Original Scientific Paper

doi:10.5937/jaes14-9842 Paper number: 14(2016)1, 353, 54 - 60

ON THE IMPORTANCE OF MANAGERIAL AND ORGANISATIONAL VARIABLES IN THE QUANTITATIVE RISK ASSESSMENT

Maria Francesca Milazzo*
University of Messina, Messina, Italy

Common practises for Quantitative Risk Assessment (QRA) include the estimation of frequencies of releases and related initial causes; these are a function of several parameters such as components failure rates, probabilities of human error, equipment damage and managerial factors. The availability of general values for such parameters from the literature simplifies the work of the risk analyst, but standardised results are provided, which unfortunately do not permit taking into consideration the plant's specificity. The specificity of the establishment is defined through its management system, thus if managerial and organisational 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 for risk-based decisions. This paper aims quantifying the effects of managerial and organisational variables on the frequency of losses of containment of pipeworks, by using a simple and flexible method developed by Milazzo and co-authors in 2010. Such a methodology has been tested on a new case-study and the results of the assessment have been evaluated from both the sensitivity and uncertainty points of view. An application has been shown with respect to the alkylation unit of a refinery.

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

INTRODUCTION

Several factors, including human elements, hardware or technical elements and the environment/climate where workers operates, contribute to safety in major hazard plants [24,7], such factors act through a complex interaction. In this frame, organisational and managerial aspects affect the human behaviour; this finally has an effect on the system performances. By analysing the mechanism of interaction, it can be evidenced that the role of management is central to the safe functioning of plants, in particular in chemical industry, where some reactions are not always easy to be managed or controlled. Due to the loss of control of chemical process, incidental scenarios, such as fires explosions and toxic dispersions, could occur.

Davoudian et al. [02] suggested assessing the effects of managerial and organisational variables on safety by modelling the system (plant) as a whole and, then, quantifying and incorporating managerial and organisation impacts into Quantitative Risk Assessment (QRA). After this study, several interesting approaches were suggested to describe the formal organisation of processes and the numerous previously mentioned interactions at different levels. A detailed overview on these approaches was given by Nivolianitou and Papazoglou [17], this review was more recently updated by Milazzo et al. [12].

The literature shows that approaches for the quantitative assessment of managerial and organisational impacts mainly derive from the nuclear field [9-15]. The modelling of such impacts is essential, mainly because Quantitative Risk Analysis (QRA) provides useful information to support decisions, which are obviously based on an economical appraisal applied to several solutions [1]. The most relevant methods for the quantification of management-related safety problems in chemical industry are the MACHINE (Model of Accident Causation using Hierarchical Influence Network) [4], the Integrated Safety Method ISM [14], the Work Process Analysis Model WPAM [2,3], the System Action Management approach SAM [22], the Omega Factor Method [16], the I-Risk (Integrated Risk) approach [20-21], the

---

* *University of Messina - Dipartimento di Ingegneria Contrada di Dio, 98166, Messina, Italy; mfmilazzo@unime.it*

Organisational Risk Influence method ORIM [18] and, finally, the ARAMIS methodology [23].

This work aims testing a simple and flexible method for the quantification of the effects of managerial and organisational factors on the frequency of loss of containment of pipeworks, which was suggested by Milazzo et al. in 2010 [12]. The data (percentage of the causes of failure), needed for the assessment of such factor, have been updated with respect to those used by Milazzo et al. An application allowed testing the method, it relates to a new case-study from the chemical industry, i.e. a refinery. Then both the sensitivity and the uncertainty of the results have been assessed by using the qualitative approach suggested in Milazzo and Aven [11].

The structure of the paper is the following: in the first section, the approach of Milazzo et al. is briefly described; the second section gives the application to the case-study; in the third section, results are discussed and commented in terms of sensitivity and the uncertainty.

METHODOLOGY

The approach suggested by Milazzo et al. [12] for the quantification of the frequencies of loss of containment (or random rupture) in pipeworks is based on two steps:

I. (i) the definition of the relationship between the measures of prevention of incidents, adopted by the Company, and the causes of failure leading to the loss of containment;
II. (ii) the estimation of the weight coefficients for the causes of failure, to be used for the modification of the frequencies by including the effects of managerial and organisational factors.
III. Subsequently, the frequencies of breakage/rupture, obtained from the literature and commonly used in QRA, are modified according to the equation proposed by Papazoglou et al. in 1999 [18].

