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Domino Effects in the Process Industries: A Review

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Abstract

Owing to an ever-increasing population and to the associated need for more goods and materials, plants that are more chemical are coming into existence around the world, which are mostly settled together so-called chemical clusters. This leads to increase of potential hazards and its severe consequences in this industrial sector. Among the most catastrophic industrial destructive accidents are those where a “domino effect” takes place, causing the Confrontation of a serious crash as well as the spread of a main incident that has recently occurred, maybe, several plant as well as equipment. Due to the high complexity of the incident and evolutionary situation as well as the greater degree of specificity of input information necessary, many features are employed to evaluate domino effects. It is because of that purpose alone that such incidents are exceedingly uncommon and most often result with in risk analysis of biochemical actions, the quantitative assessment as well as the risk mitigation by domino scenario being left out. This paper provides an exhaustive detail of the Quantitative Assessment for various Risk Caused because of the various domino accidents process as well as chemical industries.

Keywords: Domino Effect, Domino Accidents, Quantitative Assessment, Population, Quantitative Risk Analysis

1. INTRODUCTION

The relevance of domino hazard was recognized since the early times of process safety. In the 1980s, three milestone projects were promoted in Europe to answer to the public who are more concerned about the risk factor which is possessed but facilitating the hazardous facilities: the Canvey Island (United Kingdom) (HSE, 1978, 1981), Rijnmond (The Netherlands) (COVO, 1982), and Ravenna (Italy) (Egidi et al., 1995) quantitative area risk analysis studies. The results of these studies explicitly recognized the hazard due to domino effects, in particular in highly congested areas where several industrial facilities are present.

In 1982, the first European Directive aimed to maintain a specific ratio of domino hazards in order to control major accidents, also hazard already required the identification as well as assessment of domino hazards (Directive 82/501/EEC). Efforts have been recorded since the beginning of the 1990s towards developing quantitative methods for assessing domino incidents. By viewing this as an outer incident inside a failure tree as well as increasing the frequency rate of comparable accidents, Bagster&Pitblado (1991) developed a method towards integration of domino incidents within risk analysis. Several studies followed later 1995 as well as focused on particular topics like as escalator frequency evaluation (Pettitt et al. 1993) and escalation of the fire-induced domino assessment (Contini et al., 1996; Gledhill and Lines, 1998) and (Latha et al., 1992; Morris et al., 1994).

A relevant step forward toward the analysis over domino accident scenarios was made in the late 1990s, with the studies of Khan with Abbasi (Khan and Abbasi, 1998a,b) and that of Delvosalle and coworkers (Delvosalle, 1998). However, the limited available for computational analysis which is also available at the time still made difficult application for techniques to real industrial facilities. In recent times, so in order to develop the technique and tools to include the statistical analysis of domino scenario inside quantitative risk analysis (QRA) approaches has been a significant research effort (Antonioni et al., 2009; Cozzani et al., 2005, 2006). The QRA is presently the most extensively utilized instrument for providing risk assessment data in development of chemical industries due to typical incidents. Although QRA is clearly not an accurate depiction of the reality, it is the finest analytical forecasting tool known to date for evaluating the risk of complex systems or storage systems.QRA comprises of a series of approaches for the risk estimation of loss of life or economic damage presented by a specific method (CCPS, 2000; Mannan, 2005; Uijt de Haag and Ale, 1999). The purpose of QRA in the industrial risk assessment is the measurement of a risk demonstrated through risk indexes, including such specific local risk (LIR), annually individual risk and societal risk (F-N), hystograms of personal risk numbers of persons exposed to (I-N), potential loss of life (PLL) as well as expectation value (EFV) indicators. The risk analysis is focused on a particular approach to assessing the risk of industrial installations (Egidi et al., 1995; Uijt de Haag and Ale, 1999).

