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Accident Frequency Evaluation to Support Dynamic Risk Studies

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The safety enhancement of Oil&Gas offshore operations asks for improvements in the currently applied tools for risk estimation and evaluation. The present contribution is addressed at the development of a method for the dynamic evaluation of hydrocarbon leaks frequency from process equipment and piping. Specific indicators were scored in order to obtain modification factors aimed at tailorizing the frequency values. The method is suitable for the implementation in dynamic risk assessment, in order to provide an updating mechanisms that allow revising the accident frequency during the lifecycle of the facility. The potentialities of the method were tested with a demonstration case study. Results highlighted the importance of technical and managerial aspects in the estimation of accident likelihood and risk.

1. Introduction

Quantitative Risk Assessment (QRA) in the framework of Oil&Gas offshore operations is based on consolidated procedures. Nevertheless, the need of safety improvement asks for more advanced tools for hazard identification and risk evaluation (Paltrinieri et al., 2015a). Besides considering technical aspects (e.g., malfunctions and process upsets), operational errors, organizational aspects, such as lack of attention and motivation to the safety culture, may lead to risk increment in terms of likelihood of undesired failures (Ale et al., 2014). Not all those aspects may be investigated with conventional QRA techniques, which have also the disadvantage of being intrinsically static and failing to capture risk variations during the lifecycle of a plant or production site (Kalantarnia et al., 2009).

In fact, due to ageing (e.g., erosion, corrosion, fatigue), defective maintenance associated to poor safety culture, the likelihood of an accident may increase with time, thus frequency values used in QRA might not be the same after many years of operation (Beerens et al., 2006).

In the literature, there are several examples of frequency modification factors that “tailor” the leak frequency values to the facility under analysis (Pitblado et al., 2011). Nevertheless, the complexity - in terms of information required or evaluation time - or arbitrariness of the methods lead to difficulties in QRA implementation. Moreover, those methods are applied in order to modify an existing QRA at the beginning of operations and not in a dynamic perspective.

In order to obtain time-varying risk evaluation, several methodologies were recently developed for Dynamic Risk Assessment (DRA) of industrial facilities (Paltrinieri et al., 2015b). DRA methods are aimed at evaluating the risk by updating initial failure frequencies of events as new information are made available during a specific operation. Therefore, the strength of DRA is connected to the use of case-specific data and to the availability of updating mechanisms that allow revising the accident frequency in time.

In the present work, a novel method was developed obtaining time-varying leak frequency modification factors able to link the equipment and management quality features of the facility under examination to the worsening/betterment of the initial accidental frequency values. The modification factors may be used either to obtain a simplified evaluation of risk increment or decrement connected to a given process unit or to support the application of advanced DRA techniques by updating failure frequency data. The methodology is based on

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the evaluation of technical, operational and organizational factors. The application to a simplified case study was undertaken in order to show potential benefits in the application of the methodology.

2. Background

Frequency modification factors are aimed at “tailorizing”, e.g., introducing a modification to the generic accident frequency (f_b, the baseline frequency value). Those factors usually take into account the HSE management of the site of interest, maintenance policy, equipment working conditions, external severe environmental impacts, and other relevant issues, which could induce a decrement or an increment of f_b, according to the present relationship:

$$f = f_b \prod_m MF_m \tag{1}$$

where f is the modified frequency value and MF_m are the modification factors. Several methods are available in the technical and scientific literature for the determination of MF_m, as summarized in Table 1.

Table 1: Brief summary of frequency modification methods available in the literature

Method	Description	Reference
CCPS	Based on arbitrary expert judgment evaluation	(CCPS, 2000)
API 581	Based on the determination of equipment and management modification factors obtained from design data and site inspection	(API, 2000)
MANAGER	Based on the determination of a management modification factor obtained from site inspection implicitly covering technical aspects	(Pitblado et al., 1990)
DNV	Based on the scoring of safety barriers, obtaining frequency reduction factors and implicitly covering managerial aspects	(Pitblado et al., 2011)

The arbitrariness of the CCPS method lead to difficulties in QRA implementation (Pitblado et al., 2011). MANAGER and DNV methods are more complex and rigorous, but they individually focus only on managerial and technical aspects, respectively. Even if the integrated evaluation of technical and managerial aspects is foreseen by API 581 method, it is not suitable for application, since the penalties were never updated; hence it may results not conservative. Finally, none of the mentioned methods was designed in a dynamic perspective, in order to support a continuous update of accident frequency values for dynamic risk assessment.

