the calculated ttf, the probit for vessel failure was obtained (see Table VIII) and the failure probability was calculated. Credible combinations of final scenarios were then calculated by the approach discussed in section 2. A probability threshold of 10^{-5} was fixed in the present case-study to limit the computational complexity. As shown in Table IX, four combinations were found to exceed the threshold. The risk indexes including escalation scenarios were then calculated using the Aripar-GIS software (Egidi et al. (1995), Spadoni et al. (2000), Spadoni et al. (2003), Cozzani et al. (2006)). The results are reported in Figure 5, that shows the local specific individual risk. No significant differences are present in the extension of areas affected by the higher individual risk values (10^{-5} events/year) when escalation effects are considered, due to the low frequencies of such scenarios. However, the figure evidences that due to the massive toxic dispersion triggered by escalation, the risk contour of 10^{-7} events/year reaches a distance of about 300m from the primary event when escalation is considered, thus affecting numerous facilities of the industrial area. Thus, an amplification of the risk profile is experienced when domino scenarios are considered.

Table VIII: Escalation vector and vulnerability assessment of secondary units in case-study 1.

Equipment	Type of fire exposure	Heat load (kW/m^2)	Time to failure (s)	Escalation probit
S101	Full engulfment	74	983	4.07
S102	Distant source radiation	50	1485	3.31
S103	Distant source radiation	25	3400	1.78
S104	Distant source radiation	12.5	7784	0.25

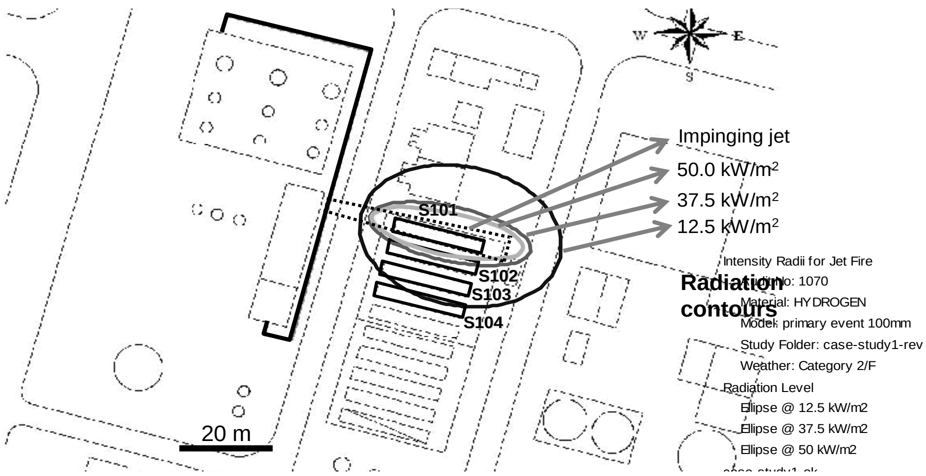

Figure 4. Consequence assessment of the primary jet fire for target equipment identification

Table IX: Domino scenarios above combination probability threshold (10^{-5}) set for case-study 1.

ID combination	Involved targets	Combination probability
1	S101	1.76×10^{-1}
2	S102	4.55×10^{-2}
3	S101 and S102	8.01×10^{-3}
4	S103	6.41×10^{-4}

4.2 Results of Case-Study 2

A few primary events were found to be able to damage a high number of potential targets (up to 15). The maximum number of domino scenarios that needed to be assessed for a single primary event was as high as 32767. More than 5000 domino scenarios resulted in an overall frequency value higher than the selected cut-off value of 10^{-12} events/year. As shown in Figure 3, the plants in the area of concern are located in two quite distant zones. Since the separation distances among these zones were far higher than the threshold distances for escalation, a separate analysis was carried out for the two areas. Individual risk and societal risk were calculated using the Aripar–GIS software. In the following, for the sake of brevity, only the results obtained for the southern area (lower part of Figure 3) will be presented, since similar results were obtained for the other area. Figure 6 shows the individual risk contours calculated respectively not considering and considering domino effect in the analysis. The increase of the overall individual risk is remarkable for the 10^{-6} events/year contour. The risk contour at 10^{-7} events/year is also enlarged, although to a lesser extent. This effect is mainly due to toxic dispersions, that may take place as secondary events triggered by fires (both jet and pool fires). Also societal risk was calculated, using available data on resident population. The results are shown in figure 7. The figure points out that the F/N curves without and with domino effect partially overlap, showing only a limited difference in the frequency values. This is mainly due to the low population density of the area. As a matter of fact, land use planning regulations forbid to use the surrounding of the industrial area for residential buildings. However, the low difference is also due to the very low frequencies of the more severe secondary accidents.

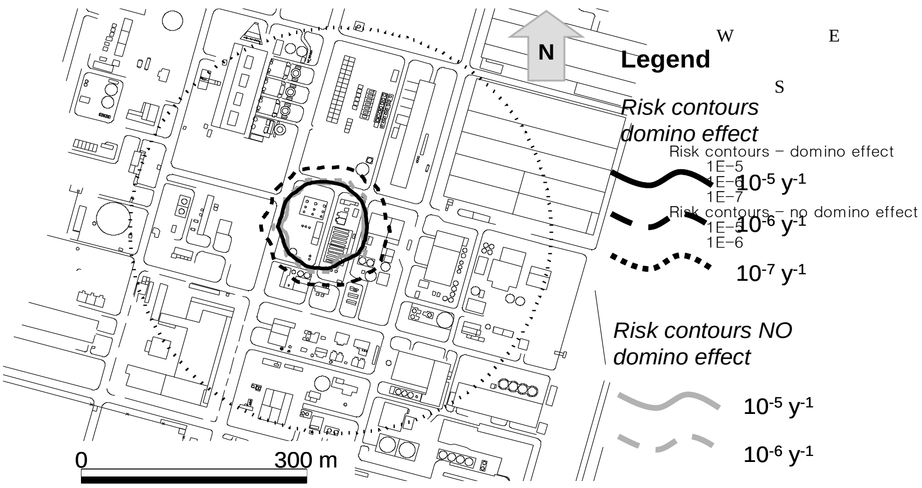

Figure 5. Individual risk curves evaluated for case-study 1.

4.3 Discussion

The results obtained for both case-studies pointed out that the quantitative assessment of escalation hazard is a key tool to understand the credible and critical domino scenarios in complex industrial sites. The approach provides detailed information that allows going much more in detail than in a "worst-case" analysis. As shown in case-study 1, the methodology provides a detailed identification and quantitative analysis of escalation scenarios, yielding detailed

results on domino scenarios and related frequencies. The analysis of an extended industrial area, reported in case-study 2, shows that considering domino effect in risk calculations causes an increase of both
individual and societal risk. However, since the expected frequencies of severe domino scenarios are reasonably low, separation distances may be effective in preventing the involvement of population in industrial accidents. This suggests on one hand that the proposed method is not over-conservative and, on the other hand, that the quantitative assessment of domino scenarios is an important complement in the analysis of industrial risk. The results of case-study 2 also allow the identification of the "escalation hot-spots", intended as critical escalation sources. Moreover, the results also allow the identification of the critical domino targets present in the area (the toxic pressurized storages responsible of the dispersion scenarios). Thus, the approach proposed, based on a quantitative assessment of the contribution of domino effect to risk indexes, resulted of fundamental importance in order to identify critical

Figure 6. Individual Risk (events/year) contours calculated for case-study 2 (southern area only, lower part of figure 3). Dashed lines: without considering domino effect; solid lines: considering domino effect.

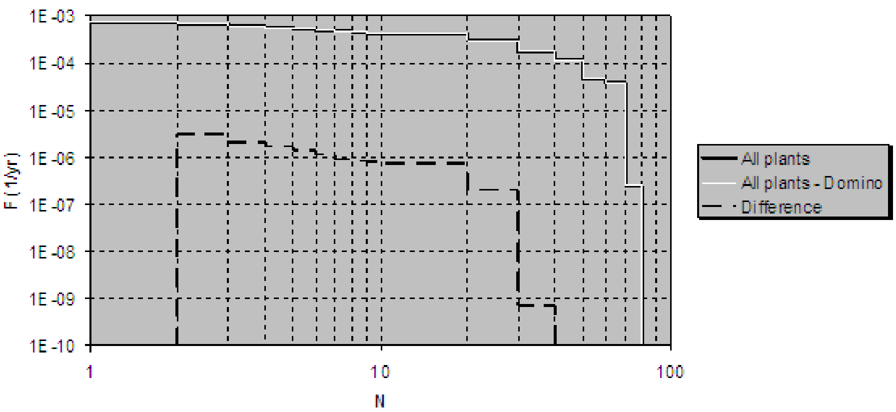

Figure 7. Societal risk with and without considering domino effect for case-study 2.

equipment and to prioritize actions addressing escalation prevention and protection in the area of concern.

5. Conclusions

The present study was devoted to the analysis of domino effect in complex industrial layouts. A methodology was developed based on the results of previous studies on the probabilistic assessment of domino effect. Case-studies based an actual industrial layout analysis were analyzed in order to test the potentiality of the proposed approach in a land-use planning perspective. The study evidenced that the increase in the individual risk due to escalation events may give an important contribution to industrial risk, since high severity scenarios may result from the simultaneous damage of several process units. However, the methodology proposed allows the identification of critical areas and of population involvement by the use of societal risk indexes, providing useful information for the inclusion of hazards posed by domino scenarios in the analysis of land-use planning.

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NUMERICAL MODELLING OF FLASHING LIQUID JETS DUE TO LEAKAGE OF LIQUEFIED GAS STORAGE

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ABSTRACT

One of the missions of the INERIS is to assess accidental risks induced by industrial activities. The use of liquid gases is very widespread in industry but a large potential hazard exists in case of accidental release. These substances can be flammable and explosive like the LPG or toxic like anhydrous ammonia. In case of an accidental leakage due to a vessel breach or a line rupture, a violently change phase could take place inside theses products. This phenomenon called flashing jet are still bad understood and many strong hypothesis are often used to predict by modelling its physical consequences in the near field like thermodynamic behaviour of the whole jet, pool formation. However all these physical consequences have to be well evaluated in order to better estimate the explosive cloud or toxic cloud formation. The objective of the INERIS-CORIA work is to develop a new numerical model with the aim of simulating two phase jet resulting from a leakage in a pipe containing a liquefied gas. The work focuses especially on the effect of the vaporization and boiling process in the jet. A thermodynamic equilibrium model for vaporization was thus developed. To test the model, an atmospheric two-phase jet of butane, emanating from a circular orifice is considered. The modelling results show that the calculated temperature behaviour in the spray jet by comparison with the observations is generally satisfactory. This result cannot be obtained with classical vaporization model.

Keywords : Thermodynamic Equilibrium, flash-boiling, two-phase flow, droplet, vaporization

Introduction

Context

Accidental releases to the environment of pressurized liquid gases under ambient conditions could generate a large flow rate when the breach appears on the liquid filled containment. The superheated released liquid can form a two phase explosive or toxic cloud mixture. Potential consequences of these accidental releases are injuries, fatalities, destruction of installations and possible evacuation from the surrounding area of the accident. Examples of fatal accidents [1, 2, 3] involving superheated liquids showed huge consequences. Predicting behaviour of the liquid-gas cloud mixtures by modelling is of direct relevance for industrial risk assessment.

At the breach level, in the case of an accidental release of pressurized liquefied gas, the product released in the ambient air is suddenly placed under temperature and pressure conditions that are such that a part of the liquid vaporizes violently. This phenomenon is generally called a "flash".

In order to calculate safety perimeters around industrial installations, one of the objectives of atmospheric dispersion research projects of INERIS is to improve models of flashing releases in realistic industrial environments.

Equivalent source term models exist for flashing release in current long range dispersion models intended to predict toxic effects or explosive cloud formation. Several factors can, however, invalidate simplified equivalent source models, especially in the very near field where many complex phenomena can occur and where obstacles can be found.

We can easily say that total mass released and the release duration are major parameters. Others parameters as the velocity, thermodynamic state, and amount and droplet sizes of imbedded aerosols of the material at the exit of the rupture are also required as inputs to the jet and dispersion modelling.

A number of experimental, theoretical and numerical studies have been carried out [5, 6, 7] to perform calculations of two phase mass flow rates. Several empirical and analytical models were developed based on hypothesis related to saturation conditions. In order to have a better use of the models, they have been compared with measured data obtained during experimental tests performed by INERIS since the 90’s [8]. These comparisons allowed us to conclude that to reach a good agreement between measured data and calculating flow rate is difficult but conservative models are clearly pointed out. This issue is relevant in a risk assessment.

Recent critical review [4] of term source modelling for toxic release scenario for pressurized liquefied gases showed there is "still a significant uncertainty in the overall modeling process". Main difficulties come from modelling suspension, evaporation of aerosol and rainout.

The aim of the present work is to improve the acknowledge and the numerical modelling of aerosol evaporation.

Jets experiments

In order to improve model of flashing releases in realistic industrial environments, INERIS carried out two-phase butane and propane jet releases [9] into the atmosphere and ammonia [10] jet releases in a congested environment. Indeed most leakage problems from breakages of vessel or line rupture result in the formation of jets due to difference between the internal and the external pressure. These experiments involved to measure the main characteristics of the jet and to increase the understanding of the behaviour of superheated (flashing) liquid jets.

Modelling objective

Basic principles of flashing jets are summarized in Figure 1. The jet consists in 3 areas:

4. The expansion zone (flash boiling, atomization): Here, the fluid expands from the vessel hole pressure to the atmospheric pressure. At the end of this zone, we assume that the jet consist only in gas phase and liquid phase. Both of them are at the boiling temperature. During the expansion, jet atomization occurs and the liquid jet ends here in droplets.

5. The entrainment zone (secondary break-up, droplets evaporation): the turbulent jet drives the ambient air. The energy brings by the air, of which the temperature is greater than that of the jet, is used for droplet vaporization in the two-phase jet.

6. The final dispersion zone: The entrainment by the air atmosphere heats the jet and decreases its velocity up to the wind speed.

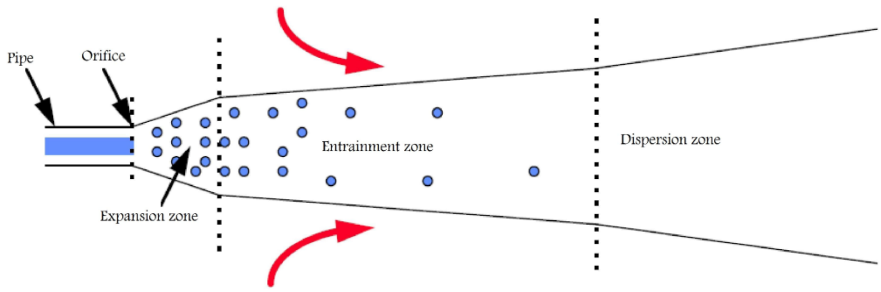

Figure 1. Schematic representation of the areas of the flashing jet

The objective of this work is to develop a numerical model with the aim of simulating thermo dynamical behaviour of a two phase flow resulting from a breach or leakage in a vessel containing liquefied gas. A focus is made on the entrainment zone where a strong decrease of temperature was measured.

This paper aims to present the first results and comparisons between modelling calculations with experimental data.

A description of approaches used to simulate thermodynamic process inside flashing jets is given in Section 2. Results and discussion are presented in Section 3.

Methods

The first step of the work includes models used to describe the jet up to the end of expansion zone. These will be used as boundary conditions for the simulation of the jet from de beginning of the entrainment zone. In the second step, precisions are given on the new phenomena brought by the flashing liquid jet and the models suggested for it.

Expansion zone

To represent the flash boiling phenomenon that occurs at the exit of the injector up to the end of expansion zone, the isenthalpic Homogeneous Equilibrium Model (HEM)
has been used. The model is used to determine the vapour mass fraction at the end of the zone.

The model supposes that the gas and liquid have the same velocity and the same saturation temperature due to the thermodynamic equilibrium assumption between the two phases. The mixture of the phases is homogeneous. These assumptions imply that:

1. The two-phase flow is considered as a homogeneous fluid with properties at the middle of those of liquid and gas phase.
2. The flow quickly tends to a thermodynamic equilibrium (no energy exchange between the liquid-gas system and the outside). So it is supposed to have this thermodynamic equilibrium during the expansion.
3. Isenthalpic expansion: the enthalpy of the flow is constant while its entropy decreases.

There is another HEM model with Isentropic expansion, the entropy of the flow is constant while its enthalpy decrease. This causes the fall in temperature of the system [12] showed that both of the assumptions are unrealistic but fewer errors are involved with the isenthalpic expansion.
In the case of this work, the HEM model presents the advantage of vapour/liquid mass fraction estimation. This will help to determine the mass flow of each phase from the total mass flow given by the experimental data.

Isenthalpic HEM Model:

$$h(T_{\exp}) = (1 - X) * h_l(T_{\exp}) + X * h_g(T_{\exp}) = Cte \quad (1)$$

$$\int d(H) = \int C_{pl} dT \quad (2)$$

From the equation (1) describing the enthalpy conservation, we introduce (2) After a derivation by X:

$$h_l(T_i) - h_g(T_i) = -\int C_{pl} dT + \int C_{pg} dT + \left((1 - X) + X * \frac{C_{pg}}{C_{pl}}\right) * C_{pl} * \frac{dT}{dX} \quad (3)$$

By supposing $X << 1$ and $C_{pg} < C_{pl}$, we see that the term $-(1 - X) * C_{pl} * dT / dX$ in (3) is equal to latent heat vaporization:

$$Lv(T_b) = -(1 - X) * C_{pl} * \frac{dT}{dX} \quad (4)$$

The heat exchange due to vaporization is supposed greater than the heat due to warming: $C_{pl} * dT \ll Lv$. By taking account of this assumption after the integration of (4), we finally have:

$$X_{exp} = C_{pl} \frac{T - T_{exp}}{Lv} \qquad (5)$$

At the end of expansion zone, the jet is in atmospheric pressure. So the liquid, which is in thermodynamic equilibrium with its vapour, is at its boiling temperature $(T_{exp} = T_{eb})$ Another issue of this work is the determination of the velocity induced by the pressure drop inside the injector and by the flash effect. The maximum kinetic energy can be estimated by the pressure drop and the variation of thermodynamic energy in the flow. Here, the velocity is considered to be driven mainly by the pressure drop, thus it is determined by the Bernoulli law. Additional velocity could be considered due to the flow expansion (liquid to gas) however there is also a reduction of velocity due to pressure loss.

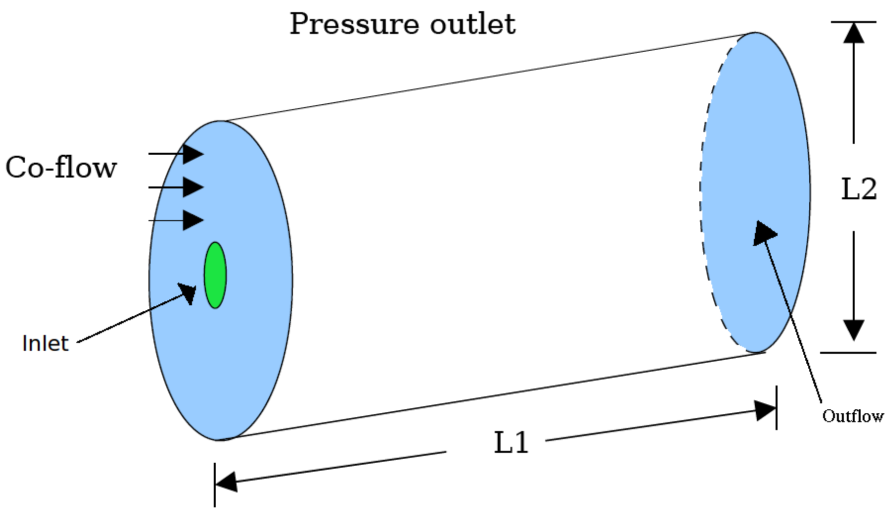

Figure 2. Computation area

All the above work is useful to estimate values in the jet at the end of expansion zone. The simulations start at this point, since the CFD model used is the two-phase Euler-Lagrange description model. The experimental case presented in this paper comes from the data base of the FLIE (Flashing Liquids in Industial Environment) project [13]**Error! Reference source not found.**. The numerical software used for this study is numerical package FIRE V8.41 from AVL.

The chosen case is whose of a vessel of liquid butane at 7.78 MPa. The liquid is released through a pipe and reaches the ambient air in a two-phase jet. This jet emanates from a circular orifice of 10 mm in diameter. The mass flow rate conservation between the orifice and the end of expansion zone give the diameter

this end zone : D = 60.45 mm. The numerical domain in which the butane is spreading is presented in Figure 2. It consists in a cylinder of 36 m in length and 6 m in diameter. To simulate a rejection of liquefied gas with wind effect, a co-flow of air surrounds the spray injection. The mass fraction of each phase is given by the HEM model. The boundary conditions are recapitulated in Table 1. Finally, the turbulence is modelled with the K−Ɛ model and the applied gravity is 9.8 m/s^2.

Table 10. Boundary layer conditions

Variable	Inlet	Coflow	Outflow
Material	Butane (liquid & gas)	air (gas)	
Velocity (m/s)	29.49	1	-
Temperature (°K)	272.6	300.15	-
Mass flow rate (kg/s)	1.33	-	-
Vapour mass fraction	0.17	-	-
Droplets size (µm)	100	-	-
Turbulence intensity	10	1	-
Length scale	0.005	0.1	-

Abramzon vaporization model

Vaporization is based on Abramzon vaporization model [11]. By considering ρ and D the density, and the binary diffusion coefficient in the gas around the droplet, k and a, the droplet diameter and thermal conductivity, Sh and Nu the Sherwood and Nusselt number, the mass transfer rate $\dot{m}$ m is given by (6) and (7):

$$\dot{m} = \pi \rho a D \ln(B_M + 1) Sh \tag{6}$$

$$\dot{m} = \pi \frac{a k}{C_{pg}} Nu \ln(B_T + 1) \tag{7}$$

Usually, the mass Spalding number B_M (equation (8)) and the thermal Spalding number B_T (equation (9)) are supposed to be the same $(B_M = B_T = B)$. One part of the energy available in the gas phase goes for the evaporation of liquid phase. The other part goes for heating the droplet. This is described in equation (10) below.

$$B_M = \frac{Y_{Fs} - Y_{F\infty}}{1 - Y_{Fs}} \tag{8}$$

$$B_T = \frac{\rho_s v_s C_{pg}}{h_c} \tag{9}$$

$$h_c (T_\infty - T_s) = \rho_s v_s L + \frac{Q}{\pi a^2} \tag{10}$$

In the three equations above ((8), (9), (10)), YF is the vapour mass fraction of droplet material in the gas phase, vs is the velocity in the gas phase and hc is the

droplet convection coefficient. The subscripts s and ∞ mean the values at the droplet surface and far from droplet.
The introduction of the thermal Spalding number in (10) combined with equation (7) give the heat quantity necessary for droplet heating.

$$Q_l = \left\{ \frac{l_q}{K}\left(T_\infty - T_s\right) - \frac{L}{C_{pg}}\left(T_\infty - T_s\right) \right\} \tag{11}$$

However thermodynamic conditions at the end of the expansion zone are very particular in the case of flashing jets. Thermodynamic equilibrium assumption imposes that the liquid and gas temperature are the same and equal to the boiling temperature. Additionally, near the inlet boundary conditions of the jet droplet, environment is composed of pure vapour $\left(Y_{F,\infty} \approx Y_{F,s} \approx 1\right)$. Thus, this is a limit case between boiling and vaporization. As seen in equation (8), with these conditions, B_M is uncertain. However, the security brought by putting the maximum value of the both vapour mass fraction at 0.99 is not sufficient. Thus, some simulation cases have shown that the classic Abramzon vaporization model is not suitable for post flashing two-phase jet. So there is a necessity to develop another model for vaporization.

New model: Thermodynamic Equilibrium Model (TEM)

We propose a special procedure to solve this problem. It is considered a thermodynamic system (see Figure 3**Error! Reference source not found.**) at its initial state with certain liquid mass fraction (y_l) and vapour mass fraction (y_v) in the presence of other gas like air $\left(y_g\right)$. The liquid temperature (T_l) differs from vapour temperature $\left(T_g\right)$. Like in HEM model, we consider thermodynamic equilibrium model at the final state. The physics assumptions here are:

- Ideal gas.
- Mass conservation (12).
- Isolated system with constant pressure transformation: enthalpy conservation (13).

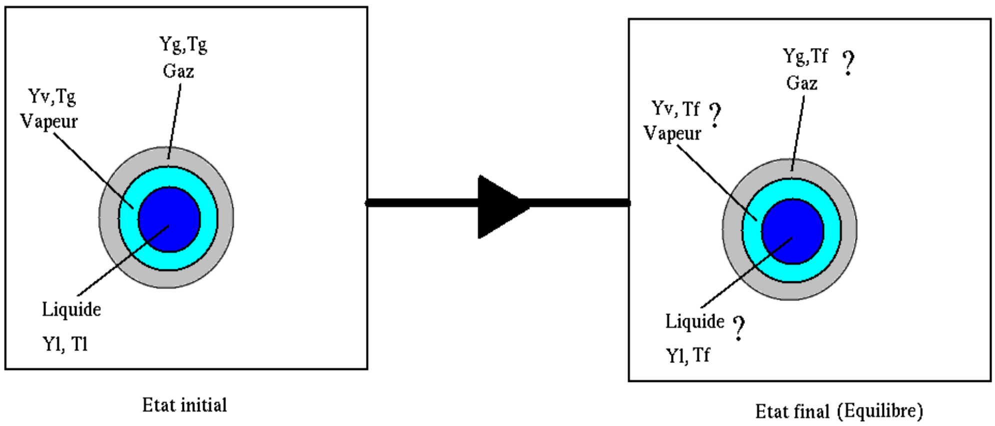

Figure 3 : Initial and final state in the thermodynamic system

$$\sum_k y_k^{initial} = \sum_k y_k^{final} = 1 \qquad (12)$$

$$H_t = \sum_k \left(H_k y_k\right)^{initial} = \sum_k \left(H_k y_k\right)^{final} = cte \qquad (13)$$

$$f\left(T^{final}\right) = H^{initial}\left(T_l^{initial}, T_g^{initial}\right) - H^{final}\left(T^{final}\right) \qquad (14)$$

The first step of this method is to find the enthalpy at the initial state with de quantities y and T in (13). Knowing that the enthalpy is constant, the second step consists in finding the new values of these quantities by applying a method for finding the zero of the function $f\left(T^{final}\right)$ (14). At the final state, thermodynamic equilibrium implies that the liquid and gas are at the same temperature.

This method can be more interesting than the Abramzon model, because not only it resolve the particular problem of flash-boiling, but also it integrates the condensation phenomenon, which is supposed to occurs during the jet spreading.

The test of this model is done with the butane properties. The purpose of the test is to see if it is consistent by varying the initial quantities of y and T. In this paper we show the test of the model by varying the initial liquid mass fraction, with the liquid and gas temperature at 272.5°K and 350°K respectively. The total pressure is equal to 0.1MPa.

The Figure 4 shows the final temperature (left-aligned) and the final mass fractions of liquid and vapour (right-aligned) in the system. The model is consistent with the physics. If the liquid initial amount is small, because of the great temperature in the gas compared to the liquid temperature, it evaporates completely. The temperature evolution in this case of total evaporation is linear, accordingly to the ideal gas law. But, the system come to a stage where the energy in the gas phase is not sufficient to completely evaporates the liquid. Thus, as we can see in figure 5, which compare the vapour saturation pressure of butane at the final temperature and the butane vapour pressure in the system, there is an equilibrium between the two phases when liquid remain in the system.

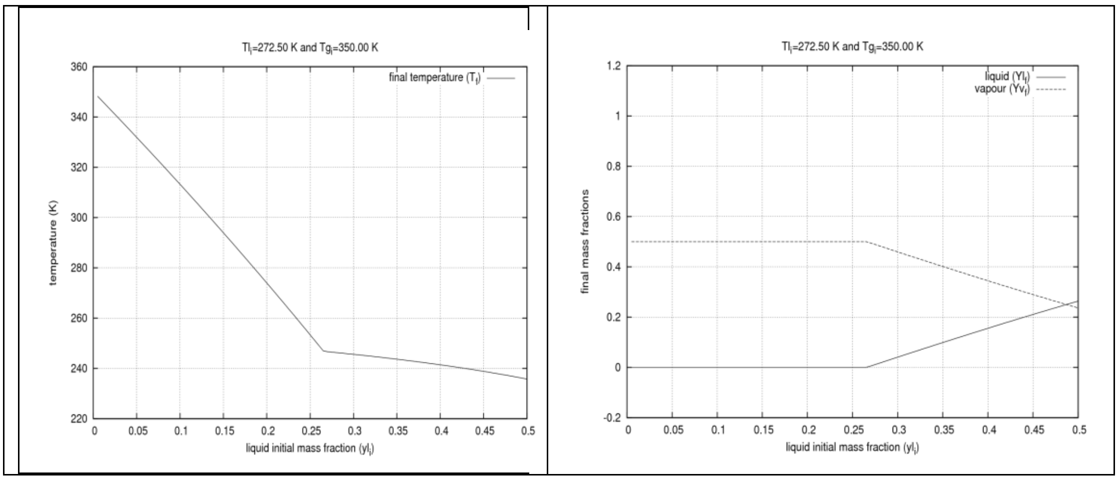

Figure 4. Test of the model of mass and enthalpy conservation by varying the initial mass fraction

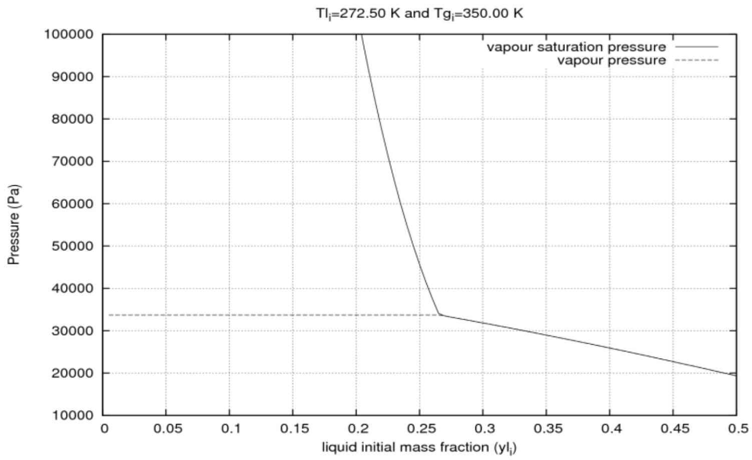

Figure 5 : Comparison between the vapour saturation pressure and the butane vapour pressure in the system

Implementation on TEM in FIRE:

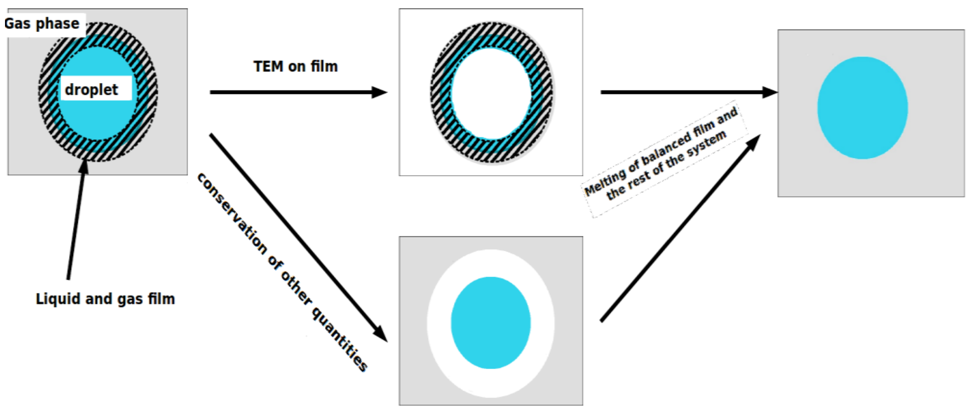

Figure 6: Usage of the TEM model in two-phase flow module of FIRE

The next step is to introduce this model in the FIRE software. However, this model did not give information on how long it takes to evaporate. So, the model is completed to finally have the mass transfer rate between liquid and gas phase. This is done by adding a film of evaporation (Figure 6). It consists in taking an amount β_l of liquid (15) and β_g gas (16) which will be applied to the model. At the current state of the work, these amounts of liquid and gas are not yet determined precisely and have the same value β. In this paper, we will just compare the results given by taking account two different values of β.

$$\beta = \frac{m_{liquidfilm}}{m_{droplet}} \qquad (15)$$

$$\beta = \frac{m_{gasfilm}}{m_{gasincell}} \qquad (16)$$

Results and Discussion

It is complicated to have experimental results on the types of jets described above. But the INERIS were able to have more reliable measurements in temperature. These measurements show the same behaviour as seen on Figure 7 showing the evolution of the temperature in the jet axis with β=10% .
The spray is surrounded by a hot gas environment. However, the temperature of the spray decreases up to a certain distance. Due to the initial droplet boiling temperature, close to the injection, the vaporization process dominates the flow. Since evaporation is an endothermic phenomenon, the spray jet cools down until there is no droplet enough. Thus the spray temperature rises only once the liquid vaporization does not have enough influence in the flow.

