A short cut methodology for flood-technological risk assessment

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This paper discusses some methodological issues characterizing the development of a short-cut methodology for Na-Tech risk assessment, with particular reference to the integration between flood – and technological – related hazards. Actually, flood events can involve industrial areas increasing the level of risk for people, especially in densely populated areas where major hazard factories and flooding areas overlap. In spite of its potential high relevance, risk from industrial accidents triggered by floods has so far received little attention.

1. Risk assessment in Na-tech research

The current disaster management panorama considers the Na-tech risk as one of the main fields of work for future research. It refers to the risk due to industrial accidents caused by natural hazards, such as floods, earthquakes, hurricanes, volcanic eruptions. In fact, as shown in the literature (Cruz and Steinberg, 2005; Steinberg and Cruz, 2004; Steinberg *et al.*, 2004; Burby *et al.*, 2003), there is a significant need for integrated methodologies capable of estimating and reducing damages in areas where different typologies of hazard are present.

In fact, recent events highlighted the vulnerability of industrial sites in case of natural hazards, because of the involvement of geomorphologic and meteorological conditions, manufacturing processes, infrastructure systems, and people (*e.g.* earthquake in Kobe, Japan, 1995; earthquake in Koecli, Turkey, 1999; environmental pollution in Baia Mare, Romania, 2000; floods along the Elbe River Basin, Germany, 2002; Hurricane Katrina in New Orleans, USA, 2005).

Earthquakes, floods, drought, volcanic eruptions, and other natural hazards cause each year around the world tens of thousands of deaths, hundreds of thousands of injuries, and billions of dollars in economic losses. The current frequency of natural disasters and the magnitude of past events, as a measure of the risk size, generated a growing awareness about the potential damage considered by natural hazards. Consequently, an increasing number of studies and researches on risk management were carried out in different disciplines (*e.g.* meteorology, hydrogeology, land use planning, civil engineering). The interactions between natural and industrial hazards are often poorly handled by the current risk management systems, while they may cause catastrophic effects, as shown by a number of recent events (OECD, 2006). Direct and remote damages were reported not even for industrial activities (*e.g.* pipelines rupture, uproot of tanks, economic costs) but also outside of the plants (*e.g.* deaths and injured inhabitants, air pollution, soil contaminants).

Therefore are necessary methodologies to compare consistently technological accidents and disasters due to natural hazards. These allow discussing the consequences of a disaster with the aim of identifying possible integrated risk prevention measures. Risk assessment methodologies for natural and technological hazards were usually carried out separately for the single hazard typologies. These methodologies become more articulated when several hazards (industrial accident, transport of dangerous materials, floods, earthquakes, and hurricanes) affect simultaneously the same area. Multi-risk situations make more difficult the technical assessment and the managerial process addressed to define and implement interventions for risk prevention. Apart from a few specific cases, current methodologies do not attempt to combine different assessments to a unique holistic one (Grunthal *et al.*, 2006).

Despite the management of both industrial and natural hazards is supposed to address interactions with other hazards, nonetheless it is widely acknowledged that actual prevention efforts and response capabilities are often inadequate. Till today, natural and technological hazards were generally studied as separate events. Consequently, little information on their interactions was produced. For instance, multi-risk emergency response plans consider different type of hazards as threat for the local area. Nevertheless, they are not usually expected to occur simultaneously (OECD, 2006). To avoid these difficulties, integrated risk assessment should not focus on a singular process but on multiple processes. The development of innovative methods (to identify, assess, and manage risks where natural and technological hazards coexist) is required.

2. Comparing flood and technological risks

Na-Tech risk assessment, with particular reference to the integration between flood – and technological – related hazards, represents a recent controversial field of research. In recent years, floods and industrial accidents were two major sources of risk, which received a renewed attention from the public and policy-makers in most of the European countries (OECD, 2006). The emergent debate concerns the adequacy of existing regulations and their enforcement on flood areas where hazardous industrial installations are developed. Actually, flood events can involve industrial areas increasing the level of risk for people, especially in densely populated regions.

