SIE 2015
6th International Symposium on Industrial Engineering
24th-25th September 2015
FACULTY OF MECHANICAL ENGINEERING
STEINBEIS ADVANCED RISK TECHNOLOGIES
INNOVATION CENTER FME

EFFECTS OF MANAGEMENT AND ORGANISATIONAL VARIABLES IN RISK ASSESSMENT

Maria Francesca Milazzo
Dipartimento di Ingegneria Elettronica, Chimica e Ingegneria Industriale (DIECII), Università degli Studi di Messina, Italy

Abstract. *The standard Quantitative Risk Assessment approach includes the estimation of accidental frequencies; these are a function of various parameters such as components failure rates, probabilities of human error, equipment damage and managerial factors. The availability of general values from the literature for such parameters simplifies the risk analysis, but unfortunately provides standardised results which do not permit taking into consideration the plant specificity. If managerial and organizational factors are neglected or not proper assessed, risk analysis for two identical establishments, characterised by totally different management systems, gives the same results and this appears absolutely unacceptable especially when risk analysis is used as a tool for risk-based decisions. This paper aims quantifying the effects of managerial and organisational variables on the frequency of losses of containment in pipeworks, by using a simple and flexible method developed by Milazzo et al. Such a methodology has been tested on a new case-study and results have been evaluated from both the sensitivity and uncertainty point of views.*

Key words: *Industrial safety, Quantitative Risk Assessment, Loss of containment, Cause of failure, Pipework.*

1. INTRODUCTION

Safety in major hazard plants involves a complex interaction amongst human elements, hardware or technical elements and the environment/climate where each worker operates [1-2]. Organisational and management aspects affect the human behaviour and ultimately influence system performances. In this frame, the role of management is central to the safe functioning of plants, in particularly in the process industry, where reactions are not always easy to be managed or controlled.

To quantify the effects of management and organisational variables on safety, Davoudian et al. [3] suggested assessing the impact of such factors on plant safety by modelling the system as a whole and, then, quantifying and incorporating management and organisation impacts into Quantitative Risk Assessment (QRA). After this, several interesting approaches were suggested to describe the formal organisation of processes and the various previously mentioned interactions at different levels. A review of these approaches was given by Nivolianitou and Papazoglou [4], which was more recently updated by Milazzo et al. [5].

Approaches for the quantitative assessment of management and organisation impacts mainly derive from the nuclear field [6-7]; specific methods for the quantification of management-related safety problems in chemical industry are the MACHINE (Model of Accident Causation using Hierarchical Influence Network) [8], the ISM (Integrated Safety Method) [9], the WPAM (the Work Process Analysis Model) [3,10], the SAM (System Action Management) approach [11], the Omega Factor Method [12], the I-Risk (Integrated Risk) approach [13-14], the ORIM (Organizational Risk Influence) [15] and, finally, the ARAMIS methodology [16]. As suggested by the literature, the modelling of such interactions is essential, mainly because Quantitative Risk Analysis (QRA) provides useful information to support decisions.

This work aims quantifying the effects of managerial and organizational factors on the frequency of *loss of containment* of pipeworks using a simple and flexible method suggested by Milazzo et al. in 2010 [5], which has been updated in the present work, by using more recent data related to the percentage of the causes of failure, and tested on a new case-study.

The paper is organised as follows: in the first part, the proposed approach is briefly described; in the

second part an application to case-study is given; in the third part results are discussed and some comments about the sensitivity and the uncertainty associated with the results of the proposed method are also presented, based on the approach suggested in Milazzo and Aven [17].

2. METHODOLOGY

The approach suggested by Milazzo et al. [5] for the quantification of the frequencies of *loss of containment* (or *random rupture*) from pipeworks is based on two steps: (i) the definition of the relationship between the measures of prevention of incidents, adopted by a Company, and the causes of failure leading to *loss of containment* and (ii) the estimation of the weight coefficients for the causes of failure, to modify the frequencies by including the effects of managerial and organizational factors. Subsequently, the frequencies of breakage/rupture, obtained from the literature and commonly used in QRA, are modified according to the equation derived by Papazoglou et al. in 1999 [18].

Thus the proposed method of Milazzo et al. consists of an examination of the whole plant (as suggested by Davoudian et al. [3]), to define how the measures of risk prevention adopted inside the establishment can influence the frequency of rupture. To make this an auditing of each unit of the establishment is needed, this allows identifying the causes of failure which can occur and the measures which can prevent them. The weight coefficients for the causes of failure are the percentages of failures, which must be determined for each unit of the establishment.

