FREQUENCY ASSESSMENT OF LOSS OF CONTAINMENT INCLUDING THE EFFECTS OF MEASURES OF RISK PREVENTION

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ABSTRACT

This paper presents a method for the quantification of the effects of measures of risk prevention of the frequency for rupture of pipework. Some methodologies, given in the literature for this purpose, assume that each plant under analysis is characterized by the same combinations of causes of failure and prevention mechanisms but this assumption is not always true. The approach suggested here is based on the methodology proposed in 1999 by Papazoglou for the quantification of the effects of organizational and managerial factors. Taking advantage of this methodology the objective of the assessment of the influence of measures of risk prevention in pipework has been achieved through the definition of the links between the causes of failure and the measures adopted by the company in order to prevent and/or to mitigate them.

1 INTRODUCTION

Accidental analyses in chemical plants have shown that the main causes of incidents are often due to deficiencies in the corporate structure, which can influence the safety of these installations. The use of appropriate risk analysis techniques permits the identification of the cause and evolution of accidents and the calculation of the frequencies of top events associated with process anomalies and loss of containment.

The likelihood of an accident is a function of various parameters such as components failure rates, probabilities of human error, etc. The availability of general values for these parameters from literature data simplifies risk analysis, unfortunately, it is also obvious that the use of such information provides standardized results which do not permit taking into consideration plant specific managerial and organizational factors. If managerial and organizational factors are neglected, the risk analysis for two identical establishments, characterized by totally different management systems, gives the same results and this appears unacceptable especially when risk analysis is used as a tool for risk-based decisions.

In the nuclear field, several quantitative studies (Izquiedo-Rocha & Sanchez-Perea, 1994; Montmayeul et al., 1994), have been performed to approach management-related safety problems. In recent years, also in the chemical industry, great attention has been paid to the study of the relationship between the managerial system and the safety level of chemical plants (Papazoglou & Aneziris, 1999; Thomas, 1980).

The main object of this work is to study the influence of measures of risk prevention on the frequency of loss of containment in pipework. In order to achieve this aim it has been necessary to define the relationship between the measures of prevention of the risk adopted by a company and the causes of failure in piping. Once the relationship between the individual causes of failure and the measures of risk prevention have been established and after the estimation of the weight coefficients for the causes of failure, it has been possible to modify the frequencies taking account managerial and organizational factors.

In the first part of the paper, some methodologies for the quantification of measures of risk prevention, currently available in the literature, will be discussed. Finally in the second part the proposed approach and its application will be described.

2 ACCIDENT FREQUENCIES IN THE CHEMICAL INDUSTRY

Frequency calculation for incidents in the chemical industry and consequence quantification of the associated accidental scenarios are fundamental steps for quantitative risk analysis.

The general procedure for frequency evaluation comprises the definition of the top events, *risk identification*, and then the application of appropriate techniques and equations derived from probability theory.

Risk identification is the most critical step in the overall analysis, in this phase it is important to consider all the initial causes of incidents. The available techniques for risk identification are historical-statistical methods, based on examination of incidents happened in the chemical industry and recorded in databases, and/or analytical methods, such as PHA (Preliminary Hazard Analysis), HAZOP (Hazard and Operability Analysis), FMEA (Failure Modes and Effects Analysis).

Analytical methods, mentioned above, are applied only for the identification of top events associated with process deviations or failures of components. The assessment of loss of containment requires a specific approach.

Events related to loss of containment, sometimes called *random ruptures*, are caused by accidental phenomena such as uncontrolled wearing, anomalous corrosion, pipe defects, etc. These events are not associated with process anomalies, but, as already mentioned, are often due to deficiencies in the corporate structure.

In this study attention has been paid to the *random rupture* of pipework because incident analysis, reported in Lees (1996), shows that loss of containment in the chemical industry, frequently, does not occur from vessels but from pipework and associated fittings.

3 LOSS OF CONTAINMENT EVENTS

The pipework-fittings system includes the piping itself, flanges and joints, and fittings, such as the many types of valves, bellows, etc, together with the pipe supports. As already mentioned, a large proportion of failures of containment in process plants occurs in the pipework. For this reason suggestions for reducing piping failures have been given in the past.

Kletz (1994) has given information on some 50 major pipe failures and associated fittings in process plants and some suggestions for preventing each failure. He also made proposals for the reduction of pipework failures by improved design and inspection of the pipework.