Thus the method of Milazzo et al. consists of an examination of the whole plant (as suggested by Davoudian et al. [02]), to define how the measures of risk prevention adopted inside the establishment can influence the frequency of rupture. This is made by auditing each unit of the establishment, in order to allow identifying the causes of failure which can occur and the measures which can prevent them. The weight coefficients for the causes of failure, which are used to apply the method, are the percentages of failures and relate to each unit of the establishment.

Papazoglou et al. [18] analysed data of incidents in chemical industry and showed that the frequencies of release from various equipment spans two orders of magnitude and has certain symmetry around the average values. Thus, the frequencies of failure can be modified by using the following equation, whose application needs the weight coefficients ai (percentage of the cause of failure i):

where: fmod = modified frequency of failure (frequency of the loss of containment); fav = average frequency of failure based on world-wide experience (average frequency of the loss of containment); ai = weight coefficient for audit area i (percentage of the causes of failure in the audit area i); xi = parameter indicating the judgement of the effectiveness of the prevention measure related to the cause of failure i.

The parameter xi 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.

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 [12]. To achieve this scope, the approach of Milazzo et al. firstly excludes the causes of failure that can be prevented through the adoption of appropriate prevention measures, then, applies the mathematical model represented by equation (1) and uses installation-specific information to support the calculation of the percentage of the causes of failure.

APPLICATION

To test the approach previously described, a case-study was chosen, it is a refinery (confidential). As an example, in this paper, only the alkylation unit is described.

Alkylation unit

The alkylation process produces gasoline with a high octane number, starting from the gaseous by-products of other units, especially from the cracking and reforming. These by-products are generally constituted by mixtures of iso-butane and olefins having 3-5 atoms of carbon. Acid catalysts are employed to achieve acceptable reaction rates without reaching high temperatures. Due to the acid environment, this unit is considered the most critical of a refinery from the point of view of the prevention and management of random ruptures.

Failure causes and preventive measures

The application of the method of Milazzo et al. aims estimating the influence of prevention measures on fav, which were a priori judged GOOD (xi = - 1). Thus the problem is to determine which causes of failure can be prevented by the measures adopted by the Company. An audit was made to identify causes of failure, preventive measures and related effectiveness.

Table 1 gives all the relevant causes of failure and their percentage. This data was extracted from a European database of DVN (Det Norske Veritas) [6] and was used for the elaborations of the present work. The weight coefficients of Table 1 needed to be corrected to account for the evidence that modern design and manufacture might reduce the number of failures due to certain causes. The way to correct the weight coefficients was defined in agreement with the plant management of the establishment.

Table 1: Percentage of causes of failure [06]

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

Table 1: Percentage of causes of failure [06].

Failure cause	Partial cause	[%]
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

The measures, adopted by the Company to prevent failures (such as corrosion, erosion, pipe defect and other structural damages) are radiographic testing, ultrasonic testing, liquid penetrant testing, magnetic particles testing and visual inspections. Information on equipment's past life is stored in 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 in detail. Data of Lees [10] allowed distributing the corrosion causes of Table 1 amongst several sub-causes as given in [12].

A detailed analysis of the fluid flowing in the piping and the process conditions were necessary to define which sub-causes occurs. Secondary causes, which were considered not credible, were excluded and the percentage of failures due to the corrosion was corrected. Then, in order to estimate the effect of measures of risk prevention on fav, through equation (1), a judgment xi for each adopted measure has been formulated. Each one was defined in terms of efficiency in identifying a given failure causes.

Average frequencies

To show how the approach works, only one incidental hypothesis is described. The event is a breakage of a pipe coming from the alkylation reactor, three dimensions of leakage were considered (see Table 2). The average frequencies (fav) are those given in the Safety Report (the document refers to the data from HSE [8]).

After the a priori exclusion of some causes of failure, the modification of the mean frequency (fav) obtained from the literature was needed. This value was reduced by a percentage equal to the excluded causes of failure. Thus equation (1) was applied to the a priori modified frequency.

RESULTS

The frequencies of loss of containment modified by the application of the method are shown in Table 3. Several examined case-studies showed that the frequencies of random events generally decrease from 1 to 2 orders of magnitude.

Table 2: Leakage cases and frequencies.

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	$1\ 10^{-6}$

Table 3: Leakage cases and frequencies.

ID	Event	f_{av} [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	$9.75\ 10^{-8}$

The entity of the risk reduction is visualised in Figure 1 by using a risk matrix, where the x and y axes respectively give the consequence and the frequency of the events.