By analysing the *loss of containment* data, Papazoglou et al. in 1999 showed that the frequencies of release from various equipment of chemical plants spans two orders of magnitude and has a certain symmetry around the average values. Thus, the frequencies of failure can be modified using the following equation, whose application needs the weight coefficients a_i (percentage of the cause of failure i) [18]:

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

where: f_{mod} = modified frequency of failure (frequency of the *loss of containment*); f_{av} = average frequency of failure (average frequency of the *loss of containment*) based on world-wide experience; a_i = weight coefficient for audit area i (percentage of the causes of failure); x_i = parameter indicating the judgement of the effectiveness of the prevention measure related to the cause of failure i (following the audit).

The parameter x_i assumes the following values:

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

As highlighted by Milazzo et al. [5], the use of the same statistical data for each installation under analysis does not permit to take into account plant-specific information. Different installations may differ from the point of view of the percentage of causes of failure, thus it is necessary to correct the weight coefficients taken into account their specificity. To achieve this scope, the proposed approach consists, firstly, of the exclusion of the causes of failure that can be prevented through the adoption of appropriate prevention measures and, then, of the application of the mathematical model represented by equation (1) using installation-specific information to support the calculation of the percentage of the causes of failure.

3. CASE-STUDY

The approach, described in Section 2, was applied to the quantification of the frequency of the *losses of containment* of pipeworks of an alkylation unit included in a confidential refinery.

3.1. Alkylation unit

The alkylation unit of a refinery aims obtaining gasoline with a high octane number, starting from the gaseous by-products of other processes, especially from the cracking and reforming units. These gases are generally constituted by mixtures of isobutane and olefins having 3÷5 carbon atoms. To obtain acceptable reaction rates without reaching high temperatures, acid catalysts are employed. Thus due to the acid environment, this unit is considered the most critical from the point of view of the prevention and management of random ruptures.

3.2. Failure causes and preventive measures

The application of the approach of Section 2 aims at the estimation of the influence of prevention measures on f_{av}, which were judged *a priori* GOOD (x_i = - 1). Thus the problem is to determine which causes of failure can be prevented by certain measures adopted by the Company. To identify the causes of failure, the preventive measures and their effectiveness, an audit was made.

Table 1 provides an overview of the relevant causes and their contribution, in terms of percentage, to the failure of process pipes; this data was extracted from the handbook of failure frequencies [19] (a European database of DVN, Det Norske Veritas) and was used for the elaborations necessary in the present work.

The weight coefficients of Table 1 needed to be corrected to account for that modern design and manufacture might reduce the number of failures due to certain causes and to assess the effects of managerial and organizational factors. The way to correct the weight coefficients was defined in agreement with the plant management of the establishment.

The measures, adopted by the Company to prevent failures (such as corrosion, erosion, pipe defect and other structural damages) are the following: radiographic testing, ultrasonic testing, liquid penetrant testing, magnetic particles testing and

visual inspections. Regarding the case-study, phenomena and maintenance activities, which characterised the equipment's past life, were collected from a database managed by a specific software developed by the Company, this was essential to identify and assess the causes of failure occurring in each pipework.
The corrosion phenomenon was analysed more in detail, based on data of Lees [20]. Such data allows distributing the corrosion cause of failure of Table 1 in several sub-causes (a complete description is given in [5]). A detailed analysis of the fluid flowing in the piping and the process conditions were necessary in order to define which sub-causes occurs. Secondary causes, which were considered not credible, were excluded and the percentage of failure modes for corrosion was corrected.
Then, in order to estimate the effect of measures of risk prevention on f_{av} through equation (1), it was necessary to formulate a judgment x_i for each adopted measure. Each one was assessed in terms of efficiency in identifying a given failure causes.

Table 1. Percentage of causes of failure, source [19].