In order to decrease the number of loss of containment events, a proper design of even small bore pipework is recommended. Thus the pipework should be designed for ease of maintenance and, in the case of rupture, there should be easy access to the point where the failure has occurred.

Safety in piping systems has been the object of a study by the Institution of Chemical Engineers (IChemE), reported in Lees (1996), where the main features considered were: layout, quality control, construction, pipe supports, and vibration. The study has also concluded that the main causes of failure are vibration, external corrosion, inadequate temporary supports, blocked-in liquids, water hammer, steam hammer, cavitation and pressure surge.

There is a considerable amount of data available on pipework failures (Lees, 1996), but the range of values quoted is wide and tends to be confusing. There are several important distinctions to be made concerning the type of failure and the pipe size. Based on these considerations, complete pipe breaks, or guillotine fractures, constitute only a small proportion of failures and the breakdown rate tends to be higher for small than for large diameter pipes.

A survey of pipework failures in plant in the nuclear, chemical and other industries had been described by Blything and Parry (1986) quoted in Lees (1996). The data were analysed as *causes of failure* and *root causes*. Essentially, causes of failure are the mechanical causes, such as corrosion, fatigue and water hammer, and root causes are activities such as error in design, operation and maintenance. Results are given as cause of failure vs. root cause and have been identified for chemical plants, refineries and for nuclear and steam power plants. Data for chemical plants are summarized in Table 1, where the percentage of incidents is separated for direct causes and main activities (Lees, 1996). Table 2 gives the direct causes of failure obtained from two different sources (Lees, 1996; Thomas, 1980).

Finally, incidents can also be classified under three headings: direct cause, origin of failure or underlying cause and recovery from failure or preventive mechanism. Table 3 shows the underlying causes vs. the recovery from failure, this distribution is the result of a study of pipework failures in process plants made by Bellamy and co-workers (Lees, 1996). This study reviewed 921 incidents from incident databases such as HSE MARCODE, MHIDAS and FACTS.

Table 1. Causes of failure in chemical plants and refineries: – *cause of failure* vs. *root cause*(Lees, 1996)

	Design	Installation	Design /Installation	Operation	Maintenance	Manufacture	Unknown	Unspecified	Total
Corrosion									
- external	18	8	-	2	4	-	-	1	33
- internal	56	1	2	1	1	1	-	3	65
- stress	15	-	1	-	-	-	-	-	16
Erosion	2	1	-	-	1	-	-	-	4
Restrain	1	2	4	-	-	-	-	-	7
Vibration	9	1	3	1	-	-	-	1	15
Mechanical	28	10	5	11	12	18	2	21	107
Material	5	7	10	-	4	2	-	21	49
Freezing	13	1	-	2	-	-	-	1	17
Thermal fatigue	2	1	-	2	-	1	-	1	7
Water hammer	2	1	1	4	-	-	-	-	8
Work system	6	4	36	47	49	-	-	2	144
Unknown	-	-	-	-	-	-	29	1	30
Unspecified	1	1	13	3	3	-	-	33	54
Total	158	38	75	73	74	22	31	85	556

Table 2. Causes of failures in pipework: direct causes

Failure causes	Percentage of incidents	
	P.F.Lees (1989)	H.Thomas (1980)
Manufacture & fabrication:	31.9	
- base materials (defects)		9.6
- welding		11.8
Material selection	--	28.8
Corrosion	9.3	24.6
Erosion	0.8	
External load	3.0	--
Impact	4.8	--
Thermal shock	3.8	1.3
Mechanical shock	12.1	
Fatigue	1.5	
- low cycle		7.8
- vibration		4.3
Expansion & Flexibility	--	2.7
Wrong or incorrectly located in-line equipment	4.0	--
Operator error	18.2	7.0
Unknown	1.5	--
Other	9.1	7.0
Total	100.0	100.0

Table 3. Causes of failures in pipework: *underlying causes* vs. *recovery failure* (Lees, 1996)

Underlying cause	Recovery failure						
	Not recoverable	Hazard study	Human factors review	Task checking	Routine checking	Unknown recovery	Total
Natural causes	1.8	-	-	0.2	-	-	2.0
Design	-	24.5	2.0	-	0.2	-	26.7
Manufacture	-	-	-	2.4	-	-	2.4
Construction	0.1	0.2	1.9	7.5	0.2	0.4	10.3
Operation	-	0.1	11.0	1.6	0.2	0.8	13.7
Maintenance	-	0.4	14.5	12.7	10.3	0.8	38.7
Sabotage	1.2	-	-	-	-	-	1.2
Domino	4.5	0.2	-	-	0.3	-	5.0
Total	7.6	25.4	29.5	24.4	11.1	2.0	100.0

4 FREQUENCY OF LOSS OF CONTAINMENT

The analysis of loss of containment events permits a complete description of all the potential incidental events, which are the initial causes for the release of hazardous substances.