3. Methodology

3.1 Overview of the methodology

In the present work, a methodology for the determination of leak frequency modification factors is presented. The method is aimed at determining modification factors considering technical and managerial aspects in a dynamic perspective, thus in order to be suitable for implementation in dynamic risk assessment. In particular, technical aspects are obtained from the improvement of API 581 method, while managerial aspects, both organizational and operational, are based on the concept of resilience (Woods, 2006). The hierarchical structure of the methodology is shown in Figure 1.

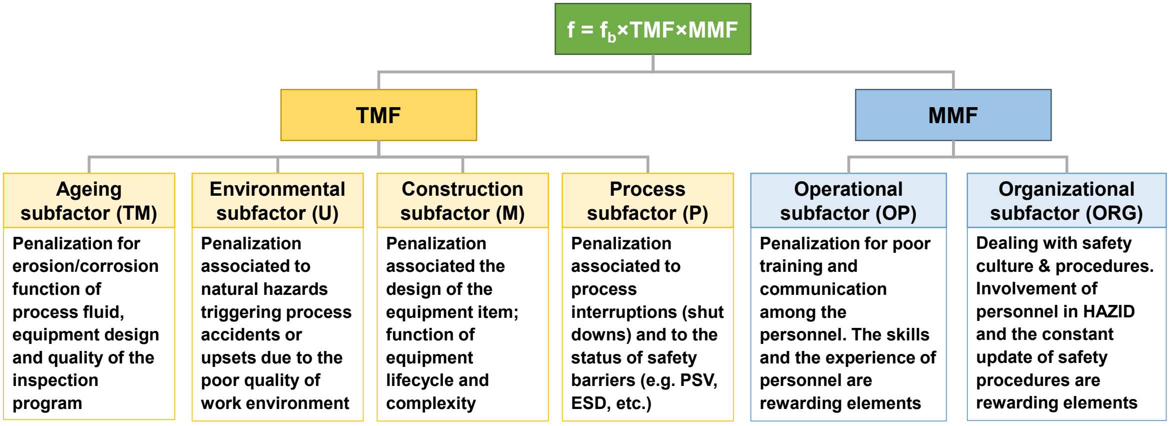

Figure 1: Hierarchical structure of the methodology aimed at the determination of the leak frequency modification factor in TEC2O method.

The method is named “TEC2O”, since it considers technical, operational and organizational aspects in an integrated approach. As shown in Figure 1, the baseline frequency value (f_b) is modified following Eq. (1) through a Technical Modification Factor (TMF) and a Management Modification Factor (MMF). TMF and MMF are obtained combining different scores, which in turn are the result of the monitoring of sound and quantitative indicators. The use of quantitative input data constitutes an advantage with respect to common literature methods based on subjective evaluations (see Table 1).

Indicators are converted in scores which are based on arbitrary scale. Furthermore, in case a quantitative value of an indicator is not available, a qualitative score may be directly assigned. An important aspect is that the set of indicators proposed is changeable. It should be established in collaboration with the Company before applying the method. Finally, it is important to highlight that TEC2O must be applied to each piece of equipment of the plant under study, even though several indicators are related to the facility or the company.

3.2 Technical modification Factor

This factor aims at synthetically account for the lifecycle of the equipment, in order to penalize “old” units that may be more prone to result in leaks and failure due to ageing, erosion and/or corrosion phenomena. Moreover, external factors (environmental issues, seismic zone, harsh weather areas, etc.) are considered.

TMF contributes only as a worsening element, since the failure likelihood of typical mechanical and electrical components or systems increases with time, with growing rate approaching (or in some cases extending) the end of design life.

Figure 1 shows the complete structure of the TMF. It is divided into four parts, each of them taking into account a different technical aspect, monitored through indicators. TMF structure was the same as the API 581 “equipment modification factors”. More details on the definitions of indicators are reported elsewhere (Landucci & Paltrinieri, 2015), some examples are provided in Figure 2.