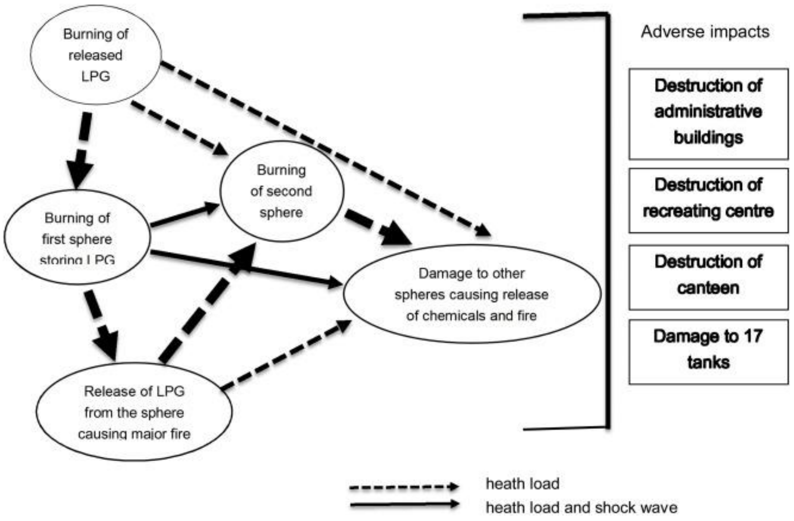

Figure 1:*Domino Effect.*

Since its origins in the 1980s and early 1990s, the overall strategy of QRAs is constant. QRAs are increasingly complex, extensive as well as built on slightly more accurate modeling. The ongoing optimization of computer programs as well as modeling (i.e. dispersal estimates, impact assessment, etc.) is linked to the breakthroughs in information technology and also the continuously improved computer power computation. The use of QRA to study the risks posed by hazardous facilities has been facilitated by the increase of computer power in a way that now thousands of scenarios can be treated in a reasonable time.

QRA techniques are now widely used to assess risks posed by installations extracting, processing and/or storing hazardous substances, and QRA is now an important tool which is used for the purpose of constant development, along with the continued operation as well as expansion of configuration of the procedure that meet society’s growing safety expectations.

Although QRA is quite a mature along with consolidated tool factor, its application to domino effect to date are also limited. Despite their importance, domino effects are usually excluded from QRAs. Actually, important computational resources are necessary for the quantitative analysis of domino effects is not easyavailable also not easy to obtain in this decade. Moreover, layout information and meteorological conditions (e.g. wind direction) play an extremely vital role in determining the escalation probability. Thus, a much more extended use of geographical information is required than in conventional QRA applications.

Domino accident quantification under the QRA system has been made possible in recent times by the methodologies and modeling of specialized development tools specific geographical data systems (Cozzani et al., 2005), which are supplemented by (Cozzani et al., 2006). Subsequent development in this topic has examined various pathways for assessing the probability of escalating scenarios, such as Bayes analysis as well as Monte Carlo approaches. And in subsequent comments, we describe the current approaches for the quantitative evaluation of domino theory, starting with instruments designed to support the quantitative assessment of domino effects in typical QRA techniques.

1.1 Quantitative Risk Assessment of Domino Accidents

A quantitative evaluation of the industry risk produced by domino-scenarios may be made in the event of a traditional QRA of the facility evaluated. The assessment of the situation with regard to domino contributions might be seen as a further responsibility to establish a risk management framework and place of interest. In this table, we present four standard steps of QRA (identification, frequency evaluations, effect evaluations as well as risk estimates) which are required for the evaluation of the quantitative domino situation (Antonioni et al., 2009; Cozzani et al., 2005). (CCPS, 2000; Uijt de Haag and Ale, 1999).In addition, the table provides the necessary instruments for each phase of the evaluation. For the evaluation of domino situations, the instruments emphasized in the table are specific. As the chart shows, the quantitative examination of domino scenarios requires three key groups of tools:

1. Threshold values to identify possible escalating targets.

2. Models of equipment damage

3. Specific frequency and impact measurement methods and processes for the entire domino scenario.

Table 1:*Stages Evaluation on tabular basis.*

Stage	Step	Tools Needed
1. Risk identification	1.1 Primary event estimate evaluated. 1.2 Possible destination	Models for impact assessment Values of thresholds

	unit's recognition 1.3 Each secondary situation to follow the loss of every target unit shall be identified.	
2. Calculation of Frequency	2.1 The possibility of harm for each target unit is estimated. 2.2 Each conceivable secondary scenario combination is identified. 2.3 Conditional computation of probabilities for every conceivable secondary scenario combination	Models for likely damage to equipment Software tools specialized Software tools specialized
3. Consequence assessment	3.1 Primary scenario impact evaluation 3.2 Evaluation of the effect of each suggested alternative scenario	Models for risk assessment Models for risk assessment
4. Risk recomposition	4.1 Vulnerability map computation with each conceivable case combination 4.2 Individual risk computation with each potential pair of scenarios of each major event under consideration 4.3 Total risk index calculation	Models for human dignity Program for risk recomposition