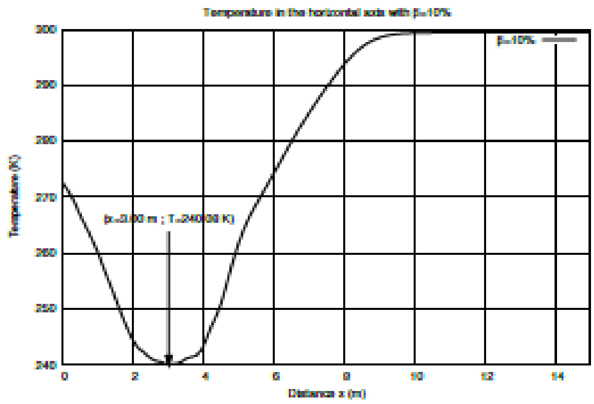

Figure 7: Temperature evolution in the jet axis

INERIS has done temperatures measurements with thermocouples at different points on three axis (up, horizontal and down) in the jet as seen on Figure 7. The comparison of these measurements with computation results (β=10%) in Figure 9 shows that the simulations are not far from reality. The differences can be explained by the fact that the choice of β and the calculations on the boundary conditions are not yet accurate.

Conclusion

The modelling results with the TEM model show that the calculated temperature behaviour in the spray jet by comparison with the observations is generally satisfactory. This result cannot be obtained with classical vaporization model.
As a perspective to this work, a model is under development to calculate the value of β by taking account the turbulence in gas phase, the time step, the droplet area. Finally, the assumptions used to calculate the boundary conditions bring many lack of precisions. It would be desirable to do a CFD model of the material flow from inside the vessel to the end of expansion zone.

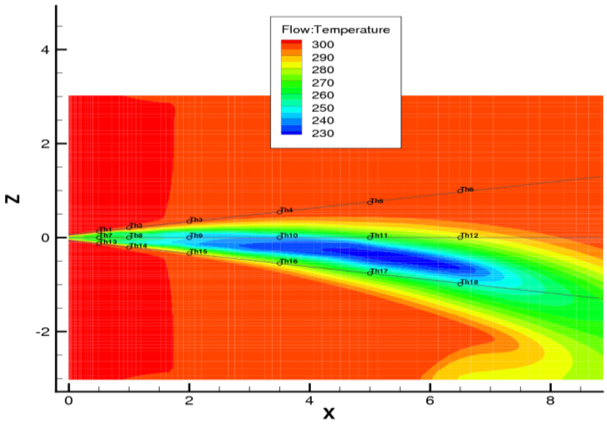

Figure 8 : Temperature field in a vertical plane passing through the simulated jet axis with the experimental thermocouples positions : Th1-Th6 = up axis; Th7-Th12 = horizontal axis; Th13-Th18 = down axis

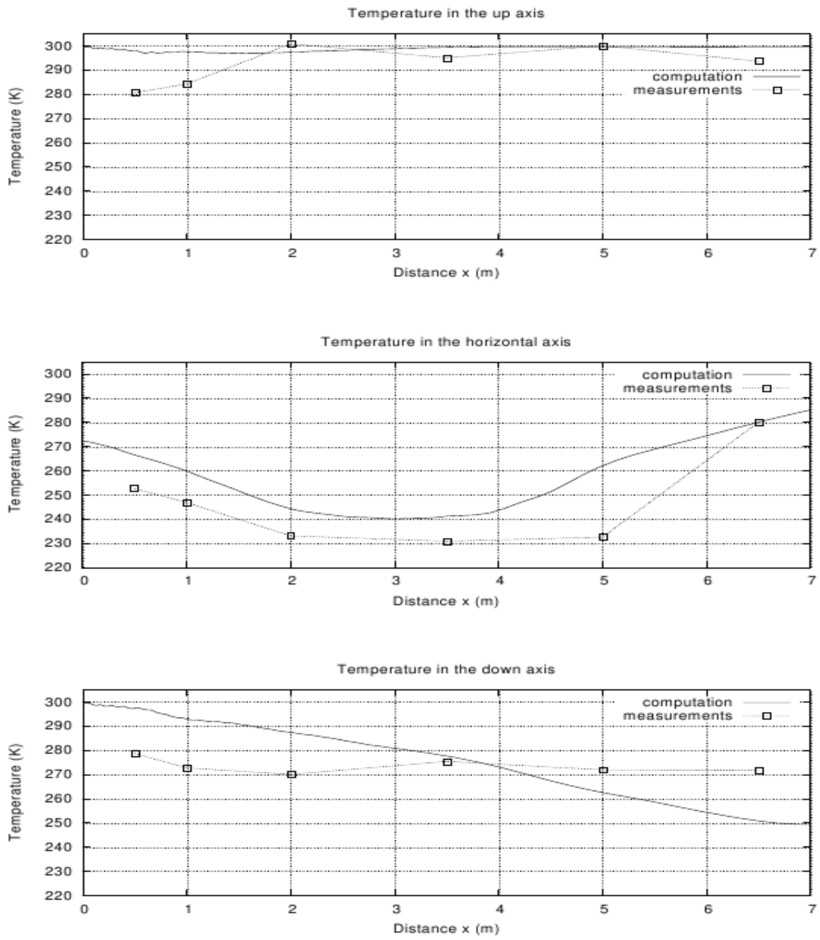

Figure 917 : Temperature comparison between experimental and simulation (with β=100%) results in the up (a), horizontal (b) and

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Fire hazard evolution control assessment through smoke temperature real-time measurements

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Abstract

One of the main problems for fire fighters is to know about the fire behavior vs. time and its propagation in the different parts of a building and to other buildings. The main purpose of this paper is to show how it is possible through temperature measurements in the smokes to analyze the behavior of a fire in a confine space and to have information about the effects of a chosen strategy to put out the fire, in order to improve the decision support. When fire fighters have to put out an enclosed fire, smokes are one of the most important dangers they have to face. Smokes are very hot and contain much combustible gases and combustible particles such as soot. Consequently, under the effect of high temperature these smokes may ignite leading to a flashover phenomenon. Another danger comes from the fact that the smokes may be driven to every part of the building and propagates the combustion everywhere. In this study, it is shown that despite these smoke problems it is possible to have information on the fire behavior through temperature measurements in the smokes. The presented case is an example of a general situation and consists in a fire in a bedroom on the second floor of a multi storey building. This room contains usual furniture of a bedroom. Temperatures are recorded from K thermocouples located at different places in the zone on fire. The test procedure consists in measuring temperature during the fire evolution in order to compare its values at different locations and different time to detect the different events created by the fire and by the fire fighters actions. This analysis shows that real time temperature measurements inside a multi-compartment on fire give more accurate information about the fire behavior in order to improve the fire fighters security and efficiency.

Keywords: compartment fire, smoke temperature information, decision support, thermal accidents, fire fighters efficiency.

1. Introduction

When fire fighters have to put out an enclosed fire, smokes are one of the most important dangers they have to face. Smokes are very hot and contain much combustible gases and combustible particles such as soot. Consequently, under

the effect of high temperature these smokes may ignite leading to a flashover phenomenon. Another danger comes from the fact that the smokes may be driven to every part of the building and propagates the combustion everywhere.
As a consequence, one of the main problems for fire fighters is to know about the fire behavior vs. time and its propagation in the different parts of a building and to other buildings. These data may be given from temperature measurements made in the smokes in different parts of the buildings since the temperature of the smokes is an indicator of the heat release power evolution of the fire. This temperature analysis could be a way to decision support for fire fighters if that temperature captors had been installed during the construction.
Temperature is a parameter very used to analyze compartment fires, especially physical phenomenon. Estimations of temperatures were made in compartment fire [1] in order to characterize the fire. Temperatures were used to study the fire safety in an industrial warehouse [2]. The temperature is a part of parameters used to determine the height of the interface air smoke in a room on fire [3]. The temperature is also a part of parameters which allow estimating the applicability of fire modeling as an alternative to large-fire tests [4].It also intervene in computational fluid of compartment fires [5] and in model for predicting fire suppression in spaces by water mist systems [6]. Zone model in compartment fire in buildings are analyze through temperature, as well [7] or in numerical comparison of enclosure fire in a multi-compartment buildings [8]. Physical interpretations are drawn from compartment fire tests by the analysis of the temperatures [9]. The more important for the presented study, an example of the evaluation of smoke ventilation in fire fighting in multi-storey buildings [10] and the positive pressure ventilation for high rise buildings used in this study [11].

Besides these studies, we are going to show that despite the smoke problems it is possible to have information on the fire behavior through temperature measurements. The chosen case is an example of a general situation and consists in a fire in a bedroom on the second floor of a multi storey building.

2. Main goal of the study

The smoke problem exists in many situations in fighting compartment fires. This is an important danger for the fire fighters when they have to fight a fire in confined compartment. But the smoke can be used as indicator of the fire situation. Their composition, their temperature at different location, their opacity can give much information about the fire behavior and the effects of the strategy engaged by the fire fighters.
Information from fire situation can be obtained from several methods. The main one is visibility. Visibility is the first parameter that fire fighters want to be improved when they progress into the smokes. They have a direct assessment of its evolution when they progress in the smoke. But visibility does not give good information from the fire situation. For example, near the fire the visibility may be good but with high temperatures in the top smoke layer, about 900°C, which is a real danger for fire fighters because rollovers or explosion may occur. Monoxide concentration does not give correct information of the fire situation because its concentration may be weak while the smoke temperature is high; this is the case after a flashover. CO_2 concentration may be at a correct amount in

smoke lower layer because of the natural ventilation created by convection due to the fire heat, or mechanical ventilation of fans, while the smoke temperature is high in the upper smoke layer, which may produce an explosion due to the mixing of hot smokes and fresh air drawn in from outside. On the other hand, temperature may give useful information at the location where the fire fighters are and of the fire evolution.
Moreover, monoxide and dioxide information are not easy to measure and to analyze immediately in order to give useful information for decision support. The simplest method is to get temperature data. They can be recorded with simple thermocouples located at precise locations inside the building on fire or with infrared camera used from outside or inside the building when firefighters are exploring the different rooms searching for victims and fire through smoke.
Real scale experiments were carried out to show how temperature measurements may be used to get useful information from the fire situation and improve decision support. All these experiments gave similar results. One of these experimental conditions is described and its results are detailed.

3. Experimental conditions

The fire sets in a bedroom in the second floor of a building doomed for destruction so it was possible to create a real situation without any risk. As shown in figure 1, the room overlooks the street and its door opens onto a corridor parallel to the street. The entire wall overlooking on the street is a glass façade. The corridor is closed just near the room door and opens onto the staircase. As shown in figure 2, the room is furnished with a table, a desk with a computer with its tower and its keyboard, three chairs, and a bed. There is a wardrobe with clothes on the corridor wall.

Twelve K thermocouples are used to record temperature data. As shown in figure 1, they are located as follow:

- Inside the room at each corner behind the window, one thermocouple 30cm under the ceiling and another one at mid height,
- inside the room close to the door, three thermocouples, one 30cm above the floor, one at mid height and another 30cm under the ceiling; the temperature above the floor and the temperature at mid height represent the temperatures at which the fire fighter legs and head are exposed when they progress on their knees,
- in the corridor close to the door, two thermocouples, one 30cm above the floor and the another 30cm under the ceiling,
- in the middle of the corridor, two thermocouples, one 30cm above the floor and the another 30cm under the ceiling,
- one thermocouple in the staircase, under the ceiling at the second level.

Temperature data are recorded with LabView software at a frequency of 5Hz.
Table I gives the different actions of the fire fighters during the test. In order to analyze the ventilation efficiency, it was decided not to attack the fire with water hose before the visibility has improved, considering that the visibility is the first parameter that fire fighter can use to assess the ventilation effect. However, the visibility is not the main parameter which can guaranty the security of the fire

fighter because the visibility may be good but with a hot smoke layer (800-900°C) under the ceiling which may be very dangerous.

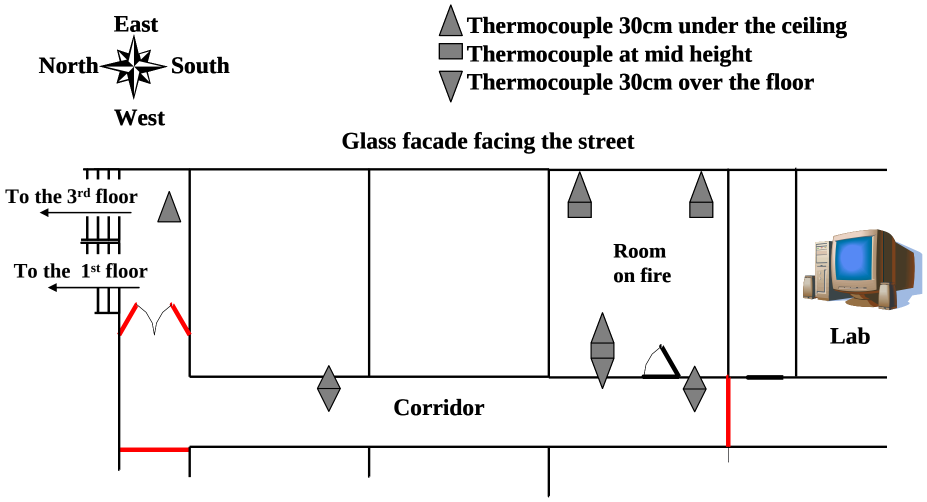

Figure 1: Compartment situation in the building and the thermocouples location.

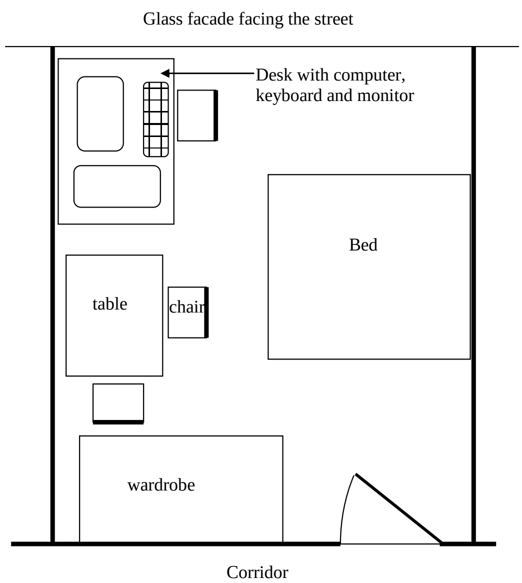

Figure 2: Combustible furniture in the fire test room

The usual fire fighters equipments were used to carry out the test, usual fire fighting vehicles, and ladder and water hose.

Overpressure ventilation, usually called positive pressure ventilation, is created at the beginning by one and next by two portable fans located in front of the main door of the building, successively.
The main door of the building and the window of the test room are on the same facade so that the wind has no effect on the overpressure ventilation created by the fans

The fire is ignited on the bed representing a cigarette still burning. Before any action on the fire a time delay is left to represent the time between the fire start and fire brigade arrival. This delay is estimated to less than 4min. It is important to note that during this delay a flashover occurs. In order to analyze information provided by temperature data, the two main actions on fire, ventilation and water attack are separated: as shown in table I, first ventilation with one fan, next with two fans and at the end with fans and with one water-hose (500l/min).

Table I: the events during the experiment

Time	Event
0min	Fire ignition
1min 30s to 3s	Plateau
3min	Flashover
3min 45s	1st fan start
6min	2nd fan start
7min 40s	Fire attack with water, extinction

4. Experimental results

4.1 Temperatures evolution vs time in the room on fire in front of the window

As shown in figure 3: the evolution of the temperatures just in front of the window in the room on fire shows several parts:

- 0 to 1min 30s: fire growing on the bed,
- 0 to 3min; extension of the fire from the bed to the other furniture in the room
- at about 3min: a flashover occurs, temperatures rise from about 500°C to over 800°C; at the same time the glass window explodes so that an outlet for the smokes is created,
- at 3min45s a first fan is started: temperatures still increase to more than 900°C during less than one minute and then decrease to 800°C, this decrease is due to the effect of the first fan that brings in fresh air; it is not possible to draw any conclusion about the heat release rate decrease from this temperature decrease,
- at 6min the second fan is started: the temperatures decrease of only about 100°C, they are still at a high dangerous level for fire fighters and fire propagation,
- at 7min 40s the fire is attacked with water-hose: temperatures decrease to about 600°C and after a plateau still decrease to about 200°C.

It is important to note that these temperatures are measured in the smoke after the fire considering the flow created by the fans from outside at the main door to outside through the window. The high level of these temperatures shows their dangerousness and the risk of propagation of the fire they represent.

4.2 Temperature evolution vs. time inside the room on fire just near the door

The location inside the room on fire just close to the door is the place where the fire fighters enter progressing to find victims and the fire. The evolution of the temperatures at this place shows similar parts than in front of the window. The fire growing and the plateau are clear, as well, but temperatures show stratification from bottom to top. Above the floor, e.i. at the level of the legs of fire fighters progressing on their knees, the temperature is only 200°C, and at mid height of the room, e.i. at the level of their head temperature is only 320°C, which is acceptable wearing a fire suit. If fire fighters were standing up, temperature at their head level would de higher than 550°C. These temperature levels show stratification before the flashover occurs. When the flashover occurs, all the temperatures suddenly increase until reaching 700 to 800°C.

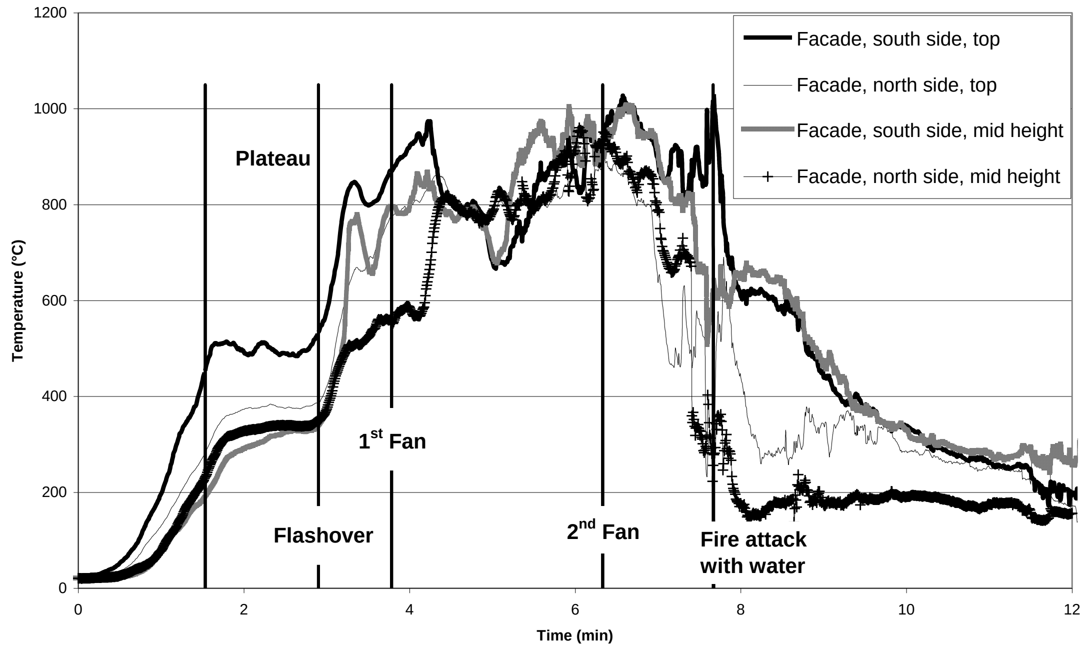

Figure 3: Temperatures evolution vs time in the room on fire

At 3min 45s when the first fan is started, temperatures decrease to 600°C becoming at the same amount from bottom to top. The fan has just a little effect on the decrease of the temperatures in the room on fire. This decrease stops after about one minute then temperatures increase again to a high amount of about 800°C.

At 6 minutes after ignition, the second fan is started. During a few seconds temperatures still increase and suddenly decrease from 800°C to 400°C when the water-attack is started, after what temperatures decrease to 200°C at the top and under 100°C under mid height. The fire is finally completely extinguished with water-hose.

4.3 Temperature evolution vs. time in the corridor through which the rescue teams come

Temperatures in the corridor show a different evolution until the first fan start. Under the ceiling where the smoke flows, temperatures increase up to 450°C close to the door and to only 200°C at the middle of the corridor. The flashover is clearly detected under the ceiling near the door by the sudden temperature increase from 200°C to 450°C. Temperatures 30cm above the floor remain at a low level, under 50°C, which is quite acceptable. The temperature under the ceiling at the middle of the corridor does show a clear evolution as the other temperatures under the ceiling close to the door and in the room do. This temperature shows a plateau until the global temperature decrease.

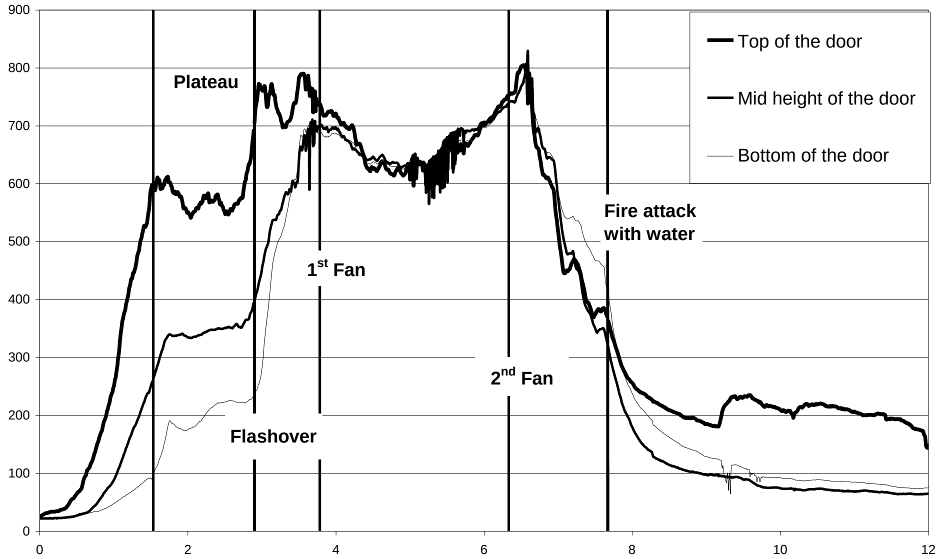

Figure 4: Temperature evolution vs time inside the room just near the door

When the first fan is started, the temperature under the ceiling near the door of the room shows a sudden decrease of 200°C from 450°C to 250°C. But this temperature increases again about one minute later indicating that fresh air drawn in by the first fan pushed up again the heat release rate due to oxygen brought in with fresh air. Consequently, only the first fan is not sufficient to draw out all the heat released by the fire.

Temperature under the ceiling at the middle of the corridor shows so clearly neither the fire evolution nor the effect of the mechanical ventilation. Nevertheless, this temperature shows that the conditions are quite acceptable for a fire fighters standing up in the corridor since the temperature at this location is at most 200°C. We must consider, in the direction of the flow of air and smoke created by the fan, this location is before the fire so only a little smoke is drawn back from the fire.

Temperatures above the floor near the door and at the middle of the corridor remain under 50°C all along the fire evolution showing that the smoke is clearly stratified which hot layer spread under the ceiling. At these location conditions are quite good for the fire fighters progressing on their knees.

1. Analysis of information from real time temperature measurements

Temperatures may be analyzed in several ways. In this study, temperatures are analyzed through large variations and sudden changes in level. These details are compared with the events during the test in order to draw out information about the fire evolution.

On figure 3, which shows temperature evolution just in front of the window inside the room on fire, four events can be identified from temperatures evolution: 1) the ignition until 500°C, 2) a plateau at 500°C, 3) a sudden temperature increase which is clearly a flashover, 4) another plateau around 850°C and 5) the temperature decrease under the overpressure ventilation and at end water hose.

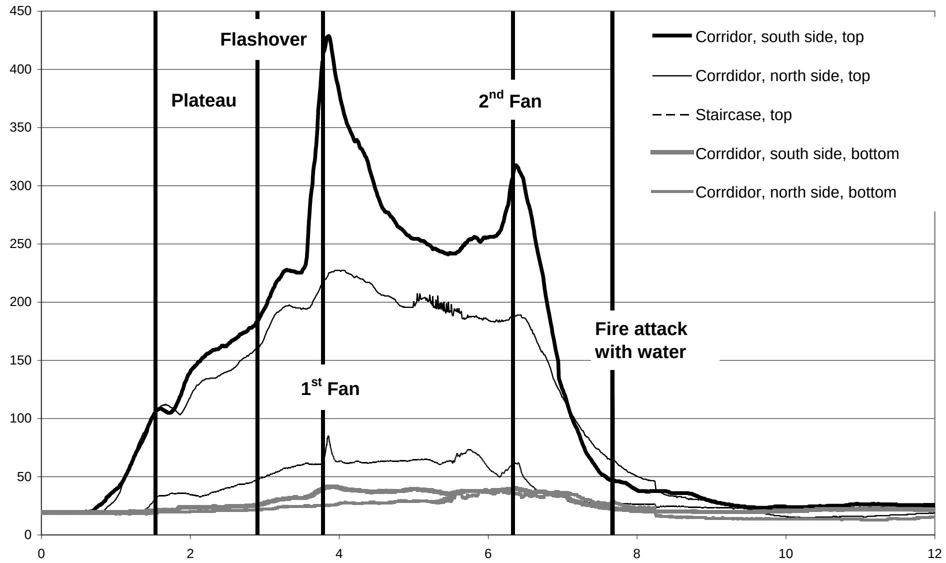

Figure 5: Temperature evolution vs time in the corridor through which the rescue teams come

These temperature allow to detect dangers, the possible flashover occurrence during the first plateau at 500°C, the flashover and the high temperature plateau around 850°C in spite of the first fan action. At the end these temperatures show the positive effect of the second fan start and at the end of the water-hose. It should be noted that temperatures at mid height are at similar level although the glass window has exploded.

Temperatures evolutions near the door inside the room, e.i. before the fire in the direction of the air and smoke flow created by the fan, show the same events but with besides a temperature decrease after the first fan start which does not last a long time. This brings to light that the first fan is not sufficient to control the smoke movement and draw them outside through a chosen way which is the window. Temperatures at this location, at mid height and above the floor which

are acceptable at the beginning for fire fighters become dangerously very high after the flashover and remain at this level until the second fan start.
Temperature in the corridor under the ceiling near the door shows similar evolution, as well. The flashover appears clearly. It is also clear that the first fan is not sufficient to decrease the temperature, in fact the fire is reactivated by the fresh air and some smoke flows back again under the ceiling. It is only when the second fan is started up that the temperature decreases which is clearly shown by the temperature decrease under the ceiling.

As a consequence, the temperature level and evolution become good indicators of the events which occur and of actions which are led. So it can allow to identify and show the dangers which can appear.
The method used to draw out the smoke so to draw out the heat released by the fire which is one of the most danger, is mechanical ventilation applied with portable fans. The temperature evolution at different locations shows the effect of the fans. There are two main decreases in the evolution of temperatures level under the ceiling from the staircase to the window. The first is produced by the first fan start but it does not last a very long time which means that the fan power is not sufficient to control the smoke movement in order to draw them out through the window and to prevent them to flow back to the corridor and to the staircase. It is only when we start up the second fan that a real control of the movements of smokes can be obtained. The temperature decreases everywhere including after the fire in the direction of the gas flow created by the two fans. If the temperatures are decreased as soon as we start up one fan then two fans it means that these temperatures can serve to estimate the efficiency of these fans.
In the same way, the temperature plateau at about 550°C after the growing phase is an indicator of the flashover risk. In this test, the flashover does not spread to the corridor because the window has exploded and due the overpressure created by the first fan even if it is not sufficient to completely control the smoke movement. The flashover develops outside through the window as shown in figure 6.

Figure 6: The flashover which develops outside under the overpressure effect created by the fans

The last thing shown by the evolution of the temperatures is the complete control of the fire at first when the second fan is started up and then when the extinction with the water hose has begun.

The analysis of this test shows that the measure of the temperatures in various places allows having information on the state of the evolution of the fire, on the efficiency of implemented means and on the risk with which fire fighters may have to face.
As a consequence one of the main applications which may be drawn from this study is to install in the new constructions temperature sensors connected with a control center which may be used by officers for decision support, and by the fire fighters progressing into the fire to immediately have more accurate information about their situation in the fire. This temperature information may allow improving the security and the efficiency of the fire men in their operation against compartment fires.

2. Conclusion

In compartment fires, smokes are a real danger for fire fighters, they also represent an important risk of propagation of the combustion because of their high temperature. But on the other hand, it is possible to draw some information to know about the situation of the fire and to know the effect that the actions led by the fire fighters. The distribution of the temperatures in the different spaces gives indications onto the place of the fire, onto its area(extent), and onto its evolution. When temperatures in the smokes are quite the same from top to bottom and at high level the fire fighters is probably not far from the measurement location. When temperatures are stratified from top to bottom with low level near the floor, fire fighters are probably in an air flow from outside or in a room where there is no fire. In this case, the high temperature under the ceiling is due to the smoke back layering or due to the spreading of the hot smoke layer in a room. It is well known that a plateau around 600°C is an indicator of a flashover occurrence risk. A global decrease of temperature followed by a temperature increase means that an action, such as mechanical ventilation or water-hose, is not really efficient, whereas a global decrease of several hundred degrees with no increase reveals the efficiency of the action led by fire fighters. As a consequence, temperature analysis during fire fighting operations may be a way to decision support if temperature sensors have been installed during the buildings or designed specifically for fire fighters conditions in compartment fire attack.

