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Frequencies assessment of loss containment including the effects of measures of risk prevention and mitigation

Keywords

frequency, piping, risk assessment, loss containment, failure cause

Abstract

The question of how the effects of management and organisational variables can be incorporated into assessment of frequency of loss containment events is currently of considerable interest. Usually these typology of events arises from an uncontrolled accidental phenomena or a combination of active and latent human errors in areas such as design, operations and maintenance. In the 2006 a development of a methodology for the quantification of the effects of measures of risk prevention or mitigation on the frequencies of rupture of pipework has been presented, the approach is based on the methodology proposed by Papazoglou in 1999. Taking advantage of Papazoglou methodology the estimation of these effects has been achieved through the definition of the links between the failure causes that are the origin of incidents and the measures adopted by the company in order to prevent and/or to mitigate them. After an overview on the failure causes in piping, the aim of this paper is to present the application of the recent modified methodology.

1. Introduction

Loss of containment from a system in chemical industries, frequently, does not occur from vessels but from pipework and associated fittings. At least much attention should be paid to the piping and fittings as to the tanks.

Many accidental analysis in chemical plants have shown that the main causes of events, related to loss of containment, are often due to gaps in the corporate structure, which can influence the safety of these installations.

In recent years a great attention has been paid to the study of the relationships between the managerial system and the safety level of a chemical installation.

It is obvious that the likelihood of an accident is a function of various parameters such as the failure rates, the probabilities of human error, the time of control tests, etc. The availability of these probabilistic parameters simplifies risk analysis, because it is often possible to use literature data, unfortunately, it is also obvious that the use of such information provides standardized results which do not permit to take in consideration managerial and organizational factors.

The managerial and organizational factors include workers training, maintenance management, operating and emergency procedures, control and verification of the performances, etc.; all of these are of primary importance for industrial safety.

2. Failures in pipework

The system pipework-fittings 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 in the previous paragraph, a large proportion of failures of containment in process plants occur on the pipework. Some suggestion for reducing piping failures have been given in the past. In order to decrease the number of loss of containment, usually, a detailed design of even small bore pipework is recommended. Thus the pipework should be designed for ease of maintenance, if it may have to be broken, there should be adequate access to reach the point where the failure has occurred.

Safe in piping systems has been the object of a study by the Institution of Chemical Engineers (IChemE), where the principal features considered were: layout, quality control, construction, pipe supports, and vibration. It has, also, observed that the main causes of failure are vibration, external corrosion, temporary supports, blocked in liquids, water hammer, stem hammer, cavitation and pressure surge.

There is a considerable amount of data available on pipework failures, 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 [2]. The data were analysed by "failure cause" and "root causes". Essentially, failure causes 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 failure causes vs. root causes and have been distinguished for chemical plants and refineries and for nuclear plants and steam plants. Data for chemical plants are summarized in T*able 1*.

Table 1. Failure in chemical plants and refineries – "Failure causes" vs. "Root causes" [2].

	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**

Incidents can classified under the three headings: direct cause, origin of failure or underlying cause and recovery from failure or preventive mechanism.

Table 2 gives the direct causes of failure and *Table 3* the underlying causes vs. the recovery failure.

Table 2. Failures causes in pipework: direct causes [2]-[5].

Failure causes	**Percentage of incidents**	
	P.F.Lees (1989)	**H.Thomas (1980)**
Manufacture & fabrication: - base materials (defects) - welding	31.9	 9.6 11.8
Material selection	--	28.8
Corrosion Erosion	9.3 0.8	24.6
External load	3.0	--
Impact	4.8	--
Thermal shock Mechanical shock	3.8 12.1	1.3
Fatigue - low cycle - vibration	1.5	 7.8 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. Failures causes in pipework: "Underlying causes" vs. "Recovery failures" [2].

Underlying cause	**Recovery failures**						
	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**

3. Calculation of the frequency of loss of containment

Events related to loss of containment, or random ruptures, are caused by accidental phenomena such as uncontrolled wearing, anomalous corrosion, pipe defects, etc., thus they are not associated with process anomalies, but are often due to gaps in the corporate structure.
The analysis of loss of containment events permits a complete description of all the potential incidental events, which are the initial causes for a release of a dangerous substances. Their identification consists of the following steps:

- identification of the handled and stored dangerous substances inside the establishment;
- characterization of pipework and equipment and definition of the relative operative conditions;
- identification of the units of the plant, which are characterized by the same operative conditions;
- definition of representative cases of leakage for each unit.