The theory and the tools used for complete assessment of domino scenario are discussed in the following. The process requirements for a quantitative risk analysis owing to domino scenario is shown in Figure 1. Figure 1. Since Cozzani etc. (2005) initially devised the process, it has a generic value because it is the basis for statistical assessment of domino effects irrespective of the appropriate tools used to perform any evaluation step. Moreover, key procedural stages may be ignored or conducted on a different degree of detail, depending on the purposes of the study. The flowchart in Figure 1 therefore offers the framework for a quantitative evaluation of domino effects.

The technique (Gate G3 after stage 9), as illustrated in the diagram, may be iterated to analyze secondary or even greater domino effects. But, as noted above, the difficulty as well as processing resources required also for evaluation rise with assessment levels exponentially. The significant contribution to risk indexes is generally "first level" scenario.

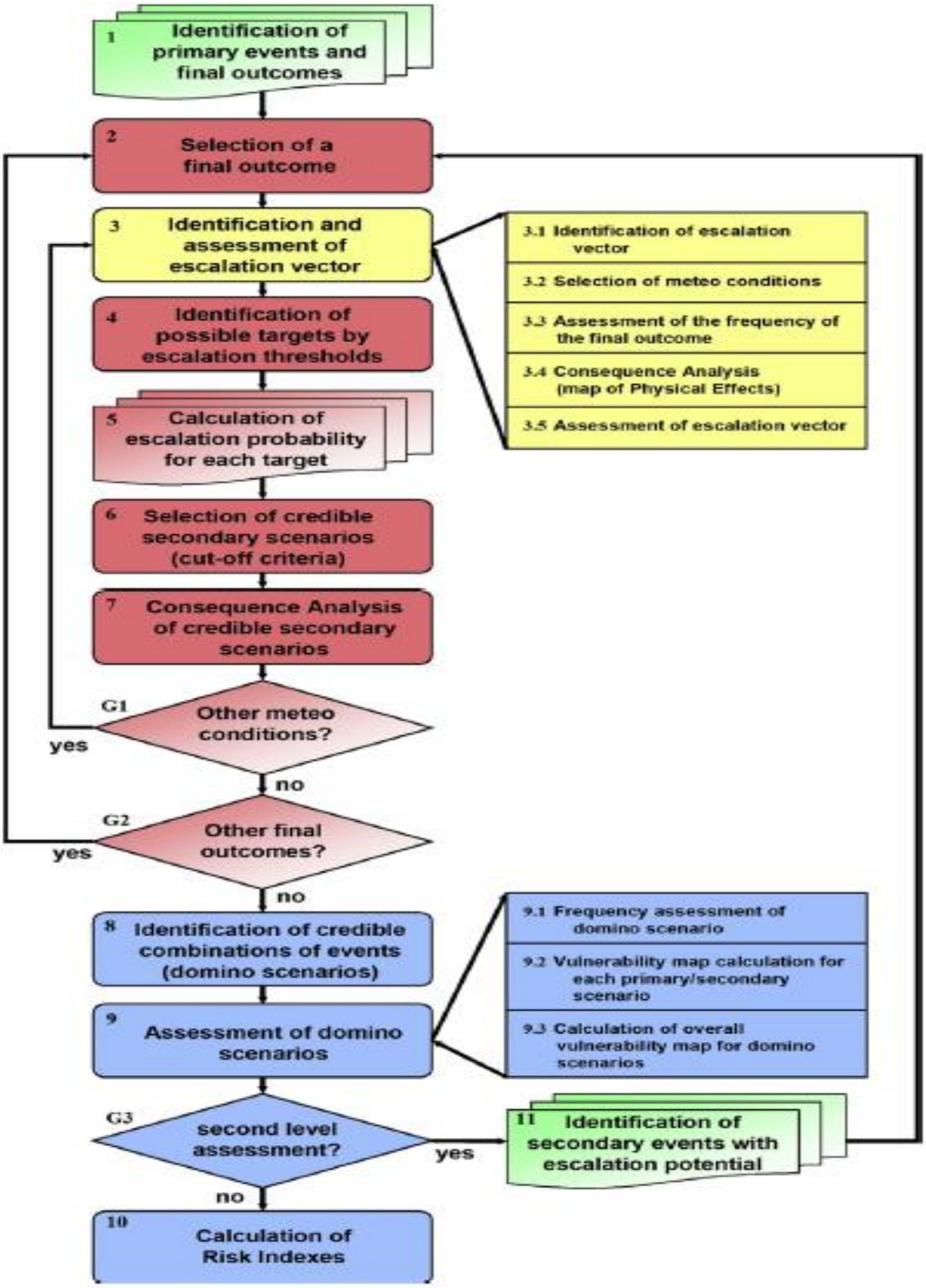

Figure 2: *Flowchart of the calculation for risk indexes.*

1.2 Data Required for the Quantitative Assessment of Domino Effect

The underlying data are collected in depth for the process indicated in Figure 1. Therefore, the most important facts required in the quantitative assessment of such domino effect should be summarized.

Figure 1 Comprehensive flow diagram to analyze the quantitative danger of domino hazards (G: gates). (The readers are recommended to the digital version of this book for colorful edition of this image.)

- The layout of a site is studied
- The location on the design of an identified risk which might act as the main incidents of concern
- Comprehensive characterization of all major events
- The location of any likely escalating problems (equipment with relevant inventories of hazardous substances, etc.)
- Follow-up analysis following damage to target equipment should be conducted for the second incident.

In order to detect low gravity, start events, a list of important episodes identified in HAZOP analyses may be crucial. It is rather evident that nearly all the data necessaries are available by a regular QRA and hence no major additional data gathering work is required for the assessment approach. HAZOP may, on the other hand, be expressly tailored to investigate the potential of domino effects.

2. IDENTIFICATION OF RELEVANT PRIMARY EVENTS