Acknowledgements

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HI2LO: A 3D unsteady code for the numerical simulation of shock wave propagation and dispersion phenomena in large scale heterogeneous media

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Abstract

This paper deals with the modelling and the numerical simulation of fluid dispersion in highly heterogeneous media such as cities, urban places, industrial plants and even countries. Examples of phenomena under study are chemical products dispersion from damaged vessels, gas dispersion in an urban place under explosion conditions, shock wave propagation in urban environment etc.
A 3D simulation code (HI2LO) has been developed in this aim. To simplify the consideration of complex geometries, an heterogeneous discrete formulation has been developed. When dealing with large scale domains, such as countries, the topography is considered with the help of elevation data. Meteorological conditions are considered, in particular regarding complex temperature and wind profiles. Heat and mass transfers on subscale objects, such as buildings, trees and other obstacles are considered too. Last, a high order numerical scheme in space and time is used to compute mass concentration of pollutant.

Keywords: Discrete model, heterogeneous media, compressible flows, dispersion.

1. Introduction

In many physical and industrial applications fast efficient computations are needed for safety studies. Two types of difficulties appear when dealing with such numerical simulations. First, the topology of the medium under interest may be very complex regarding the presence of many obstacles or objects of different types. Second, large disparities in both space and time scales often require attention. This is the case when dealing with the dispersion of gases from explosions in strongly heterogeneous media such as urban places, cities or hilly ground.

A new discrete model is proposed hereafter for highly heterogeneous gas dynamics flows. In this context, obstacles of very different sizes may be present. Large Eddy Simulation (LES) is no longer appropriate to solve the gas dynamics equations over such complex geometries, as the time to generate the mesh is prohibitive, as well as the computational time on long time scale events. Thus an homogenized model with cells of large dimensions containing obstacles is more appropriate [1]. This type of model belongs to the class of averaged multiphase flows models as described in [2, 3] but with a single phase, the other phases corresponding to obstacles being motionless. Such an heterogeneous model must consider the volumes occupied by the solid obstacles as well as their effects on the macroscopic flow dynamics. In this aim, the local pressure forces are determined by considering internal boundaries and specific Riemann solvers, or specific boundary solvers. In that sense, the method presented in this paper is quite close to embedded boundary methods (or cut-cell) approaches [4, 5] when dealing with the geometry description. It differs when very small obstacles are present, such as trees for which the exchange surface is not those of the cut-cell.
We summarize in the present paper the discrete model of [1] and complement it to mass concentration determination. In this aim, the high order ADER scheme is used to lower the numerical diffusion and handle correctly concentration fields. Last, mass diffusion and heat exchanges are introduced both at macroscopic and subscale levels.

2. The discrete model

The presentation begins with the inviscid multi species gas dynamics equations in the absence of mass diffusion that will be considered latter. To be concise, the non-dissipative model is addressed first for the sake of simplicity:

$$\frac{\partial \vec{U}}{\partial t} + \nabla . (\vec{F}) = 0 \tag{1}$$

$\vec{U}$ represents the conservative variables vector and $\vec{F}$ the flux vector,

$$\vec{U} = (\rho Y_k, \rho, \rho\vec{u}, \rho E)^T, \qquad \vec{F} = (\rho Y_k \vec{u}, \rho\vec{u}, \rho\vec{u}\otimes\vec{u} + P\bar{\bar{I}}, (\rho E + P)\vec{u})^T.$$

ρ, $\vec{u}$ and P represent respectively the mixture density, the velocity vector and the pressure. Y_k is the mass fraction of the chemical species k and E is the total energy, defined by,

$$E = \frac{\|\vec{u}\|^2}{2} + e(P, \rho, Y_k)$$

The thermodynamic closure of System (1) is given by the ideal gas equation of state for the mixture,

$$e(P, \rho, Y_k) = \frac{P}{\rho(\gamma - 1)} , \tag{2}$$

with the following definitions:

$$P = \sum_{k=1}^{N} P_k , \qquad \frac{1}{\rho} = \frac{T}{P}\sum_{k=1}^{N} Y_k C_{vk}(\gamma_k - 1), \qquad \gamma = \frac{\sum_{k=1}^{N} Y_k c_{pk}}{\sum_{k=1}^{N} Y_k c_{vk}} .$$

2.1 Integration on an heterogeneous control volume

System (1) is integrated on an heterogeneous control volume containing both fluid and solid, as shown in **Figure 1** and over a time step.
Space and time integration provide the discrete heterogeneous model. The procedure starts with,

$$\iint_{\Delta V \Delta t} \left(\frac{\partial \vec{U}}{\partial t} + \nabla \cdot \vec{F} \right) dt\, dV,$$

where V corresponds to the fluid volume within the cell, which is not necessarily equal to the cell volume, because of the possible presence of internal solid volumes.
The mass conservation equation is considered hereafter as a calculation example. The following integral has to be computed,

$$\iint_{\Delta V \Delta t} \frac{\partial \rho}{\partial t}\, dt\, dV + \iint_{\Delta V \Delta t} \nabla \cdot (\rho \vec{u})\, dt\, dV. \qquad (3)$$

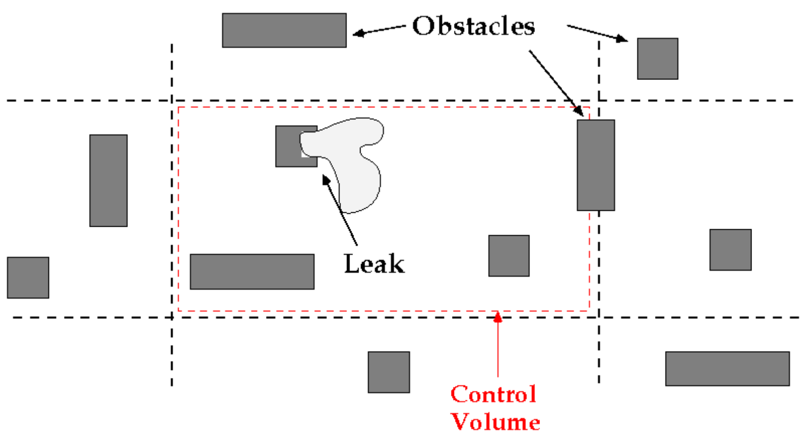

Figure 1. Representation of the heterogeneous control volume. Internal obstacles can potentially burst and let some gases escape within the cell.

Green-Ostrogradski theorem is used to transform the volume integral into a surface one. Typical surfaces to consider are shown in the **Figure 2** where $\vec{n}$ the outward normal vector for the fluid.

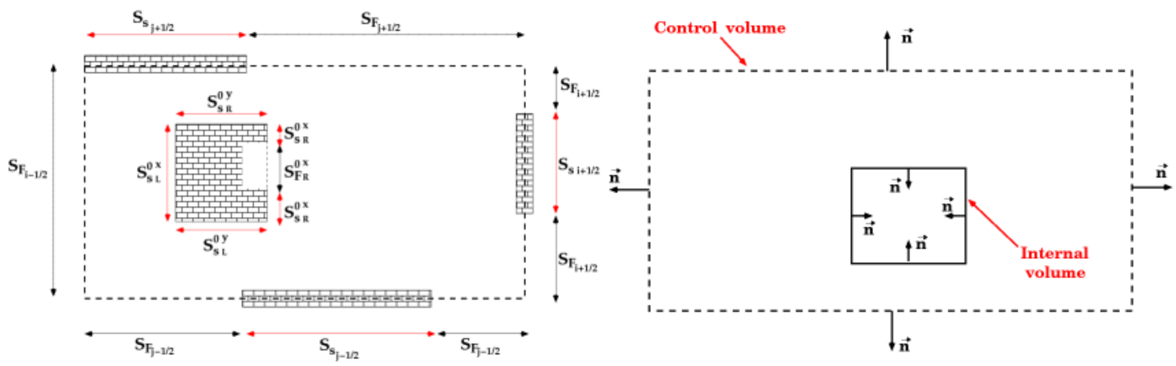

Figure 2. The left picture shows the integration surfaces which can be solid or fluid. The picture on right provides definitions for the outward normal vector.

The integration surfaces can be fluid or solid. Solids may appear inside the cell and at the cell boundaries. With the definitions of **Figure 2** it is possible to split the surface integral of Equation (3) in several parts,

$$S = S_F + S_S + S_F^O + S_S^O,$$

S_F and S_S are respectively, the fluid surface and the solid surface on the cell boundary. S_F^O and S_S^O are respectively the permeable surface and the solid surface contained within the cell. Thus,

$$\begin{aligned}
S_F &= S_{F,i+\frac{1}{2}} + S_{F,i-\frac{1}{2}} + S_{F,j+\frac{1}{2}} + S_{F,j-\frac{1}{2}} + S_{F,l+\frac{1}{2}} + S_{F,l-\frac{1}{2}},\\
S_S &= S_{S,i+\frac{1}{2}} + S_{S,i-\frac{1}{2}} + S_{S,j+\frac{1}{2}} + S_{S,j-\frac{1}{2}} + S_{S,l+\frac{1}{2}} + S_{S,l-\frac{1}{2}},\\
S_F^0 &= S_{FL}^{0x} + S_{FR}^{0x} + S_{FL}^{0y} + S_{FR}^{0y} + S_{FL}^{0z} + S_{FR}^{0z},\\
S_S^0 &= S_{SL}^{0x} + S_{SR}^{0x} + S_{SL}^{0y} + S_{SR}^{0y} + S_{SL}^{0z} + S_{SR}^{0z}.
\end{aligned} \tag{3}$$

For the mass conservation equation, the flux contribution related to the solid surfaces vanishes. Regarding fluid surfaces at cell boundaries, conventional Riemann problem [6] is solved to determine the fluxes. When dealing with internal obstacles, the same reasoning applies. Solid walls result in vanishing flux and a tank boundary condition is used if the surface is permeable. The fluxes integration thus results in,

$$\Delta t \int_S \rho(\vec{u}.\vec{n})dS = \Delta t \left\{ \begin{aligned} &\left((\rho u)^* S_F\right)_{i+1/2} - \left((\rho u)^* S_F\right)_{i-1/2} + \left((\rho v)^* S_F\right)_{j+1/2} - \left((\rho v)^* S_F\right)_{j-1/2} \\ &+ \left((\rho w)^* S_F\right)_{l+1/2} - \left((\rho w)^* S_F\right)_{l-1/2} + \sum \left\{(\rho u)^* S_{FL}^{0x} - (\rho u)^* S_{FR}^{0x}\right\} \\ &+ \sum \left\{(\rho v)^* S_{FL}^{0y} - (\rho v)^* S_{FR}^{0y}\right\} + \sum \left\{(\rho w)^* S_{FL}^{0z} - (\rho w)^* S_{FR}^{0z}\right\} \end{aligned} \right\} \tag{4}$$

The variables marked with the superscript "*" correspond to the ones computed at a cell boundary with the help of a Riemann solver. Thus, the discrete model for the mass equation reads,

$$(\bar{\rho}V)_{i,j,l}^{k+1} = (\bar{\rho}V)_{i,j,l}^{k} - \Delta t \left\{ \begin{aligned} &\boxed{\left((\rho u)^* S_F\right)_{i+1/2} - \left((\rho u)^* S_F\right)_{i-1/2} + \left((\rho v)^* S_F\right)_{j+1/2} - \left((\rho v)^* S_F\right)} \\ &+ \boxed{\left((\rho w)^* S_F\right)_{l+1/2} - \left((\rho w)^* S_F\right)_{l-1/2}} + \boxed{\sum \left\{(\rho u)^* S_{FL}^{0x} - (\rho u)^* S_{FR}^{0x}\right\}} \\ &+ \boxed{\sum \left\{(\rho v)^* S_{FL}^{0y} - (\rho v)^* S_{FR}^{0y}\right\} + \sum \left\{(\rho w)^* S_{FL}^{0z} - (\rho w)^* S_{FR}^{0z}\right\}} \end{aligned} \right\}. \tag{5}$$

It corresponds to a Godunov type scheme for heterogeneous cells. The fluxes related to the cells boundaries are marked in dashed lines while those related to internal volumes are marked with solid lines. The same calculation method is used for all the equations of System (1) to get the full discrete model. Some care has to be taken with the momentum equation. The calculation details are given in [1].

2.2 Validation of the discrete model

<u>2.2.1 Interaction of a shock wave with obstacles</u>

The model is tested over some significant experimental flow configurations. The interaction of a shock wave with solid plates inside a square cross section shock tube is considered. The experimental configuration is shown in the **Figure 3**. Internal obstacles in the discrete formulation are used to model the vertical plates.

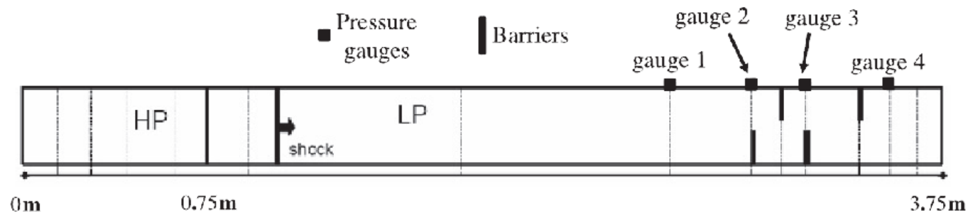

Figure 3. Experimental configuration of shock tube with vertical obstacles.

Vertical plates of two different sizes have been used in the experiments: plates of surface *A*/4 and *A*/2, where *A* is the tube cross section. Pressure gauges located at different places are considered to get pressure profiles versus time.

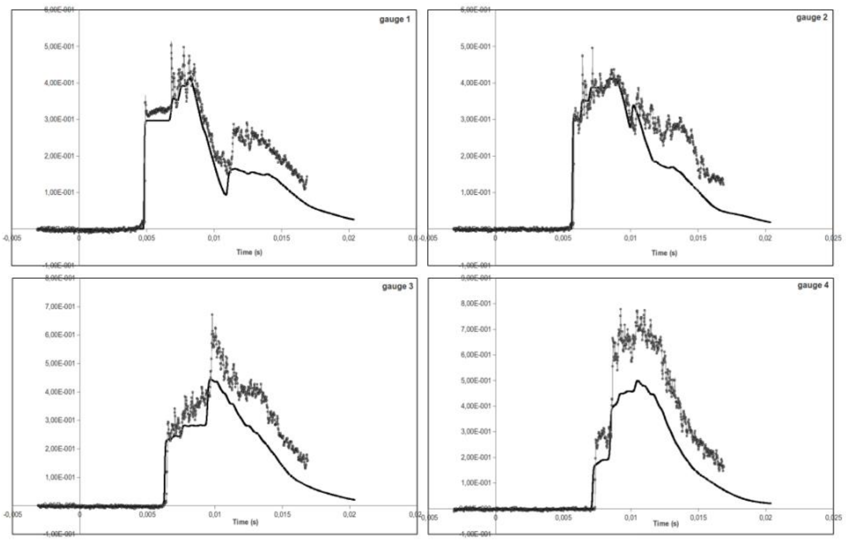

Figure 4. Pressure signals obtained with HI2LO (lines) compared to the experimental ones (symbols) at 4 different locations in the shock tube. The vertical obstacles have a surface equal to A/2 and the shock wave Mach number is 1.1.

Figures 4 and **5** show the recorded and computed pressure signals at the various stations. Note that the computed pressure corresponds to an averaged value and not to a local one, such as the measured one. Good agreement is obtained, particularly regarding the wave dynamic that is well reproduced. The computed results are obtained with a very coarse mesh as it involves 4 cells only in each cross section.

<u>2.2.2 Blast wave in an urban canyon</u>

In this section, the propagation of shock wave between two parallel walls is studied. The experimental data of [7] have been used. The aim is to compute wave propagation from an explosion located between two walls of varying heights. The experimental configuration is shown in **Figure 6.**

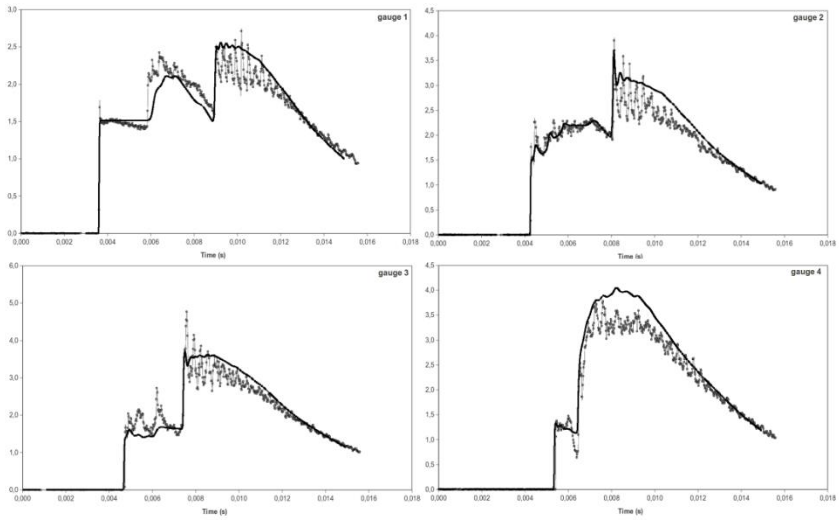

Figure 5. Pressure signals obtained with HI2LO (lines) compared to the experimental ones (symbols) at 4 different locations in the shock tube. The vertical obstacles have a surface equal to A/4 and the shock wave Mach number is 1.5

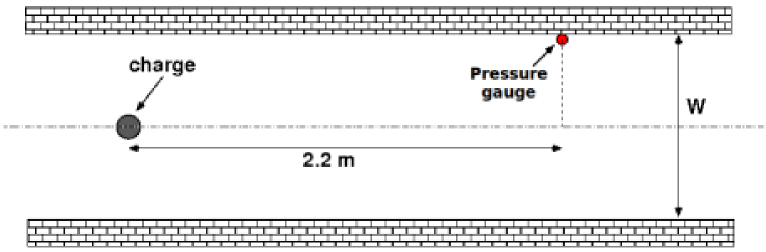

Figure 6. Blast wave in urban canyon experimental configuration.

A constant volume explosion is used to model the charge with an equivalent TNT equal to 1.32 (more details are given in [7]). Two configurations are studied, summarized in the **Table 1**. The results are shown in the **Figure 7,** where the pressure signals for each case are plotted. Experimental results and numerical ones are in a good agreement. In particular the wave dynamics and amplitudes are correct.

Table 1: Experimental configurations for urban canyon blast waves.

Case	Street width: W(mm)	Obstacles height: H(mm)
(a)	400	150
(b)	400	600

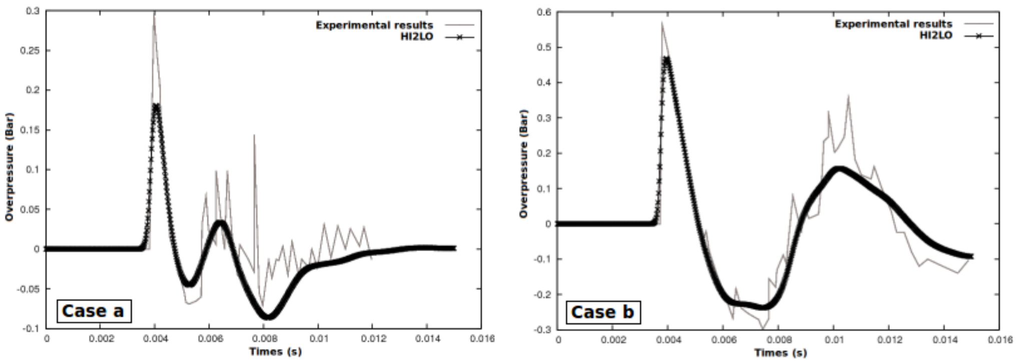

Figure 7. Comparison of pressure records with HI2LO (symbols) and experimental ones (lines).

3. A high order scheme for the concentrations: ADER

The aim is now to track pollutant concentrations in the same type of heterogeneous media as previously. The use of a first order finite volume scheme results in huge numerical diffusion and forbids the correct prediction of concentration fields. The solution we have considered consists in using a third order version of the ADER scheme [8,9] for the mass concentrations. In Section 4, physical diffusion phenomena will be included.

3.1 The ADER scheme

The ADER scheme allows the determination of a high-order flux to be used in a finite volume type scheme. This scheme was introduced in [8,9] and is based on the resolution of the Generalized Riemann Problem (GRP) [6]. It also uses polynomial reconstruction of the variables [12-14].
In the present approach the mass fraction equations only are solved with the third order ADER scheme for simplicity reasons as well as numerical cost. Let's define by $q = \rho Y_k$. The generalized Riemann problem is given by the following Cauchy problem, in the one-dimensional case,

$$\frac{\partial q}{\partial t} + \frac{\partial f(q)}{\partial x} = 0, \text{ with } f(q) = qu. \tag{6}$$

$$q(x,0) = \begin{cases} p_i(x), & x < 0 \\ p_{i+1}(x), & \text{else} \end{cases}$$

$p_i(x)$ and $p_{i+1}(x)$ are the Newton polynomials of order K respectively in cells i and i+1. In the conventional Godunov method, the variables are piecewise constant functions, while they are now piecewise polynomial functions, as shown in **Figure 8**: The solution of the Cauchy problem (6) is given by the time Taylor series expansion:

$$q_{i+1/2}(\tau) = q(0,0) + \sum_{k=1}^{K} \frac{\partial^k}{\partial t^k} q(0,0) \frac{\tau^k}{k!} \tag{7}$$

With $q(0,0^+)$ denotes the solution of the conventional Riemann problem. The successive time derivatives have to be expressed in term of the spatial derivative with the help of Equation (6).

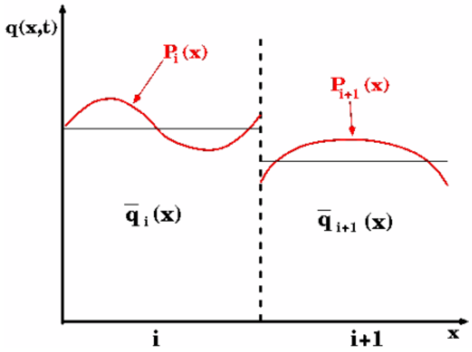

Figure 8. Polynomial reconstruction is used for variable q in each computational cell.

It is necessary to get an evolution equation for these derivatives. It is possible to show that all spatial derivatives satisfy the following equation,

$$\frac{\partial q_x^{(k)}}{\partial t} + \left(\frac{df}{dq}\right)\frac{\partial q_x^{(k)}}{\partial x} = 0, \tag{8}$$

where $q_x^{(k)}$ represents the k[th] spatial derivative. To express the fluxes at the cell edges, several Riemann problems have to be solved, for the variable q and for its derivatives as shown in the **Figure 9**.

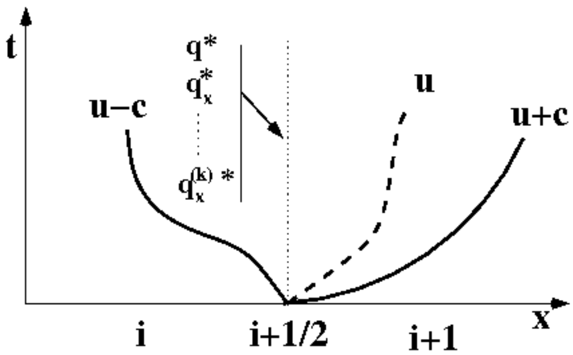

Figure 9, Structure of the solution of the generalized Riemann Problem in x-t plane. The waves are curved, contrary to the classical case

After solving the Generalized Riemann Problem the fluxes are computed with (7). As shown latter, this scheme improves considerably transport equations solutions.

3.2 Algorithm summary and numerical examples

The ADER scheme can be summarized as:

- Compute variable polynomial reconstruction in each cell.
- Determine the cell variables at each cell boundary.

- Solve the conventional Riemann problem for the leading order solution.
- Solve the Riemann problem for spatial derivatives.
- Compute the flux time integral.

Results obtained with the third order ADER scheme are now compared with those obtained with others schemes on a basic test problem. It consists in the transport of a Gaussian profile at a constant velocity. Several schemes are considered:

- The Godunov first order scheme [6].
- The MUSCL-Hancock higher order scheme [6].
- The ADER third order scheme.

The transport velocity is equal to 1 m/s and the mesh contains 100 cells. Periodic boundaries conditions are used in the computations. All the results are compared with the exact solution. **Figure 10** shows the Gaussian function after 10 s of physical time. **Figure 11** shows the results after 100 s. When using the first order scheme, the Gaussian function disappears quickly, while the higher order schemes preserve better the Gaussian shape. Nevertheless, the MUSCL Hancock method tends to deform the Gaussian function while the third ADER scheme keeps the right shape.

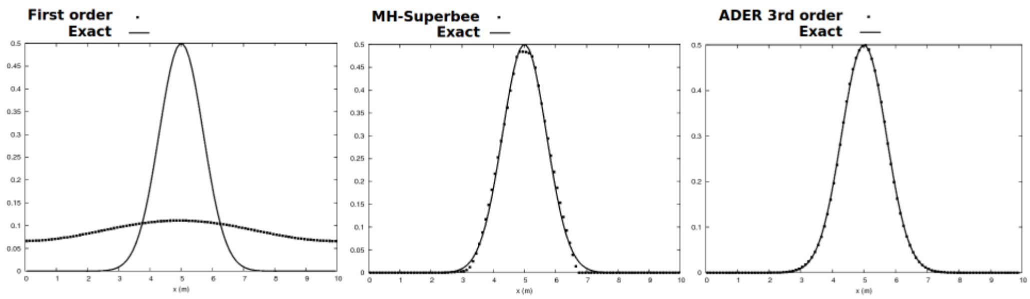

Figure 10. Gaussian profiles obtained with three different schemes (symbols) compared to the exact solution (lines) at time t =10 s.

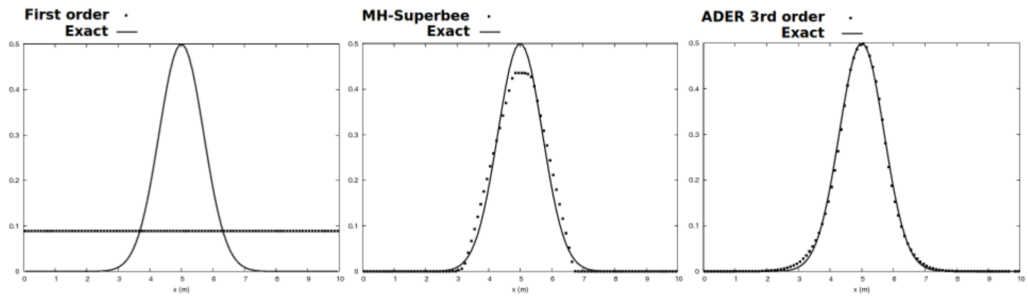

Figure 11. Gaussian profiles obtained with three schemes (symbols) compared to the exact solution (lines) at time t =100 s.

These results clearly show that the ADER scheme is very accurate for the present application involving dispersion phenomena.

4. Diffusion phenomena

As the numerical diffusion is now correctly managed by the ADER scheme, it is interesting to consider physical diffusion phenomena such as the molecular one, or the turbulent one, as well as heat transfer. Details on the way these phenomena are considered are given hereafter.

4.1 Molecular diffusion

The formulation given in [15] is used. A diffusive flux appears in the mass fraction evolution equations. These fluxes imply an additional term in the total energy equation. Let us rewrite these two equations as,

$$\frac{\partial \rho Y_k}{\partial t} + \nabla \cdot \left(\rho Y_k \vec{u} + \vec{F}_k \right) = 0 \tag{9}$$

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot \left((\rho E + P)\vec{u} + \vec{Q} \right) = 0 \tag{10}$$

With the following definitions,

$$\vec{F}_k = \sum_{k=1}^{N} C \vec{d}_l, \quad \vec{d}_k = \frac{1}{P}\left\{ \nabla P_k - Y_k \nabla P \right\}, \quad \sum_{k=1}^{N} F_k = 0.$$

$$\vec{Q} = \sum_{k=1}^{N} h_k F_k, \quad h_k = \frac{P_k}{\rho_k} + e_k(P_k, \rho_k)$$

C is a diffusive coefficient and P_k is the partial pressure of species k. When using these definitions, it is possible to show that the system satisfies the entropy inequality. These terms allow to model turbulent diffusion (with an appropriate diffusive coefficient) but also mass deposition on solid surfaces by imposing the mass flux, or a mass exchange coefficient at the walls. To illustrate the influence of the diffusive terms, two computations are made in two limit situations: without and with diffusion. We consider an array of solid obstacles in a uniform wind. An internal obstacle is also present, one of its faces being permeable and connected to a tank condition containing the pollutant (see the left picture of **Figure 12**).

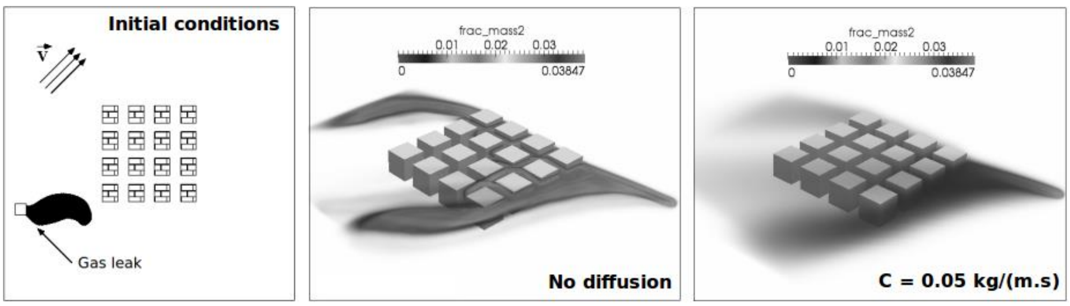

Figure 12. The initial and boundary conditions are sketched on the left figure. The mass fraction of pollutant at time t =3 s is shown in the middle figure when mass diffusion is omitted and on the right figure when it is considered. Both concentration fields are computed with the ADER scheme.

Part of our future work will be devoted to the selection of optimal diffusion parameters, in order to retrieve the conventional solutions for atmospheric dispersion of neutral pollutants, accounting for meteorological boundary conditions and stability classes.

4.2 Heat transfer

To model heat transfer, conductive heat flux is added to the total energy evolution equation (equation (10)) which become,

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot \left((\rho E + p)\vec{u} - \vec{q} \right) = 0$$

with $\vec{q} = \lambda \nabla T$ the heat flux and λ the thermal diffusivity. This last equation is integrated on the control volume depicted on **Figure 2**, resulting in heat fluxes at the cell boundaries as well as heat exchange terms at the solid surfaces.