Their identification consists of the following steps:

- identification of the process and stored dangerous substances inside the establishment;
- characterization of the pipework and equipment and definition of the operating conditions;
- identification of the units of the plant, which have the same operating conditions;
- definition of representative causes of leakage for each unit.

The calculation of accidental frequencies can be made using the Fault Tree method for events deriving from process deviations, while the analysis of the loss of containment events requires a specific approach. A commonly adopted method for calculating the frequency of occurrence of these events is the API 581 Methodology, other similar methods are available based on the use of statistical leak frequency data specific to “random ruptures”.

The estimation of the frequency of loss of containment events must include the quantification of the influence of measures of risk prevention. Some methodologies are given in the literature (API 581; Papazoglou & Aneziris, 1999; Thomas, 1980) for this purpose, these assume that each part of the plant under analysis is characterized by the same percentage of causes of failure. This consideration is not acceptable.

4.1 The API 581 methodology

The method proposed in the standard API 581 *Risk Based Inspection Guideline*, , supplies a generic value of frequency of release from pipes and other main process equipment, this is a statistical average value. The standard provides a way to correct this value, depending on the specific characteristics of the system under examination and using appropriate correction factors based on the complexity of the system (number of flanges, valves, etc.).

The generic frequency is calculated using literature or incidental data for similar systems. In the API 581 standard frequencies of release are given for four diameters of hole: 1/4", 1", 4" and full bore (hole dimension equal to the pipe diameter). These are calculated assuming a log-normal distribution of the data, generic frequencies of release are the mean values.

The API 581 methodology defines a modification factor for the frequencies for each type of equipment, *equipment modification factor*, based on its complexity and its location. In order to take into account differences in the safety management system of an establishment, the method also defines an adjustment factor, *management systems evaluation factor*.

4.2. Quantification of the influence of management and organizational factors

The most common methodologies for the quantification of the influence of organizational and managerial factors on the frequency of release from pipework and vessels are the methods of Thomas (1980), developed in 1980, and the approach of Papazoglou & Aneziris, proposed in 1999. Both methods are based on the analysis of incidental data in the chemical industry.

The approach of Thomas to the estimation of frequency of leakage and rupture for piping and vessels is based on a statistical analysis of failures. The total frequency is initially identified through a global estimation based simply on the size, shape, welds and the age of the equipment. Subsequently, the results can be modified using specific factors for the type of equipment and the influence of the curves of learning for technology and design. Unfortunately these graphical correlations are based on obsolete data, new technologies are currently available, the factors evaluation requires valid data.

The method of Papazoglou permits the quantification of the effects of organizational and managerial factors on the frequency of leakage from vessels and pipes defining a link between an audit of the safety management system (SMS) and a quantitative risk analysis (QRA).

Another approach for the quantification of the influence of management and organizational factors has been proposed by Maschio et al. (2006), which is based on the methodology proposed by Papazoglou. First of all the method permits the exclusion of the causes of failure that can be prevented through the adoption of appropriate prevention measures. Thus it is possible to apply the method of Papazoglou using realistic values of the percentage of the causes of failure.

As mentioned in the previous section, in order to take into account the influence of managerial and organizational factors, also the API 581 methodology for the evaluation of the accidental frequencies uses the *management systems evaluation factor*. This adjustment factor is estimated on the base of the percentage of failure causes.

4.3 The method of Papazoglou

The *Papazoglou method* aims to quantify the organizational and managerial factors based on an audit of the safety management system (SMS). A Safety Management Audit, SMA, allows to verify the compliance of the safety management system with an ideal scheme. This can be made by analysing a number of combinations of causes of failure and mechanisms for the prevention of accidents. A number of important areas of concern are identified and each area is assessed from the SMS point of view through the audit as being GOOD, AVERAGE or POOR.