The basis of this evaluation is to identify primary events with a non-negligible escalating probability (step 1 in Figure 1). The event tree methodology is employed for identifying the potential end results from the pertinent "top events" indicated by traditional HAZOP (e.g. pool fire, vapor cloud explosions, and jet fires) (CCPS, 2008). As an alternative, a specific domino-HAZOP technique, the “Instrument Domino Effecten” (IDE) methodology (RIVM, 2003), approaches based on reference scenarios (Uijt de Haag and Ale, 1999), or bow–tie diagrams available for the “critical events” identified (Delvosalle et al., 2006) may be applied.

These methods also allow the assessment of the expected frequency of each final outcome (Step 3.3 in Figure 1). In a QRA framework, all final outcomes that generate a credible escalation vector should be considered for the assessment. Thus, at the end of Step 1 a list of escalation vectors and final outcomes associated to all relevant primary events should be obtained. The actual relevance of each of the final outcomes identified in Step 1 is assessed in Steps 3 and 4 of the procedure.

Conventional modeling which is used for the consequence analysis may be used to calculate a map of the physical effects generated by the outcome (e.g., radiation intensity due to a jet fire and maximum overpressure due to a blast wave), thus obtaining the intensity of the escalation vector (Step 3 of procedure in Figure 1). The comparison between escalation thresholds and the value of the escalation vector at the position of all relevant secondary targets allows the identification of equipment items that may be damaged by the escalation vector, thus starting a secondary scenario. In carrying out this procedure, specific attention should be devoted to scenarios influenced by meteorological conditions (wind direction and speed and category of atmospheric stability), such as pool fires or dispersions leading to a vapor cloud explosion; when such scenarios are considered, the assessment should be repeated considering all different meteorological conditions relevant in the area (Step 3.2 and gate G1), as usually done in a QRA study (Egidi et al., 1995; Spadoni et al., 2000).

Quantitative Risk Caused by Domino Accidents 213 Clearly enough, if no secondary target is identified in Step 4 for a given final outcome, this may be disregarded in the following steps of the analysis. Thus, Step 4 is crucial to limit the complexity of the analysis.