5. Very large scales

The same formulation is used to compute flows at very large scales on natural topographies, such as those of a country. The dissipative effects are now modelled as turbulent ones with appropriate correlations. Elevation data are used to reproduce the topography. Some results of large scale computations are shown. Two chemicals species are used in these computations, with a logarithmic wind profile. The burst of an obstacle on hilly ground is studied. An internal obstacle connected to a tank boundary condition is used to model burst effects. The tank pressure is equal to 5 atms. Numerical elevation data are used to reproduce part of Corsica Island. **Figure 13** shows the position of the internal volume responsible for the polluting source.

Figure 13. Position of the polluting source and wind orientation

In the **Figure 14** and **Figure 15**, the mass fraction of the pollutant is plotted at different instants with two different angles of view. The effects of topography on the wind direction are visible.

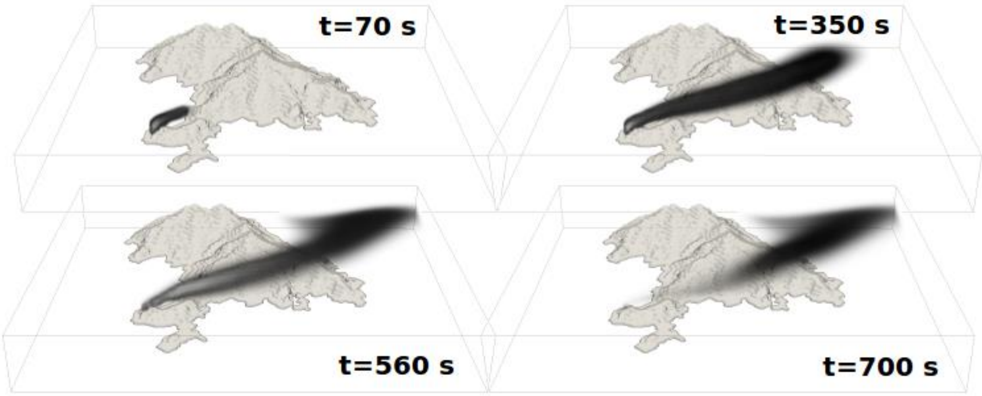

Figure 14. Evolution of the concentration field from the polluting source (side view)

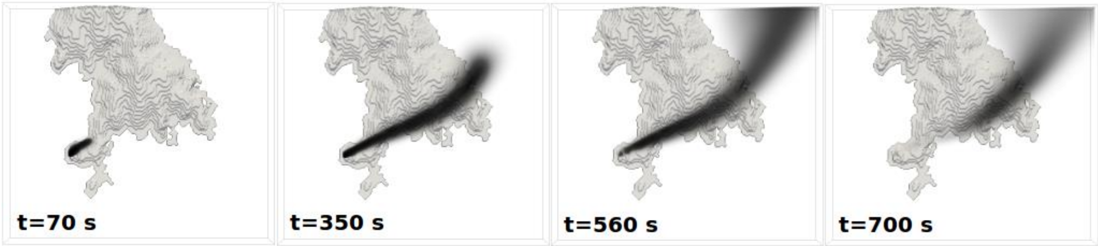

Figure 15. Evolution of the concentration field from the polluting source (top view).

5. Conclusion

A 3D computer code has been built to consider highly heterogeneous media such as cities, hilly ground or other specific geometrical domain. Its structure and formulation enables the consideration of complex domains quite easily. The physics considered at present corresponds to gas mixtures, with transport, wave propagation, heat and mass diffusion, at molecular and turbulent levels. The code HI2LO is parallel. It is planned to extend its capabilities to two-phase flows and low Mach number flow conditions.

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Industrial Risks and Land use Planning – Study of blast window resistance

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Abstract

Technological Risk Prevention Planning (PPRT) is a French tool for managing land-use planning near upper-tier SEVESO industrial facilities. Its purpose is to protect the population against industrial hazards. Risk limitation measures may include for example window reinforcement for new or existing blast risk exposed buildings. In order to better define technical guidelines for window reinforcement, INERIS developed an innovative experimental device. INERIS has studied window behaviour and has evaluated blast capacity of different kinds of glass panels (monolithic or insulated glasses with or without anti-explosion film, laminated glasses...), mobile frames or window locking or anchorage systems. Results show that all window components have to be considered to improve safety.

Keywords: PPRT, window, blast loading test

1. Introduction

Most of experimental studies consider blast loading with high intensity and short duration simulating detonating devices. Moreover they have mainly focused on the behaviour of monolithic glass panels (annealed or tempered). Weisman et al. [1] or Giltaire and al. [2], [3], [4] studied the response of monolithic or laminated glass subjected to blast shock wave within a short time (inferior to 10 ms). Coevert and al. [5] also studied security window film and insulating glass panel to high intensity blast load with a positive duration of approx. 1 ms to 10 ms.

In this paper, INERIS presented tests results of window subjected to a blast loading from accidental explosion characterized by a low intensity (20-50 mbar) and long duration (100 ms). These tests allowed to:

- Evaluate blast load capacity of different insulating glass panels
- Study the response of the whole window taking into account glass, frame, locking and anchorage system;
- Identify what the weak points are;

2. Experimental device

Tests are realised at a tunnel extremity. Window is fixed on rigid steel test frame. Steel and wood panels are placed on test frame around the window. It forms with tunnel walls a 25 m^3 box. An explosive charge is placed at the center of the box.

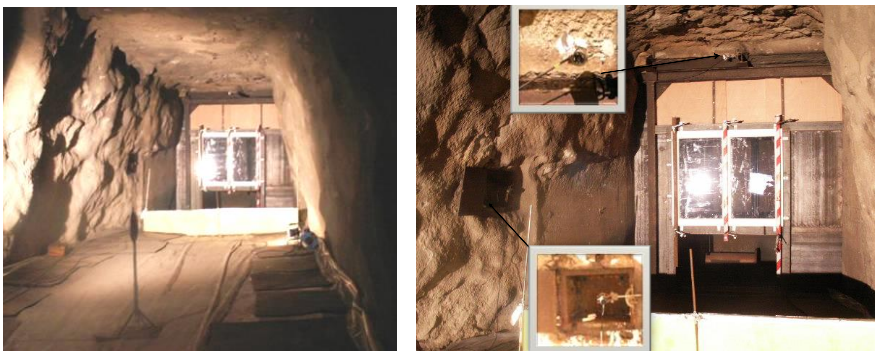


Figure 1: Experimental device outsideface

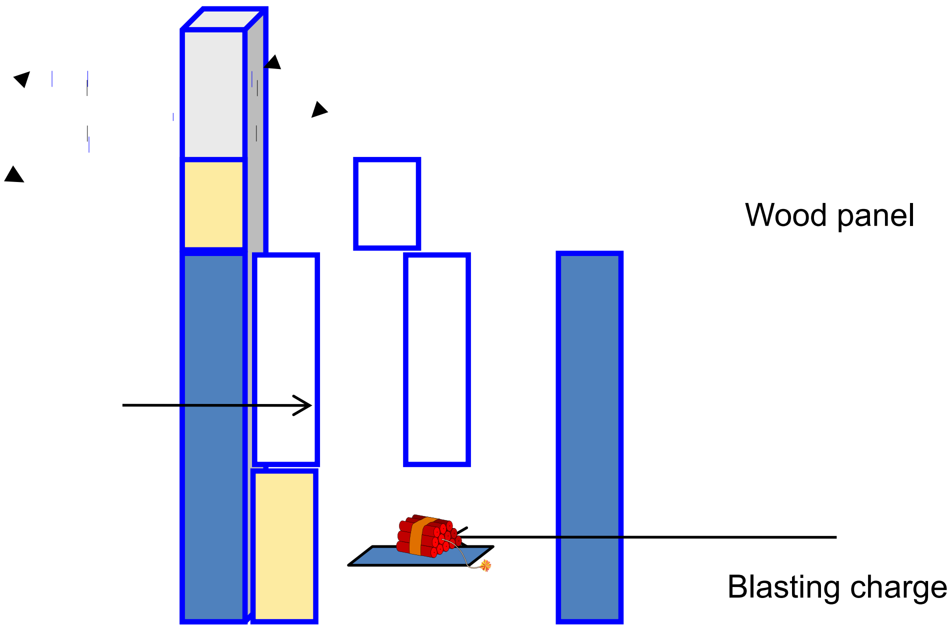


Figure 2: Schema of experimental device

Two pressure gauges record the blast load magnitude and time development impinging the window. One gauge is placed on the room floor. The other one is positioned on test frame near the window.

Figure 3: Blast pressure gauge

3. Tested windows

Tests allow to study:

- The blast capacity resistance of 1.20 m x 1.05 m different glass panels
  - Annealed insulating glass 4/16/4
  - Insulating glass 4/16/4 with daylight or wet-glazed security window film
  - Insulating glass fabricated with laminated glass 44.2/8/44.2

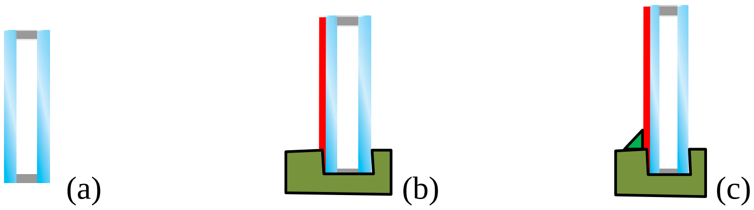
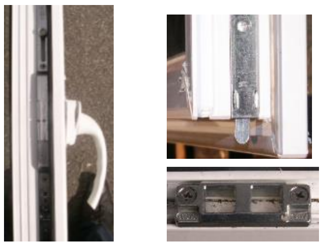


Figure 4: (a) Insulating glass, (b) insulating glass with daylight security window film, (c) insulating glass with wet-glazed security window film

- The behaviour of 1.40 m x 1.20 m French style inwards opening double window composed of
  - PVC frame and standard locking system
  - Wood frame and reinforced locking system



1 and 2 - – standard locking system (catch + strike)

Figure 18: Standard locking system window

2 - Reinforced locking system (catch + strike)

Figure 5: Reinforced locking system window

4. Results analysis

The evaluation of glazing performance is done in accordance with the evaluate hazard rating criteria in **Table** [6]

Table 1: Hazard rating criteria for tests

Hazard rating	Hazard ratio description
A	**No break**
B	**No Hazard**
C	**Minimal hazard**
D	**Very low Hazard**
E	**Low hazard**
F	**High hazard**

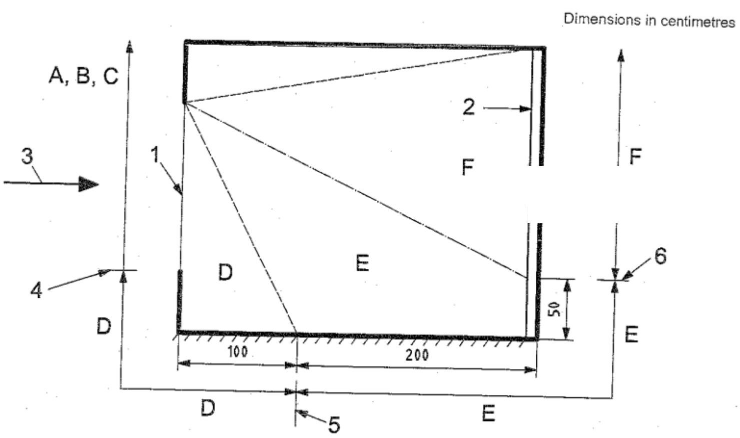


Figure 6: Cross-section through witness aera

Glazing shall be considered as “blast-resistant” only if it achieves a “minimal hazard” rating C or safer.

A complete window is considered as “blast-resistant” only if:

- Glass achieves a “minimal hazard” rating C or safer.
- Window is still fixed to frame after the test
- Mobile frame are still closed after the test
- None piece of window is projected outside

5. Experimental results and discussion

5.1 Blast capacity resistance of glass panel

An initial series of [20-50 mbar] overpressure peak tests was performed to study the resistance of different glass panels. All panels were a 1.08 m x 0.60 m.
Tests results are given in **Table** and **Table** .

Table 2: Glass panels subjected to blast load (part 1/2) – Results of blast tests

N°		**1**	**2**	**3**
Glass		4/16/4 Annealed Insulating glass		4/16/4 Annealed Insulating glass + Wet-glazed security window film
Dimensions of glass panel		h=1.08 m l= 0.60 m	h=1.08 m l= 0.60 m	h=1.08 m l= 0.60 m
Characteristic of blast wave	**Incident peakoverpressure (mbar)**	20-25	35-50	45-50
	Positive phase duration (ms)	> 500 ms	> 500 ms	> 500 ms
Hazard level		A	F	A

Table 3: Glass panels subjected to blast load (part 2/2) – Results of blast tests

N°		**3**	**4**
Glass		4/16/4 Annealed Insulating glass + daylight security window film	44.2/8/44.2 Laminated Insulating glass (annealed glass)
Dimensions of glass panel		h=1.08 m l= 0.60 m	h=1.08 m l= 0.60 m
Characteristic of blast wave	**Incident peakoverpressure (mbar)**	50-55 mbar	65-70
	Positive phase duration (ms)	> 500 ms	> 500 ms
Hazard level		F	A

Table shows that annealed insulating glass panels resist an incident of 20-25 mbar overpressure for hundreds of ms equivalent triangular duration. There was no damage to the glass. However increasing overpressure to 35-50 mbar causes the same glass to break (Figure) with most fragments projected up to 3 m (**Figure**).

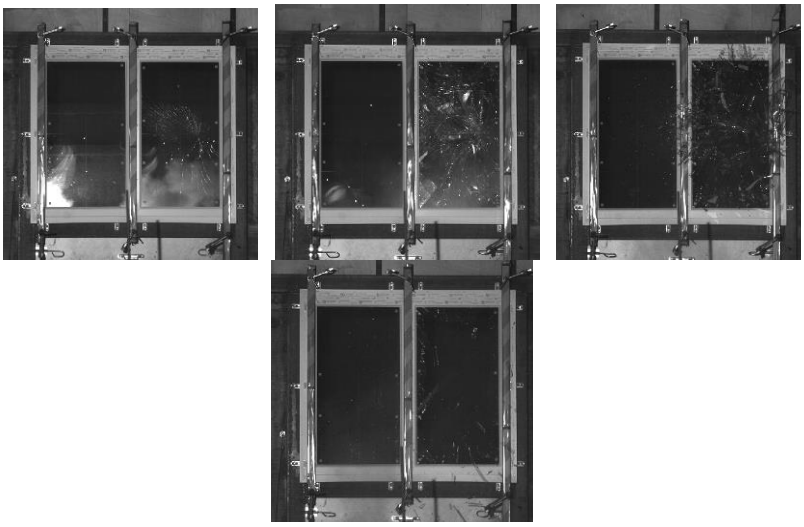


Figure 7: Insulating glass subjected to a blast wave

Figure 8: Fragments landed on the floor – zone 0-3 m

Insulating glass with a security film was also tested. This kind of film is applied internaly. Glass panel with a window film did not resist to a [20-50 mbar] blast load. During the blast The “Inner” pane was projected in one piece 2 meters from the window and the outer pane shuttered projecting pieces up to 3 m from the window. (Figure and Figure).

On the other hand the use of wet-glazed window film does improve glass resistance. In that case, the glass does not shutter and the film stays on the frame. There is no glazing hazard (B rate).

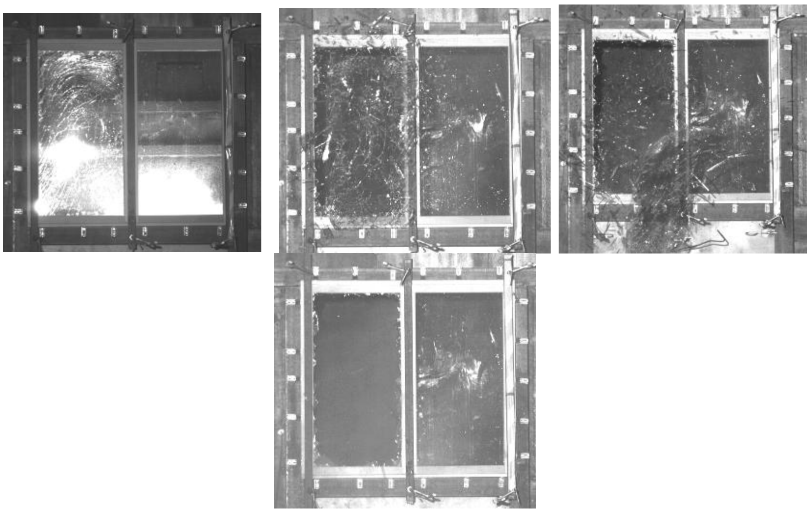


Figure 9: Annealed Insulating glass with daylight security window film subjected to blast wave

Figure 10: Annealed Insulating glass with daylight security window film – Post test

Another blast test also show that insulating glass made with laminated glass resists to a 50 mbar blast incident overpressure with a hundred milliseconds equivalent load duration.

Figure 11: Annealed Insulating glass with wet-glazed security window film – Post test

5.2 Blast capacity resistance of windows

A second test series studied the response of a French style inwards opening double window to a blast wave: resistance of the anchorage system, the fixed and mobile frame or locking system. All windows have a 1.25 m x 1.40 m^2 size. Test results are given in Table and **Table** .

Table 4: Window subjected to blast load (part 1/2) – Results of blast tests

Dimensions of window		h=1.25 m x l= 1.40 m	
Opening window		French style inwards opening double window	
Anchorage system		Standard anchorage system : angle brackets clipped to the window and fixed to the structural framing	Reinforced anchorage system with angle brackets
Locking system		Standard locking system (catch + strike)	Standard locking system (catch + strike)
Frame		PVC	PVC
Glass panel		4/16/4	4/12/44.2
Blast wave	**Incident peakoverpressure (mbar)**	20-25	55-60
	Positive phase duration (ms)	> 500 ms	> 500 ms
Results		Deformation and rupture of anchorage system Rupture of frame Opening the window Projection of the window between 1 m and 2 m	Opening the window Rupture of mobile frame Projection of the window casement between 2 m and 3 m

Table 5: Window subjected to blast load (part 2/2) – Results of blast tests

Dimensions of window	h=1.25 m x l= 1.40 m	
Opening window	French style inwards opening double window	
Anchorage system	Reinforced anchorage system with angle brackets	Reinforced anchorage system with angle brackets
Locking system	Standard locking system (catch + strike)	Reinforced locking system Individual closure of the openings
Frame	Wood	Wood
Glass panel	4/16/4	44.2-8-44.2

Blast wave	60-65	65-70	65-70
	> 500 ms	> 500 ms	> 500 ms
Results		Opening the window Rupture of mobile frame Projection of one of the opening at approximately 2 m	Mobile frames remain closed Glass panels intact

The inward opening window has a standard anchorage system constituted of 6 angle brackets (**Figure**) which are clipped to the window and screwed to the structural frame. Test results show that this system is not sufficient to resist a 20 mbar incident overpressure blast wave. **Figure** shows deformation of angle brackets, an opening of window and a projection of the window between 1 m and 2 m.

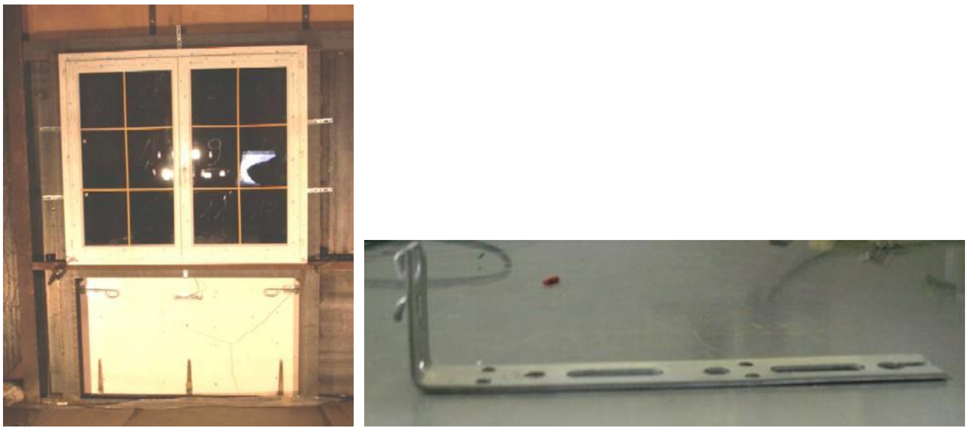


Figure 12: Window fixed with angle bracket (at left) – Angle bracket (at right)

Figure 13: Response of window to blast wave (at left) - Angle bracket after the test (at right)

For the second test the anchorage is reinforced in order to retain the window to the structural frame. Window is subjected to a 50 mbar incident overpressure. It does not resist either but the weak points have changed as shown in **Figure** , the mobile frames were broken and projected between 1 and 2 m. However fixed frame remained screwed to the building. The use of wood frame produces the same test results (**Figure**).

Figure 14: Projection of mofile frame of French style inwards opening window composed with PVC frame (at left) or wood frame (at right) and a common locking system (catch and strike)

Given the results of previous tests, a French opening window with a reinforced locking system illustrated in Figure was tested. The window is composed of wood frame, laminated insulating glass and a reinforced anchorage sysem. It was subjected to a blast wave with a 50 mbar incident overpressure and an equivalent positive phase duration of hundreds milliseconds. Tests results showed that the configuration resists. The Glass panel was intact, The frame remained closed and attached to the frame (**Figure**).

Figure 15: French style inwards opening window with reinforced locking system, laminated glass and reinforced anchorage system subjected to blast wave – Photography after blast test

6. Conclusion

These experimental tests have produced new data on the response of windows subjected to a low incident overpressure and a long duration (hundreds of milliseconds) blast load.

Blast loading tests showed that a wet-glazed security window film improves the insulating glass panel resistance. Laminated insulating glass is also a good technical solution. However it is not sufficient to have a resistant glass panel. Reinforcing locking system and anchorage system are also recommended. All window elements have to be considered to improve safety.

Thanks to an experimental study and a theoretical analysis INERIS produced a practical guide [7] giving elements for improving the integrity of window subjected to a blast load**.** For instance, this guide gives recommendation on type and size of glass panel that can be used for various blast wave intensities and various blast wave types (deflagration or shock wave). It also indicates requirements for the locking system, the design and the number and position of the anchorage points.

Acknowledgments
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Technological Risk Prevention Plans (TRPP) – Specific studies to estimate the building's vulnerability due to overpressure, thermal and toxic effects in Haute Normandie

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Abstract

Efectis France is one of the important actors of TRPP. He has written the technical prescription guidelines for buildings exposed to thermal effects in the goal to protect occupants inside the buildings, called the stakes. Since 2008, EFECTIS France has performed for public (or private customers) specific studies to assess the buildings vulnerability exposed to overpressure effects, to transient or continuous thermal effects and to toxic effects. In Haute Normandie, EFECTIS France has realized this kind of studies for the Port Jérome TRPP, for LUBRIZOL TRPP closed Rouen and the one of Le Havre TRPP is in course (including more than 100 stakes after a first selection realized by authorities). EFECTIS France will present the methodology used for the specific studies of vulnerability. The different steps for each building are: identification of all dangerous phenomena impacting the building, physical characterization of buildings, vulnerability analysis including reinforcement prescriptions and inherent costs. For the regional studies, EFECTIS France will present the application of this methodology for existing buildings.

Keywords: Technological Risk Prevention Plans, building's vulnerability, overpressure effects, thermal effects, toxic effects

1. Introduction

Technological Risk Prevention Plans (TRPP) called in France PPRT (Prevention Plans of Technological Risk) are performed to manage urbanism in the vicinity of industrial establishments all over France in order to protect population. For

that, the TRPP needs to estimate the building’s vulnerability (with the aim of protecting occupants inside the buildings) in case of accidental phenomena produced by SEVESO plants.
Especially, specific studies must be performed to evaluate the impact of overpressure, thermal and toxic effects on buildings (called the stakes) near these SEVESO sites.

For these applications, EFECTIS France has produced for the French ministry, the technical prescription guidelines for buildings exposed to thermal effects.
Since 2008, EFECTIS France has performed specific studies to assess the building’s vulnerability exposed to overpressure effects, to transient or continuous thermal effects and to toxic effects. Most of these studies are performed for public customers as DREAL (Direction Régionale de l'environnement, de l'Aménagement et du Logement, old denomination) / DRIRE (Direction Régionale de l'industrie, de la Recherche et de l'Environnement, new denomination). Using conclusions of these vulnerability studies DREAL/DRIRE define the best strategy to adopt for each stake issue concerned by the TRPP field. Some specific studies are realised for private customers when administration procedure is in progress.

In a first part, we will present vulnerability studies performed by EFECTIS France, works in progress and possible future work. A focus will be made in Haute Normandie region.
In a second part, we will present the methodology which is applied to realise all the vulnerability studies taking into account overpressure effects, transient or continuous thermal effects and toxic effects.

In a third part, we will present an application of this methodology for an existing building. This stake is an administrative building exposed to overpressure effect, continuous thermal effect and toxic effect. For this building, the intensity of worst effects is quantified, the constructive dispositions are characterized, its vulnerability is determined, thus the adapted reinforcements with its inherent costs, are proposed.

2. Vulnerability studies realised, works in progress and possible future works

Since 2008, EFECTIS France has performed for public (or private customers) specific studies to assess the buildings vulnerability exposed to overpressure effects. More than 25 studies have been achieved in different regions in France (including overseas areas) and between 5 and 10 vulnerability studies are in progress (Figure 1).

For the specific Haute Normandie region, two vulnerabilities studies have been achieved (Figure 2, blue circles):

- Port Jérôme TRPP closed to Notre Dame de Gravenchon including :
  - more than 50 industrial buildings
  - 4 public buildings
  - 5 sample habitations

- Lubrizol TRPP closed to Rouen including
  - 8 industrial buildings
  - 4 dwellings buildings

For the specific Haute Normandie region, one vulnerability study is in progress: Le Havre TRPP, for which EFECTIS France has a contract to study (Figure 2, red circle):

- more than 60 industrial buildings

- 2 public buildings
- 9 sample habitations

Finally, for the specific Haute Normandie region DREAL Haute Normandie is preparing a new TRPP in the Rouen area concerning lots of buildings:

- more than 600 industrial buildings,
- 20 public buildings
- 3 000 habitations

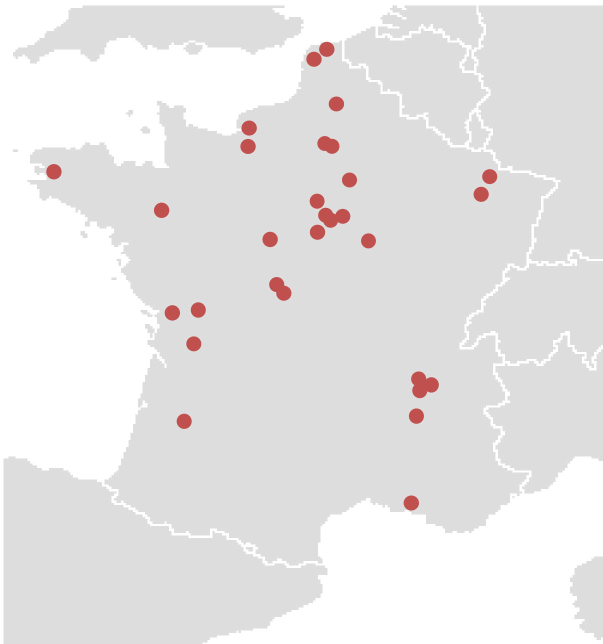

Figure 1. Main TRPP studies realised by EFECTIS France till 2012

Figure 2. TRPP studies performed or works in progress by EFECTIS France till 2012

3. Methodology applied to perform vulnerability studies

Vulnerability studies are realised using the following methodology:

- To quantify the intensity of worst effects of investigated buildings
- To characterize the investigated buildings
- To characterize its vulnerability
- To propose reinforcements
- To assess the inherent costs

3.1 To identify and to quantify the intensity of worst effects of investigated buildings

DREAL/DRIRE establishes different maps for overpressure effects, to transient or continuous thermal effects and to toxic effects in the whole area of the TRPP. For each stake and each effect (thermal, overpressure and toxic), they give the range of intensity according to the appropriate guideline.

For each building the first step of our work consists to quantify the worst intensities due to overpressure effects, to transient and continuous thermal effects and to toxic effects. For each effect, physical rules are used to determine the precise intensity of the effect on the stake in accordance with technical studies realised by the SEVESO industrial building at the origin of the phenomena.
More precisely, different parameters are estimated:

- For the overpressure effect: overpressure intensity, duration, shape of the signal (blast or shock wave) and façade of the stake which is the first impacted by the pressure wave.
- For the continuous thermal effect: thermal intensity and façades of the stakes which are impacted.
- For the Boiling Liquid Expanding Vapor Explosion (BLEVE) or other transient thermal effect induced by fire: thermal dose, duration and façades impacted during the aggression

- For the Unconfined Vapour Cloud Explosion (UVCE) or Vapour Cloud Explosion (VCE) transient thermal effect (flash-fire) : duration and area of the stake impacted
- For the toxic effect: calculation of the attenuation coefficient (ratio of the toxic cloud concentration and the irreversible effects threshold) for the stake

3.2 To characterize the investigated buildings

The physical characterisation of each building is realised by visits of the building and by collect of plans or information provided by the owner or the lodger. During the visit, different investigations are conducted:

- Photographic report inside and outside the building
- Measurements of the global building and the structure of the building
- In case of toxic effect, identification of a potential confinement room
- Generic information such as the specific activity of the building, the maximum number of people inside (outside) the building …

These investigations have not to be destructive. As a consequence, if documentations are not available and observations are insufficient, only verbal information of the owner or the lodger is taken into account. If all these information are not sufficient, assumptions proposed on the different guidelines are used to complete the physical characterisation.

3.3 To determine the building vulnerability

Knowing the characterisation of the building and the worsts effects impacting it, the vulnerability can be studied by:

- Simplified approaches using data and tables presented on the different national guidelines according to the overpressure effects, transient or continuous thermal effects or toxic effects.
- Advanced approaches where advanced calculations are necessary to conclude.

Moreover, to evaluate the impact of one effect on one specific part of the stake, it is considered the effect do not challenged all the other parts of the building. For instance, when studying the impact of the overpressure effect on the global structure of the building, it is supposed that façades and roof stay in place and that all mechanical efforts received by these elements are transferred to the structure of the building:

For overpressure effects, both the intensity and the duration of the effect are taken into account on the analysis. Different methods can be used:

- Empirical approaches giving the impact of the effect on the structure using database (simplified approach)
- Analytical approaches calculating a constraint level on the structure which is compared to the failure constraint limit of the building (semi-advanced approach)
- Numerical calculations using a finite element method (FEM) to study the structural behaviour of the building (advanced approach)

- For thermal effects, both the intensity and the duration of the effect are taken into account on the analysis. Different methods can be used:
- Using database of the thermal guidelines (simplified approach, for incident fluxes less than 8 $kW.m^{-2}$)
- Calculation of the thermal heating of facades and roof using 1D FEM software to calculate the heat transfer by conduction (advanced approach, for incident fluxes less than 12 $kW.m^{-2}$)
- Calculation of the tenability condition inside the building using Computational Fluid Dynamics (CFD) software to calculate the temperature on the volume inside the building (advanced approach)
- For toxic effects, different steps are necessary:
- During the visit or by analysing plans, locate a confinement room
- Provide a first technical diagnostic taking into account the identified room and the global stake (size, dilapidation, general organisation inside the stake …)
- Determine the n50 (air change rate at 50 Pa) value taking into account the attenuation ratio through tables of guidelines (especially for residential buildings) or calculations (Specific tools developed by French Ministry)
- Realise in situ measurements of the n50 using a blow door

- These parts will allow knowing the impact of all effects on glasses, roof, facades, building structural stability, tenability conditions inside the building …
- Verification criteria are as follow:
- For structural deformation due to an overpressure effect, two parameters are analysed: the ductility ratio and the rotation angle at the boundaries. Criteria are given on Table I according to [7].