The calculation of accidental frequencies is made using the *Fault Trees* method for events deriving from process deviation, while the analysis of the loss containment events requires a specific approach. The more adopted method for these events is the *API 581 Methodology* [1], other similar methods are based on the use of statistical leak frequency data for "loss of containment events".
The estimation of the frequencies of loss containment events must include the quantification of the influence of measures of risk prevention or mitigation. Some methodologies are given in the literature for this purpose; however these assume that each plant under analysis is characterized by the same combinations of failure causes and prevention mechanisms, but this assumption is not always true.
In the following part of the paper the methodologies for the quantification of measures of risk prevention or mitigation, currently available in literature, are reported, finally a recent development of an approach and its application are described.

3.1. API 581 Methodology

The method proposed in the standard API 581 "Risk Based Inspection Guideline", [1], supplies a generic value of frequency of release from pipes and other main process equipments, this is made considering a statistical average value. Therefore the standard indicates the way to correct such value, depending on the specific characteristics of the examined system and using appropriated correction factors bases on the complexity of the system (number flanges, valves, etc.).
The generic frequencies can be calculated using literature or incidental data relative to similar systems. In the API 581 standard the suggested frequencies of release are given for four diameters of leakage: 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 and the generic frequencies of release represent the median values.
The methodology API 581 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 account of the differences in the safety management system of an establishment, the method also defines an adjustment factor, "management systems evaluation factor".

3.2. Methods for the quantification of the influence of management and organizational factors

The methodologies, currently available in literature, for the quantification of the influence of organizational and managerial factors on the frequencies of release from pipework and vessels are the method of Thomas [5] and the method of Papazoglou [4], both based on the analysis of incidental data in chemical industries.
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 dimension, the shape, the 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, these require valid data.
The *method of Papazoglou* permits the quantification of the effects of organizational and managerial factors on the frequencies of leakage of vessels and pipes defining a link between an activity of 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 in [3], which is based on the

methodology proposed by Papazoglou. The method previously permits to exclude the failure causes that can be prevented through the adoption of appropriate measures of prevention. Thus it is possible to apply the method of Papazoglou using realistic value of percentage of failure causes.
It can be noted that, in order to take into account the influence of managerial and organizational factors, also the *API 581 methodology* [1] for the evaluation of the accidental frequencies uses the "management systems evaluation factor", but unfortunately today the procedure for the definition of this adjustment factor is still not consolidated.

3.3. The method of Papazoglou

The *Papazoglou method* aims to quantify the organizational and managerial factors using an activity of audit of the safety management system (SMS).
A Safety Management Audit, SMA, constitutes the way to verify the accordance of the safety management system with an ideal scheme. This can be made analysing a number of combinations of failure causes and mechanisms of prevention of accidents, therefore 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 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 chemical plant taking into account its specific structure and its potential failure modes, etc. Using the results of a QRA it is sometimes possible to decrease the risk through actions 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 decisions.
By means of the combination of generic failure causes categories (underlying causes categories) and prevention mechanism (recovery mechanism), 54 audit areas of the SMS are defined but only 8 of them, indicated MAAs main audit areas, are meaningful from the point of view of 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 activity are aggregated 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 aggregating the eight assessments into a single number.

The method is based on an analysis of the frequencies of incidents happened 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 frequency of release for the various plants spans two orders of magnitude and exhibits a certain symmetry around their median values.
According to this observations the following equation was proposed, which can be used for the modification of the frequency of release:

$$\log f_{\mathrm{mod}} = \log f_{md} + \sum_i a_i \cdot x_i / 100 \qquad (1)$$

where f_{mod} is themodified frequency, f_{md} is the median frequency of failure based on the world-wide experience, a_i is the 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 chemical industries 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 likelihood of accidents in pipework, vessels and hoses these are shown in [4].