Industrial risk and flood risk prevention are quite complex activities by themselves, including the governance of engineering methods, social expectations, economic priorities, and political approaches. Nevertheless, integrated risk situations make more difficult the technical assessment and the managerial process addressed to define and implement the interventions for risk reduction and mitigation. Methods and tools to identify and assess coexisting risk scenarios need to make professionals and public officials able to deal with them, through the comparison and the integration of risk elements.

In this context, risk assessment is the main step for identifying the level of the possible physical damages due to an industrial accident caused by a flood.

Risk assessment generally includes the following phases: hazard identification, that is the definition of possible hazardous events that can generate an accident; Preliminary Risk Analysis by using short-cut methodologies; Quantitative Risk Analysis (QRA) by the estimation of the frequency of occurrence (F) and the consequences (C) of a specific hazardous event; planning of the appropriate protection and prevention measures; risk monitoring and control.

With reference to QRA, risk usually refers to the so-called "Societal Risk", which is often represented using F-N curves. These curves, used in literature for the risk assessment of various hazards (industrial accidents, airplane accidents, transport of dangerous materials, and flood), represent the expected frequency of occurrence of a certain event in the future (Jonkman, 2005; Bell and Glade, 2004; Guzzetti, 2000). Particularly, a F-N curve shows the annual frequency of occurrence of an event with N or more fatalities on a double logarithmic scale.

With reference to these considerations, risk assessment is formally the appraisal process of both the type and the level of threats posed by a hazard affecting a specific area. Because of this, risk estimations for hazardous events require to know what is the likelihood or probability of each event as well as the magnitude and the nature of its consequences. These consequences depend both on the event characteristics (typology, frequency, location) and on the vulnerability of exposed assets (social, environmental, and building) that suffer losses caused by the specific event. To estimate how a particular event may diversely affect the social and building environment, also human and physical vulnerabilities should be considered. In this sense, in spite of only moderate event intensity, the total losses may be considerably due to the large number and the high values of structures and people exposed to the hazard.

A large number of QRA methods and tools for predicting the possible consequences of industrial accidents are currently available. Most of these methods are implemented in dedicated software that proliferated in recent years, thanks to the development of computers and information systems. In fact, especially for industrial risk, the assessment of possible damages related to an accidental event is developed by the use of programs based on well-accepted algorithms.

Consequence assessment in case of flood risk may be considered in terms of average event mortality (number of fatalities/number of events) which is a parameter representing the loss of life estimated for a single event (Jonkman, 2005). Flood fatalities are rarely examined in depth to identify, classify, and quantify trends, understand causes and circumstances of events. As suggested in the literature (Penning-Rowsell *et al.*, 2005), there are three broad sets of characteristics which influence the degree of immediate harm to people in case of flood. These are: the flood's characteristics (*e.g.* water depth, water velocity), the location features (*e.g.* inside/outside of buildings, residence typology), and the population characteristics (age, gender, health).

Specifically, the literature presents different typologies of flood (Jonkman, 2005): freshwater flooding (river floods, flash floods, coastal floods, drainage floods), tidal wave/bore, tsunamis, and dam breaks. These are catalogued based on forces, pressures, motion, oxygen deprivation, chemical reaction due to contaminants, debris impact, and flood-related fire consequences. However, heavy rainfalls can influence location distributions, especially considering the use of warning systems. In fact, other flood characteristics, potentially relevant to loss of life and major injuries, are: speed of onset and flood warning, flood duration, presence of debris contaminant, nature of floodwater, presence of defenses, nature of floodplain, nature of the built area.