Table I: Criteria for the structural deformation due to an overpressure effect

Structure Type	**Ductility ratio (-)**	**Rotation angle (°)**
Steel beam	10	2
Concrete wall (mechanical resistance function)	10	2
Concrete or brick wall (no mechanical resistance function)	-	1
Steel panel on façade	1.75	1.25

Moreover considering a structure composed of beams and columns, the global stability of the structure is acceptable if the following criterion is verified:

$$\frac{\delta}{H} < \frac{1}{25} \tag{1}$$

Where δ the maximum displacement of the structure and H is the height of the building.

- For condition tenability due to thermal effects, criteria are given by thermal guideline [2]:
  - Inside ambiance temperature less than 60°C
  - Inside wall flux less than 2.5 $kW.m^{-2}$

- Degradation temperature of combustible component of the façade upper than the façade heating
- Critical temperature of other materials upper than the façade heating

These criteria can be adapted by taking into account the specificity of each building and especially, the location of people and fire loads inside the building.

- For condition tenability due to toxic effects, the analysis consists in comparing the calculated n50 value with the in-situ measurement if available.

3.4 To propose reinforcements and to estimate inherent costs

According to the vulnerability of the building and to the objectives that have to be reached, reinforcements are proposed such as changing or protecting glasses, reinforcing columns or beams, adapting or creating confinement rooms, adding insulation on façades … In accordance with the DREAL/DRIRE, different levels for the reinforcement are proposed from a global reinforcement to a reinforcement of a single room of the building.
Costs of these reinforcements are also estimated. These estimations will be used by the authorities in order to take a decision for the strategy to apply for each building (global or single reinforcement, to repurchase the building …).

4. Application of this methodology for an existing building

This chapter presents the application of the methodology for an existing building of a TRPP of 34 stakes (Figure 3).
The presented stake is an administrative building located inside an industrial site where different risks have been identified from SEVESO industrial buildings such as VCE, UVCE, jet flames, toxic gas leakages …

Figure 3. Map of all stakes of the TRPP and localisation of the studied stake

4.1 Identification and quantification of worst effects on the building

Using global phenomena maps given by DREAL/DRIRE, the different worsts effects for the administrative building are as follow:

- For the overpressure effect, the building is located inside the deflagration / chock wave intensity and duration levels of 35 – 50 mbar and 20 – 100 ms.

- For thermal effects, only continuous aggression occurs. The building is located inside 3 – 5 kW.m^{-2} thermal intensity range.
- For toxic effects, the building is located inside the CL1% area, corresponding to the lethal concentration of the gas mixture studied.

Analysing all phenomena and maps, characteristics of worst effects are determined by EFECTIS France:

- For the overpressure effect, the worst phenomena are 2 UVCE leading to deflagration of 37 mbar during 162 ms in the Est/Nord direction.
- For thermal effects, the worst phenomenon is a fire pool due to a canalisation break leading to a thermal solicitation of 3.4 kW.m^{-2} on Est wall.
- For toxic effects, the worst phenomenon is induced by a leakage on an ammonic storage. It leads to a concentration of 3 400 ppm closed to the stake.

4.2 Characterization of the investigated building

The physical characterisation of the building has been realised by visiting the building and collecting plans and information.

This administrative building is a two level steel structure with offices and staff parts. Façades are composed of steel sandwich panel (Figure 4) with thermal insulation plus plasterboards on inside walls. There is a phonic isolation on the staff part. The roof is composed of steel sheet without thermal isolation and there is a false ceiling. All windows are double-glazed on an aluminium frame opening inside the building. Finally, doors and sectional doors are present on façades.

The indicated confinement room identified during the visit is the refectory located on the ground level with a habitable surface of 29 m², a height of 2.7 m with a false-ceiling and plasterboard insulation on walls. There are windows on the interior walls but also on the façade. This room includes water and it is near water closed.

Figure 4. One façade of the studied stak

4.3 Characterization of the building vulnerability

Knowing the characterisation of the building and the worsts effects impacting it, the vulnerability is studied considering one effect by one effect.

For overpressure effects,

- The nature of the façades and the range of the aggression show that these façades are non-vulnerable (due to especially to the presence of plasterboard on walls and of the important fixation points on it).
- Nevertheless, calculations show that the structure of the building is vulnerable due to the range of the aggression (Figure 5). More especially, the criterion δ /H </1/25 is not respected.
- Taking into account steel purlins on the roof, it is vulnerable because the ductility ratio is upper than 10 (criterion non respected).
- According to the guidelines, all glasses of windows and all glasses of doors are vulnerable due to the range of the aggression

For thermal effects,

- The nature of the façades and the range of the aggression show that these façades are non-vulnerable (due to especially to plasterboard and/or thermal insulation on walls and façades)
- In the staff part where only a single sheet is present, heat transfer calculation show that the ambient conditions inside this part are at a temperature less than 60°C. As a consequence, this part of the building is not vulnerable too.

For toxic effects, the surface of the room and the volume of the room allow determining the permeability per unit area equal to 10 $m^3.h^{-1}.m^{-2}$ at 4 Pa [10]. Calculations using CONFINE give values of n50 between 2.3 to 4.1 $vol.h^{-1}$ according to different external boundary conditions. The n50 measured on the refectory is 41 $vol.h^{-1}$.

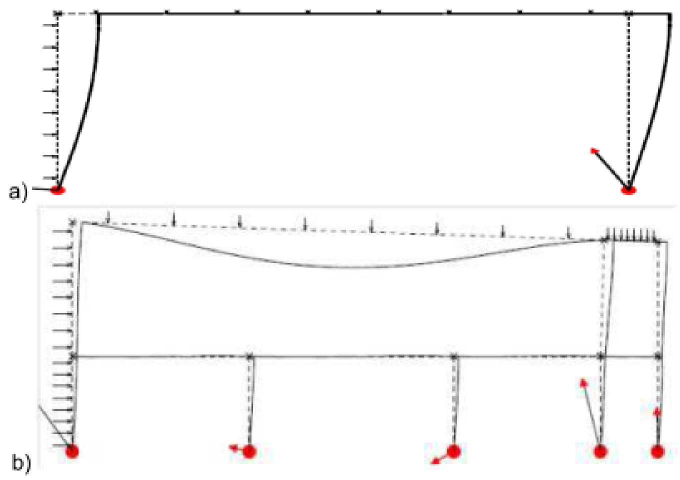

Figure 5. Deformation of the building due to the worst overpressure effect a) staff part b) offices

4.3 Reinforcements and inherent costs for the studied stake

Knowing the vulnerability of the stack, different reinforcements can be proposed and the inherent costs can be estimated.
To prevent overpressure effects,

- Complementary columns can be added for each frame: complementary FEM calculations allow determining sections of these complementary profiles (IPE 360 and IPE400 according to the location inside the building) to reduce the displacement/height ratio.

- Complementary purlins can be added on the roof each 1.5 m to reduce the ductility ratio.
- An anti-fragment membrane can be applied on all glasses of windows and doors

For thermal effects, no reinforcement is necessary for this stake.
For toxic effects, due to the poor permeability of the refectory room, lot of reinforcements are necessary such as:

- To add doors and partition walls to create airlock space
- To replace existing doors and windows
- To close all leakages as cables paths (draught proofing)
- To reinforce the false-ceiling using plasterboard plus air insulation
- To add survey equipment

The range of costs for these reinforcements can be summarized on the Table II. The elementary costs are based on building commercial list [12].
DREAL/DRIRE will compare these costs to the estimated value of the stake in order to define the best strategy to adopt. Particularly, one can imagine that only a part of the identified reinforcements can be realised in order to prevent a specific risk.

5. Conclusions

Technological Risk Prevention Plans are in progress in France in order to evaluate the impact of accidental phenomena of SEVESO sites on third parties.
Vulnerabilities studies are technical reports that physically characterize each stake and define reinforcements taking into account accurate intensities received by the stack. Inherent costs are also defined and can be compared to the market value of the building.

Table II: Range of costs for the different reinforcements proposed

Building part	**Range of costs (€ HT)**
Structure (columns)	16 200
Roof (beams)	11 100
Façades	0
Doors and windows	31 800
Confinement room	22 300
Total	82 400

In that context, these vulnerability studies are realized in order to help authorities to define and to choose the strategy to adopt for each stake taking into account the location of it inside the perimeter of the TRPP, the identified risks in terms of probability and intensity, its activity, the number of people concerned, the reinforcement costs, the building market value …
Moreover, these technical studies are indicative reports. These studies can be updated by the authorities, the owner or the lodger taking into account complementary information on the physical characterization, reduction of impacted intensity due to reduction of certain risks, changing a part of the strategy of the TRPP

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Mobile Ad-Hoc Network Designed to Communicate During Crisis

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Abstract

When a natural or industrial disaster occurs, communications become crucial both for rescue teams and for alerting populations. When local or global infrastructures are damaged or destroyed, communication and alert systems rely on temporary infrastructure that has to be powered-supplied but also carefully positioned in order to cover the whole area within which rescue teams operate. While unavoidable for long-term coordination of the different rescue actions, such a system may require a relatively long time for setting it up, incompatible with the first hours. Having a ready-to-use communication system during the first hours is a necessity. Mobile ad hoc networks (MANET) may be one solution for providing such an emergency communication system. The current work is an attempt to measure qualitatively and quantitatively the performances and the reliability of mobile ad hoc networks in real world environments.

Keywords : Networks, MANET, communication

Introduction

The French Normandy region is rich of many highly sensitive and dangerous industrial [1] as well as natural sites, more than half are located in Le Havre and its surrounding. The Direction of the information about Major Risk (DiRM) of the urban community of Le Havre city have in charge to think about and to propose solutions for all aspects of risk prevention and management and crisis management. In particular, DiRM continuously tries to improve its alert systems by developing and adding new vectors of communication to inform the population in case of disaster. However, today, all communication solutions are based on infrastructures and in case of major damage in the neighborhood of the disaster, infrastructure might be out of order and GSM-like networks, if still up, might be overloaded or blocked, weakening the whole alert system.

Many scenarii have been envisaged [2], [3], and the unavailability of classical infrastructure based communication networks for whatever reasons constitutes a critical one. Indeed, the absence of communication infrastructure usually means that coordination between actors would be difficult. In addition, in such situations people belonging to rescue teams are continuously moving making the transmission and exchange of information more tricky. While the installation of temporary infrastructure could appear as one solution, it requires: time to be set up, power-supply capacities available in the neighborhood of the initial problem and the distribution of relevant devices for the members of rescue teams.

An ad hoc network may be defined as an infrastructureless network of wireless-enable communicating devices (stations, sensors ...) and this could be an complement of the different communicating systems for managing risk. If the stations are mobile they constitute a mobile ad hoc network (MANET).

This has been discussed with the head of DiRM and all the listed elements lead them to look for alternative solutions, both ready and easy to use, decentralized, self-powered and lightweight for people participating in the rescue action, and they agreed for testing MANET-based solutions. One of their requirements for the project was to have an evaluation of the behavior of such networks in real environments. We focus our attention on the neighborhood of stations and in particular on the sensitivity of this neighborhood to various endogenous as well as exogenous conditions. Our interest for the neighborhood comes from the fact that many algorithms, protocols and applications are neighborhood-dependent.

The goal for risk management application

Until very recently, DiRM has deployed infrastructure-based alert and information systems, but the perspective of having more adaptable communication systems lead them to identify two types of final use depending on the capacity of the MANET:

Alerting population: relying on existing siren system of alert the goal would be to couple that sirens with wireless-enable devices in order to be able to broadcast warning information to stations belonging to the MANET. The mobile application is able to catch this information, to inform directly the user of the device and to perform a local broadcast of this information to the neighbors.

Supporting communication between risk actors: for this use, the purpose is to provide a geolocalized information sharing service.

Civilian population alert
Alerting people via MANET means as a matter of fact broadcasting information in a peer-to-peer way. The release would be made by the siren system of DiRM equipped with wireless interface working in ad-hoc mode. This system would emit an alert on a specific network at the same time as the sound alert. In a second time, these sirens would then play the role of static stations activating the alert on mobile stations located in or passing through their covered area.

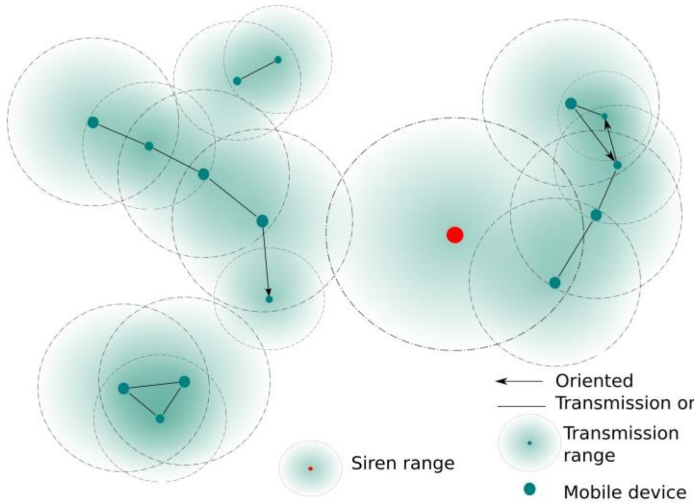


Figure 1: Siren alert context

From neighbors to neighbors, mobile stations periodically broadcast the alert message, according to their movement, new stations are met and reached by the information, allowing a fast propagation of the alert in the network. Moreover, the process is also robust since no station plays a central role and any station may appear or disappear at any moment without endangering the broadcasting process.

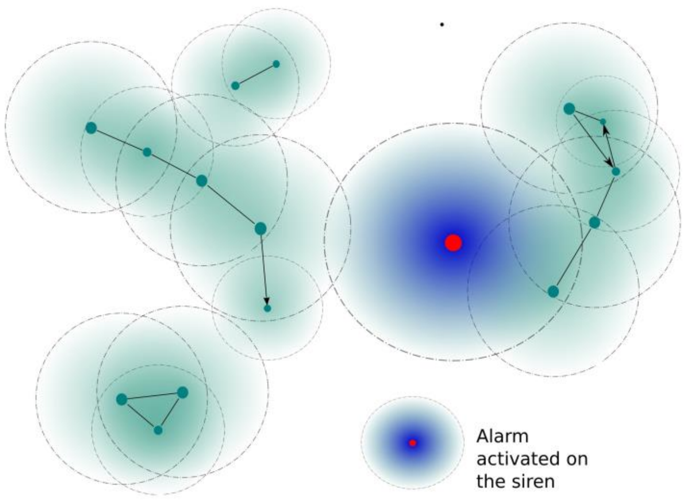


Figure 2: Mobility effect on network topology

This type of scenario is realist in dense urban area where the sound propagation is constrained by buildings and subject to hazard like wind. However, in such environments the density in mobile devices is generally high, counterbalancing the harmful effects of wind and buildings. Finally, relying on devices composing MANETs allow the alert messages to be more explicit than a simple warning, more relevant information including local maps, short messages, up-to-date informations may be transmitted.

Maintain a spontaneous network between risk actor

During an incident, rescue teams have to acquire, transmit and exchange very quickly a significant number of information (localization, type, gravity, possible injured person, etc.). One of the central ideas in this context is to exploit the capabilities of MANET devices to broadcast and exchange information between rescue teams which would be equipped with such devices.

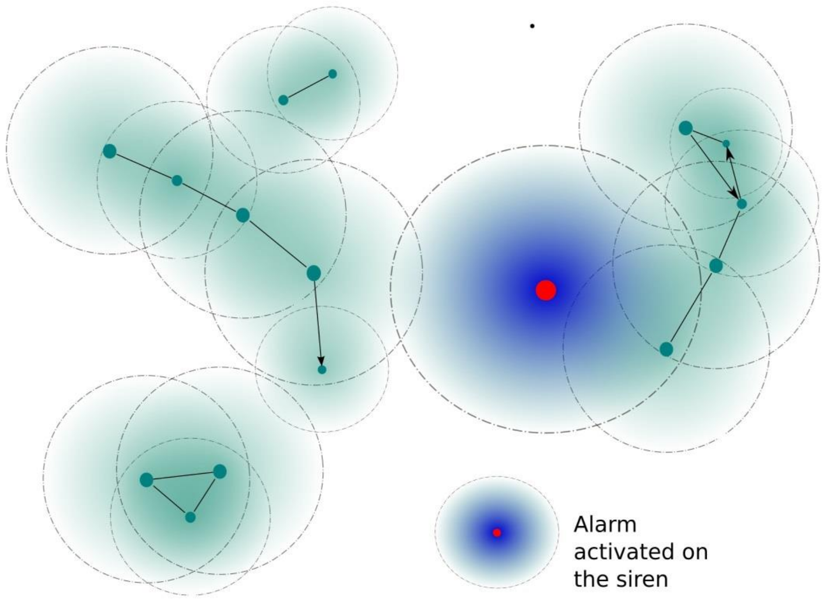


Figure 3: New nodes warned by the alert

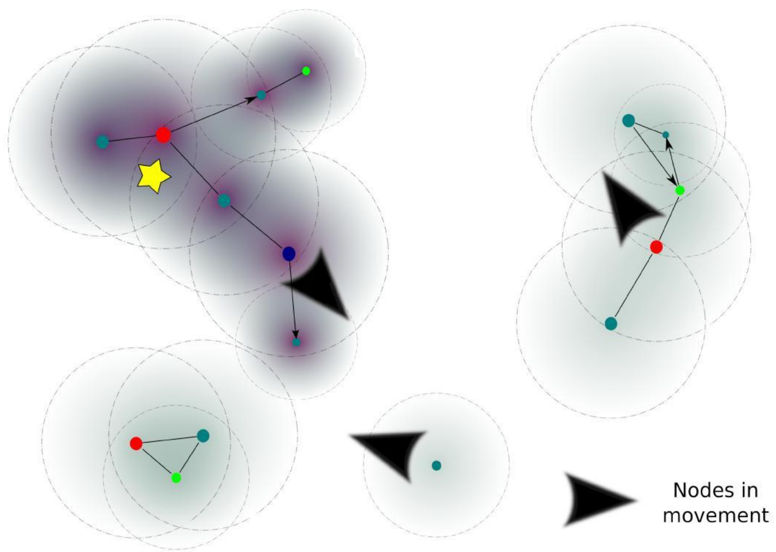


Figure 4: Information flooding to the neighborhood

Every participant possesses a wireless-enable mobile device (Pocket PC, PDA, smartphone, etc.). Every participant belongs to a group, Emergency Medical Service, Fireman, Police, etc., and can consult the information circulating on the network according to his group. Any participant may take photos, may provide oral or written notes, may annotate local maps and then share part of or the whole material. Note that all these application have already been implemented and are operational [4–6]. According to the various movements, the information propagates in the network. The information can then be run for those belonging to the relevant groups. The data are of two types: spatial localization and information about the problem: description, photo or oral message.

Of course, the quality and the fluidity of the broadcasting process depends on the properties of the neighborhoods of the stations: stability, cardinality, etc. The remaining part of this article will focus on that particular point.

Related works

On the risk management

The idea to use MANET technology in the context of natural or industrial disaster is recurrent and not new [3]. It is motivated by the fact that rescue actors of a crisis search the best ways to exchange and gather information using the most suitable communication vectors. Some experiments have demonstrated the abilities of wireless networks to deliver some services in disrupted environments [2]. However, these experiments do not study the limitations of MANETs and for the authorities of DiRM having some elements about the expected quality of the network is essential, both from the robustness point of view and from the service point of view. The evaluation of the network is unavoidable especially for emergency situations.

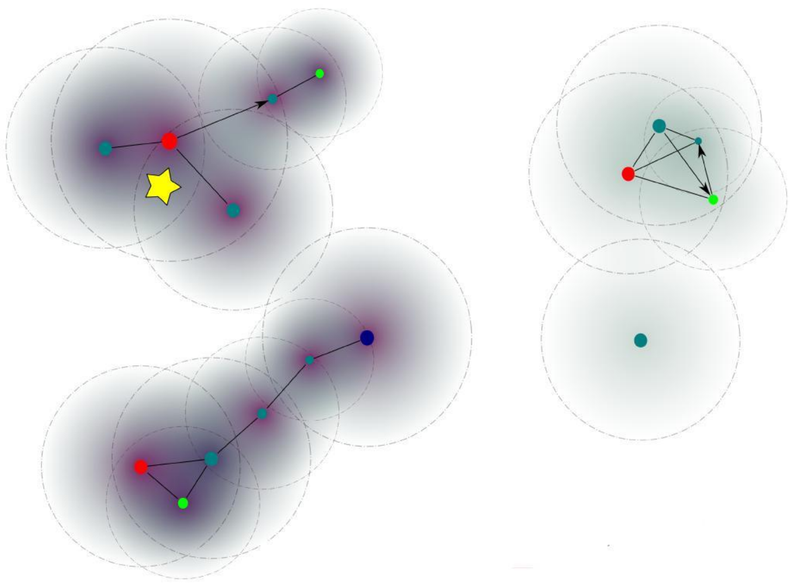


Figure 5: New rescue nodes informed about the hazard

About MANET experiments

Many of wireless networks testbeds were mostly designed for bandwidth and protocol efficiency measures. These experiments focus mainly on local results about the delay, packet loss [7], [8] or link quality [9], but only a few [10] try to understand the evolution of network topology, even in the static case, evolution caused by the instability of the connection between two nodes. Moreover, tests are usually run on indoor static networks composed of desktop computers and very few has been done on outdoors networks composed of small wireless electronic devices. For instance, in [11], real networks were tested with up to 49 nodes in a reduced indoor environment but, like large scale testbeds [8], all devices had external power supply and powerful processors. The experiments with limited mobile devices are extremely rare and study neither classical measures nor topology changes, they mainly focus on strategies for transferring data in a multihop way. Finally, in general protocols for MANETs are simulated, and most often are not validated on real ones [12].

This led us to think about an experimental protocol for testing properties of real outdoors MANETs under various conditions. For that purpose, we have built a software layer, kind of communication middleware, intended to help the stations to self-connect and self-configure in order to participate in existing MANETs. Our approach may be called ``bottom-up".

In the context of our work, the application should not require much bandwidth. So, in addition to bandwidth, we focus our analyze on more relevant measures like: the real range of communication for mobile devices, battery limitation and signal strength of network. We are convinced that a careful study of these measures will allow us to reach a better level of knowledge on the way such networks are working and to improve their quality from a communication point of view.

The MANet layer

A complete framework for testing MANET has been developed. It was primarily designed for Windows Mobile-based devices but a version for Android platform has been also developed. The framework consists mainly in a dynamic library, functional today on Windows Mobile from Win 2003 to the last Windows Mobile. The objective of this layer is twofold. On the one hand it allows the station to automatically set up sets of parameters for entering an existing MANET and, on the other hand, it enables a careful observation and logging of the connections and communications of this station.

1. This layer interacts at different levels of the mobile device architecture :
2. management of the system;
3. management of the power of the IEEE 802.11 interface;
4. settings of the wireless interface (channel, bssid, time of scanning...);

5. IP setting (randomly chosen);
6. network connection and disconnection;
7. communication management (receive, send message).

An additional piece of software manages operations of message emission and reception. To identify uniquely each node, it uses its IMEI [14] number. Communications are based on the UDP protocol. This choice was motivated by the fact that UDP supports packet broadcasting, and wireless communications in MANET consist mainly in broadcast operations since all nodes in the range of the emitting device can listen for the message. Finally, as exchanges are based on information broadcasting, IP addresses are useless, so IP addresses have been randomly attributed (no address at all would be correct also).

Two types of message are considered: HELLO messages are intended to help stations to build and maintain neighborhood information and ``classical" messages that contain application-specific data (see figures 7 and 8). As UDP communications are limited, in volume, to 1472 bytes, messages of the latter type are again divided in two classes identified by the header, a first class for small messages (up to 1472 bytes) and a second class for large messages (more than 1472 bytes). In this latter case, upon reception, the message is rebuilt (later detailed). We have limited the size of the packet to 1024 bytes.

In the framework, three threads operate simultaneously. One thread is associated to the emission of HELLO messages and to the management of the list of neighbors (let us call this thread the neighbor-thread. Another thread (emission-thread) is dedicated to the emission of application messages and a last one, the reception-thread, to the reception of all messages (HELLO and application).

Each time reception-thread receives a HELLO message, it timestamps the message and transmits it to the neighbor-thread. This one periodically updates the list of neighbors by removing neighbors for which HELLO messages have not been received for a given time, the discovery time (2 seconds for our tests), and by updating the last-reception date of neighbors for which an HELLO message has been received. Neighbor-thread periodically sends HELLO messages figure 7 containing its network identifier `ID`, its number of neighbors and the list of identifier of its neighbors v_i.

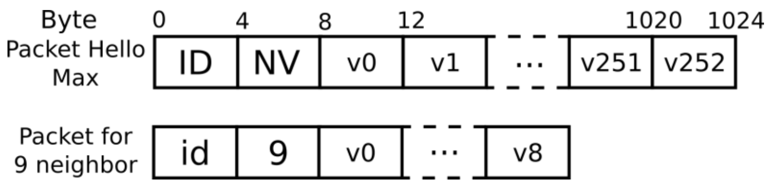


Figure 6: Hello packet

14 International Mobile Equipment Identity

The reception-thread discriminates HELLO messages and application messages. The former are transmitted to the neighbor-thread while the later are processed. Short messages are made of only one packet while long messages are composed of several packets.
A packet is composed of two parts: the header and the data. The header is made of the identifier of the source (`ID`), the number of the message (`TID`) and the number of packets (`PID`) if the packet belongs to a long message.

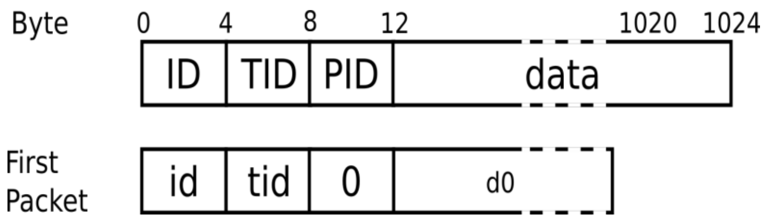


Figure 7: Unique enclosed message

When the size of the data to be transmitted is lower than or equal to 1012 bytes, only one packet is required for sending the message, and in the header the field `PID` is set to `0` (see figure 8). When the size of the date to be transmitted is larger than 1012, several packets are required for the communication. In that case, the field `PID` takes values ranging from `1` to `n` for the `n` first packets and −`n` for the last packet, indicating by the negative value the end (see figure 9). Upon reception of all the packets, the message is rebuilt and sent to the application.
When the size of the data to be transmitted is lower than or equal to 1012 bytes, only

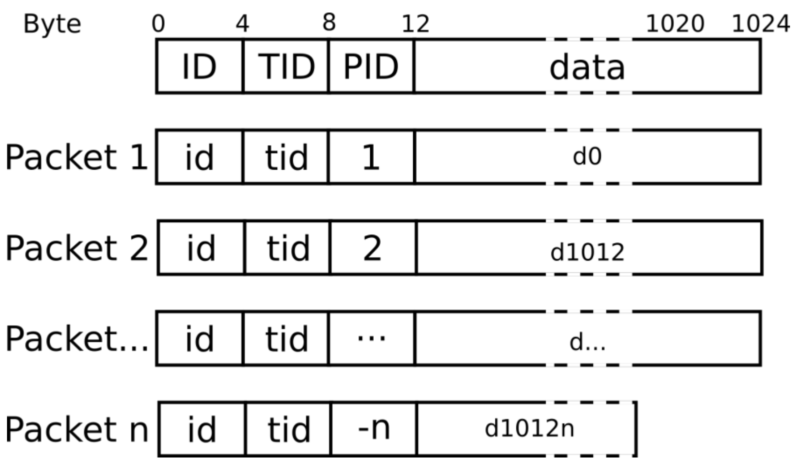


Figure 8: Discontinuous message

Experiments

In order to perform valuable tests for studying neighborhood properties in ad hoc

networks (independently of the mobility), full connected networks should be avoided, so the experimental protocol has to take this into consideration. The experimental protocol consists in two parts: a software part and an experiment part.
In these experiments, we focus on static topologies in order to prevent modifications on the neighborhood detection mechanism by mobility. If the network is a static ad hoc network, however, the whole process and framework may be reused for mobile ad hoc networks as well.
For the first experiment, the goal is to have an idea of the local perception, by each station, of the global network locally rebuilt from the received messages containing neighborhoods of other stations. The stations are not simultaneously switched on in order to observe the multi-hop nature of the network or a split ad-hoc network.

For the second experiment we try to test the sensitivity of neighborhood detection versus the network load. To do that, we fix all parameters which can directly have an influence on the neighborhood (position, mobility and transmission rate [13]).
Devices used are HTC Mega (T3333) on Windows Mobile 6.5 with broadcom 802.11 DHD Network Adapter. This adapter is tuned by the application in mode ad-hoc on channel 1 at 54MBit/s rate. The network was tested in open space, 500 meters away from the first houses, so the network is not perturbed by other Wireless station.

For the experiments, the parameters are fixed as following:
Spatial Coordinates: the coordinates (x,y,z) in meters of each device are stored in a MANET position file (.mpf) (it can be a dynamic file generated by GPS). The stations form a square, and the maximum distance between two stations is less that 5 meters. In that configuration, when the network is switched on, it is full-connected (see figure 10).
Discovery Time: the refresh delay of neighborhood; Here, 2000ms;
Send Time: the time between two emissions of message; **Variation range**: {300 ms, 150 ms, 100 ms, 50 ms, 25 ms};
Size of Data: the size can be set (by default message which contains the neighborhood); **Variation range**: {1024 bytes, 512, 256, 128, 80 bytes};
Type of Devices and number: indicates the network heterogeneity; 8 or 9 HTC Mega (T3333);
Environment: urban or obstacle-free place as an indication of radio propagation perturbations. Here, obstacle-free place;
Wireless interface setting: includes interface type, rate, mode and channel. (802.11g, 54 MBit/s rate, ad-hoc mode, channel 1);

Before beginning the experiments, all devices were synchronized on the same netbook clock.
To analyze logs, the application first sorts events according to timestamps then replay the execution step-by-step and event-by-event. The application displays topology in real-time on a dynamic graph (see Figure 16), and various information about the network (number of messages, bandwidth, message route, signal strength evolution, battery consumption ...).