4. The proposed method for the estimation of frequency of loss containment events

The methodology proposed by Papazoglou permits to evaluate 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.
Different plants might differ in design, construction, operation and maintenance procedures and practices. The assumption that they are the same, from the point of view of the percentage of failure causes, might not always be true. For this reason in this work it has been proposed a modified approach of the Papazoglou method for frequencies evaluation.
This method is based on an appropriate examination of the overall plant, then it is possible to define how the measures of risk prevention and mitigation adopted inside the establishment can influence the frequencies of rupture of pipework. In order to make this it is necessary a detailed analysis for each unit of the plant and therefore it will be possible to identify the failure causes 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 exclude previously all those failure causes that are not present in the establishment because of the adoption of appropriate measures to prevent them. The adjustment of the percentages of breakdowns allows to use 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 mitigation and failure causes of incidents in piping. These permit to incorporate in the final results a great number of the plant-specific characteristics concerning the design, operational and maintenance aspects of the installation.
The procedure described is based on the methodology proposed by Papazoglou. The Papazoglou method is based on the quantification of an activity of audit on a SMS and, however, it is based on an analysis of the failure modes in vessels and pipes.
As discussed before the proposed method modifies the frequency of release from an equipment using the equation 1, whose application demands on the definition of the weight coefficients a_i. It aims at the estimation of the influence on f_{md} of prevention measures, which have been *a priori* judged "GOOD", thus the problem is to determine which failure causes can be prevented by a certain measure adopted by the Company. In order to identify the measures adopted for preventing the failures, also in this case an activity of audit is necessary.
After the definition of the relationships between the failure causes and the measures of prevention and mitigation, the weight coefficients for the failure causes have been estimated and then it has been possible to modify the frequencies taking account the prevention and mitigation measures.
The *a priori* exclusion of some failure causes concurs to modify the value of the median frequency of failure obtained from literature, f_{md}, which will be reduced of the percentage equal to the excluded failure causes, therefore the methodology proposed by Papazoglou will be applied to the value of frequency a priori modified.

4.1. Weight coefficients for the failure causes

Many data regarding the main causes of release from piping are available in literature, this information are summarized in *Table 2* (direct causes).
The evaluation of the weight coefficients can be made using the failure data reported by Lees [2], because these percentages are relatively more recent and specific for piping of the chemical industry. Nevertheless it is necessary to verify the congruence between the data of Lees and the failure causes evidenced inside the examined establishment. In some cases the values of weight coefficients need to be corrected taking into account that modern design and manufacture and the use of new base materials might reduce the number of failures due to certain causes.
The correction of the data of *Table 2* can be made according with the plant management of the establishment.

4.2. Weight coefficients for the corrosion phenomena

Concerning pipework in [2], phenomena such as corrosion and mechanical failures causes have been analyzed in detail, thus the analysis of incidental data has allowed to distribute these failure modes as shown in *Table 4.*
Causes of general service, 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 the *Table 4*, it is possible to detail the failure causes for corrosion and mechanical failures, thus the single values of *Table 2* can be split in the contributions associates to each type of corrosion and/or mechanical failure.
In order to split the data of *Table 2*, a detailed analysis of the fluid flowing in the pipework and the process conditions was necessary. The analysis allows to define which typologies of corrosion can occur in the

equipment.

Table 4. Corrosion and mechanical failure causes.

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**

4.3. Weight coefficients for the human error

In order to better quantify the influence of the measures of risk prevention and mitigation on frequency of rupture of pipework, a more detailed analysis of the human errors has been carried out.
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 regards the installation. A study of human error as cause of piping failures has been made by Bellamy and co-workers, [2]. They have classified incidents in direct causes, origins of failure and recovery mechanisms.
Their data showed that operator error contributed 18.2 % to the direct causes of pipework failure, whilst defective pipe or equipment contributed 31.9% and unknown causes 9.1%. *Table 5* gives the distribution of human errors in underlying causes, it is possible to see that the predominant errors are in maintenance. A shown in *Table 5*, the operator error usually can be evidenced as other failure causes (es. impact, corrosion, etc). Therefore, using *Table 5*, it can be split in the failure modes of *Table 2* and then included in the other typologies of failures. The proportional distribution of the human error in the other failure causes provides the correct values for the weight coefficients a_i.
The distribution of the human error in the failure causes of *Table 2* is possible after matching "failure causes" and "underlying causes" categories through a subjective expert judgement. The matching "failure causes/ underlying causes" is given in *Table 6*.

Table 5. Human error distribution in “underlying causes”.

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

Table 6. Matching "failure causes/ underlying causes".

