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Criteria for the identification and management of domino effects: an approach to the area risk evaluation

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The paper presents a set of technical and operational criteria provided for the identification and management of domino effect by the Competent Authorities, with the consequent necessity of elaborating a specific area risk evaluation in case of high concentration of industrial establishments. The approach foresees: 1. preliminary identification of establishments potentially affected by domino effects; 2. exchange of information, between establishments operators, needed to: review the actual potential of domino effects and, in case, the accident analyses; estimate effects on equipment; provide, if domino scenarios are identified, for additional measures to prevent and mitigate the scenarios; 3. domino establishments final identification.

Domino effects need to be considered due to their potential for risk escalation associated with the events chain, through an increase in the likelihood of a major accident or the potential consequences. These results must be considered in the internal emergency procedures of the establishments potentially involved, in the area external emergency plan and consequently integration of the safety requirements for land use planning, and information to potentially involved public in the nearby area. The domino effect analysis also plays a main role in the context of an evaluation of the overall risk in an industrial area with the presence of many hazard sources, being a necessary stage for preparing a quantitative area risk study. In these sites, it is necessary to evaluate the significance of an aggravation of the risk based on the possible peculiarities of the site where the industrial plants are located, such as the presence of vulnerable territorial elements in the damaged areas around each establishment.

Among sources of risks, an increasing role will play in the NaTech events, also due to ongoing climate changes. Therefore, it is necessary, while identifying the hazards and assessing the major risks of industrial sites, to pay attention to the natural hazards that may affect them, also considering the multiple simultaneous scenarios that they may trigger, giving a relevant contribution to the overall risk in an industrial area.

Keywords: domino; Seveso; major accidents; threshold; area risk; NaTech

* 1. Introduction

The Seveso III Directive 2012/18/EU, implemented in Italy by a legislative decree issued in 2015 - D.Lgs. 105/2015, is aimed at the prevention of major accidents involving dangerous substances. The D.Lgs. 105/2015 covers establishments where dangerous substances may be present (e.g. during processing or storage) in quantities exceeding certain thresholds. Operators of the establishments are obliged to take all necessary measures to prevent major accidents and to limit their consequences for human health and the environment. Depending on the amount of dangerous substances present, establishments are categorized into lower and upper tier, with different obligations. The requirements include, among others: notification of all concerned establishments; deploying a Major Accident Prevention Policy (MAPP) through the implementation of a Safety Management System for Prevention of Major Accidents (SMS-PMA); producing a Safety Report (SR) for upper-tier establishments; producing an Internal Emergency Plan (IEP) for upper-tier establishments; providing information in case of accidents (Marrazzo R., 2008).

Article 9 of Directive 2012/18/EU (Domino effects) states that Member States shall ensure that the competent authority identifies industrial establishments or groups of industrial establishments where the risk or consequences of a major accident may be increased because of the geographical position and the proximity of such establishments, and their inventories of dangerous substances (Official Journal of the European Union, L 197, 2012).

This paper aims to describe a technical and operational proposal for the implementation of Article 9 of the Seveso III, providing a set of criteria for the identification and management of domino effects in industrial establishments included in the scope of this Directive. The proposal is based on an analysis of the state of the art about methodologies for the quantitative assessment of the contribution due to the domino effect to individual and societal risk evaluation. The mentioned criteria do not yet address NaTech events, in particular for identifying and assessing the role played by the natural hazards, also due to ongoing climate change, that may severely affect the site, triggering multiple simultaneous scenarios.

**2. Procedure for identifying preliminary domino Groups (pdG)**

The Competent Authorities (CA) identify the preliminary domino Groups (pdG), i.e. groups of two or more establishments where it is possible to have the occurrence of domino effects, based on technical references and information received from operators, and prepares the list of establishments included in pdG.

The CA preliminarily identifies the establishments from which domino effects may originate (Establishment Source of Domino Effect - EstSDE), according to the cases specified in the following.

1. Identification of establishments, from which accident scenarios may arise that determine damage areas, related to specific threshold values, that fall within the boundaries of one or more receptors establishments (Establishment Receptor of Domino Effect - EstRDE).