Failure cause	Partial cause	[%]
Corrosion	Wrong material	1.68
	Corrosive contamination	0.38
	Exceptional conditions	1.01
	Aggressive environment	1.03
	Poor protection	0.74
	Zinc embrittlement	0.06
	Cooling water circuit	0.06
	Galvanic corrosion	0.33
	Unknown	4.11
Erosion	Turbulent flow	0.01
	Unfavourable flow path	0.22
	High flow speed	0.14
	Erosive external environment	0.05
	Unknown	0.27
	Erosive contents	0.11
External pressure	Removed pipe supports	0.28
	Failure of pipe supports	0.98
	Poor design of supports	1.14
	Unknown	0.11
	External pressure	0.48
Temperature	Insufficient material specification	0.87
	Thermal pressures	0.38
	Change of contents	0.60
	Thermal shock	0.38
	Poor pipe specification	0.02
	Domino effect	0.54
	Unknown	1.01
Wrong installation	Wrong parts' placement	0.16
	Installation error	2.64
	Insufficient equipment	1.09
	Unknown	0.11
Procedural error	Pipe not cleaned before opening	4.38
	Wrong pipe worked on	0.87
	Wrong equipment status	3.62
	Wrong operations' order	2.90
	Wrong (dis)connection	0.76
	Pipe insufficient insulated	1.56
	Equipment not brought back to normal status	0.33
	Unknown	3.78
Impact	Impact of a nearby installation	1.68
	Human impact	0.85
	Falling object as a result of a natural cause	0.22
	Vehicle impact	1.57
	Unknown	0.43
Total		**100**

3.3. Average frequencies

In this paper, only one incidental hypothesis is described, as the aim is to show how the proposed approach works. The event is a random breakage of a pipe coming from the alkylation plant and three cases were considered as shown in Table 2. Related average frequencies of occurrence (f_{av}) were collected from the Safety Report of the establishment (the document refers to the frequency data from HSE [21]).

Table 2. Cases of breakage/rupture and related frequencies, source [21].

ID	Event	f_{av} [event/y·m]
Rn1a	Hole size 3 mm diameter	$1\ 10^{-5}$
Rn1b	Hole size 25 mm diameter	$5\ 10^{-6}$
Rn1c	Guillotine rupture	$1\ 10^{-6}$

The *a priori* exclusion of some causes of failure requires also the modification of the mean frequency (f_{av}) obtained from the literature. This value was reduced by a percentage equal to the excluded causes of failure. Then equation (1) was applied to the *a priori* modified frequency.

4. RESULTS

Table 3 shows the frequencies of *loss of containment* modified by the application of the method. Several applications showed that the frequencies of *random events* generally decrease by about an order of magnitude or more in some cases (Figure 1).

Table 3. Modified frequencies.

ID	Event	f_{mod} [event/y·m]
Rn1a	Hole size 3 mm diameter	$9.75\ 10^{-7}$
Rn1b	Hole size 25 mm diameter	$4.87\ 10^{-7}$
Rn1c	Guillotine rupture	$9.75\ 10^{-8}$

In Figure 1, the entity of the risk reduction is visualised by using risk matrixes, where the *x* and *y* axes respectively give the consequence and the frequency of the events. The consequence axis shows four classes of effects defined as follows: D high percentage (50 %) of fatalities, C low percentage of fatalities (1 %), B irreversible effects and A reversible effects (see details in [22]). Three levels of risk are also indicated in the matrix to be used for the risk-based decisions, these are the acceptable level (white zone), the ALARP level i.e. As Low As Reasonable Possible (grey zone) and the unacceptable level (red zone).
The results of Figure 1 allow verifying that the Company through the adoption of certain preventive risk measures reduces the risk level for these events from the ALARP zone to the acceptability.