As mentioned above, the method proposed by Papazoglou is able to link the results of a management audit with the QRA model. This is possible by defining a factor modifying the average frequencies, which is calculated on the basis of the relative importance of each area of audit and the corresponding assessment. A QRA gives quantitative indexes which define the risk level of a plant taking into account its specific structure and its potential modes of failure, etc. The results of a QRA can help in the identification of optimum risk reduction actions by reducing the incidental frequencies and/or mitigating the consequences of the undesired events. For this reason the QRA represents a basic support for risk based decision making.

By means of the combination of generic causes of failure categories (underlying causes categories) and prevention mechanism (recovery mechanism), 54 audit areas of the SMS are defined but only 8 of them, indicated as main audit areas (MAAs), are meaningful from the point of view of the numbers of incidents.

The underlying cause of failure categories are: design (DES), maintenance activities (MAINT), operations during normal activities (OP), construction/installation (CON), manufacture/assembly (MANU), natural causes (NAT), domino (DOM), sabotage (SAB) and unknown origin (UO).

The recovery or preventive mechanisms are the mechanisms that theoretically could have recovered or prevented the failure. The categories of mechanism are appropriate hazard study of design as-built, e.g. HAZOP (HAZ), human factors review (HF), task-driven recovery activities (CHEC), routine, regular, recovery activities (ROUT), not recoverable (NR) and unknown recovery (UR).

The Papazoglou methodology consists of the following phases:

- in the first step of this approach the results of the audit are grouped through a subjective expert judgement into eight qualitative factors, one for each MAA. This is done by translating the results of the audit into an assessment of the elements of each MAA, then each area is assessed as GOOD, AVERAGE or POOR.
- the second step consists of grouping the eight assessments into a single number.

The method is based on an analysis of the frequencies of incidents that have occurred in the chemical industry, in particular Papazoglou found that the analysis of the loss of containment data, reported in the RIDDOR database, indicates that the frequencies of release for various plants spans two orders of magnitude and shows a certain symmetry around their mean values.

According to this observation the following equation was proposed, which can be used for the modification of the frequency of release:

$$\log f_{\text{mod}} = \log f_{md} + \sum_i a_i \cdot x_i / 100 \tag{1}$$

where f_{mod} = modified frequency; f_{md} = mean frequency of failure based on world-wide experience; a_i = weight coefficient for audit area i; and x_i = parameter indicating the judgement of the MAA i of the SMS following the audit.

Concerning x_i, it can assume the following values:

- -1 if the plant is judged GOOD
- 0 if the plant is judged AVERAGE
- +1 if the plant is judged POOR

The analysis of observed incidents in the chemical industry has assessed the relative frequency of occurrence for the eight MAAs, the normalization of these frequencies has provided the a_i values indicating the importance of each SMS area in terms of the likelihood of accidents in pipework, connections and vessels (Papazoglou & Aneziris, 1999).

5 THE PROPOSED METHOD FOR THE ESTIMATION OF THE FREQUENCY OF LOSS CONTAINMENT EVENTS

The methodology proposed by Papazoglou permits the evaluation of each part of the SMS, for this reason this is an excellent way to evaluate the organization and managerial factors. This method implies that each installation under analysis is characterized by the same combinations of origins of failure and mechanisms to prevent and/or mitigate them and thus by the same percentage of failure causes. It is known that different plants are characterized by differences in construction, operation and maintenance procedures and practices, thus they differ from the point of view of the percentage of causes of failure. In order to take into account these differences, in this work, a modified approach for the Papazoglou method for frequencies evaluation is proposed.

The modified method is based on an examination of the whole plant and permits to define how the measures of risk prevention adopted inside the establishment can influence the frequencies of rupture of pipework. In order to make this a detailed analysis for each unit of the plant is necessary and, from this, it will be possible to identify the causes of failure which can occur in each unit and the measures which can prevent them.

The proposed method is innovative since through its application it is possible to identify and exclude from the analysis all those causes of failure that are not present in the establishment because of the adoption of appropriate measures to prevent them. The adjustment of the percentages of causes of failure allows the use of realistic coefficients, this is fundamental for the application of the method.

The analysis of the overall plant allows a complete identification and quantification of the relationships between measures of risk prevention and causes of failure in piping. These permit the incorporation in the final results of a great number of plant-specific characteristics concerning the design, operational and maintenance aspects of the installation.

The proposed method modifies the frequency of release using equation 1, whose application depends on the definition of the weight coefficients a_i. The approach aims at the estimation of the influence on f_{md} of prevention measures, which have been judged *a priori* "GOOD", thus the problem is to determine which causes of failure can be prevented by a certain measure adopted by the Company.