The CA will obtain the needed information for the identification phase by the documents sent by the operators according to Seveso regulations (Safety Report, Notification, Land Use planning documents). n case of missing or lacking information, for the sole purpose of the application of the procedure, a conventional damage distance of 1000 m from the bounds of the EstSDE will be preliminary and conservatively taken.

Any pdG present in the area can be identified based on the overlapping of the damaged areas associated with each potential EstSDE, identified with the criteria and references mentioned above, with the areas of the nearby establishments (EstRDE), shown on the maps contained in the Safety Reports or in the Notification sent by the operator.

The pdG will consist, in the simplest case, of one EstSDE and one EstRDE.

Each EstRDE may be, in turn, also an EstSDE, due to accident scenarios that can occur within its boundaries.

1. As far as the establishments located in industrial parks can be considered, the methodology here is described as part of a unique single pdG, without further evaluation.

At the end of this phase, in case a) and case b), pdG formed by two or more establishments may, therefore, be identified for further evaluation.

Figure 1 provides the summary diagram for setting the preliminary identification stage of the "domino groups."



Figure 1: Summary diagram for the preliminary identification of the "domino groups"

**3. Exchange of information among the pdG operators to identify the definitive domino groups (ddG)**

The CA requires operators of the establishments belonging to the same pdG to share the information needed to allow to check the actual likelihood of domino effects and, if so, to review and adjourn, given the nature and extent of the overall hazard of major accidents, the relevant Seveso obligations (Major Accident Prevention Policy, Safety Management Systems, Safety Reports, internal emergency Plans, etc.).

The inclusion of an establishment in a pdG needs, for the operators concerned, a further analysis of the situation, to responsibly exclude the possibility of occurrence of domino effects between the establishments concerned.

Any special circumstances that may determine the possibility of an inter-establishment domino effect for conditions less heavy than those that led to the identification of pdG, should be responsibly highlighted at this stage by the operator and considered as the basis for the identification of domino effects themselves.

Based on the results of the domino effects identification carried out by the operators of establishments belonging to preliminary domino Groups (pdG), the definitive domino Groups (ddG) will be identified.

Some essential elements to be considered for an effective exchange of information between operators are pointed out below.

First, the operators must identify where vulnerable fixed, mobile or temporary targets are effectively placed, within the impact area, and identified using the damage threshold reported in technical literature and standards.

For the assessment of the domino effect, each pdG operator must:

* identify the most significant objectives (targets, e.g. tanks, large equipment, or pipelines containing toxic or very toxic substances, flammable liquefied gas, flammable liquids, storage of combustible and explosive substances, etc.), in the damaged area associated with the possible accident caused by domino effect; this area is dependent on the inherent hazard of the equipment (resulting from the type of substance, the amount present in the target, the operating conditions, the structural conditions), its location (connected to the plant configuration, the position on the ground, the view factors, the presence and efficiency of active and passive protection) and the type of scenario;
* estimate the probability that, given a certain physical effect on a vulnerable target, the possible damage does take place, i.e. the probability of domino effect, given the source scenario.
* evaluate the escalation of the consequences due to the domino effect (comparing it with the damage due to the source scenario), in terms of effects on the structures (which can further propagate the accident), people (paying attention to targets that can cause fatalities outside of the establishment boundaries) and/or the environment (also targets that can cause significant damage to important environmental resources have to be considered).

To estimate the probability of a domino effect, operators must use specific data representative of the situation, in coherence with the Safety Reports (in case of U-T establishments), or other relevant analytical documentation reporting major accident risks carried out (in case of L-T establishments).

A rigorous estimation of the damage of a target due to the domino effect may require a structural analysis of the target, considering its strength to mechanical and/or thermal stresses induced by the initiator event.

For the estimation of the probability of damage of the target it is necessary to use the models available in the international scientific literature, mainly based on Probit functions, for different classes of equipment, which allow the calculation of the failure probability for exposure to overpressure and/or radiation (Cozzani V. et al., 2005a), (Cozzani V., 2005b), (Cozzani V., 2005c), (Reniers, G., 2013).