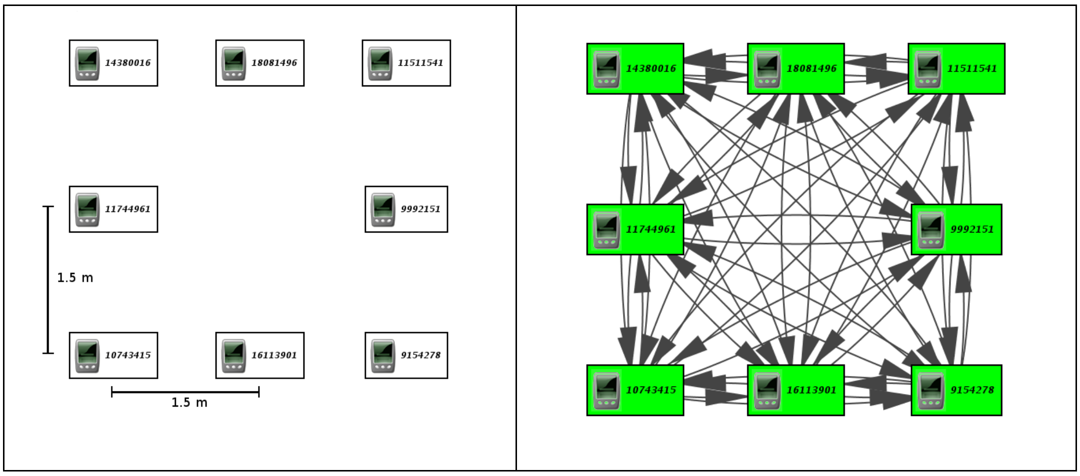


Figure 9: Spatial Coordinates when the network is down (left side) and MANET layer started with neighborhood discovery (right side). Each edge represents an unidirectional neighborhood link.

First experiments - neighborhood construction

During the first experiments 9 devices were placed directly on the ground, the spatial distribution is like a 3x3 grid where the nodes are spaced out of 25m and disposed on the ground. For testing, we consider the broadcasting of its own 1-hop neighborhood as the application. Figure 11 the color white on device represents an idle device which has its wifi layer non-activated, in red the devices which are activated and look for the network and green is dedicated to connected devices. Edges illustrate the neighborhood of stations. Each edge defines a neighbor and its referent, it allows to indicate a non-symmetric perception of stations.

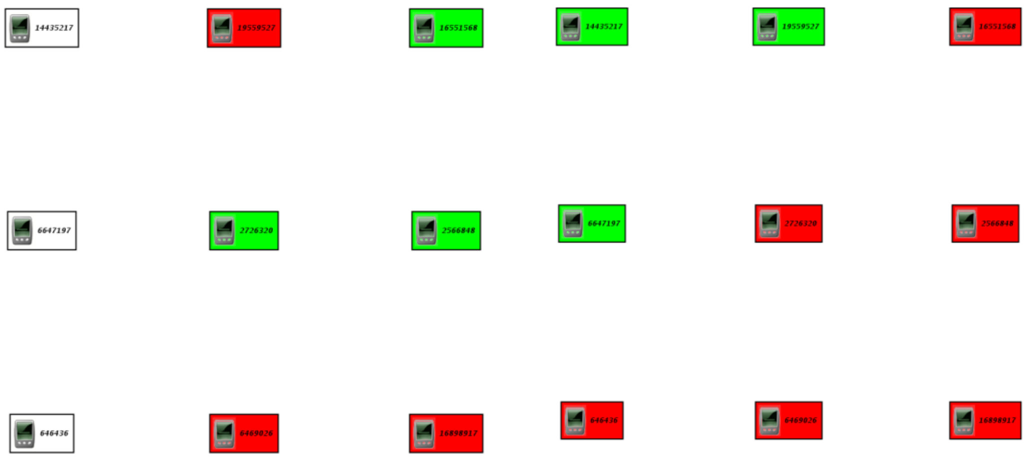


Figure 10: Spatial arrangement of the 9 mobile devices, at 45.981 seconds for the left and 221.588 seconds for the right.

The first experiments show a difficulty for the station to connect to the network since no neighborhood appear, this situation is confirmed by the number of received messages showing that when stations are located on the ground they are unable to receive messages (see figure 12).

For the second experiments, the 8 devices were spaced out by 20 meters and were located at 1,2 meters height (see fig 13) from the ground. This height might correspond to the fact that the devices are carried by human beings. The distance between each node is decreased to be sure that the connections can be established. One station has never started the test phase due to low power battery.

Notice that the distance is not the reason of the connection in comparison with the first set of experiments since, in the second set of experiments, two stations spaced out by more than 60 meters are connected while stations put on the ground and located at distance lower than 30 meters were unable to connect to each other. It appears then clearly that putting stations directly on the ground has a huge incidence on the wave propagation and thus on the network topology.

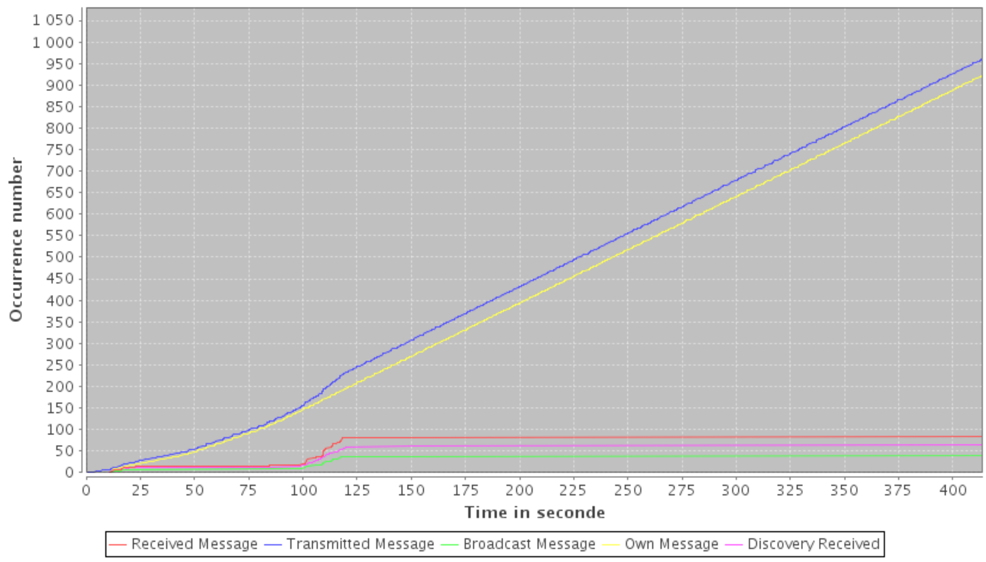
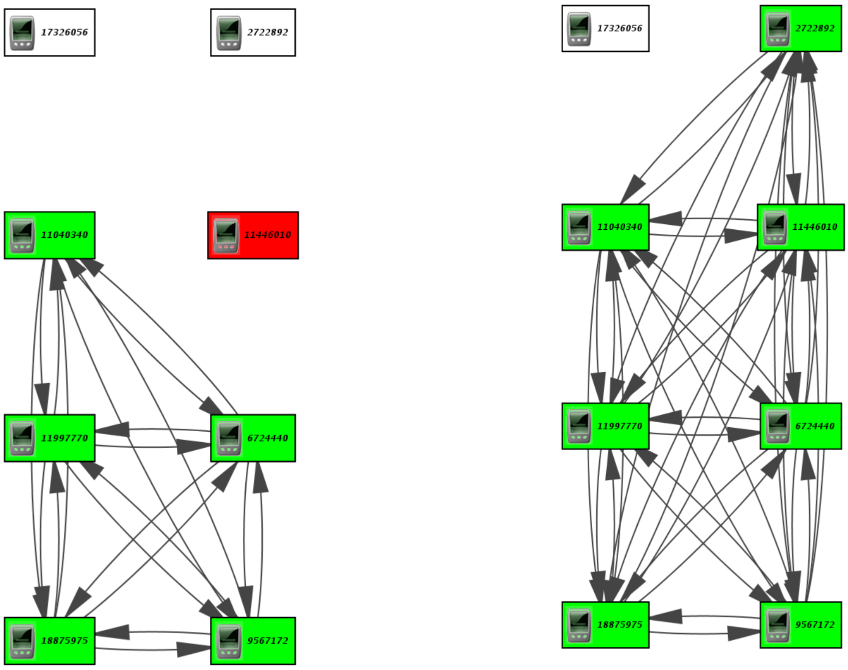


Figure 11: Sum of all types of messages for all devices in experimentation with 9 devices.

Figure 12: The spatial arrangement of working network, 58.115 seconds for the left and the



network is fully connected at 250.139 seconds**.**

The sum of communication (see figure 14) of the entire network shows an increase of communication and a normal behavior with little packet lost.
+Within this set of experiments we measure the sum of neighbors (SoN). This value corresponds to the sum of neighbors of each station. This corresponds to the number of arcs in the communication graph. For a full-connected network with eight stations, this value is equal to 56.

During the first test a message is sent every ∆ ms. We make ∆ varying from 300 to 25. From 300ms to 100ms no noticeable change occur for the value of SoN. The value is close to 56 (left side of figure 15). The topology of the network is close to be full-connected as illustrated on figure 16. When ∆ is equal to 50ms, the neighborhoods are less stable and the average value of SoN is close to 54. Finally, when we increase the frequency of the emissions, for a value of ∆=25 ms, the neighborhoods are no longer stable and the mean value of SoN decreases down to 26.8, which means that more than 50% of the neighbors are lost. This clearly appears on the right side of figure 16. Moreover, after 30s of test, that can be considered as a transitional period, the value of SoN varies between 11 and 38 as illustrated on figure 15.

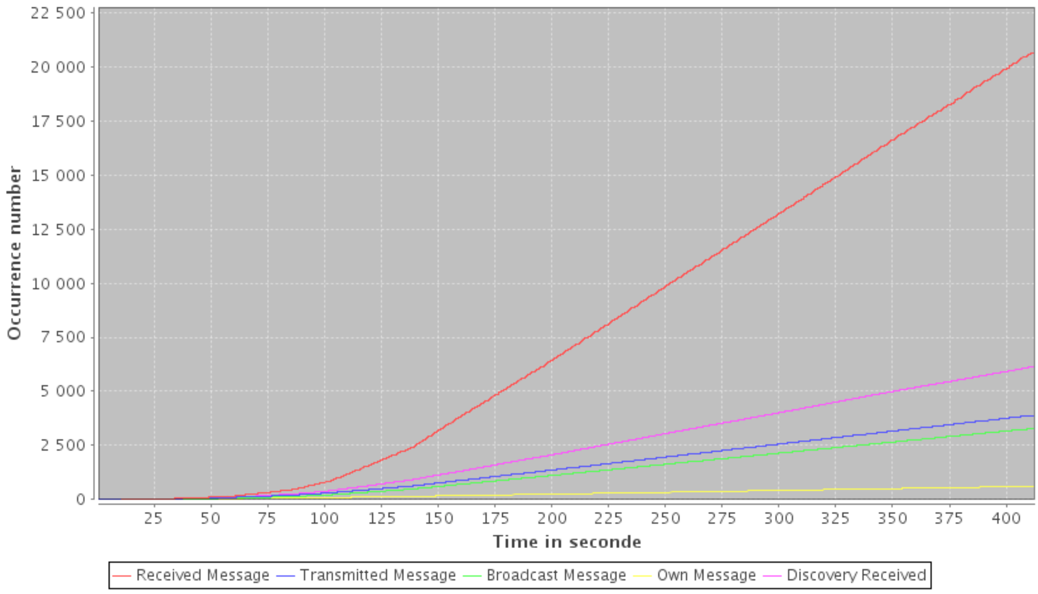


Figure 13: Sum of all type of message for all devices in experimentation

Second experiments - neighborhood stability

With fixed Data Size (80 bytes)

Remark about the transitional period: during the first 5 seconds after switching on the network, the only exchanged messages concern neighbor detection. This explains why in the first few seconds the value of SoN tends to its maximum as the network is not congested (the situation corresponds to the right side of figure 10). Then, the value of SoN decreases according to the neighborhood refresh mechanism.

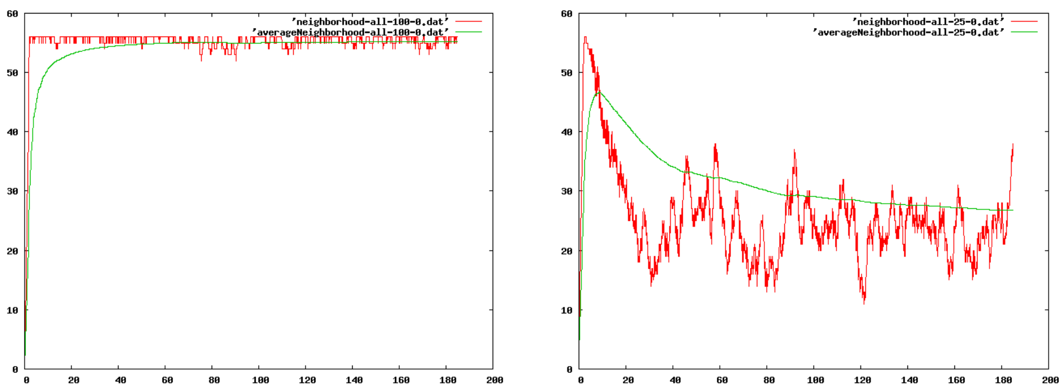


Figure 14: Global neighborhood evolution on left for 100ms and on right 25ms. Time corresponds to x axis and global neighborhood to the y axis.

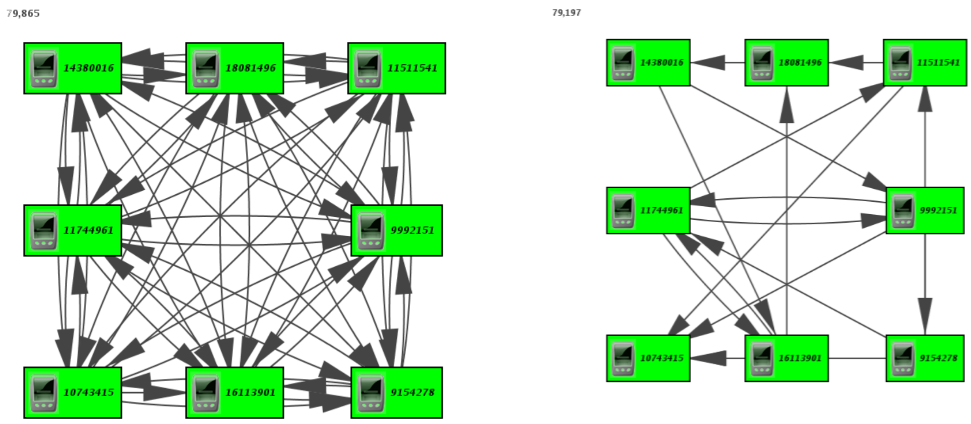


Figure 15: State of the network for different values of Δ. When Δ=100 ms, the network is not congested and is full-connected most of the time (left side). When Δ=25 ms, the neighbor detection mechanism fails because of the congestion.

With fixed Send Time (150ms)

In this second set of experiments, we fixed the period of emissions to 150ms. We focus on the same measure: the sum of neighbors (SoN). During this test, a message is sent by each station every 150ms but the size of the packet varies from 80 bytes to 1024 bytes. From 80 bytes to 256 bytes no noticeable change occur for the value of SoN. This value is close to 56 (left side of figure 17). When the size is equal to 512 bytes, the neighborhoods are less stable and the average value of SoN is close to 50. Finally, when we increase the size of the packet up to 1024 bytes, the neighborhoods are no longer stable and the mean value of SoN decreases down to a value less than 50. This appears on the right side of figure 17. But what is more important is that, after 30s of test, that can be considered, as previously, as a transitional period, the value of SoN varies between 56 (full-connected network) and 40.

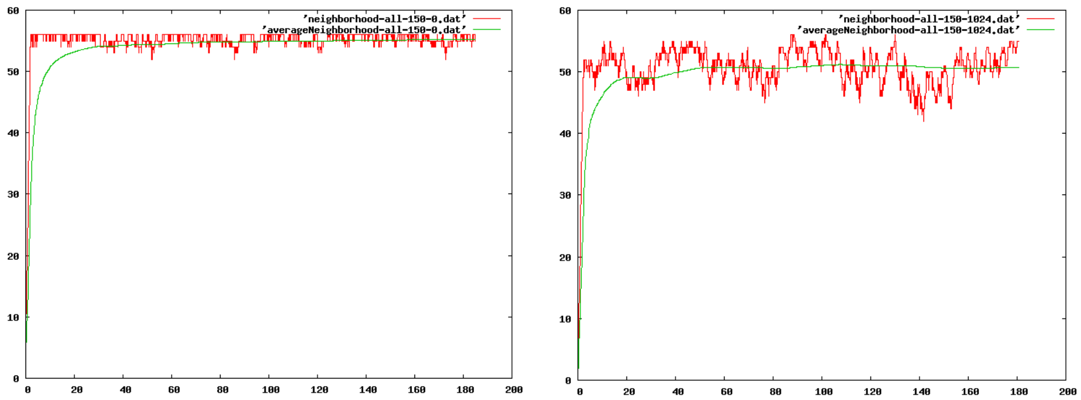


Figure 16: Stability and variation of the neighborhoods when the size of the packets vary from 80 bytes (left side) to 1024 bytes (right side), for a fixed period of emission equal to 150ms.

Conclusion

The analyses of the results stemmed from our experimental framework show that neighborhood may be unstable in spite of use in normal conditions. The neighborhood management is a key for most routing protocol in MANET. So, a bad management of communication can have huge effects on the neighborhood and thus the routing cannot be effective.

We have started next steps which are to design a routing protocol which avoid the neighborhood instability, and to test it in mobile topology and real configuration. The results are promising, actually we are able to command, the network of sirens located in the territory of the agglomeration called ``CIGNALE".

This technology could consolidate the special stand-alone radio systems which provide monitoring, maintenance facilities and triggering synchronized from a single location for the system of alert.

Acknowledgments

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Figure 17: Interconnection between CIGNALE and MANET

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Support Decision Toosl to lower risks in urban planning operation

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Abstract

Urban systems are built and developed in a natural environment including landscape, soil and subsoil. This environment is both a resource and a constraint. The interactions between urban and natural environment thus take on a very important social, environmental and economic dimension. Despite this, the criteria of sustainable development and, then, the governorship of the urban systems, generally underestimate the problem, and sometimes even ignore it completely. In any cases, there is a lack of global consistency and the thematic approaches are favoured. By associating urban stakeholders (community, city planners) with the scientists (social sciences and earth sciences), the D2SOU project aims at developing the basis and tools necessary for the integration of soil and subsoil in urban development.

Keywords: Land use planning and management, Assessment, Risks management, Sustainable Development, Support Decision Tool.

1. D2SOU project : Soils and subsoils as a sustainability criterion for urban development

1.1 Creation of tools for urban developers, policy makers and project leaders to favour a comprehensive and coherent integration of soil and subsoil issues in urban development

Urban systems are built and developed in a natural environment including landscape, soils and underground water. This environment constitutes at the same time a resource (space, water, aggregates, geothermal energy, storage capacities.) and a constraint or a source of risk (rugged landscape, adequacy to construction and underground works, geological risks, polluted soils). The interactions between urban and natural environment thus take on a very important social, environmental and economic dimension. In spite of that, the criteria of sustainable development and, thereby, the governorship of the urban systems, generally underestimate these problems, and are even, sometimes, completely unaware of them. Most approaches remain thematic when a sustainable approach would require accounting consistently for these various dimensions.

By associating urban stakeholders (communities, developers) with scientists (social sciences and geosciences), the project D2SOU funded by the National Agency of Research aims at developing the bases necessary for taking into account in an integrated manner the soil and sub-soil issues in urban development.

Various visions of the project arise: perception of the stakes and space-time scales are not the same according to the different actors. This diversity of actors and their concerns lead us to develop two tools:

a qualitative debate-aid tool based on multicriteria methods of analysis. The objective is to develop an exploitable tool in multi-actor public concertation;

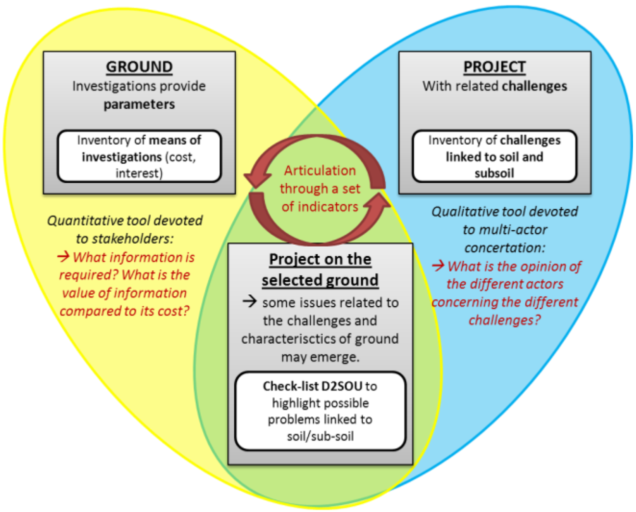
a quantitative decision-making aid tool devoted to stakeholders. The aim is to model how data can be gathered on the soil in order to feed the decision process. These data (which can be collected by geophysical or geotechnical methods, but that can also have different origin, including cartography) must be combined in such a way that they lead to “indicators” that bear relevant information regarding the decision process. These indicators can be either qualitative or quantitative, some of them being possibly quantified on the basis of a statistical/probabilistic analysis, which accounts for the quality/reliability of the information.

A tool that favours an economic cost/benefit approach concerning the interest of using different means of investigation (geophysical, geotechnical, etc.) is being developed.

The articulation between the two tools is achieved through:

- the use of a check-list that makes an inventory of main issues that may be encountered during typical urban development projects, at the scale of the project or at wider urban scales,
- a set of relevant indicators that agglomerate the information from basic data in order to make it usable in the multi-actor public concertation.

A conceptual framework is proposed in the paper, based on the expertise of the project partners in data gathering (soil investigation), in operational urban development or in project management. It is validated and tested on several real test cases, corresponding to specific urban projects. The methodology also includes experimental phases focusing on ground investigation in order to test the adequacy of investigations in the context of urban development (kind of information, scale, cost, technique, etc.). The ability of geophysical and geotechnical methods, used alone or in combination, is also quantified during these investigations.



1.2 An integrative methodology : first results

1.2.1 The Integraal framework for Sustainability Assessment.

The following six-step scheme, conceptualised by C3ED / REEDS around 2007, is referred to as the INTEGRAAL procedure.

The general sequence of INTEGRAAL is represented in the scheme below:
Although presented here as a sequence of steps, Integraal is not to be conceived as a rigidly linear process. The principle is to constitute a “deliberation forum” that offers opportunities to participants to explore progressively, or in parallel, different aspects of the agreed problem. In the view of the C3ED team, deliberation exercises can be iterative, allowing participants to go deeper and to gain or exploit more detailed information (e.g., in the choice and mobilisation of different indicators). It can be expected, as collective learning continues, that new policies for addressing the issue or sub-issues will be identified, new issues, stakeholders and values may be declared, and new information or analysis requirements may be highlighted.

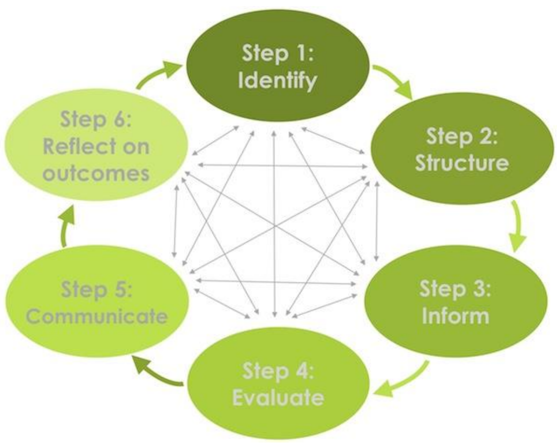


Figure 1 : Integraal method process

Step ONE — Identification by the stakeholder community of the social choice problem, or range of options. This task delivers the context, the scale, and the dynamics of the exercise.

Step TWO — Organise the social choice problem in terms of the actors concerned, **the situations or options being assessed, and the value criteria**.

This means developing in a pragmatic way, typologies or classifications of:

(1) the **stakeholders** who are impacted by the problem or by the impact of the means of addressing it;
(2) the **policies**, **strategy options**, or **scenarios** to be appraised; and
(3) the **issues** against which the performance of the policies, options or scenarios will be appraised.

(for example: preservation of the environment, decent work, health, etc.)

Step THREE — Identify and mobilise information and tools for system representation (e.g., maps, models of processes and systems).

These information and tools can help to 'ground' the deliberations in a robust knowledge base and, more particularly, this will assist in populating catalogues of indicators representing the stakeholders' reference points when working to evaluate situations and scenarios.

This step leads to the definition of **indicators**, which are units of information obeying to certain structural qualities.

Step FOUR — Mobilise the actors for tasks of deliberation.

This step relies on the framework and information developed in steps 1-3 above. It produces outcomes in the formal sense of a multi-actor multi-criteria evaluation. It also provides insights and learning to participants via the discussions that take place and observation of the respective positions adopted and of how these evolve through the collective learning that occurs.

Deliberation exercises of current performance or future options, are undertaken in a multi-stakeholder multi-criteria perspective at appropriate scales (e.g., from farm to region to nation…), corresponding to defined contexts or "theatres" of collective debate and action. There may, in principle, be many discrete evaluation exercises — hence our term "piecewise deliberation" — that can be loosely coupled by engaging common typologies of stakeholders and performance values, or by considering the same or analogous strategies.

REEDS has developed a tool, the **Deliberation Matrix (KerDST)**, which can be used to organise the interfacing of the options for evaluation relative to the stakeholders and relative to the performance criteria.

Step FIVE — Communication of Results & Recommendations.

This step includes, but is not limited to, the final reporting stages of an evaluation exercise. It also includes all tasks "along the way" of information sharing relating to the design and preparations of deliberations, documentation of discussions and intermediate results.

Communication must and will take place around all aspects of the social learning process and its outcomes (e.g., the framing of evaluation tasks, the selection of indicators, the determination of reference values (by whom, for whom?), and the reporting of outcomes of multi-criteria evaluations).

A great number of documents might be produced, many destined to remain unpublished in a process punctuated by higher-profile benchmark & strategic reports, brochures, and scientific publications. Management of these products (e.g., with CMS technologies on a website) becomes a significant task in itself.

Step SIX — Reflection on the outcomes obtained and, in an **iterative** sense, return to Step ONE of the process in order to review the entire evaluation sequence or, as seems fit, to formulate new specific evaluation problems.

1.2.2 First results of our methodology

Within the D2SOU project, the INTEGRAAL method (REE3DS-UVSQ) is implemented to promote the integration of soil / subsoil in urban projects. The INTEGRAAL method has been developed in recent years through various research projects. It identifies five consecutive steps (Identify, Organize, Represent, Evaluate and Communicate) of a recursive process of multi-criteria and multi-actor evaluation. This evaluation aims at making more readable the diversity of challenges and viewpoints associated with a problem and at engaging actors in a concertation process. The first step of the process is the identification of actors, challenges and possible scenarios. Some of the challenges are "specific" to the nature of the project (functionality, structure, etc ...) and others are "localized" in the sense that. they relate to the site and its environment (including soil / subsoil). The "Structure" step enables the project team to settle questions that should be considered. A specific tool is developed for:

- accessing a database that highlights the soil/subsoil topics potentially impacting urban development projects,
- accessing a database gathering the soil / subsoil means of investigation
- assessing the "value of information" they provide.

The step "Represent" is essential for launching following steps of concertation ("Evaluate" and "Communicate"). The data that characterizes the soil / subsoil (sometimes very technical) must be used and linked with the project challenges by developing a system of relevant indicators.

1.3 **Innovative aspects**

The D2SOU project has several innovative results:

- An analysis of the "urban development project" system leading to the identification of actors and challenges;
- The application of a multi-criteria and multi-actor approach for urban projects;
- The provision of tools for project managers to ensure proper consideration of issues related to soil and subsoil: checklist to take into account all aspects of soil / subsoil ; access to learning sheets explaining the different issues related to soil and means of investigation; tool for calculating the value of information. All these tools will be made available on Internet at the end of the project;
- Implementation of combined geophysical and geotechnical methods to acquire optimal information in an urban context. To achieve this, experiments have been performed on three fields of study offered by the associated partners (municipalities or developers): Pessac (33), Mignaloux-Beauvoir (86), Chelles (77).

1.4 **Implementation of the INTEGRAAL method in the framework of the D2SOU project**

1.4.1 A multi-criteria / multi-actors approach

The « Identify » step will allow us, taking in account the urban planning project, to highlight several issues:

- « specific » link to the nature of the project (function, structure, environmental implementation, etc…)
- « local » link to the project geographical site and its environment (bond to soil issues).

The « Structure » step will permit the urban planning project team (non-expert of soils/underground issues) to think about what we called « the check list of good questions ». A specific tool has been developed to access a database introducing means of soils / underground investigation and to evaluate their real added value on these issues.
The « Represent » step is significant for the next deliberation and communication steps. Through this step, we want to define soils / underground data (mainly technical) and link them with project issues elaborating an efficient indicators system.

Thus, stakeholders are able to express their concern on project issues taking in account these informations.

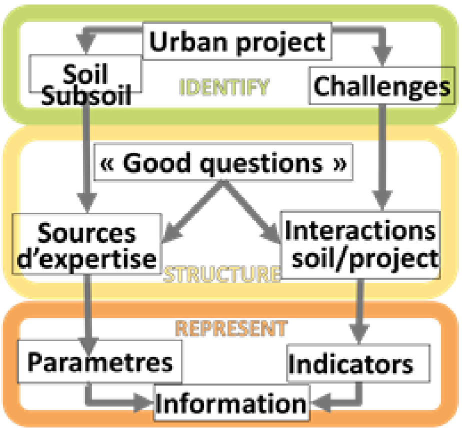


Figure 2 : Implementation of Integraal method within the project

1.4.2 The "check list of "good questions"" tool to improve projects assessment

To put in perspective the interaction between the project and soils / underground and to take into account issues linked to these thematic in project management, we propose to use a « check list of good questions » in order to audit a project or to help auto evaluation from the project team.
Several kind of interaction between the project and its soils / underground component can exist. These synergies can be classify as below :

- Based on the « cause » part of interaction :
  - Impact of the project onto soils / underground
  - Impact of current soils / underground on the project (soils typologies related to buildings basement,
- Based on thematics : legislation, risks mitigation, soils / underground natural events.
- Based on the trilogy Soil / Project / external issues : urban planning project can be structured on 3 pillars : (1) specification of the project which impact its content, (2) soils constraints, (3) external issues (eg. Legislation). An inconvenient of this classification is several issues can be put in multiple groups.
- Sense of interaction / SWOT analysis:
  - Strenghs : e.g. soils stability,
  - Weaknesses : e.g. soils contamination,
  - Threats : e.g. conflicts with soils uses,
  - Opportunities : e.g. geothermic energy.
- Based on contract owner expectations : socio-eco aspects, NIMBY effect, legislation ;
- Based on project timeline and phases.