In order to identify which measure can prevent or mitigate a failure and its effectiveness, also in this case an audit is necessary. After the definition of the relationship between the causes of failure and the measures of prevention, the weight coefficients for the causes of failure are estimated and, then, it is possible to modify the frequencies taking into account the prevention measures.

It is obvious that the a priori exclusion of some causes of failure requires modification of the mean frequency of failure obtained from the literature, f_{md}. This value will be reduced by a percentage equal to the excluded causes of failure. The methodology proposed by Papazoglou will then be applied to the *a priori* modified frequency.

5.1 Weight coefficients for the causes of failure

Many data regarding the main causes of release from piping is available in the literature, this information is summarized in Table 2 (direct causes). The evaluation of the weight coefficients can be made using the failure data of Lees, because these percentages are relatively more recent and specific for piping in the chemical industry. Nevertheless it is necessary to verify the consistency between the data reported by Lees and the causes of failure evidenced inside the examined establishment.

In some cases the values of the weight coefficients need to be corrected taking into account that modern design and manufacture and the use of new materials might reduce the number of failures due to certain causes. The correction of the data of Table 2 can be made using specific correction factors defined in agreement with the plant management.

5.2 Weight coefficients for corrosion phenomena

Concerning pipework (Lees, 1996), phenomena such as corrosion and mechanical causes of failures have been analysed in detail, thus the analysis of incidental data allows the distribution of these failure modes as shown in Table 4. General causes of failure, which are emphasized in Table 4, are general corrosion, stress corrosion cracking and fatigue. The number of failures caused by brittle fracture is small.

Using the data of Table 4, it is possible to detail the causes of failure for corrosion and mechanical failures, thus the single values of table 2 can be split into the contributions associated with each type of corrosion and/or mechanical failure. In order to divide the data of Table 2, a detailed analysis of the fluid flowing in the pipework and the process conditions is necessary. The analysis allows the definition of which types of corrosion can occur in the equipment.

5.3 Weight coefficients for human error

In order to improve the quantification of the influence of the measures of risk prevention on the frequency of rupture of pipework, a more detailed analysis of human errors has been carried out.

The literature on human error in process plants shows that a large proportion of serious incidents is attributable to errors in maintenance work, while the most frequent human error in pipework failures concerns the installation. A study of human error as cause of piping failures has been made by Bellamy and co-workers (Lees, 1996). Incidents have been classified as direct causes, origin of failures and recovery mechanisms. This data showed that operator error contributed 18 % to the direct causes of pipework failure, whilst defective pipe or equipment contributed 32 % and unknown causes 9 %.

Table 5 gives the distribution of human errors in underlying causes, it is possible to see that the predominant errors are in maintenance. As shown operator error usually can be disguised as other causes of failure (eg. impact, corrosion, etc). Therefore, using this table, human error can be split into the failure modes of Table 2 and then included in the other types of failure. The distribution of operator error in the other causes of failure provides the correct values for the weight coefficients a_i.

Table 4. Causes of corrosion and mechanical failure (Lees, 1996)

Corrosion	%	Mechanical failure	%
Cavitation	0.3	Abrasion, erosion or wear	5.4
Cold wall	0.4	Blister, plating	0.1
Cracking, corrosion fatigue	1.5	Brinelling	0.1
Cracking, stress corrosion	13.1	Brittle fracture	1.2
Crevice	0.9	Cracking, heat treatment	1.9
Demetallification	0.6	Cracking, liquid metal pen	0.1
End grain	0.4	Cracking, plating	0.6
Erosion-corrosion	3.8	Cracking, thermal	3.1
Fretting	0.3	Cracking, weld	0.6
Galvanic	0.4	Creep or stress rupture	1.9
General	15.2	Defective material	1.6
Graphitizzation	0.1	Embrittlement, sigma	0.3
High temperature	1.3	Embrittlement, strain age	0.4
Hot wall	0.1	Fatigue	14.
Hydrogen blistering	0.1	Galling	0.1
Hydrogen embrittlement	0.4	Impact	0.1
Hydrogen grooving	0.3	Leaking through defects	0.4
Intergranular	5.6	Overheating	1.9
Pitting	7.9	Overload	5.4
Weld corrosion	2.5	Poor welds	4.4
		Warpage	0.4
Subtotal	55.2	Subtotal	44.8

Table 5. Human error distribution in *underlying causes*, (Lees, 1996)

Underlying causes	%
Design	8
Manufacture	2
Construction	8
Operation	22
Maintenance	59
Sabotage	1
Total	100

The distribution of the human error in the causes of failure of Table 2 is possible defining the links between *failure causes* and *underlying causes* categories through a subjective expert judgement.