In case of unavailability of specific data or significant uncertainties regarding the evaluation of initiating events or the target characteristics, approximate assumptions given in technical literature and standards can be used by operators, to estimate the domino effect probability (Snamprogetti, Assindustria, 2003), (ARPAV, 2005).

Through a keen consideration of elements pointed out above, the operators of establishments included in a pdG, must identify the actual domino scenarios, each characterized by the occurrence of one of more single scenarios arising from damaged targets; therefore domino effects analysis will possibly increase the number of accident scenarios that need to be considered by the operators: single scenarios plus domino scenarios, each with its frequency and consequences.

**4. Individuation of the definitive domino Groups (ddG)**

Operators inform the CA of the activities and results obtained: e.g. a declaration that domino scenarios are not identified, otherwise the list of the identified domino scenarios with their frequencies and consequences, detailing the technical and/or management measures, already existing or additional, taken to eliminate or remotize possible direct or indirect domino scenarios, etc.

Based on additional information received, the CA so can identify the definitive domino Groups (ddG), i.e. clusters where there is the actual possibility of the occurrence of domino effects, updating the list of establishments included in domino Groups.

In the following control activities, when presenting definitive domino groups, the CA may request integrative information to the operators involved, aimed to assess the possible domino effects and cumulative effects of the proposed interventions, i.e.: during the evaluation of the Safety Report; in the event of changes in establishments, plants, or storage; during land use planning procedures in the areas characterized by the presence of major accident risk establishments.

**5. Consideration in quantitative analysis and area risk evaluation of NaTech events as sources of domino effect**

Since the 1990s, the use of the acronym NaTech (Natural Hazard Triggering Technological Disasters) has become widespread to define an incidental event in which a Natural disaster, such as floods, strong winds, earthquakes, landslides, lightning, etc. triggers or amplifies one or more Tech(h)nological disasters.

In the technical and scientific literature, we find simple definitions, such as the following, which include among NaTech events: *accidents triggered by natural hazards or disasters* (OECD 2015)*;* amore detailed definition, of uncertain paternity, but largely andpractically adopted by safety experts, is the following *“technological incidents such as fires, explosions and toxic releases that can occur within industrial complexes and along distribution networks following natural disasters”.*

NaTech events have been relatively rare in the past: for example, incident data extracted from the European Commission’s eMARS database (EU Commission JRC/MAHB, 2024) and those resulted from a survey in 5 EU countries (EU Commission JRC/MAHB, 2014) show that from 1985 to today, on average, one major NaTech incident has occurred per year in EU countries.

In Italy, over the last 20 years, have been collected by ISPRA in its own industrial accident database at least 27 NaTech events (not classifiable as *major hazards accidents*, according to the criteria deducible by the EU Directives criteria) occurred affecting refineries, chemical and petrochemical industries and gas pipelines.

However, an increase in NaTech events is expected in the next years (Cruz A.M. et al.2004), due to the increase in the frequency of certain natural hazards.

In particular, the increase of the frequency of floods, and more generally of hydrological and meteorological events due to ongoing climate change, will likely be accompanied, in the absence or lack of adaptation measures, by an increase in the number of NaTech events, also due to the ever-increasing number of industrial structures and urbanized areas exposed to risk (because of economic and social development).

It is therefore necessary, while identifying the hazards and assessing the major risks of industrial sites, to pay attention to the natural hazards that may affect them. NaTech events may give a relevant contribution to the overall risk in an industrial area, being such events characterized not only by low probability but unfortunately also by high impact.