In order to easy our work, we have chosen to create our check list from the Soil / Project / External issues point of view: “good questions” have been gathered in 3 groups :

- « Soil»
- « Project »
- « External Issues »

Even if with this classification we can put some item in multiple groups, it appears to be the most relevant one.
Then, this list has been implemented in a double entry excel sheet. It allows us for each question, to see how its responds to contract owner expectations and how it can be appreciated. 4 categories have been created :

- « Barrier and legislation outcomes »
- « Technical and economics aspects »
- « Social acceptance »
- « Opportunities ».

As to obtain a synthesis of contract owner expectation and improve its perception of soils and underground issues as a sustainable criteria to practice urban planning.

1.5 Added-value of technique prospection in urban planning process

1.5.1 Choice of a best compromise on the basis of prior hazard assessment

The basic idea is that many hazards may influence the development of a project. The term “hazard” includes all items that must be accounted for since, if not anticipated, they will have negative consequences, either on the project or on its environment. Such hazards (archeological remains, unexpected soil conditions, area sensitive for ecological reasons…) can impact the project in terms of cost or delay but also in terms of performances (the project will lack to satisfy its requirements if it provokes a soil pollution in a sensitive area…). The same word also covers some possible positive properties (opportunities) which, if anticipated, may help in designing a better project (geothermal potential, soil that may used on site…). Figure 1 describes how technical choices can be assessed regarding consequences. Here are compared the consequences of a “basic solution” BS and those of a “cautious solution” CS.
The choice may result from a risk/benefit analysis with the following steps:

- Each hazard must be qualified on in terms of probability of occurrence p_H and, when it occurs, distribution of probability of hazard magnitude p(M). The hazard magnitude can be described on a 5-level Likert scale, from 1 to 5, the 0-value corresponding to no hazard. When having no site-specific knowledge, one may assume prior distribution for these parameters, which may result for a general knowledge of the context (regional context, similar projects, company expertise…).

  Example: hazard = bad soil condition
  Probability of occurrence p_H = 25 %
  Distribution of magnitudes p(M) : 1 (minor):30%; 2 (moderate):30%; 3 (significant):20%; 4 (severe):15%; 5 (very severe): 5%

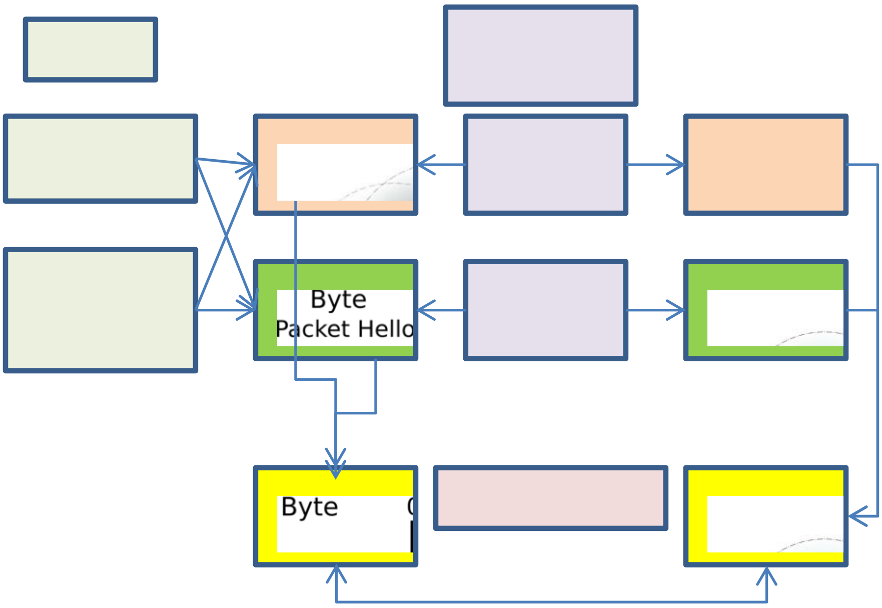


Figure 3. Framework of the decision process regarding the technical solution.

- Two technical solutions will be weighted: a "basic" solution which is a usual one, with only a small attention paid to risk and a "cautious" solution, with a higher attention paid to risk. The latter is more expensive, and does not avoid all risks.
- For the two solutions, cost and impacts are assessed. The risk is assessed by evaluating the <u>impact</u> I(M) of each technical solution with regards to each possible risk magnitude. Impact can be quantified on a 11-level Likert scale, from -5 to +5 where negative values correspond to adverse consequences and positive values correspond to beneficial consequences (opportunities). It must be noted that impact covers any type of consequences due to hazard occurrence: delay, overcosts, loss of technical performance, impact to environment. Thus a key issue will be to weight the impact values I(M). This could be done using a collaborative approach involving the project team members.
- Risk is finally quantified by:

$$R = p_H \sum_M [\ p(M) \times I(M)\ ]$$

Table 1 summarizes the data used for this evaluation.

Table 1. Principle of cost and risk evaluation for the two basic and cautious solutions and one given hazard.

Hazard	p_H	25%						
	M	0	1	2	3	4	5	
	P(M)		30%	30%	20%	15%	5%	
Techniques								*Costs*
Basic solution	Impact	0	-1	-2	-3	-4	-5	C_{BS}
Cautious solution	Impact	0	0	0	-1	-1	-2	$C_{CS} = C_{BS} + OC$

								Total risk
Basic solution	Risk	0	-0.075	-0.150	-0.150	-0.150	-0.0625	*-0.5875*
Cautious solution	Risk	0	0	0	-0.050	-0.0375	-0.025	*-0.1125*

Since each project may be subjected to many hazards (archeological remains, watertable level, possibility of bad soil properties…), the above analysis must be lead for each hazard and all consequences (costs and risks) must be summed.
This analysis can also be refined since the "cautious solution" may be replaced with a series of solutions ranked in terms of "caution level", from the basic solution to the more cautious one. In this case, cost and risk are quantified for each solution and the comparison must help in identifying the best compromise.
At the end of this process, all technical choices can be compared in terms of both costs and resulting risk.

1.5.2 Quantifying efficiency of a prospection technique regarding hazard assessment

The next issue is the evaluation of added-value that may result of using one or several prospection technique, in order to improve the knowledge about possible hazards on a given site, and to adapt the technical choice in order to reduce the negative consequences.
The idea is that, after having used a prospection technique PT (this concept may be extended to any way of gathering additional information which about hazards which may influence the project, including for instance on site visit or library work), one will be able to update his evaluation of hazards and thus make a more appropriate choice. The updated information upon hazards will be noted with a "prime" symbol: p'_H instead of p_H for probability of occurrence, p'(M) instead of p(M) for the distribution of hazard magnitudes.

Each PT can be assessed in terms of cost (including real costs and time to cover a given area) and efficiency. Efficiency corresponds to the ability to (a) detect the hazard (or checking that it does not exist) and (b) quantifying its magnitude. Of course, efficiency depends both on the technique and the type of hazard. A simple way for quantifying efficiency is that of defining a matrix E_{ij}(PT, H), where:

- PT designs the prospection technique
- H designs the hazard type
- i and j are the magnitude of the hazard (on the 0-5 scale), i being the "real value" and j being the assessed value.

The efficiency of a given technique can be quantified by experts, and checked thanks to feedback experiences. With this notation system, a perfect technique corresponds to a diagonal matrix with E_{ij}(PT, H), = 1 if i = j and E_{ij}(PT, H), = 0 if $i \neq j$. For any real technique, E_{ij}(PT, H) values for $i \neq j$ may be non zero, either because of (a) false alarm ($i = 0$ but $j \neq 0$), (b) non detection ($i \neq 0$ but $j = 0$) or (c) simple uncertainty in hazard magnitude assessment ($i < j$ if the hazard is overestimated or $i > j$ if it is underestimated).

The effect of using a PT will be to replace the prior distribution [p_H, p(M)] which is not site-specific, with an updated posterior distribution [p'_H, p'(M)] which would provide a better picture of the real hazards on site. Figure 2 describes the process in this situation.

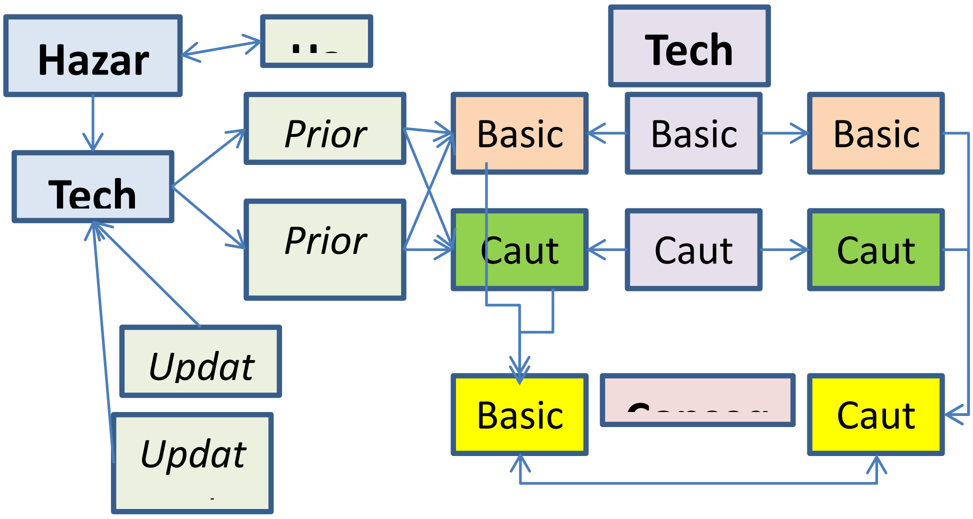


Figure 4. Framework of the decision process regarding the technical solution, using a prospecting technique in order to improve the site-specific knowledge.

Thus the problem to be solved is twofold:

- problem A: what is the best compromise (between risk and cost) regarding the technical solution for the project?
- problem B: what prospection technique(s) would have to be used in order to improve the quality of the choice of the technical solution for the project?

<u>1.5.3 Quantifying added-value of a prospection technique for project management</u>

The next issue is the evaluation of added-value that may result of using one or several prospection technique, in order to improve the knowledge about possible has about the site.
It must be added that the prior risk evaluation is only performed in a statistical way, when the real decision would have to be fitted to the specific site conditions. In fact, if p_H = 20%, this means that the hazard only occurs one time out of five. Thus the choice of the basic solution will be the best one four times out of five, while a more cautious one will be best fitted in the other cases (and the "caution level" will have to be fitted to the magnitude of hazard).

This leads to define two reference situations:

- Decision with <u>only prior knowledge</u>: in this case, the best compromise is that defined above, on the basis of assumed prior distribution of hazards,
- Decision with <u>full knowledge:</u> this comes to say that the choice is done on the basis of existing (and fully known) site-specific hazards. If one comes back to Table 1, when comparing only two possible choices, this will lead to choose the "basic solution" in all cases where there is no hazard and the "cautious one" when hazard occurs. The total risk will be that of the cautious solution (-0.1125 with the values taken in the example), but the total cost will be reduced to:

$$C_{TOT} = (1 - p_H)\, C_{BS} + p_H\,(C_{BS} + OC) + CT = C_{BS} + p_H\, OC + CT$$

Where CT is cost of the prospecting technique. This means that the overcost OC is only paid when the hazard exists, thus saving money. This would be possible as soon as one uses a PT that detects all existing hazards, even if it is not able of sizing them. It would also be possible to decrease further this cost by using a more efficient technique that would reduce the uncertainty about the hazard magnitude, such as one will be able to adapt the caution level of the technique to the assessed hazard magnitude.

However, it must be kept in mind that full knowledge is unreachable in practice and that the real decision process is in fact that of decision with non perfect knowledge. The idea is that the updated information regarding hazards will improve the quality of the decision process, and lead to a cost which will lay between the two bounds (only prior knowledge / full knowledge).

One must also remind that when analyzing costs, the cost balance must include the PT cost, and that it some situations the total cost $C_{TOT} = C_{BS} + p_H$ OC + CT may be higher than the initial one.

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Modelling and analysis of large systems with high availability constraints

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Abstract

High availability constraints ensure a high level of operational performance that must be maintained during a contractual measurement period. Such constraints must be satisfied, particularly, for critical systems related to global security and human safety. High availability often results from material redundancies and lead to large stochastic discrete event models with numerous states. Markov processes and stochastic Petri nets can be used to model, simulate and analyze such systems but their use is limited by the so called "combinatorial explosion" problem. This paper investigates the fluidification of stochastic Petri nets to overcome the previous problem. The main contribution is to propose a modular modeling of active and passive redundancies with Petri nets. Some approaches are then proposed to obtain equivalent behaviors in the long time with stochastic and continuous Petri nets.

Keywords: Reliability analysis, Redundancies, Petri nets, Fluidification.

1. Introduction

Reliability and availability analysis are major challenges to improve the global security and the safety of processes. Users want their systems, for example, airplanes or computers, to be ready to serve them at all times. Availability refers to the ability of the user community to access the system, submit new work, update or alter existing work, or collect the results of previous work. If a user cannot access the system, it is said to be unavailable. The terms downtime and uptime are used to refer to periods when a system is unavailable and available. Scheduled and unscheduled downtime must be distinguished. Scheduled downtime results from maintenance operations and has little impact upon the user community. Unscheduled downtime events typically arise from hardware or software failures or environmental anomalies. Examples of unscheduled downtime events include power outages, failed CPU, over-temperature related shutdown, and so on. Such downtime must be considering at first in order to evaluate the availability of the system.

Mean availability can be expressed as the percentage of uptime in a given year. The table I shows the downtime that will be allowed for a particular percentage of availability, presuming that the system is required to operate continuously (without maintenance periods).

Table I : Availability and downtime

Mean availability	Downtime per year
90% ("one nine")	36.5 days
95%	18.3 days
99% ("two nines")	3.7 days
99.5	1.8 days
99.9 ("three nines")	8.8 hours
99.99 ("four nines")	53 minutes
99.999 ("five nines")	5.3 minutes
99.9999 ("six nines")	32 seconds

High availability implies no human intervention to restore operation in complex systems. For example, availability limit of 99.999% allows about one second of downtime per day, which is impractical using human labor. Human intervention for maintenance actions will certainly exceed this limit. Availability limit of 99% would allow an average of 15 minutes per day, which is realistic for human intervention. So, high availability refers to availability at less equal to 99%.

Redundancy is used to eliminate the need for human intervention and to reach high availability requirements. For complex dynamical systems with numerous interdependent components and high availability constraints, the modeling and analysis methods are mainly based on stochastic discrete event models like Markov models (Rausand et al., 2004) or stochastic Petri nets (SPNs) (Molloy, 1982). Such models are mathematically well founded and lead either to analytical results or numerical simulations. The first contribution of this paper is to propose modular models of the redundancies with SPNs. The compact and systematic design of SPNs is highlighted as an advantage in comparison with other state space models like Markov models. Estimation of availability with SPN simulations results as a consequence. But, in case of large systems, simulation and analysis methods lead to the problem of combinatory explosion that limits the use of state space models. In this context, fluidification can be discussed as a relaxation method (Recalde and Silva, 2002; 2004). The main idea of PNs fluidification is to replace a discrete SPN by a continuous one. The second contribution of the paper is to investigate some fluidification methods to evaluate the availability.

2. Stochastic Petri nets for availability evaluation

2.1 Petri nets

A Petri net (PN) is defined as $<\boldsymbol{P}, \boldsymbol{T}, W_{PR}, W_{PO}>$ where $\boldsymbol{P} = \{P_i\}$ is a set of n places and $\boldsymbol{T} = \{T_j\}$ is a set of q transitions, $W = W_{PO} - W_{PR} \in (\mathbf{Z})^{n\times q}$ is the incidence matrix. $M(t, P_i)$ stands for the marking of place P_i at time t, $M(t)$ is the PN marking vector at time t and M_I the PN initial marking. The marking changes when a transition fires. Transitions fire depending on the marking vector and on the firing conditions. The marking variation is given with respect to the firing vector $X \in (\mathbf{Z})^q$ such that $\Delta M = W. X$. For a complete description of PN models and analysis, one can refer to (David *et al.*, 1992, Recalde and Silva, 2002).

2.2 Stochastic Petri nets

A stochastic Petri net (SPN) is a timed PN with transitions firing periods that are characterized by exponential probability density functions (pdf) with firing rate μ_j, $j = 1,\ldots,q$ (Ajmone et al., 1987; Molloy, 1982). The marking of the place P_i of a marked SPN at time t will be referred as $M(t, P_i)$. The SPNs considered in this paper are bounded, reinitialisable, with infinite server semantic, race policy and resampling memory. As a consequence, the considered SPNs have a reachability graph with a finite number N of states $\{S_1,\ldots,S_N\}$ and their marking process is mapped into a Markov model with state space isomorphic to the reachability graph (Bobbio et al., 1998). The generator G of this Markov model can be computed from the reachability graph and from the firing parameters of the SPN. The state probabilities $\pi_k(t)$, $k = 1,\ldots,N$ of Markov model and the mean marking $M_{mm}(t, Pi)$, $i = 1,\ldots,n$ of SPN satisfy:

$$M_{mm}(t, Pi) = \sum_{k=1,\ldots,N} m_{k\,i} . \pi_k(t) \quad (1)$$

where m_{ki} stands for the number of tokens in place P_i when the system is in state S_k.

2.3 Example

Petri nets can be used to model systems with failures and repairs (Schneeweiss, 2001). The simplest example is to consider a system composed of a single component (Figure 1). This component is assumed to fails and repairs with respect to exponential pdf. The failure rate is denoted by λ and μ stands for the repair rate. The place P_1 stands for the safe state and P_2 for the defect one. The transition T_1 represents the occurrence of a fault and the transition T_2 represents the end of the repair process.

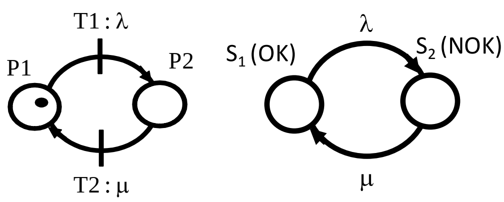

Figure 1: Failure and repair process of a single component; SPN (left); corresponding Markov model (right)

One can notice the similarity of both representations. In fact, the SPN in Figure 1 (left) is equivalent to the Markov model (right) with generator G:

$$G = \begin{pmatrix} -\lambda & \lambda \\ \mu & -\mu \end{pmatrix} \quad (2)$$

The resolution of the Chapman Kolmogorov equation (Rausand et al., 2004) leads to the determination of the mean availability $A(\infty)$ with respect to parameters λ and μ.

$$A(\infty) = \pi_1(\infty) = M_{mm}(\infty, P_1) = \frac{\mu}{\lambda + \mu} \quad (3)$$

To conclude with this example, one can notice that high availability requirements are achieved only if the repair process is at least 99 times quicker than the failure process.

3. Modular models of redundancies with PNs

The simple example provided with Figure 1 does not enhance the advantages to use SPNs in comparison with Markov models. Such advantages will appear as evidence when redundancies are considered. Two kinds of redundancies can be considered: active redundancies and passive redundancies.

3.1 Models of active redundant systems

Active redundancies are used to achieve high availability by including enough excess capacity in the design to accommodate a performance decline. Systems with active redundancies include several identical components working together. A simple example is an aircraft with two separate engines. The aircraft continues to fly despite failure of a single engine. A more complex example is multiple redundant power generation facilities within a large system involving electric power transmission. Malfunction of a single component is not considered to be a failure unless the resulting performance decline exceeds the specification limits for the entire system.

Figure 2 provides the usual representation of active redundancies with SPNs. A number n of identical component is considered. Components running simultaneously are represented by the tokens in place P_1. Non reparable (left) and reparable (right) processes are considered. In both cases, the sojourn time of any token in place P_1 is a random variable (rv) with exponential pdf of parameter λ. The duration to fire transition T_1 is also a rv with exponential pdf of parameter $\lambda.M(t, P_1)$. When a component fails or is repaired, this parameter changes as $M(t, P_1)$.

The SPNs in Figure 2 are used to represent total or partial active redundant system. A total redundant system is said to be available as long as $M(t, P_1) \geq 1$. In comparison a partial k / n redundant system is said to be available as long as $M(t, P_1) \geq k$. Mean availability with partial and total redundancies is easy to work out, with the evaluation of the marking $M(t, P_1)$.

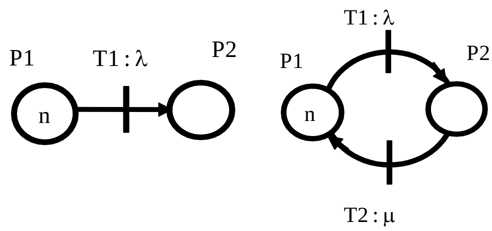

Figure 2: Active redundancies with n identical components; Failure process for non reparable systems (left); Failure and repair processes for reparable systems (right)

In Figure 3, the case of non identical components is considered. This representation will be preferred when the redundant components have different failure and repair rates. More precisely, in Figure 3, p classes of components are considered and n_i stands for the number of identical components in class i. In comparison with the previous model, the SPN in Figure 3 is composed of 2.p places, and availability will be evaluated according to the sum of marking variables $M(t, P_{11}) + \ldots + M(t, P_{p1})$.

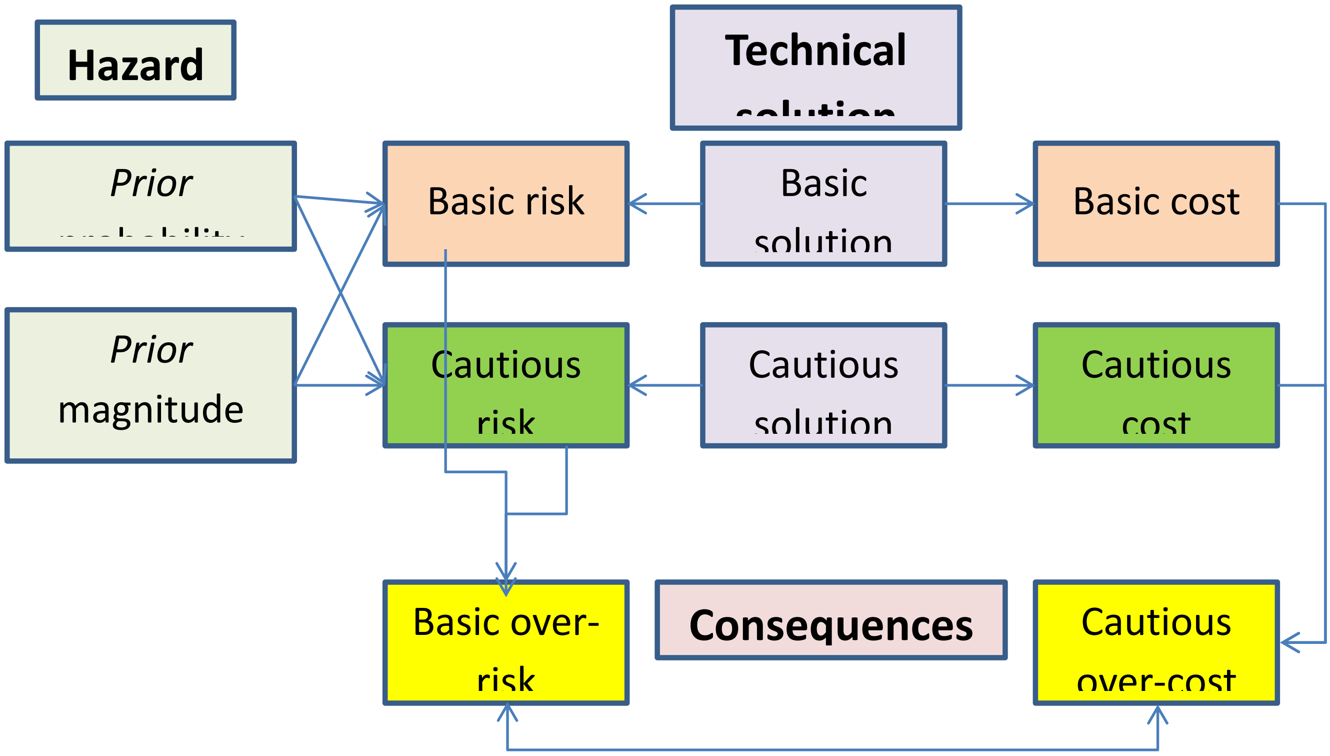

Figure 3: Failure and repair processes for active redundancies with p classes of n_i components $i = 1,\ldots,p$

Models of passive redundant systems

Passive redundancy is used in complex systems to achieve high availability with no performance decline. Multiple components are incorporated into a design that includes also a method to detect failures and automatically reconfigure the system to bypass failed items and replace them with safe ones. This is used with complex systems that are linked. For example, the rescue wind turbine in aircraft is a passive redundant component that will be used only when the power generators are out of order and when all batteries are down. In that case the rescue turbine will produce the energy required to maintain the main control devices of the aircraft.

Figure 4 provides the usual representation of passive redundancies with SPNs for reparable systems. The duration to fire transition T_1 is a rv with exponential pdf of parameter $\lambda.\min(M(t, P_1), M(t, P_3)) = \lambda.\min(M(t, P_1), 1)$. In Figure 4-left, concurrent repairs are considered and in Figure 4-right, non concurrent repairs are considered.

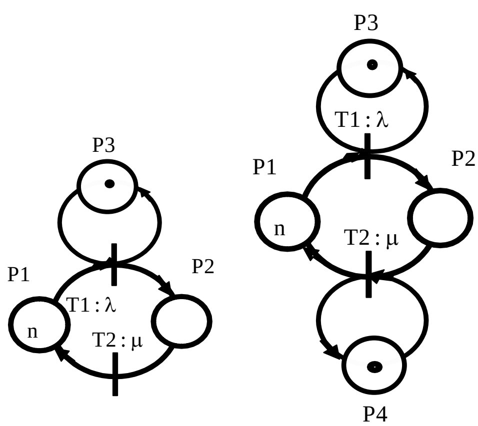

Figure 4: Failure and repair processes for passive redundancies; concurrent repairs (left); non concurrent repairs (right)

4. Availability evaluation with SPNs

4.1 Analytical background

SPNs can be used to evaluate usual indicators of reliability as characteristic times (MUT, MDT, MTTF or MTBF) and also instantaneous indicators as reliability or availability. In this work we will consider the particular case of mean availability. The basic idea is to use the equivalence that exists between the reachability graph of the SPN and the corresponding Markov model. The N states of the reachability graph are first separated into two classes: the class OK of N_s safe states and the class NOK of N_d defect ones. Let us denote $\Pi_s \in [0, 1]^{1 \times Ns}$ as the row vector of the state probabilities for normal states and $\Pi_d \in [0, 1]^{1 \times Nd}$ as the row vector of the state probabilities for defect ones. The Chapman Kolmogorov equation of the associated Markov model can be written as in (4):

$$\frac{d\left(\Pi_{OK}(t) \quad \Pi_{NOK}(t)\right)}{dt} = \left(\Pi_{OK}(t) \quad \Pi_{NOK}(t)\right).\begin{pmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{pmatrix} \tag{4}$$

where G_{11}, G_{12}, G_{21} and G_{22} are sub-matrices of the generator G with appropriate dimensions. Thus, state probabilities are given by (5):

$$\Pi(t) = \Pi(0).exp\left(\begin{pmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{pmatrix}.t\right) \tag{5}$$

and the mean availability is given by (6):

$$A(\infty) = \Pi(\infty).\begin{pmatrix} 1_{Ns} \\ 0_{Nd} \end{pmatrix} = \Pi_{OK}(\infty).1_{Ns} \tag{6}$$

with $1_{Ns} = (1,\ldots1)^T$ of dimension N_s.

4.2 Stochastic estimator by means of simulations

SPNs can be used to estimate the mean availability (and also other indicators) by means of simulations with time horizon D. For that purpose, the probability of each state S_k is estimated with equation (7):

$$\tilde{\pi}_k(D) = \frac{1}{D}\int_0^D f_k(t).dt \text{ and } \tilde{\pi}_k(\infty) = \lim_{D\to\infty}\left(\tilde{\pi}_k(D)\right) \tag{7}$$

The functions $f_k(t)$, $k = 1,\ldots,N$ are defined with equation (8):

$$f_k(t) = 1 \text{ if } M(t) = S_k \text{ and } f_k(t) = 0 \text{ if } M(t) \neq S_k \tag{8}$$

4.3 Examples

Let us consider again the example of Figure 1 with parameters λ = 1.5e-5 TU^{-1} and μ = 1e-4 TU^{-1}. The simulation of the system over time interval [0 : 1e7] leads to the estimation of state S_1 probability reported in Figure 6. For this example, the availability equals the probability of state S_1 and tends to the mean availability $A(\infty)$ = 0.87. This numerical estimation coincides with the theoretical value of the mean availability provided by equation (2) and the considered system is not high available.

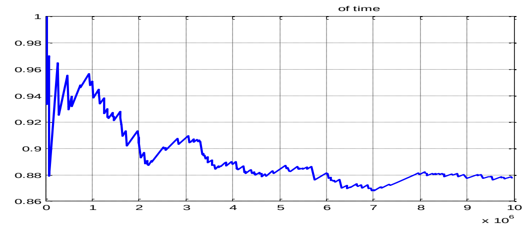

Figure 5: Estimation of the state S_1 probability with SPN simulations for the system of Figure 1

Let us consider an active redundant system with 3 identical components with the same parameters λ = 1.5e-5 TU^{-1} and μ = 1e-4 TU^{-1}. The SPN and Markov model are described in Figure 6. The simulation of the SPN leads to the estimation of the mean availability $A(\infty)$ = 0.998 (Figure 7).

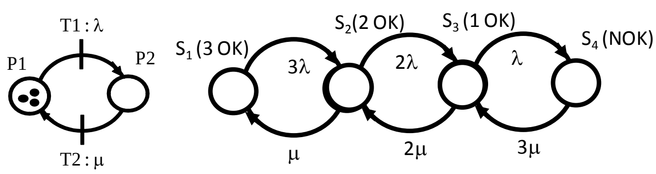

Figure 6: Active redundancies with 3 identical components

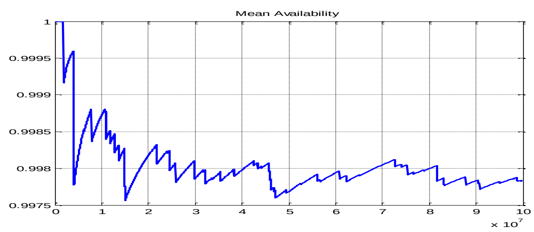

Figure 7: Estimation of the mean availability with SPN simulations for the system of Figure 6

5. Performance evaluation for systems with redundancies

5.1. Modular modeling

As long as high availability is considered, systems with numerous redundant components must be represented. Each process proposed in figures 2 to 4 is a modular sub-model that can be included in the representation of a large system with redundancies. Figure 8 represents the connection of the failure and repair processes in large systems. The server with redundancies is represented by the transition T_3 that is connected to the sub-model $\{P_1, P_2, T_1, T_2\}$ (a failure process for n reparable components with total active redundancies). A simplified representation of the system is used with $\{P_3, P_4, T_3, T_4\}$.