Failure causes	Underlying causes
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	Sabotage
Creep	Maintenance
Other and unknown	--

5. Application to a case-study

The methodology described for the quantification of the influence of the measures of prevention and mitigation of risk on the frequencies of release from vessels and pipeworks has been tested through the application to a real industrial plant.
This approach has been applied for the calculation of the frequencies of the random events which can potential occur in the pipework. The case study is 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 and mitigation on the failure causes has been discussed

and defined according with the plant management.
For this reason, in order to define which failure causes can be prevented by a certain measure adopted by the Company, an activity of audit has been performed
In this paragraph an example of application is described. It has been supposed a rupture of a pipe coming from a vessel containing a flammable and toxic. Two dimensions of leakage have assumed, 5% and 20% of 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 the *Tables 2* and *4*, the percentages of failure causes have been corrected as discussed and defined with the plant management. The corrected values have been normalized.
Then the initial frequencies have been reduced of the percentage of excluded failure causes.

5.1. The modified procedure for the quantification of frequencies

The application of the modified method can be made through the following steps:

- Definition of the weight-coefficients a_i, which comprises a detailed analysis both for human error and corrosion causes;
- Formulation of the judgements on the inspecting techniques;
- Calculation of the frequencies using the equation 1.

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

5.2. 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 adequately the frequency of rupture reducing its value of the percentage of the failure causes (P_i), that can be prevented using this measure.
Also in this case the *a priori* exclusion of some failure causes concurs to modify the value of the initial frequency that will be diminished of the percentage of excluded failure causes.
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 the inspections in-service.
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 result equal to the product of the corrected value of a_i multiplied for the effectiveness of the measure.
In this case it has been proposed the use of the effectiveness classes defined in API 581 Risk-Based Inspection Base Resource Document and shown in *Table 7*.

Table 7. Qualitative Inspection Effectiveness Category.

Highly Effective: Inspection methods 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%)

5.3. Results

The frequencies have been modified and results have been given in the Table 8. It can be noted that generally the frequency of the random event decreases about a 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 congruence of the proposed procedure with a conservative method. The comparison of the results demonstrates the validity of the proposed methodologies.

Table 8. Results.

Leak dimension	Frequency	Modified frequencies (proposed method)	Modified frequencies (direct reduction)
5%	1.93E-03	1.13E-04	4.47E-04
20%	1.25E-04	7.35E-06	2.90E-05

The entity of the risk reduction can be visualized using risk matrixes (*Figure 1*). The matrix constitute 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 graph 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.

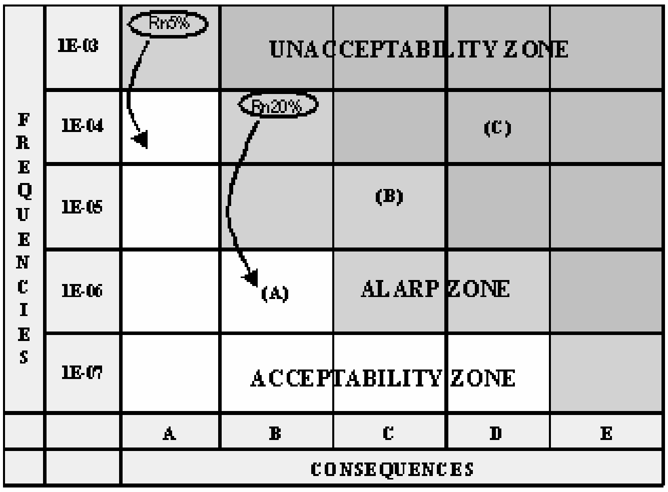

Figure 1. Risk matrix.

6. Conclusions

The objective of this work has been the definition of an approach for incidental frequencies calculation taking into account managerial and organizational factors. This necessity is due to the observation that the main cause of accidents are events like improper functioning or mechanical breakdowns of equipment, these are often due to gaps in the corporate structure.

Furthermore the use of appropriate risk analysis techniques does not permit to take into account the management and organizational factors which are of primary importance in defining the real risk level of a chemical plant and therefore for the planning of the resources and the procedures of emergency.

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

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

The proposed method appears innovative, since through its application, it is possible the a priori exclusion of all the failure causes that are not present in the establishment because of the adoption of appropriate measures to prevent them. The correction of the percentages of breakdowns allows to use the real weight-coefficients.

The approach proposed in this work is suitable to the various industrial activity at major risk, it requires for each case to modify the weights coefficients associates to the single failure causes and to formulate the judgments on the measures of prevention and mitigation of the risk adopted by the company, in such way it is possible to reproduce the plant-specific characteristics concerning the design, operational and maintenance aspects of the installation.

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