Each selected technical indicator is periodically monitored. Inspections are critical in this phase in order to capture possible mechanical deterioration of the components and/or to monitor the quality of the working environment. In this work, it is suggested to use all the technical indicators and the same weight for each of them. Clearly enough, in case an aspect is deemed not relevant by the Company, a null weight can be assigned to one or more indicators.

On the basis of the indicators status, an average score is assigned to each of the four parts ($S_{t,j}$ where j = 1,..4), ranging from 1 to 6 (1 = good; 6 = bad). In this work, the score range was defined in accordance with other methods dedicated to dynamic risk assessment, such as the Risk Barometer (Paltrinieri and Hokstad, 2015).

The combination of the scores using weights (wt_i) leads to the calculation of the overall technical score ε:

$$\varepsilon = \sum_{i=1}^{n} S_{t,i} wt_i \qquad (2)$$

In the present work, and equal weight was assigned to each score (e.g., wt_i = 0.25). This can be modified by the Company. Finally, the technical score ε is converted into the TMF using the rules reported in Figure 2.

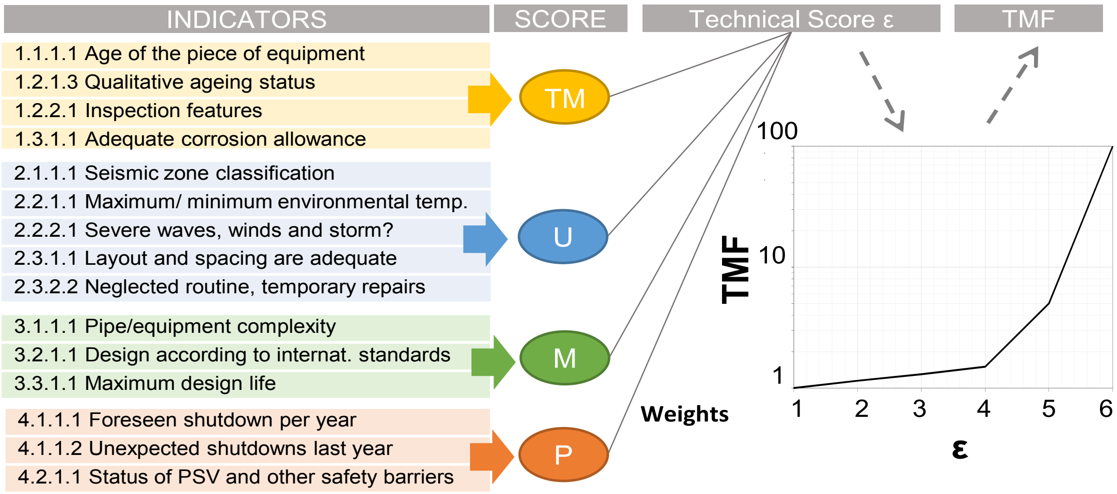

Figure 2: Schematization of the procedure for converting technical indicators into the technical modification factor (TMF).

3.3 Management modification Factor

The evaluation of the management modification factor is based on the concept of resilience and follows the REWI (Resilience based Early Warning Indicators) methodology (Øien et al., 2010). Managerial aspects are related to definition of safety procedures, training and competencies of operators, safety culture, frequency of maintenance operations and communication at different levels of the organization. Those elements are strictly related to the likelihood of an accident/incident, but are difficult to be quantified and converted into a factor implemented in a QRA. In order to introduce a quantitative evaluation, the REWI method proposes the use of indicators which are quantitative parameters, so they can be monitored, modified and updated in time.

According to the work of Øien et al. (2010), the MMF is divided into two main subfactors (see Figure 1): operational subfactor and organizational subfactor. Indicators are converted into scores according the scheme reported in Figure 3. More details on the definitions of indicators are reported elsewhere (Landucci and Paltrinieri, 2015).