Floods cause enormous damages on global scale and the need of improvement of methods and tools to prevent the related risk is well recognized. Floods are characterized by excessive and unexpected overflow of water into areas that are not normally submerged. The greatest hazard associated with floods is rapidly moving and rising water. As aforementioned, flood events may provoke health consequences that can be also psychological (mental) or physiological (physical). Particularly, negative physical effects may be lethal or non-lethal. No generally accepted classification method, to assess flood fatalities, exists in literature, but loss of life estimations are often used to assess the safety of flood protection systems, such as dams and dikes. This is the reason why, one of the most used methods to assess flood consequences focuses on death, as one specific physical effect that may result from an array of medical causes. In addition, according to Jonkman and Kelman (2005), connections between psychological health effects and mortality in flood disasters persist in literature. However, quantitative assessments are quite difficult due to the challenges played by the collection of long-term data (different classifications with varying levels of detail) and the necessity of attributing a specific death index to a particular cause, long after the event (different classifications are used).

The flood damages assessment requires considering the possibility of generating further industrial accidents. In fact, accidental hazmat releases may be provoked by a flood because of the floodwaters rising. These may generate: the uproot of tanks, the rupture of underground oil or gasoline pipelines, the dislodge of storage tanks, the liberation of chemicals stored at ground level, the disruption of water purification and sewage disposal systems, and waste overflow (Noji, 1991; Young *et al.*, 2004). Human health, such as stress and respiratory problems, can be adversely affected when acute or chronic exposure to hazardous materials occurs because of floods. Fires unchaining, when flammable gases or liquids are released and ignited, poses an additional threat to human health. A significant number of causalities in floods is due to fires originated by the spillage of flammable components from oil and gasoline storage tanks with a resulting pool spreading and pool ignition (Young *et al.*, 2004).

The physical impact of a flood on an industrial site with a hazmat release is strongly influenced by its characteristics (*e.g.* arrival time, flow direction, depth of water) and the plant features (*e.g.* building standards, systems design, presence of warning systems, presence of toxic or reacting substances, elasticity of slender units, structural resistance, permeability and drainage capability of components, anchorage to the ground). For this reason, structural vulnerability of the plant represents a strategic element for risk assessment. However, a detailed analysis of the flood – industrial risk requires a large amount of resources and information up to the structural details of plants and buildings that can be flooded as well as to the detailed modeling of flood.

These resources are hard to find even when major risk industries are involved. In fact, Na-tech events triggered by floods are usually not considered in risk assessment. Consequently, when SMEs or small/medium storages are involved it is unrealistic to develop a detailed QRA for flood-industrial risk assessment. It follows that there is a call for more simplified risk assessment methods capable of performing a first-attempt estimation of the vulnerability of an industrial plant under flood conditions. The result of this preliminary risk assessment may be used at least as a screening methodology for deciding when a more detailed risk assessment is required.

Focus of this manuscript is developing a short-cut risk assessment methodology for a preliminary investigation of the plant vulnerability to flooding.

3. The AHP methodology for assessing the vulnerability of an industrial plant to a flood

Considering Na-tech events, one of the main current efforts is the definition of a risk assessment methodology for flood and technological events. According to a probabilistic approach that considers risk as the combination of the event frequency and its related consequences, a risk assessment methodology should account for both the combined frequencies and the related consequences. The combined frequency represents the integration of the two distinct frequencies: the former for the flood event and the latter for the triggered industrial accident(s). The consequences assessment, on the other and, considers the estimation of possible damages due to a Na-tech event.

As suggested in Booysen *et al.* (1999), the evaluation of industrial flood damages requires four main industrial components: plant and equipment, raw materials, goods, and structure. According to this, in risk assessment a set of unit damage functions may be used for computing the damages produced on an industrial plant. Separate functions may be developed for structural damage, damage to the plant assets, and production damage.

However, one of the main goals in risk assessment consists in estimating the structural vulnerability of the industrial plant to a flood (*i.e.* the resilience of the plant to face a flooding event). Furthermore, in the current methodological approaches industrial vulnerability assessments do not account for natural hazards triggering industrial accidents. Therefore, preparedness, mitigation, and response plans do not incorporate simultaneous disasters. Consequently, risk management is planned only for either natural or technological disasters, but not for a Na-tech events (OECD, 2006).