The links *failure causes/underlying causes* are given in Table 6.

Table 6. Links between *cause of failure/underlying cause*

Cause of failure	Underlying cause
Manufacture/fabrication	Manufacture/Construction
Corrosion & Erosion	Maintenance
External load	Maintenance
Impact	--
Thermal shock	Design/Operation
Mechanical shock	Design/Operation
Fatigue (vibration)	Design/Operation
Fatigue (low cycles)	Design/Operation
Wrong or incorrectly located in-line equipment	--
Operator error	--
Creep	Maintenance
Other and unknown	Sabotage

6 APPLICATION TO A CASE-STUDY

The methodology described by Maschio et al. (2006) for the quantification of the influence of the measures of prevention of risk on the frequencies of release from vessels and pipework has been tested by its application to a real industrial plant. This approach has been used for the calculation of the frequencies of the random events which can potentially occur in pipework. The case study presented here is for a petrochemical plant (confidential).

In this case the initial frequencies of failure have been collected from the Safety Report of the establishment, then the influence of the measures of risk prevention on the causes of failure have been discussed and defined in agreement with the plant management. In order to define which causes of failure can be prevented by a certain measure adopted by the Company, an audit has been made.

An example is described. The rupture of a pipe coming from a vessel containing a flammable and toxic liquid has been hypothesized. Two dimensions of leakage have been assumed, 5% and 20% of the pipe diameter, and then the modification of the frequencies of release has been made using both the proposed methodology and the method of the direct reduction of the percentage of the failure causes.

Using the data of Table 2 and 4, the percentages of causes of failure have been corrected as discussed. The corrected values have been normalized. Before the application of the modified procedure, the initial value of frequency has been reduced by the percentage of excluded causes of failure.

6.1 The modified procedure for the quantification of frequency

Application of the modified method can be made using the following steps:

- Definition of the weight-coefficients a_i, which comprise a detailed analysis both for human error and corrosion phenomena;
- Formulation of judgements on the inspection methods;
- Calculation of the frequencies using equation 1.

In order to estimate the effect on f_{md} of measures of risk prevention through equation 1, it is necessary to formulate a judgement x_i for each preventive measure. The attribution of the judgements has been made by analysing each pipe-line and defining which causes of Table 2 and sub-causes of Table 4 can be detected by each measure.

6.2 The method of the direct reduction of the percentage of the failure causes

Using the data of Table 2, it is also possible to modify the frequency of rupture reducing its value by the percentage of the failure causes (P_i) prevented using this measure. Also in this case the *a priori* exclusion of some causes of failure modifies the value of the initial frequency that will be reduced by the percentage of excluded causes of failure.

A more complete quantification of the influence of the routine inspections must take into account also their effectiveness. The effectiveness represents the percentage of failures identified during these inspections.

In order to apply this method it has been necessary to identify which causes of Table 2 and sub-causes of Table 4 can be detected using a certain inspection technique, then the value of P_i will be equal to the corrected value of a_i multiplied by the effectiveness of the measure. In this case the use of the effectiveness classes defined in *API 581 Risk-Based Inspection Base Resource Document* and shown in Table 7 has been adopted.

Table 7. Qualitative Inspection Effectiveness Category

Highly Effective: Inspection methods that correctly identify the anticipated in-service damage in nearly every case. (90%)
Usually Effective: The inspection methods will correctly identify the actual damage state most of the time. (70%)
Fairly Effective: The inspection methods will correctly identify the true damage state about half of the time. (50%)
Poorly Effective: The inspection methods will provide little information to correctly identify the true damage state. (40%)
Ineffective: The inspection methods will provide no or almost no information that will correctly identify the true damage state. (33%)

6.3 Results

Table 8 shows the frequencies of loss of containment modified by the application of the method described. A number of applications of the method shows that generally the frequency of the random event decreases by about an order of magnitude or more in some cases.

The method of the direct reduction of the percentage of the failure causes, has been applied in order to compare the methodologies and to verify the consistency of the proposed procedure with a conservative method. Comparison of the results demonstrates the validity of the proposed methodology.