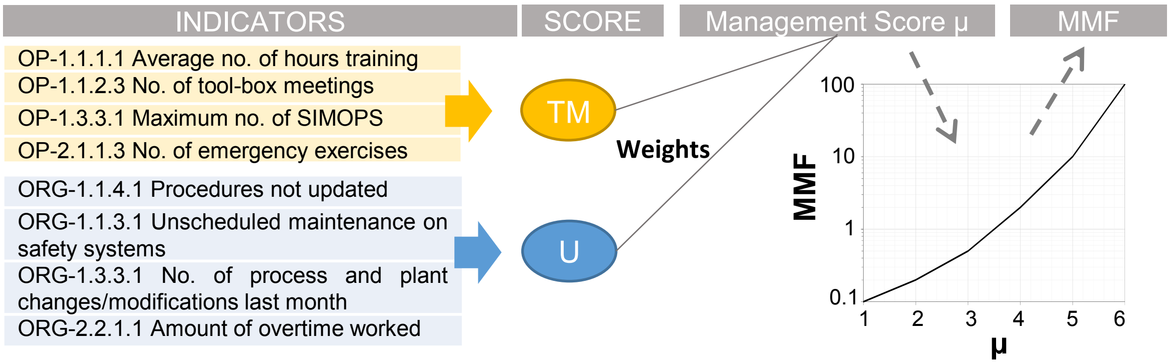

Figure 3: Schematization of the procedure for converting indicators into modification factors for the management modification factor (MMF).

The Company may change this procedure on the basis of the specific case under analysis. Nevertheless, in case an indicator is only subjected to qualitative evaluation in absence of more precise data at a given time, only the following three scores are applied: “Good” = 2, “Average” = 4 and “Bad” = 6. Hence, even in presence of a qualitative good situation, an intrinsic penalty is associated due to the fact that insufficient indicator monitoring was performed. The combination of the scores associated to each indicators using weights (wm_j and wm_k respectively for operational and organizational indicators) leads to the calculation of the operational (OP) and organizational (OR) scores as follows:

$$OP = \sum_{j=1}^{m} S_{op,j} wm_j \tag{3}$$

$$OR = \sum_{k=1}^{p} S_{or,k} wm_k \tag{4}$$

In the present work, and equal weight was assigned to each indicator score (e.g., $wm_j = 1/m$, $wm_k = 1/p$; where “m” and “p” are the total number of operational and organizational indicators, respectively). The Company may agree to change the relative weights in order to stress a specific operational or organizational issue.

Then, OP and OR are combined using the following relationship to calculate an overall management score μ:

$$\mu = \psi OP + (1-\psi) OR \tag{5}$$

where Ψ = 0.5 in the present version. As in the case of the other weights (wm and wt), even Ψ may be changed according to the indication of the Company. Finally, the management score is converted into the MMF using the rules reported in Figure 3.

It is possible to see that MMF may increase the loss of containment frequency, due to poor safety attention and insufficient preparedness of operators to emergency situations, but it may even reduce it (see Figure 3). In fact, in case training and procedures are updated, a proactive approach to the safety issues is maintained in all the lifecycle of the plant, the likelihood of accidents is reduced despite the ageing of the plant (penalized by the technical modification factor).

4. Definition of a simplified case study

In order to exemplify the methodology application, a sample case study was defined. The analysis focused on a three-phase separator of an offshore platform. A corrosive/erosive service was considered, assuming also a relevant sand content in the raw gas stream flowing in the lines. The separator is located on a platform in a non seismic zone, with ambient temperature ranging from -10 to 50 °C. Possible severe storms may affect the area. The case study is aimed at determining the tailorized leak frequency (f) during the first 5 years of operations. A QRA study is available, in which the baseline frequency value f_b was used.

Beside the technical indicators and scores, the Company agreed to monitor the following management indicators: OP1 = Average no. of hours system training last 3 months; OP2 = No. of emergency preparedness exercises last three months; OR1 = No. of process and plant changes/modifications last month; OR2 = Amount of overtime worked. For the sake of simplicity, a schedule of random events were associated to the separator and to the facility as a whole. Those data were used as input for the evaluation of indicators and the quantification of the case study.

Table 2: Summary of the events considered for the analysis of the demonstration case study.