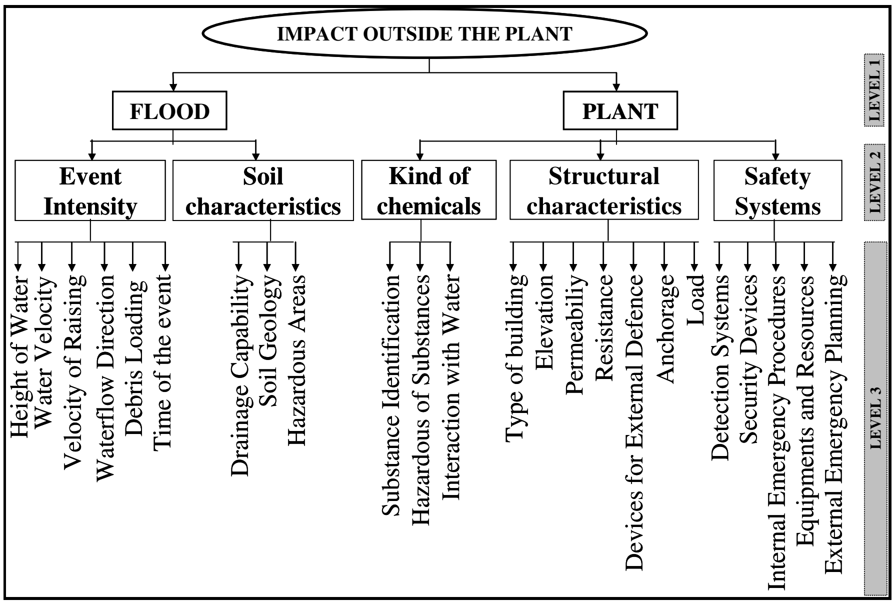
This vulnerability estimation can be performed by analyzing a series of parameters that pertain to physical, systemic, and functional aspects through the Analytical Hierarchy Process methodology (Saaty, 2006a, 2006b). AHP is a methodology to support decision–making processes by defining possible alternatives within a weighed multi–criteria framework.

The assessment of the structural vulnerability plant represents a contingent issue that can be considered in the AHP approach as the main goal in front of which operational decisions need to be taken. The AHP provides a comprehensive and rational framework for structuring a problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. The AHP, in fact, provides a method for decomposing a complex decision problem into a hierarchy of sub-problems that represent structural levels comprehending more elements. Each of these levels can be assessed by considering the weighs and the importance of each element included.

Firstly, the AHP methodology requires decomposing the goal (in this case the existence of a significant impact outside the plant due to an industrial accident triggered by a flood) into its basic parts, progressing from the general to the specific. This structure comprises a goal, criteria, and alternative levels. Each set of alternatives is further divided into an appropriate level of detail, recognizing that the more criteria included, the less important each individual criterion may become. Next, AHP assigns relative weights to these criteria. Each criterion has a local (immediate) and global priority. The sum of the weights beneath a given parent node must equal one. Finally, once the criteria are weighed and the information is collected, AHP focuses the information into the model. Scoring is on a relative basis and compares one choice to another. Relative scores for each choice are computed within each leaf of the hierarchy. Scores are then synthesized through the model, yielding a composite score for each choice at every node of the tree hierarchy, as well as an overall score.

This distinguishes the AHP from other decision-making techniques. It not only allows considering a decision in a objectively way, but it encourages communication that leads to a better global understanding of the problem and its possible solutions. For this reason, AHP is extensively used in a wide variety of decisional situations, in fields such as government, business, industry, healthcare, quality, and education. In our case, the main goal was decomposed into a three-level hierarchy, which is summarized in Figure 1.