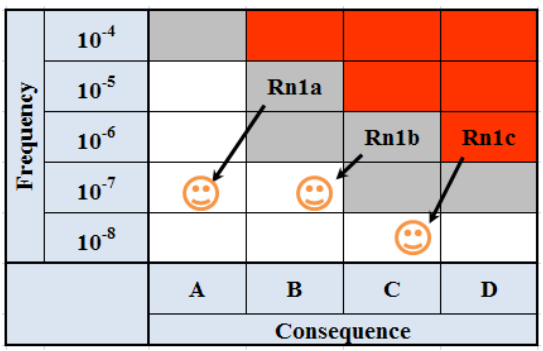

Figure 1. Risk matrix

4.1 Discussion

Given that some steps of the assessment include subjective judgments by the risk analysts, it must be known how to make the risk assessment as less as possible affected by subjectivity. A subjective evaluation implies that different analysts may provide different assessment for the weight coefficients (a_i) and, also, different judgments for the risk prevention measures (x_i). A sensitivity analysis showed the subjective parameter which is the most significant for the final evaluation [5]. The variables with the highest influence on the f_{mod} resulted the average frequency f_{av} and the weigth coefficients a_i. This conclusion is not sufficient to consider at what extent the modelling corresponds to the reality and where implementations are needed, indeed the risk analyst has to comment about its results also based on the uncertainty associated with the assumptions made in modelling to simplify the process.
To this purpose, in this paper the sensitivity and the uncertainty were evaluated, as suggested by Milazzo and Aven [17]. Their method allows the assessment and categorisation of the assumptions (so-called *uncertainty factors*) with respect to both the uncertainty and the sensitivity scores (U and S) proposed by Flage & Aven [23] (Table 4).
Table 5 gives results of the uncertainty and the sensitivity assessment; *uncertainty factors* were determined for each steps of the proposed approach of Section 2.

Table 4. Uncertainty and the sensitivity scores [22].

Aspect	Score	Interpretation
U	Low (L)	One or more conditions: – The assumptions made are seen as very reasonable. – Much reliable data are available. – There is broad agreement/ consensus among experts. – Phenomena involved are well understood; the models used are known to give predictions with the required accuracy.
	Medium (M)	Conditions between those characterizing low and high uncertainty.
	High (H)	One or more conditions: – The assumptions made represent strong simplifications. – Data are not available, or are unreliable. – There is lack of agreement/ consensus among experts. – Phenomena involved are not well understood; models are non-existent or known/believed to give poor predictions.
S	Low (L)	Unrealistically large changes in base case values needed to bring about altered conclusions.
	Medium (M)	Relatively large changes in base case values needed to bring about altered conclusions.
	High (H)	Relatively small changes in base case values needed to bring about altered conclusions.

Table 5. Uncertainty and sensitivity assessment.

Uncertainty factors (Assumptions)	U	S
Representative fluid are able to describe all fluids characteristics	L	L
Average frequencies and failure causes are based on literature data.	H	H
Efficiency of the inspection techniques	L	M
Only one failure occurs during a certain interval of time	M	M
The failure is quickly detected	M	H
Company and industry requirements are followed	L	L
Pipeworks are tested and inspected before and during the installation	L	M

The first assumption is the common use of representative classes of fluids to describe all fluid characteristics. Substances, having the same hazard typology, are usually grouped to reduce the number

of cases of release, anyway both the degree of uncertainty and sensitivity are low.

The greatest difficulty in assigning frequencies of breakage and percentage of failures is due to lack of appropriate data (second assumption). Uncertainties in this field are due to the adoption or to the adaptation of data derived from other context. This assumption leads to high degrees of uncertainty and sensitivity (see also [24]); this result is in agreement with the sensitivity assessment given in [5]. The third and forth uncertainty factors are related to the assumptions that only one failure event or failure mode occurs during a certain interval of time and failures are immediately detected when they occur. In real life the assumptions may not always hold. The fifth and sixth uncertainty factors address the assumptions that the installed pipeworks are adequately tested and inspected prior to production start up and that production is within the design criteria and requirements/recommendations. In practice, however, it is questionable whether these assumptions will be true.

The sensitivity and the uncertainty scores showed that the use of average frequency and failure causes from the literature is the factor mostly affecting the assessment. Thus the analyst must be care in selecting data.

4. CONCLUSIONS

Given that the main cause of accidents in pipeworks are often due to deficiencies in the corporate structure, many techniques have recently been developed and allow estimating managerial and organisational factors. The most common risk analysis approach conservatively includes the influence of measure of risk prevention and mitigation. This work has permitted to apply a simple and flexible approach for the calculation of *loss of containment* frequencies taking into account managerial and organisational variables.

Results showed that the frequencies of *random events* generally decrease by about an order of magnitude or more in some cases. Moreover, given that the proposed method is affected by several subjective judgements, it was possible to comment on how to make the assessment as less as possible affected by subjectivity. The sensitivity and the uncertainty were evaluated, as suggested by Milazzo and Aven [17], and the results showed that the use of generic frequency and failure causes from the literature is the factor mostly affecting the assessment. Thus their selection must point to more reliable data.

REFERENCES

[1] Schönbeck M., Rausand M., Rouvroye J. (2010) Human and organisational factors in the operational phase of safety instrumented systems: A new approach. *Safety Science*, 48(3), 310-318.

[2] Gordon R.P.E. (1998). The contribution of human factors to accidents in the offshore oil industry. *Reliability Engineering and System Safety*, 61, 95-108.