The following four classes of consequence are defined based on the effects thresholds: D high percentage (50 %) of fatalities, C low percentage of fatalities (1 %), B irreversible effects and A reversible effects (see details in [25]). Three levels of risk are defined for the risk-based decisions, i.e. the acceptability level, the ALARP (As Low As Reasonable Possible) level and the unacceptability level. In Figure 1, these levels respectively correspond to the white, the grey and the red zone.

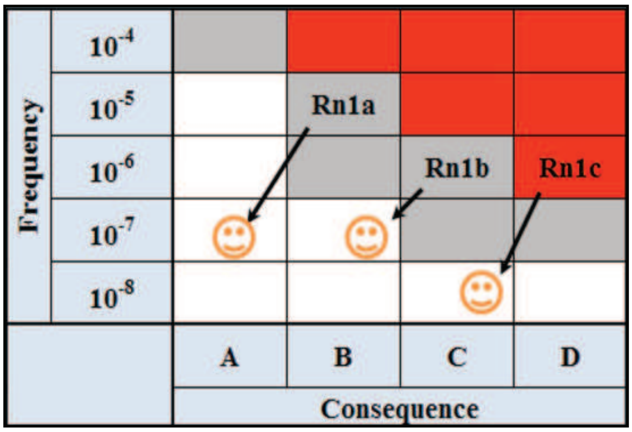

Figure 1: Risk matrix

The results of Figure 1 allow verifying the reduction of the risk level by mean of the adoption of certain preventive risk measures. The aim of the Company is bring the event from the ALARP zone to the acceptability ones.

DISCUSSION

Given that some steps of the assessment include subjective judgments by the risk analysts, it is important to know 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 (ai) and, also, different judgments for the risk prevention measures (xi). A sensitivity analysis showed the parameter which is the most significant for the final evaluation [16]. The variables with the highest influence on the fmod are the average frequency fav and the weight coefficients ai. 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 [11]. This 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 [05] and given in Table 4.

Table 4: Uncertainty and the sensitivity scores [05]

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 gives the results of the uncertainty and the sensitivity assessment; uncertainty factors were determined for each steps of the proposed approach of Section 2.

The first assumption is the common use of representative classes of fluids to describe all fluid characteristics. Substances, characterised by the same hazard, are usually grouped to reduce the number of cases of release, this determines low degrees of uncertainty and sensitivity.

Table 5: Uncertainty and sensitivity scores

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 greatest difficulty in assigning frequencies of breakage and percentage of failures is due to the lack of appropriate data (second assumption). Uncertainties are due to the adoption of data derived from other context. This assumption leads to high degrees of uncertainty and sensitivity (see also [13]). The third factor is the assumption that only one failure event or failure mode occurs during a certain interval of time and the forth ones that failures are immediately detected when they occur. It is well known that this is not absolutely true. The fifth and sixth uncertainty factors address respectively the assumptions that the installed pipeworks are adequately tested and inspected prior to the process start up and that the process is within the design criteria and requirements/recommendations. Also the truthful of these assumptions is questionable.

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 such data.

CONCLUSION

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 the effects of managerial and organisational factors in the risk assessment. Common practises conservatively include the influence of measure of risk prevention and mitigation, whereas 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 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) Abrahamsen, E. B.,Asche, F., Milazzo, M.F. (2013) An evaluation of the effects on safety of using safety standards in major hazard industries. Safety Science, 59: 173-178.
2) 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.
3) 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.
4) Embrey, D. E., (1992) Incorporating management and organization factors into probabilistic safety assessment, Reliability Engineering and System Safety, 38(1-2), 199-208.
5) 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.
6) Flemish Government, LNE Department Environment, Nature and Energy Policy Unit Safety Reporting Division (2009), Hando-

book of failure frequencies (Appendix).

7) 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.

8) Healthy & Safety Executive, (2012) Failure Rate and Event Data for use within Risk Assessments. Report available at: http://www.hse.gov.uk/ (accessed on the 1st December 2015).

9) 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.

10) Lees, F. P., (1996) Loss Prevention in the Process Industries, Elsevier, London.

11) 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.

12) 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.

13) 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.

14) 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.

15) 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.

16) 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.

17) 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.

18) Øien, K., (2001) A framework for the establishment of organizational risk indicators, Reliability Engineering and System Safety, 74(2), 147-167.

19) 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.

20) 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.

21) 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.

22) 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.

23) 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.

24) 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.

25) 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.

Paper sent to revision: 24.12.2015.

Paper ready for publication: 02.02.2016.