Addressing the issue of NaTech risk assessment, in addition to the tendential aspects deduced from historical experience, it is worth highlighting here the specific aspects of complexity that characterize it, such as:

* natural hazards can cause multiple accidents (simultaneous or in series) in large areas (such as those affected by floods and earthquakes), with domino effects that are more frequent than in the case of "conventional" accidents, with increment of frequency side in societal risk curves (Cozzani V.,2018);
* a NaTech accident can also be triggered by natural events of non-extreme intensity, which damage components of limited size (e.g. connections, pipes, rotating machines and moving parts - pumps, compressors, etc.).
* natural hazards can trigger other natural events in a cascade (e.g. an earthquake can cause a tsunami or a landslide).
* due to climate change, some natural hazards may occur in areas where they have never been observed before (see for example Medicane, i.e. extreme events that occurred in the Mediterranean with characteristics of North American hurricanes).
* in the event of a natural disaster, the vulnerability of the affected population increases, and therefore the consequences of a NaTech event may be more severe than an equivalent industrial accident that occurred in “conventional” conditions (with an increment of severity side in societal risk curves due to multiple scenarios) (Cozzani V.,2018).
* on-site and off-site response capabilities may be reduced by the natural event, due to the commitment of emergency teams to rescuing the population, which may reduce the availability of resources to mitigate the consequences of triggered NaTech events.
* safety measures adopted to prevent or mitigate conventional accidents may prove ineffective or insufficient, if not sized to withstand a natural event (barrier holes) (Cozzani V,2018).
* due to a natural hazard, it is possible that utilities (electricity, water, nitrogen, etc.) may be interrupted or reduced, resulting in total (or partial) unavailability of functions that are essential for safety (process control, shutdown, cooling, etc.), as well as the so-called “ancillary systems”, necessary for the operational management of the plants (Cozzani V.,2018).
* address NaTech needs for the integration and cooperation of industrial safety experts with other professionals who are not usually involved (geologists, hydrogeologists, civil, hydraulic, and environmental engineers, and weather experts).

Due to the aforementioned elements of complexity the experience of applying NaTech techniques and tools for domino effects evaluation and quantitative risk analysis, which represent the most powerful and sophisticated approach for the management of industrial risks (in particular if it is aimed at the integrated assessment of the so-called collective or societal risk, through the recomposition of individual risks and their representation through F-N curves), is still limited to pilot studies (Cozzani V.,2018).

However, due to some current national regulations in the EU that provide for their application in specific cases and considering skills and expertise already available in Europe and Italy too, in academia and among professionals, significant application developments for domino effects and quantitative analysis of NaTech events are underway, or expected, aimed to define standardized methods and procedures to include in overall risk analysis and related tools. In the following Figure 2, it is described in deep the analytical identification stage of the domino effect, aimed at classifying targets and estimating the domino effect probability (Cozzani, 2005b).



Figure 2: Analytical identification of the domino effects

**6. Conclusions**

The technical and operational criteria set out in this paper, which tries to respond to the obligation introduced by the Italian Authorities to implement Article 9 of the Seveso III Directive, offer sound technical and scientific support to the CAs for the identification and management of domino effects in major accidents risk industrial establishments. The identification of domino effects, due to the possible interactions between different establishments, aiming at identifying possible prevention and/or mitigation measures, is carried out to:

* re-evaluate the set of possible accidents (case studies, expected frequencies, and/or consequences).
* provide for the consideration of chains of accidents in a quantitative area risk analysis (evaluation of overall hazards in an industrial area, originating from different sources and subjects).
* maintain certain distances of separation between critical plants or equipment, to prevent the escalation of an accident or significantly reduce the probability of propagation.
* allow more accurate preparation of the internal emergency Plans and procedures, concerning field interventions, and external emergency Plans.
* integrate the industrial safety requirements in the LUP procedures.
* make available to the public and nearby sites more comprehensive information on the major accident risks arising from Seveso establishments.

The domino effect analysis plays a main role in the context of an evaluation of the overall risk in an industrial area with the presence of many hazard sources, being a necessary stage for preparing a quantitative area risk study, a sound tool that already can ensure better preparation of external emergency plans and ameliorate land use planning procedures and public information activities. Moreover, the expected increase in Natech events makes it necessary to develop, as a mitigation measure, standardized methods and procedures for their inclusion in overall risk analysis and related tools, which allow their application in the assessments carried out in compliance with regulations on the prevention of major accident risks in the countries subject to natural hazards, with a particular focus on in those countries that will be more exposed to climate change in the following years.

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