Event	Year				
	1	2	3	4	5
Worsening of inspection quality				X	X
Harsh meteorological conditions		X			
Temporary repairs made permanent, neglected housekeeping					X
Wear of the mechanical components					X
Unexpected shut down			X		
Neglected maintenance of protection barriers					X
Turnover with inadequate training		X			
Insufficient emergency preparedness exercises			X		X
Process plants relevant modifications			X	X	
Increment of overtime worked (e.g. work is transferred among shifts)		X		X	X

5. Results and discussion

On the basis of the rules described in Section 2, the relevant indicators were monitored considering the events defined in Table 2 and a score was assigned for each year of operations. The results are summarized in Table 3. Due to insufficient maintenance policy and inspection program, a worsening of plant condition status was considered. Moreover, the increment of overtime due to unforeseen plant modifications after only 2 years of operations, led to worsening of managerial indicators.

Table 3: Summary of the indicators scores (ranging between 1 and 6; 1 = good and 6 = bad) assigned on the basis of the monitored indicators in the dynamic case study

Score	Year					Score	Year				
	1	2	3	4	5		1	2	3	4	5
TM	1	1	1	2	3	OP1	2	4	2	2	2
U	1	2	1	1	3	OP2	2	2	4	2	4
M	1	1	1	1	2	OR1	2	2	4	6	2
P	1	1	4	1	2	OR2	2	4	2	4	6
ε	1	1.3	1.8	1.3	2.5	μ	2	3	3	3.5	3.5

The dynamic evaluation of the modification factors is summarized in Figure 4. As shown in Figure 4a, TMF can only be subjected to an increment during the lifecycle of the plant. Relevant increases are following the worsening of inspection and work environment quality, especially after 5 years of operation. Despite the technical indicators are worsening, the management indicators lead to low value of the MMF, which never exceed the unity for the considered case study. Hence, a proactive approach to the safety culture is deemed a critical issue for risk reduction, due to decrement of accident likelihood with respect to similar facilities.

The two modification factors are combined according to the rule depicted in Figure 1, obtaining the resultant tailorized leak frequency (f). Figure 4c shows the normalized f value, with respect to the baseline frequency (e.g., the parameter f/f_b). In the considered case, the accident likelihood was reduced by one order of magnitude, due to efficient management system. However, the technical aspects may play an important role in frequency increment. In fact, TMF contributes to a frequency increment of more than 20% with respect to the baseline situation due to the events associated to years 4 and 5.

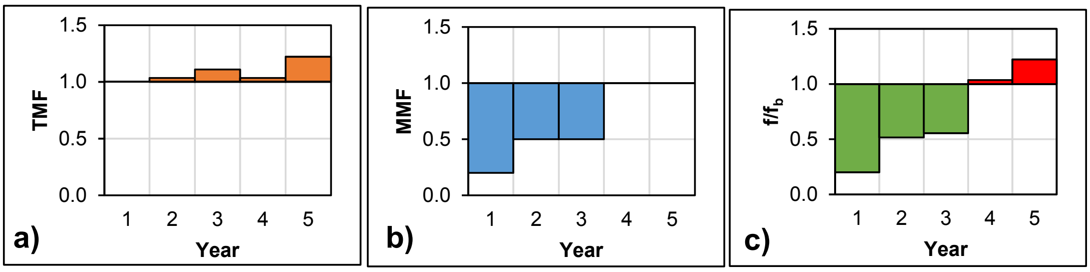

Figure 4: Results of the dynamic case study: a) Technical modification factor; b) Management modification factor; c) modified frequency value (f) normalized with respect to the baseline frequency (f_b) adopted in the QRA.

6. Conclusions and future works

Offshore O&G activities need innovative work organization in order to both create value and reduce the risks of a major accident through smarter, better and faster decision-making and execution. The present work was aimed at showing the potentialities in updating leak frequencies to support dynamic risk assessment.

A specific methodology was developed in order to be suitable for the application through all the lifecycle of an installation under analysis, accounting for technical, operational, and organizational aspects. The analysis of the case study exemplified the application of the method. The method was proved to be a potentially suitable tool in the framework of offshore O&G context, since it may be used as a novel decision-making tool based on monitoring, promoting the involvement of personnel and management.

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