The entity of the risk reduction can be visualized using risk matrixes (Figs. 1-2).

Table 8. Results

Leak dimension	Frequency	Modified frequencies	
		Proposed method	Direct reduction method
5%	1.93E-03	1.13E-04	4.47E-04
20%	1.25E-04	7.35E-06	2.90E-05

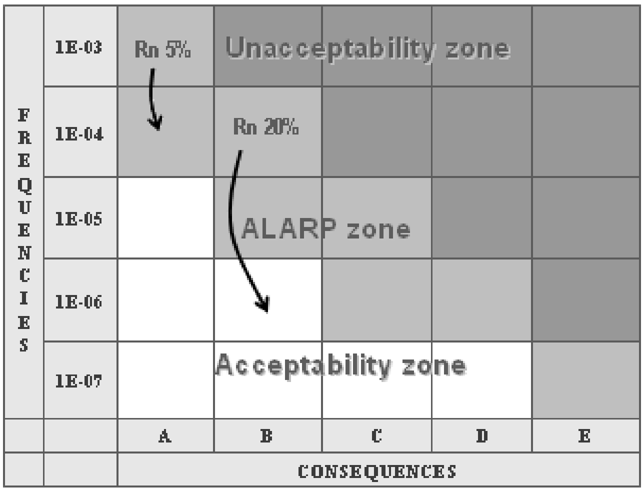

Figure 1. Risk matrix: results of modified frequencies (proposed method).

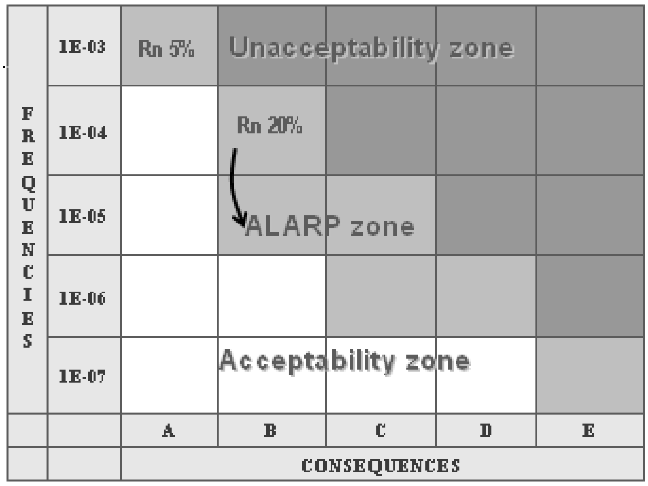

Figure 1. Risk matrix: results of modified frequencies (direct reduction).

The matrix provides a useful tool in order to define the acceptability of the risk associated with an industrial activity, for this reason the identification of three levels of risk, acceptable, ALARP and unacceptable, is necessary in particular for the risk-based decisions. Using the matrices it has been possible to verify if the adoption of certain preventive measures of the risk can move an event from a critical zone to the acceptability zone.

7. CONCLUSIONS

The objective of this work has been the definition of an approach for the calculation of loss of containment frequencies taking into account managerial and organizational factors. This necessity is due to the observation that the main cause of accidents are events that are often due to deficiencies in the corporate structure.

Furthermore the use of common risk analysis techniques does not allow taking account management and organizational factors which are of primary importance in defining the real risk level of a chemical plant and therefore for planning the resources and procedures for emergencies.

The approach suggested in this paper for the quantification of the effects of organizational and managerial factors, has been based on the methodology proposed by Papazoglou (1999). Taking advantage of this method the object of assessing the frequency correction factors has been achieved through the definition of the relationship between the causes of failure and the measures adopted by the company in order to prevent and/or mitigate them.

Regarding the application of the method it has been possible the validation of the procedure using a comparison with the method of the direct reduction of the percentages of causes of failure.

The proposed method appears to be innovative because of the *a priori* exclusion of all the causes of failure that are not present in the establishment because of the adoption of appropriate measures to prevent them. The correction of the percentages of breakdown allows the use the real weight-coefficients.

The approach proposed in this work is suitable to the various high risk industrial activities. It requires for each case the modification of the weights coefficients associated with the single causes of failure and to formulate judgment on the measures of prevention of the risk adopted by the company, in this way it is possible to reproduce the plant-specific characteristics concerning the design, operation and maintenance of the installation.

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