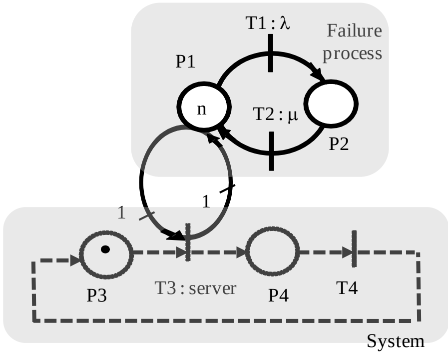

Figure 8: Failure and repair processes for active redundancies: integration of sub-models

The mean availability worked out with the sub-model in Figure 2 right and with the complete model in Figure 8 are equal. The proof is given for n = 1 and can be extended for n > 1. Assuming that the server T_3 has a firing rate x and that T_4 has a firing rate y, the SPN in Figure 8 is equivalent to a Markov model with states $S_1 = (1\ 0\ 1\ 0)^T$, $S_2 = (0\ 1\ 1\ 0)^T$, $S_3 = (1\ 0\ 0\ 1)^T$, $S_4 = (0\ 1\ 0\ 1)^T$ and generator G:

$$G = \begin{pmatrix} -(\lambda + x) & \lambda & x & 0 \\ \mu & -\mu & 0 & 0 \\ y & 0 & -(y+\lambda) & \lambda \\ 0 & y & \mu & -(y+\mu) \end{pmatrix} \tag{9}$$

The mean availability is given by the asymptotic probabilities of states S_1 and S_3:

$$A(\infty) = \pi_1(\infty) + \pi_3(\infty) = \frac{1}{D}.\left(\frac{y}{x}.\left(\frac{\lambda+\mu+y}{\lambda}\right) + \frac{\mu+y}{\lambda}\right) \tag{10}$$

with:

$$D = \frac{y}{x}.\left(\frac{\lambda+\mu+y}{\lambda}\right) + \frac{y}{x}.\left(\frac{\lambda+\mu+x+y}{\mu}\right) + \frac{\mu+y}{\lambda} + 1$$

After simplification (3) may be rewritten with (11):

$$A(\infty) = \frac{1}{1 + \dfrac{\dfrac{y}{\mu}.(y+x+\mu+\lambda)+x}{\dfrac{y}{\lambda}.(y+\mu+\lambda)+\dfrac{x}{\lambda}.(y+\mu)}} = \frac{\mu+\lambda}{\lambda} \tag{11}$$

Thus the mean availability of SPNs in Figures 2 and 8 are identical and one can conclude that the integration of the sub-model for failure and repair process does not change the availability. The advantage of including the failure and repair processes in the global system is to evaluate the influence of availability on the server activity. In Figure 8, the flow of transition T_3 depends on the redundancies that are included in the system design. The previous proof can be generalized for n redundant components and for partial k / n redundancies (arcs (P_1, T_3) and (T_3, P_1) will be weighted with k).

5.2. Example

The system in Figure 9 models a simple manufacturing system.

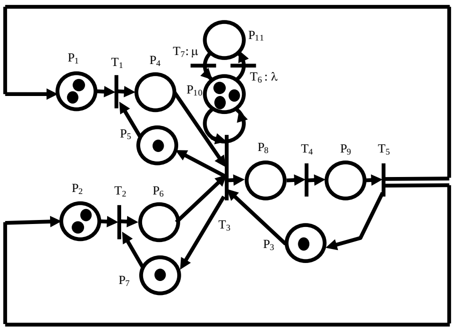

Figure 9: Assembly workshop

The final product is composed of two different parts, A and B, that are processed in machines M1 and M2 (represented by transitions T_1 and T_2), and stored in buffers P_4 and P_6, respectively. Then, they are assembled by M3 (i.e. transition T_3), and processed in M4 (i.e. transition T_4). Finally, M5 (i.e. transition T_5) packages them. During the processing of parts A and B, tool1 (tokens in place P_5) and tool2 (tokens in place P_7) are needed. Also tool3 (tokens in place P_3) have to be used in the three final operations. The machines M1, M2, M4 and M5 are assumed to be reliable and an active redundancy (n = 3) is considered for the assembly machine M3 that is assumed to have failure and repair rates λ = 1.5e-2 TU^{-1} and μ = 1e-1 TU^{-1}. The productivity of the workshop is evaluated with the computation of the output flow $X(t, T_5)$ with respect to the number k of pallets and tools : $M_I = (2k\ 2k\ k\ 0\ k\ 0\ k\ 0\ 0\ 3\ 0)^T$. The results obtained with Markov models and SPNs simulation over a time interval of D = 1000 TU are summed up in Tables 2 and 3. For k > 4, the computational effort becomes heavy because of the large number N of states and the performance evaluation with Markov model analysis is no longer computable.

Table 2: Performance evaluation with Markov models

k	*N*	$X(t, T_5)$ with Markov model	Computational effort (TU)
1	48	0.29	0.1
2	216	0.61	0.9
3	640	0.93	12
4	1500	1.25	108
5	…	…	…

Simulation with SPNs can be used to overcome the computational limitation with Markov model (Table 3). One can notice that the computational effort remains reasonable even for heavy loaded nets. The simulation error does not exceed 3% for the considered system and is less than 1% for many other cases. The addition of 3 redundant components is enough to reach high availability requirements.

Table 3: Performance evaluation with SPNs

k	$X(t, T_5)$ with SPN	Computational effort (TU)
1	0.30	0.59
2	0.61	2.0
3	0.94	4.0
4	1.24	6.8
5	1.55	11
10	2.41	30
100	2.63	39

6. Fluidification of SPNs

A usual limitation encountered with the use of SPNs simulations is the determination of the time horizon D. Tide horizons lead to approximation errors and large horizons increase the computation effort. To overcome this difficulty, SPNs can be transformed into timed continuous Petri nets (contPNs) that are compact continuous time models. Such models converge very rapidly to their steady state.

6.1 Timed continuous Petri nets

ContPNs have been developed in order to provide continuous approximations of the discrete behaviors of timed PNs (David and Alla, 1992; Recalde et al., 1999; Recalde and Silva, 2002; 2004). The marking of each place is a continuous non negative real valued function of time. $X_{max} = \text{diag}(x_{max\,j}) \in (\boldsymbol{R}^{+})^{qxq}$ is the diagonal matrix of maximal firing speeds $x_{max\,j}$, $j = 1,\dots q$ and $X(t, T_j)$ is the firing speed of transition T_j at time t that depends continuously on the marking of T_j input places. The flow through the transition T_j is defined by (12):

$$X(t, T_j) = x_{max\,j}.enab(M(t), T_j) \tag{12}$$

with:

$$enab(M(t), T_j) = \min \{M(t, P_k) / w^{PR}{}_{kj} : P_k \in {}^{\circ}\boldsymbol{T_j}\} \tag{13}$$

where ${}^{\circ}\boldsymbol{T_j}$ stands for the set of T_j upstream places.

6.2. Approximations of SPN with standard fluidification

Standard fluidification is the simplest way to transform a stochastic discrete event models into a continuous time one. Standard means that both models have the same structure (i.e. incidence matrices), parameters (i.e. firing rate of the transitions) and initial state (i.e. initial marking). In particular, $x_{maxj} = \mu_j$, $j = 1,...,q$ is used with equations (12) and (13) for standard fluidification (Recalde and Silva, 2002; 2004).

An open issue is that standard fluidification of SPNs leads to continuous models such that the steady states of SPNs and contPNs do not coincide in many cases, particularly for non-ordinary PNs or non join-free PNs. As a consequence, availability estimation provided by the steady state of contPNs is different from the one resulting from the analysis of Markov model or from the SPN simulations.

6.3. Example

The example of Figure 9 is considered again and simulated as a contPN. Standard fluidification is used and the results are reported in Table 4.

Table4: Performance evaluation with contPNs

k	$X(t, T_5)$ with contPN	Computational effort (TU)
1	0.33	0.25
2	0.66	0.22
3	1	0.22
4	1.33	0.20
5	1.66	0.22
10	2.61	0.23
100	2.61	0.22

Simulation with contPNs lead to biased results, but the errors do not exceed 8% for $k \geq 10$. One can also notice that the computation effort does not depend on the marking magnitude. Thus, standard fluidification can be used to evaluate the performance for heavy loaded net.

7. Discussion and conclusion

In this paper we have proposed a modular modeling with stochastic Petri nets to represent redundancies in large systems in order to reach high availability requirements. The usual methods (analysis of the corresponding Markov model and SPN simulations) are discussed and fluidification of the discrete event models is presented as an alternative solution that provides good approximations of the mean availability under some specific assumptions (in particular the net is assumed to be heavy loaded).

To conclude let us notice that several recent studies have been started to transform SPNs into contPNs that will provide a better approximation of the SPNs behavior in the long run. Markovian and Hybrid Markovian Continuous Petri Nets have been introduced for that purpose (Vazquez et al., 2008; Vazquez and Silva, 2009). These models are continuous time Petri nets including stochastic variables with Poisson pdf. One difficulty is that the resulting models are no longer deterministic. In (Lefebvre et al., 2009; Lefebvre and Leclercq 2011), piecewise constant timed continuous PNs have been proposed that are suitable to compute the SPNs steady state in some regions of the marking space. A homothetic approach has been also developed to provide an approximation of the SPNs steady state in the whole marking space (Lefebvre et al., 2010; Lefebvre 2011). Both approaches have been combined with interpolation and classification methods to provide an approximation of the SPN steady state (Lefebvre et al. 2012).

At this time, the estimation of mean availability for large systems with fluid models remains an open issue that will continue to attract our interest. In particular a supervised combination of SPNs and contPNs in a single hybrid model will be investigated in our future work.

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Benefit-cost analysis as a decision-support tool for risk-informed land use planning

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Abstract

We report on a case-study concerning land-use planning around an LPG importation facility surrounded by urban development. The authorities have required the operator to implement a costly technical measure which is part of national doctrine concerning the technological risks of LPG storage facilities. We have undertaken a benefit-cost analysis of different technical measures which reduce the risk generated by the facility, in order to compare the cost of the measures with their estimated benefit, over the lifetime of the facility, in terms of reduced probability and consequences of an industrial accident. Our socio-economic analysis suggests that, for the facility studied, the status quo is the most efficient in economic terms.

Keywords:benefit-cost analysis, decision-support, land use planning, technological risk

1. Introduction to benefit-cost analysis

Land use planning around hazardous establishments raises numerous questions, which cannot be resolved by binary yes/no answers:

- which criteria should society use to decide that the level of risk of an industrial facility has been reduced as low as "reasonably practicable"?
- which balance between different methods of reducing risk from a facility (investing in preventive or protective barriers on site, in protective barriers offsite, imposing forms of land use for areas near the plant which lead to a lower exposed population, *etc.*) should be implemented?

Benefit-cost analysis (BCA) is a decision-support tool which can help in the discussion with stakeholders concerning these questions. It provides a structured framework for presenting all of the components of a decision and their different weightings, increasing the transparency of the decision-making process. It provides a historical record of the elements considered in a decision, and the level of uncertainty existing at the time the decision was made.
BCA advises in favour of all decisions whose benefits, for the whole of society, are greater

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than their costs. Concerning the management of industrial risks, benefits could include the consequences of a reduction in the level of pollution or the risk of mortality from accidents. Considered costs could include spending on new safety measures and indirect costs such as impacts on and competitiveness. To compare costs and benefits, it is necessary to use a common measure. BCA uses a monetary measure, and involves the conversion of costs and benefits into euros [1].

While costs are often naturally expressed in euros, the benefits of prevention measures (reduced probability or lower consequences of industrial accidents) are more difficult to monetize. BCA makes this conversion based on citizens' preferences, attempting to estimated people's *willingness to pay* for a change in their environment (such as the construction of a railway line between two cities, or an improvement in air quality in their area, or a reduction in noise from an airport). The underlying philosophy is thus democratic, or populist, rather than technocratic or paternalist.

Concerning decisions on industrial safety, BCA will monetize individuals' willingness to pay for a marginal reduction in their exposure to technological risk. By extrapolating to a large population, this leads to the concept of *value of a statistical life* (VSL), or the cost of a fatality which is avoided by the spending on safety. Assuming that VSL = 5M€ implies that an average individual would pay 5€ to reduce his mortality risk by 1 in a million, and in a symmetric manner would accept 5€ as compensation for a 1 in a million increase in his probability of death from the specified risk; it also means that a population of 1 million people would be willing to pay 5M€ to prevent a statistical fatality. It is important to note that VSL is not what society would pay to save an *identified* life, nor should it be interpreted as a measure of the intrinsic "value" of a human life [2, 3]. This notion, which strikes some people as being immoral, is in fact implicit in any public spending on safety which is limited by an annual budget (for instance, public spending on road safety).

Willingness to pay for changes in exposure to risk can be estimated either by asking people how much they would be prepared to pay to benefit from a specific risk-reduction measure (called "direct methods"), or by observing their preferences on similar markets, such as purchasing ABS equipment in automobiles, or smoke detectors, or wage differentials for jobs which are similar in required qualifications but differ in the level of exposure to hazards (so called "revealed preference" methods, which tend to be more reliable than direct methods). Willingness to pay for an environmental "good" such as a national park can be estimated by observing the number of kilometers that people are willing to travel to benefit from the amenity, and adding travel costs and the opportunity cost of the time spent in the park. A body of research in economics over the last 30 years has accumulated evidence concerning people's willingness to pay for many aspects of their environment [4].

Benefit-cost analysis has been used since the 1970s in the USA for regulatory impact assessments of environmental legislation. It is used in the UK in a Seveso context as the recommended measure for justifying the ALARP nature of a safety investment. It is little used in France, with the exception of public spending on managing flood risk. In the next section, we report on an experimental application of the technique to a decision concerning management of technological risk generated by an LPG storage facility located in an urban area, and compare land use planning implications with the traditional analysis method used in France.

2. Case study: land use planning around an LPG storage facility

The facility studied[16] is a maritime LPG importation site located in north-eastern France, comprising butane and propane storage spheres and facilities for transferring LPG both to small trucks and train wagons, and for filling small bottles for domestic use. The facility is located in an industrial port which is surrounded by an urban area. Since industrial activity and some urban homes were located within the effect perimeter for certain accident scenarios on the plant, different technical solutions were being investigated to reduce the level of risk. Our case study consisted of comparing a number of possible changes to the facility:

- scenario 1: the implementation of a number of safety barriers and changes to management of the facility, proposed by the plant operator: removal of one of the LPG storage spheres, removal of all railway wagons on site, and a reduction in the quantity of gas stored in the spheres.
- scenario 2: the implementation of a more costly technical measure proposed by the competent authorities, involving covering the gas storage spheres with a layer of material ("mounding") to protect them from a possible impinging gas flame, as well as a reduction of the quantity of gas stored in the tanks.
- scenario 3: the complete closure of the facility, with the assumption that clients in the area currently supplied from the plant would be supplied by trucks arriving from another importation facility on the west coast of France.

We compare scenarios 1, 2 and 3 to the reference situation at the time the study was launched (scenario 0), by carrying out the following steps which comprise a BCA:

1. Specify the perimeter of the analysis, *i.e.* the list of economic agents for whom we will estimate the consequences of the different possible scenarios;
2. List the consequences of the scenarios and choose ways of measuring them;
3. Provide a quantitative prediction of the consequences for each scenario, over the project lifetime;
4. Monetize the consequences, or convert them into a monetary unit to allow comparison;
5. Discount future benefits and costs, in order to obtain the *net present value* of each scenario;
6. Analyze the robustness of the results obtained by undertaking an uncertainty analysis for the main uncertain input parameters;
7. Recommend a decision.

Hazards considered. Three types of hazards were included in the safety case for the facility, and were assessed in our study:

1. unconfined vapour cloud explosion (UVCE), due to a leak of flammable gas to the atmosphere which explodes some time after the time of release;
2. jet fire, a large flame due to a leak of gas to the atmosphere which ignites immediately;
3. BLEVE, or boiling liquid expanding vapour explosion, a very dangerous phenomenon which can occur if liquefied flammable gas stored under pressure is heated for a long period (for instance due to the presence of an impinging jet fire), leading to an increase in pressure inside the tank and a weakening of the tank structure, and eventually to the rupture of the tank body, a large release of gas and a fireball.

16 The study reported on was carried out by Valérie Meunier, with the assistance of Nicolas Treich.

The accidental scenarios considered are listed below:

- BLEVE of LPG transport trucks, railway wagons, or large LPG storage spheres;
- pipe ruptures, for pipes of small and large diameter;
- the rupture of loading mechanisms for railway wagons or trucks.

The probability and different effect distances of each scenario were estimated by a specialized firm, working for the plant operator in order to write the Safety case[17]. The BLEVE of the LPG storage spheres are the accidental scenarios with the largest effect distance in our study. The heat released can have deadly effects on people within a distance of around 600 meters, and the overpressure from the explosion can cause severe injuries (in particular due to projections of glass from windows) up to 1300m.

Consequences of a possible accident. We used assessments of the population in three zones around the plant, made for previous safety case studies. Relatively dense urbanization is present around the site (see figure 1), with 420 people (in addition to the 22 workers on site) working or living within a radius of 360m; 6700 people living between 360 and 900m; and 24500 people living between 900 and 1600m[18]. The level of traffic on nearby roads and the railway was also estimated. These allowed us to estimate the number of people who would be killed and injured for each type of accident (only BLEVE and UVCE have consequences which extend off site; effects of UVCE are largely attenuated beyond 450m by the presence of a cliff which would prevent the propagation of gas clouds).

Our study considered the following consequences of the different scenarios:

- direct costs for the facility operator: in scenarios 1 and 2, capital costs related to the safety mechanisms implemented; for scenario 3, the dismantling of the facility, the additional cost of supplying clients in the region via road transport, and the social cost of eliminating jobs.
- The indirect costs to the facility operator: in scenarios 1 and 2, such as impact on productivity (which we assumed to be negligible in scenarios 1 and 2) and strategic consequences of scenario 3, such loss of market share if cost overheads are transferred to clients (we did not have sufficient information concerning the market structure to estimate this indirect cost, and assumed it
- would be negligible).
- direct benefits linked to the reduction in the probability or the consequences of an accident due to the safety measures implemented in scenarios 1 and 3 were studied in detail, and include avoided damage to people (deaths and injuries avoided), avoided damage to the facility and to nearby industrial activity, and lost production caused by the temporary closure of activities on site after an accident.

Event probabilities and effect distances were extracted from the risk assessment studies undertaken by a consultant on behalf of the industrial operator in order to compare the different investment strategies and to write the safety case.

Consequences excluded from the study perimeter. The impact on the image of the firm in case of an accident is not included in our study, as it is very difficult to estimate, and would depend strongly on how the accident was reported in the media. The strategic

17 The safety case was approved by the competent authorities. The underlying risk assessment is undertaken using a somewhat conservative method, which tends to overestimate the probabilities and consequences of industrial accidents; when used in a BCA context, this bias (which we have not attempted to correct for) tends to overstate the value of spending on safety.

18 For simplicity, population density within the spherical red region and orange annular region is assumed to be uniform.

value for the nation of an LPG importation location is also not included in the perimeter of our study. The impact on productivity in each scenario is assumed to be negligible.

Figure 1. Aerial view of the site surroundings, with circles representing distances of 360 and 900m

Estimation of the costs and benefits of each scenario. In our study, benefits are generally associated with a smaller probability of an industrial accident, and thus with a smaller number of people killed or injured, and a lower probability of causing material damage. In the case of scenario 3, benefits are negative due to an increased expected number of people killed during road transport. The following assumptions were made to monetize different types of benefits and costs:

- Concerning averted fatalities and injuries, we use values suggested by the European Commission (2.5M€ per statistical fatality, which is an upper value recommended by the Commission for air quality regulatory impact assessments) and by the UK *Health and Safety Executive* (300k€ for a severe industrial injury) and French figures for road accidents (225k€ for a severe accident and 33k€ for a minor accident).
- For avoided material damages, the value of the industrial facility is estimated at 25M€; nearby industrial installations which would be damaged by an accident have a replacement cost of 67.5M€; LPG tankers or cargo boats potentially at port have a value of 60M€; lost production of firms in the nearby industrial zone is estimated at 5M€; houses in the potentially affected area are assumed to have an average value of 150k€ and apartments 120k€[19;] the cost of replacing window frames and windows in a dwelling is 5500€; an average household owns 1.5 vehicles, each worth 15k€.
- Concerning scenario 3, the closure of the site leads to an estimated increase in 475000 km per year in road traffic (400000 km of trucks with small LPG bottles, and 75000 km for LPG tankers). Given accident statistics concerning hazardous materials transport, this traffic leads annually to 366×10^{-5} statistical deaths, 2928×10^{-5} severe injuries and 5124

19 These values were estimated from *for sale* announcements for houses and apartments in the area.

$\times 10^{-5}$ light injuries. The environmental impact (in terms of CO_2 emissions) is estimated at 0.6€/km [5]. Dismantling the facility is assumed to have a zero net cost, since the sale of scrap metal from the installations would compensate for labour costs.

- Investments for scenario 1 are estimated by the plant operator to cost 1.5M€, and 10M€ for scenario 2. Extra operating costs for scenario 3 (primarily due to higher LPG purchasing costs at other importation sites on the French west coast and to additional road transport) are estimated to be 2.4M€ per year. The cost of lost employment on the site (both direct and indirect) over 4 years is estimated at 1.2M€.

In order to compare costs and benefits generated in different years, it is necessary to convert future costs and benefits into their *net present value*, using assumptions on a discount rate[20]. We have assumed a social discount rate of 4%, and assumed an investment horizon of 15 years (this means that the annualized cost of the safety mechanisms, used in our BCA, is obtained by dividing by the total cost by 15).

Summary of benefits and costs.
The following table summarizes the values obtained, using the assumptions described above[21]. Costs and benefits are represented per year.

	Scenario 1	Scenario 2	Scenario 3
Benefits			
Averted fatalities	6 275	6 400	-1 169
Averted injuries	2 745	2 817	-5 060
Material damage avoided			
On site	950	675	4 000
Off site	1 045	1 016	1 087
Sum of benefits	*11 015*	*10 908*	*-1 142*
Direct costs			
Investment	129 723	864 818	0
Distribution overheads	0	0	1 100 000
Other direct costs	0	0	43 241
Indirect costs			
Environmental costs	0	0	2 850
Lost indirect employment	0	0	103 778
Sum of costs	*129 723*	*864 818*	*1 249 869*
Net annual benefit	**-118 708**	**-853 910**	**-1 251 011**

Interpretation of the results

The numerical results presented can be interpreted in the following manner:

- The closure of the LPG importation site would, given our hypotheses, lead to an

20 The social discount rate represents the *opportunity cost* of other projects which could be implemented with the same money; it is related to the rate of return of bank deposits (which in turn are related to inflation).

21 The values are presented with many significant figures, but in fact comprise significant uncertainty. We have undertaken a full uncertainty analysis and obtained probability distributions for each output, but for simplicity only present median values in this paper.

increase in the level of risk to which inhabitants of the region are exposed (due to the increase in transport of hazardous materials via the road network in order to supply clients in the area).

- Scenarios 1 and 2 would result in levels of technological risk which are within the same confidence interval. However, the cost of the second scenario is 7 times greater than the first.
- An alternative manner of presenting our results is to calculate, for each scenario, the net cost to society of each statistical death averted by the implementation of the safety measure. Scenario 1 implies annual net costs of 125000€ and allows a reduction of the number of statistical fatalities of 251×10^{-5} per year. The annual social cost per averted fatality is thus 50M€. With the same type of calculation, the second scenario implies a social cost of 332M€ per statistical death averted. (Scenario 3 implies more spending for an expected mortality which is higher.) Economic analysis of public spending on prevention suggests that risk reduction projects should be implemented when the cost per averted fatality is lower than 1.5M€ (for public investment in road safety projects in France), or 2.5M€ (value used for the regulatory impact assessment of European legislation on air quality). This analysis suggests that scenarios 1 and (especially) 2 are *inefficient*, in the economic meaning of the word: a larger number of fatalities could be avoided if the spending was allocated to the reduction of other classes of risks[22].

Robustness. We have undertaken a sensitivity analysis of the results with respect to the principle uncertain variables (cost of a statistical life, discount rate, base probability of an accident, investment horizon, *etc.*). The analysis shows that the most sensitive uncertain factors are the investment horizon (time-frame for amortizing the spending on safety), the discount rate and the overheads in scenario 3 for obtaining gas from a different supplier. The uncertainty analysis shows that the conclusions are *robust*, *i.e.* that with most possible combinations of uncertain input variables, the ordering of scenarios (in terms of social net benefit) remains the same.

3. Reception of the BCA method

The results described concerning the case study were presented to the competent authorities by the operator of the plant, in an attempt to obtain approval for scenario 1, as opposed to the (significantly more expensive) measures described in scenario 2. The attempt failed, and scenario 2 was finally implemented. Several reasons were given for the rejection of the BCA (risk-informed and cost-informed) argument:

- the argument was not judged sufficiently convincing to override a *Best Available Technology* approach, which underlies the national doctrine requiring all operators of LPG spheres to implement flame-proof mounds (irrespective of costs);
- an argument based on concepts such as the statistical value of life, which is often poorly received on moral grounds in Latin cultures such as France, was seen as difficult to defend in discussions with the local population[23];
- national doctrine concerning the management of technological risk is based on uniform thresholds defining acceptable exposure to risk, and includes little latitude for the integration of cost considerations, instead of being guided by local preferences.

22 The LPG distribution sector has traditionally been quite profitable, which has led the competent authorities in France to require higher levels of safety spending than less profitable, but similarly hazardous, industrial sectors.

23 Legislation introduced in France after the AZF accident in 2001 mandates the creation of local communication/consultation bodies called *Comités Locaux d'Information et de Concertation.*

While these arguments have their merit, we believe that the cost of such decisions (in monetary terms, but also in terms of lives which could have been saved by allocating the spending to more efficient sources of safety improvement) should be presented to the public, to allow democratic debate on alternative doctrines. It is worth noting that cost considerations[24] are today a significant obstacle to the timely implementation of new land-use plans around top-tier Seveso facilities in France, called *Plans de Prévention des Risques Technologiques.*

Conclusions

Despite having been invented in France by the engineer Jules Dupuit in the mid 1800s, to assist decision-making concerning maintenance of public transportation infrastructures, benefit-cost analysis (and more generally, decision-evaluation techniques) see little use in France. Our research suggests that these techniques could provide decision-makers with a clearer view of the benefits and drawbacks of the various alternatives available in land-use planning decisions and help to establish compromises which are in the public interest. By documenting the different issues which impact the decision and highlighting the different weights accorded to different criteria, the decision process becomes more transparent and more open to public debate and critique, and could lead to land-use planning decisions which are better accepted by stakeholders.

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24 Costs concern industry and the government, in the form of compensation to people whose homes are affected by expropriation measures and future restrictions on the possibilities for economic development of large areas, but also local citizens who sometimes wish to stay in houses that they may have occupied for decades , and for whom expropriation causes significant distress.

Consequence analysis of the domino effect phenomena in the context on Land Use Planning

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Abstract

Domino effect is responsible of several catastrophic accidents that took place in the chemical and process industry. Although the destructive potential of these accidental scenarios is widely recognized, scarce attention was paid to this subject in the scientific and technical literature.

As mentioned above, accidents caused by domino effect may lead to catastrophic events, such as destroying the industrial process or storage site. Hence, enforcement measures should be taken appropriately. The identification of possible escalation events is required in the safety assessment of sites where relevant quantities of hazardous substances are stored or handled. In the European Union, "Seveso-II" Directive requires the assessment of on-site and off-site possible escalation scenarios in sites falling under the obligations of the Directive. Generally speaking, two strategies are always adopted, namely the active and passive strategy ([Cozzani et al., 2007] and [Cozzani et al., 2008]). The passive strategy involves proper design of physical barriers or protection systems (e.g. thermal insulation of process equipment), while the active strategy usually means compulsory countermeasures required by national legislation as well as international standards. As for the prevention framework against domino effect, Reniers proposed a framework "Hazwim", in which many kinds of analysis methods (including Hazop, What-If analysis and the Risk Matrix) were integrated ([Reniers et al., 2005a] and [Reniers et al., 2005b]). However, for both passive and active strategies, dominant major hazard installations should be determined in advance. Therefore, there is a much need to develop models capable of picking out critical node from a given Domino effect network.

The results evidence that quantitative risk assessment of escalation hazard is of fundamental importance in order to identify critical equipment and to address prevention and protection actions. Unfortunately no well accepted approach exists to date for the analysis of domino hazards. Only several simplified models are available ([Bagster and Pitblado, 1991], [Cozzani and Zanelli, 2001], [Khan and Abbasi, 1998], [Latha et al., 1992], [Pettitt et al., 1993] and [Reniers et al., 2005]). Nevertheless, safety distances or threshold values for the damage to equipment are currently used for preliminary assessments. However, a relevant uncertainty exists in the threshold values to be assumed in such assessments ([Cozzani et al., 2006] and [Cozzani and Salzano, 2004]).

In this paper we present how the combinations of simulation techniques on the one hand and qualitative and quantitative data on the other, will offer a comprehensive up-to-date list of cross-company domino hazards and recommended actions in industrial parks.

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7	Bellomo	Fabrice	Grand Port Maritime de Rouen	France	
8	Mr	Benjelloun	Fessel	Service Public de Wallonie	Belgium
9	Bentley	Michael	CETE Normandie-Centre	France	
10	Mrs	Bergiers	Marie-Agnès	Valmaris	France
11	Mrs	Casier	Maud	Ministère du Développement Durable	France
12	Mr	Chafouk	Houcine	ESIGELEC/IRSEEM	France
13	Mr	Chantelauve	Guillaume	INERIS	France
14	Mr	Chateauneuf	Alaa	Blaise Pascal University	France
15	Mr	Christou	Michalis		
16	Mr	Christou	Michalis	EC – Joint Research Centre	Italy
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19	Mr	Degrave	Claude	EDF-SEPTEN	France
20	Mr	Demichela	Micaela	Politecnico di Torino	Italy
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22	Mr	Devillerval	Marie-France	Mairie de Ferrières-en-Bray	France
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24	Mr	El Hami	Abdelkhalak	INSA - Rouen	France
25	Mrs	Essig	Philippe	ICSI-Institut pour une Culture de Sécurité Industrielle	France

26	Mr	Evers	Mariele	University of Wuppertal/University of Karlstad	Germany
27	Mr	Ferreira	Luís	FEUP – Faculty of Engineering	Portugal
28	Mr	Ferton	Eric	Université Littoral	France
29	Mr	Galland	Jean-Pierre	LATTS	France
30	Mr	Gille	Pierre-Edouard	DREAL - Haute Normandie	France
31	Mr	Gintautas	Dundulis	Lithuanian Energy Institute	Lithuania
32	Mr	Guezo	Bernard	CERTU	France
33	Miss	Guinand	Frédéric	LITIS Université du Havre	France
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36	Mr	Heidler	Armin	Lebens Ministerium ??	Austria
37	Mr	Henry	Christian	GRT Gaz	France
38	Mr	Kortner	Henrik	Safetec Nordic	Norway
39	Mr	Lacome	Jean-Marc	INERIS	France
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41	Mr	Lannoy	Andre	IMdR	France
42	Mr	Lapebie	Emmanuel	CEA DAM-Gramat	France
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53	Mr	Mignelli	Claudia		
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