3. ASSESSMENT OF THE EXPECTED FREQUENCIES OF DOMINO SCENARIOS

Steps 1–4 allow the identification of the relevant final outcomes and the assessment of their expected frequency, defined as f_{pe} in the following discussion (frequency of the primary event in the domino sequence). The predicted frequency (a major incident which triggers a second incident situation) of an escalate incident may also be estimated:

$f_{de} = f_{pe}.P_d$ ……………………….(1)

When fde is an expected domino event frequency (events/year), fpe is the expected primary event(PE) frequency (received in view of the top event frequency, the likely end result, and, where applicable, the probability of weather conditions), and Pd, given the prime event, an increase in probability (E):

$P_d = P\,(E \mid PE)$ ………………………. (2)

The expected frequency of the primary event is obtained in Step 3.1 of theprocedure (see Figure 2) and may be calculated considering the frequency of thecritical event, the quantified event trees and the meteorological data usually availablein a QRA study or in the safety report of the facility of concern (Egidi et al., 1995; Uijtde Haag and Ale, 1999; Spadoni et al., 2000). The amplification likelihood must be estimated using particular probability equipment damage methods or related approaches presented in the literature.

The aforementioned connections are now only true if this is acceptable to suppose that main as well as the secondary event can take place at some point solely owing to escalate. This indicates that perhaps the main as well as the secondary incident should also be viewed “mutually exclusive” from such a probability viewpoint, until escalating impacts actually happen.This hypothesis is supported if a projected main and secondary incident frequency do not have adequately small rates. It should also be noted that in the following subsidiary scenario, even although in reality still in sequential, the scenarios are preservative characterized as contemporaneous or concurrent to the major event (Depends on the selected escalate vectors as well as losses of the correlation between self-destroyed by the initial event, few minutes to few minutes just after initial event).

In a sophisticated design, a unique main event might generate more than one secondary event concurrently. In numerous earlier accidents, this has been reported. Eqn (1) is still true in this context, giving the overall likelihood that the primary event will begin a particular subsequent event. However, it should take care of the possibility of having several secondary scenarios produced by some of the same primary event the domino frequencies must be computed (Steps 8 and 9 in Figure 1).

If the potential additional concurrent escalate of secondary occurrences is omitted, escalation events can properly be regarded as probabilistically independent. Thus, the chance of a second scenario presented in a basic mixture of m k subsequent occurrences (k<N) is really the ones that follow if N secondary events are feasible:

$$P_d^{(k,m)} = \sum_{i=1}^{N} \binom{d}{i}[1 - P(d,i) + \delta(i,j)(2.P(d,i) - 1]$$

Where P_d,i is the escalate chance and for secondary ith event specified by Eqn (2), J^k_m= [$y_{1,\ldots\ldots\ldots\ldots\ldots\ldots}y_{k]}$ is an mth combo index vector with the functional δ (i,j) as stated below. ·(i,j)

$\delta(i,j)$ = {1 i€J^k_m, {0 i€J^k_m (4)

The overall amount of domino possibilities for modern, secondary incidents is really the main influencer:

V_k= N! /(N-K)! * k! (5)

The number of possible domino scenario produced by the original event is therefore complete:

$P= \sum_{k=1}^{N} \mathrm{Vk} = 2^N - 1$…………………… (6)

Where v is the total number of domino scenarios which are to be analyzed in a domino impact quantity analysis unless frequency-based cutoff criteria are used. Eqn (6) clearly shows that there are very many alternative combinations to be created. In the context of ever rising computing resources, this is no longer an issue provided there is a specific software tool (Antonioni et al., 2009; Cozzani et al., 2006).

The predicted probability of a generalized m of k occurrences is hence-

$F_{de}^{(k,m)} = F_{pe}. P_d^{(k,m)}$ (7)

In using the process, if the frequency value falls below a set threshold, (k,m) combinations can be disregarded. This is based on the risk levels regarded to be of importance in the assessment.

This makes the total chance of an escalation happening-

$$\mathrm{Pe} = \sum_{k=1}^{n} \sum_{m=1}^{n} \mathrm{Pd(k, m)} \qquad (8)$$

The expected frequency of the primary event in the absence of escalation may be calculated as follows:

$F_{de,\,n}= F_{pe}. (1-P_e)$ (9)

Figure 2 represents the results obtained in the assessment of domino scenarios for a primary event and five possible secondary targets (Cozzani et al., 2006). As shown in the figure, a clear ranking emerges for the importance of domino sequences from a probabilistic point of view.