Figure 1 - Hierarchical decomposition of the main goal



The probability of a major hazard is related to the features of plant and flood that depend on some other specific attributes (*e.g.* flood intensity, soil characteristics, chemicals typology, structural features, safety systems) which in turn depend on different alternatives.

The fist step of the AHP methodology (once the three-level hierarchy is defined) is filling in the priority matrixes for the distinct elements considered at each level. Each of the elements of these square matrices represents a quantitative evaluation of the relative importance between two parameters (*i.e.* binary and relative comparisons according to Saaty, 2006a, 2006b). The scores assigned to the matrix elements should be assigned by experts, possibly by means of the Delphi method (Linstone and Turoff, 2002). From these matrixes, the final score summarizing the relative importance of the proposed alternatives respect to the probability of a significant impact on the plant neighborhood due to a Na-tech event can be computed. It represents a sort of weighed grade associated to each alternative.

The evaluation of this score requires the identification of some numerical classes for each alternative relative to the features of the analyzed plant. As an example, Table 1 shows the suggested classification for the soil characteristics related to the flood effects. By using this numerical classification for each alternative of a given plant, together with the weight of each alternative, it is possible computing an overall KPI (Key Performance Index) related to the vulnerability to Na-tech events for a given plant located in a specific territory. Obviously, this KPI has not an absolute meaning, but it is useful for comparing different solutions for a given plant. This is an interesting opportunity for a valuable screening tool. This methodology is still under development and it will be tested on an applied case study.

Table 1 - Classification for the Soil Characteristics related to the flood effects

GOAL: IMPACT OUTSIDE THE PLANT			L 1 - Flood	L 2 - *Soil Characteristics*		
ID	Livel 3	Index Description	Index Analysis			
			Unit of measure	Range		
				high	Medium	Low
7	**Drainage Capability**	Soil capability to absorb waterflow in the time (inflow-outflow).	Level of drainage capability	not well draining	average draining	well draining
8	**Soil Geology**	The material beneath the plant structure influence the behaviour of the same structure in case of waterflow, on the basis of the water absorbability.	Type of material	clay	sand	gravel or conglomerate
9	**Hazardous Areas**	The plant can belong to an hazardous areas differently characterized for contextual and flow elements. The areas are generally defined on the basis of a reference flood (as those in the PAI for the Po River in Italy).	hazardous areas of belonging	area of outflow (A for PAI)	area of overflow (B for PAI)	catastrophic area (C for PAI)

4. Conclusions

Vulnerability assessment can help in estimating the level of risk for fixed installations that are likely to experience hazardous and toxic releases (Lindell and Perry, 1996; Young *et al.*, 2004). Damage assessments following a disaster can provide important information for restructuring responses and investigating relationships between hazmat incidence and characteristics such as disaster intensity, mitigation measures and facility typologies (Young *et al.*, 2004). Consequently, particular attention should be devoted to the assessment of these interactions by both systems while using these investigations in the relevant fields of policy, from accident prevention and flood mitigation to emergency response and through land-use planning.

Based on vulnerability and risk assessment, a set of prevention measures for industrial plants can be identified. Especially, the industrial vulnerability assessment based on the innovative AHP methodology allows identifying some technical criticalities and force points on which concentrating preventive measures. Hazard reduction solutions may include for example: gas valve shutoffs for LP gas cylinders, pipelines reinforcement, safety appliances and equipment, shutdown systems for abnormally high flowrates (*e.g.* pipeline rupture, gas leak, earthquake detection) as reported in Young *et al.*, 2004.

5. References

Bell, R. and T. Glade, 2004, Quantitative risk analysis for landslides – Examples from Bildudalur, NW-Iceland, Vol. 4: Natural Hazard and Earth System Sciences, Edt. Guzzetti, Copernicus Publications.

Booysen, H.J., M.F. Viljoen and Gdu T. De Villiers, 1999, Methodology for the calculation of industrial flood damage and its application to an industry in Vereening, Vol. 25: Water SA.