[3] Davoudian K., Wu J.S., Apostolakis G. (1994). Incorporating organizational factors into risk assessment through the analysis of work processes. *Reliability Engineering and System Safety*, 45, 85-105.

[4] Nivolianitou Z.S., Papazoglou I.A. (1998). An auditing methodology for safety management of the Greek process industry. *Reliability Engineering and System Safety*, 60, 185-197.

[5] Milazzo M.F., Maschio G., Uguccioni G. (2010). The influence of risk prevention measures on the frequency of failure of piping. *International Journal of Performability Engineering*, 6(1), 19-33.

[6] Izquiedo-Rocha J.M., Sanchez-Perea M. (1994). Application of integrated safety assessment methodology to emergencies procedures of SGTR of a PWR. *Reliability Engineering and System Safety*, 45(1-2), 159-173.

[7] Montmayeul R., Monsneron-Dupin F., Llory M. (1994). The managerial dilemma between the prescribed task and the real activity of operator: some trends for research on human factors. *Reliability Engineering and System Safety*, 45(1-2), 67-73.

[8] Embrey D.E. (1992). Incorporating management and organization factors into probabilistic safety assessment. *Reliability Engineering and System Safety*, 38(1-2), 199-208.

[9] Modarres M., Mosleh A., Wreathall J.A. (1992). Framework for assessing influence of organization on plant safety. *Reliability Engineering and System Safety*, 38(1-2), 157-171.

[10] Davoudian K., Wu J.S., Apostolakis G.E. (1994). The work process analysis (WPAM II). *Reliability Engineering and System Safety*, 45(1-2), 107-125.

[11] Patè-Cornell E.M., Murphy D.M. (1996). Human and management factors in probabilistic risk analysis: the SAM approach and observations from recent applications. *Reliability Engineering and System Safety*, 53(2), 115-126.

[12] Mosleh A., Goldfeiz E.B. (1995). An Approach for Assessment the Impact of Organizational Factors on Risk. Report no. UMNE-95-003, University of Maryland.

[13] Papazoglou I.A., Aneziris O., Post J.G., Ale B.J.N. (2002). Technical modeling in integrated risk assessment of chemical installations. *Journal of Loss Prevention in the Process Industry*, 15(6), 545-554.

[14] Papazoglou I.A., Bellamy L.J., Hale A.R., Aneziris O., Post J.G., Oh J.I.H. (2003). I-Risk: development of an integrated technical and management risk methodology for chemical installations. *Journal of Loss Prevention in the Process Industry*, 16(6), 575-591.

[15] Øien K. (2001). A framework for the establishment of organizational risk indicators. *Reliability Engineering and System Safety*, 74(2), 147-167.
[16] Salvi O., Debray B. (2005). A global view on ARAMIS, a risk assessment methodology for industries in the framework of the SEVESO II directive. *Journal of Hazardous Materials*, 130(3), 187-199.
[17] Milazzo M.F., Aven T. (2012). An extended risk assessment approach for chemical plants applied to a study related to pipe ruptures. *Reliability Engineering and System Safety*, 99, 183-192.
[18] Papazoglou, I.A., Aneziris O. (1999). On the quantification of the effects of organizational and management factors in chemical. *Reliability Engineering and System Safety*, 15(1): 545-554.
[19] Flemish Government, LNE Department Environment, Nature and Energy Policy Unit Safety Reporting Division (2009). Handobook of failure frequencies (Appendix).
[20] Lees F.P. (1996). Loss Prevention in the Process Industries. Elsevier, London.
[21] HSE (2012).Failure Rate and Event Data for use within Risk Assessments. Report available online at: http://www.hse.gov.uk/.
[22] Vianello C., Guerrini L., Maschio G., Mura A. (2014). Consequence analysis: comparison of methodologies under API standard and commercial software. *Chemical Engineering Transactions*, 36, 511-516.
[23] Flage R., Aven T. (2009). Expressing and communicating uncertainty in relation to quantitative risk analysis (QRA). *Reliability & Risk Analysis: Theory & Applications*, 2(13), 9–18.
[24] Milazzo M.F., Vianello C, Maschio G. (2015). Uncertainties in QRA: Analysis of losses of containment from piping and implications on risk prevention and mitigation. *Journal of Loss Prevention in the Process Industry*, 36, 98-107.