The technique which is explained in the above section can also exceed to the higher-level domino events (G3 in Figure 1). If a second-level domino effect is considered, the escalation probability, Pd, needs to be assessed for each secondary combination of events (primary scenario þ simultaneous secondary scenarios) selected (Step 10 in Figure 1). This requires considering a sum of physical effects (e.g. the overall radiation at a given location from simultaneous fires) or the sum of escalation probabilities (e.g. in the case of explosion followed by fire). Equation (7) may be used to assess the frequency of the upper-level domino scenario, where f_{pe} actually becomes the frequency of the domino combination of interest. It may be easily understood that extending this approach to higher level domino effects greatly increases the computational resources required to carry out the calculations.

4. ASSESSMENT OF THE CONSEQUENCES OF DOMINO SCENARIOS

Extremely complex scenarios with multiple simultaneous events may be triggered by the escalation of a primary event leading to a domino sequence. Even when employing modern methods such as Computational Fluid Dynamic (CFD) programs, a full assessment of the implications of such complex scenarios is challenging. The empirical and integrative models employed in QRA assessments are not designed to predict various scenario impacts. In addition, in the current models for outcome evaluation synergistic effect are also not put into consideration.

A detailed assessment of the consequences requires that every situation be studied with specialized instruments, takes the structure into consideration and providing a comprehensive geometric characterization of the issue in the study. In a QRA framework, however, the need to reduce computing effort demands simplified assumption to perform the impact evaluation.The repercussions of an incident may therefore be examined superimposing independently computed for each primary and secondary result evaluated the physical impacts (radiation, overpressure, poisonous gas concentrations) omitting the analysis of the probable synergetic impact. This methodology simplifies the situation excessively such that just the actual possible implications of domino scenarios are grossly estimated. However, under a QRA framework, such assumption appears to be permissible.

The impact assessment of possible domino scenarios can therefore be conducted in three steps: (1) evaluation using standard models utilized for the repercussions of the primary situation as well as of each subsequent event-

5. OTHER APPROACHES TO THE QUANTITATIVE ASSESSMENT OF DOMINO EFFECT

As mentioned with in opening of this chapter, a number of different methodologies for quantifying domino impacts have been presented in the 1980s and 1990s (e.g. Bagster and Pitblado, 1991; Gledhill and Lines, 1998; Latha et al., 1992; Morris et al., 1994; Pettitt et al., 1993). Many of these techniques also are obsolete, despite their usefulness only at time of their development in allowing at minimum an initial quantitative evaluation of domino effects in risk analysis or safety studies. In fact, the methods were based on oversimplifying assumptions that were introduced at the time due to the limited knowledge in equipment damage mechanisms and/or to the limited computational resources available. Nowadays, the use of such approaches should be considered with attention and may hardly be justified in the light of results obtained in consequence analysis, equipment damage models and software for quantitative risk calculation.

Nevertheless, besides QRA and Bayesian estimators, other approaches were also implemeteddeveloped for the assessment of domino effect. Some approaches go toward the assessment of domino effect by the use of simplified risk indexes (Cozzani et al., 2009; Zhang and Chen, 2011). A detailed original approach to quantitative assessment of domino frequencies was recently proposed by Abdolhamidzadeh et al. (2010). These authors provide a novel Monte Carlo simulation approach that can evaluate the predicted frequency of domino effects. Simulation through Monte Carlo allows repeated assessment of a system by employing randomly generated sets as inputs. This simulation methodology is especially appropriate when the fundamental possibilities of a process may be understood, and it is difficult to determine their interaction. A Monte-carlo method for the evaluation of domino effects dubbed freedom was developed via work of Abdolhamidzadeh et al. (2010) (Frequency Estimation of Domino accidents). The model was applied to the simulation of a multiunit system which may experience domino effects. The results of FREEDOM were compared to those of the QRA method presented in Section 10.2, showing a sufficient agreement even for a rather low number of simulations (n = 1000).

6. CONCLUSIONS

The relevant and considerable progress in equipment damage models and the increasing availability of computational resources make the quantitative analysis for various risk factors due to domino scenarios now possible. A well-assessed methodology was presented for the QRA of domino scenarios, based on the equipment damage models. The technique, accompanied by geo-informational development tools provides social and personal risk analysis taking into consideration of escalating key scenario.

A further progress in the quantitative analysis of domino scenarios is expected integrating the QRA approach to the development of innovative techniques based on Bayesian analysis and Monte Carlo methods.

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