Burby, R.J., L.J. Steinberg and V. Basolo, 2003, The TENURE TRAP. The Vulnerability of Renters to Joint Natural and Technological Disasters, Vol. 39: Urban Affairs Review, Eds. S. Clarke, G.L. Gaile and M.A. Pagano, SAGE Publications.

Cruz, A.M. and L.J. Steinberg, 2005, Industry preparedness for Earthquakes and Earthquake-Triggered Hazmat Accidents in the 1999 Kocaeli Earthquake, Vol. 21: Earthquake Spectra, Eds. F. Naeim and A.M. Reinhorn, Earthquake Engineering Research Institute.

Grunthal, F., A.H. Thieken, J. Schwarz, K.S. Radtke, A. Smolka, and B. Merz, 2006, Comparative Risk Assessments fort he City of Cologne – Storms, Floods, Earthquakes, Vol.38: Natural Hazards, Eds. T.S. Murty, V. Schenk, Th. Glade, Springer Netherlands.

Guzzetti, F., 2000, Landslide fatalities and the evaluation of landslide risk in Italy, Vol: 58, Engineering Geology, Eds. G.B. Crosta and R. Shlemon, Elsevier.

Lindell, M.K., and R.W. Perry, 1996, Identifying and managing conjoint threats: Earthquake-induced hazardous materials releases, Vol.: 50, U.S. Journal of Hazardous Materials, Eds. M.F. Fingas, J. Gardea-Torresdey, G. Lyberatos, J.H. Tay, Elsevier.

Linstone, H.A. and T.Murray, 2002, The Delphi Method. Techniques and Applications, Eds: H.A. Linstone and T.Murray, Portland State University and New Jersey Institute of Technology.

Jonkman, S.N 2005, Global Perspective on Loss of Human Life Caused by Floods, Vol.34: Natural Hazards, Eds. T.S. Murty, V. Schenk, Th. Glade, Springer Netherlands

Jonkman, S.N and Kelman 2005, An analysis of the causes and circumstances of flood disaster deaths, Disasters, Vol. 29, N. 1, pp. 75-97, Blackwell Publishing.

Noji, E.K., 1991, Natural disasters, Vol.: 7, Critical Care Clinics, Eds. R.W. Carlson, M.A. Geheb, Elsevier.

OECD, 2006, Italy. Industrial Hazards Triggered by Floods, OECD Publications, Paris Penning-Rowsell, E., P. Floyd, D. Rambsbottom and S. Surendran, 2005, Estimating Injury and Loss of Life in Floods: A Deterministic Framework, vol:36, Natural Hazards, Eds. T.S. Murty, V. Schenk, Th. Glade, Springer Netherlands.

Saaty, T.L., 2006a, Rank from comparisons and from ratings in the analytic hierarchy/network processes, 168, European Journal of Operational Research, Eds. R. Slowinski, J. Artalejo, J.C. Billaut, R.D., L. Peccati, Elsevier.

Saaty T.L., 2006b, Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process, vol VI of the AHP Series.

Steinberg, L.J. and A.M. Cruz, 2004, When Natural and Technological Disasters Collide: Lessons from the Turkey Earthquake of August 17, 1999, Vol. 5: Natural Hazards Review, Eds. J.E. Beavers and K. Tierney, ASCE Publications.

Steinberg, L.J., V. Basolo, R. Burby, J.N. Levine and A.M. Cruz, 2004, Joint Seismic and Technological Disasters: Possible Impacts and Community Preparedness in an Urban Setting, Vol. 5: Natural Hazards Review, Eds. J.E. Beavers and K. Tierney, ASCE Publications.

Young, S., L. Balluz, and J. Malilay, 2004, Natural and technologic hazardous material releases during and after natural disasters: a review, Vol. 322: Science of the Total Environment, Eds. J.O. Nriagu, Elsevier.