Proactive monitoring of risk-based indicators: example of application in the Oil & Gas integrated operations

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The use of safety or risk indicators may allow risk assessment to assume both dynamic and proactive features. Appropriate sets of indicators collected and evaluated on a regular basis may provide information on overall risk level variation. This contribution presents a short review of dynamic risk evaluation techniques based on human and organizational factors, from the first approaches developing indicators to the aggregation methodologies integrating risk analysis. A methodology for the evaluation and update of expected release frequencies provides an example of last generation techniques. The method is named TEC2O (Frequency modification methodology based on TEChnical Operational and Organizational factors) and was developed to obtain time-varying 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/decrement connected to a given process unit or to support the application of advanced dynamic risk assessment techniques by updating failure frequency data. The potential of TEC2O and, more in general, of last generation aggregation techniques, is described also in terms of support to risk-based decision making for Oil & Gas integrated operations through a specific case-study.

Keywords

Risk indicators; Dynamic risk assessment; frequency modification factors; Oil&Gas; Organizational aspects; Operational aspects; Integrated Operations.

1. Introduction

Prevention of major accidents in the Oil and Gas (O&G) industry claims for both continuous learning from events occurring around us and tireless surveillance of critical safety systems. This can be achieved by using appropriate indicators and effectively processing the related information allowing for a dynamic and proactive hazard and risk evaluation (HSE-Health Safety Executive, 2006). Moreover, human and organizational factors often represent the underlying causes of accidents and their monitoring through indicators may enable risk assessment with proactive capabilities (Øien et al., 2011). In fact, detection and management of early warnings in several major accidents could have avoided escalation of unwanted and catastrophic events, such as in the case of Buncefield accident occurred in 2005 (Paltrinieri et al., 2012).

The present work discusses dynamic risk assessment approaches based on proactive indicators, which are aimed at recognizing early warning signals in time to reduce major accident risk. Classification of relevant safety and risk indicators is firstly presented, also including a description of the aggregation methodologies to achieve an overall risk level evaluation.

A methodology for the evaluation and update of expected release frequencies is taken as example of last generation techniques for indicators aggregation. The methodology aiming to support dynamic risk assessment studies is named TEC2O – Frequency modification methodology based on **TEC**hnical **O**perational and **O**rganizational factors. The potential of such methodology is described also in terms of support to risk based decision making for O&G integrated operations.

2. Technical background on risk indicators

2.1 Classification and aggregation of indicators

Appropriate sets of indicators collected and evaluated on a regular basis can provide information on the overall risk level variation. Such continuous assessment is nowadays improved by advanced IT technologies allowing for real-time data sharing, process and visualization of related information and support to decision making. However, the choice of indicators may affect the ability to control risk (proactivity), rather than just reporting its increase after an unwanted event has occurred (reactivity). The former may be addressed by a set of indicators that are mainly leading, while the latter may be addressed by a set of indicators that are mainly lagging.

Leading indicators are a form of active monitoring of key events or activities that are essential to deliver the desired safety outcome evaluation (HSE-Health Safety Executive, 2006). They represent early deviations from the ideal situation that can lead to further escalation of negative consequences. Human and organizational factors often (but not always) represent such underlying causes. For this reason, the adoption of indicators addressing human and organizational factors may enable risk assessment with proactive capabilities. In practice, it is often experienced that indicators on technical equipment can be automatically retrieved from online systems such as e.g. maintenance management systems and condition monitoring systems.

Indicators on human and organizational factors are generally more difficult to obtain and will often rely on manual input and assessment.

Lagging indicators are a form of reactive monitoring requiring reporting and investigation of specific incidents and events to discover weaknesses in the system. Lagging indicators show when a desired safety outcome has failed, or has not been achieved, providing an important feedback from the system evaluation (HSE-Health Safety Executive, 2006). For this reason, they should be coupled with the leading indicators in order to more comprehensively assess risk. The approaches for the development of safety/risk indicators covering Technical, Human and Organizational (THO) causes may be grouped in the classes shown in Figure 1.

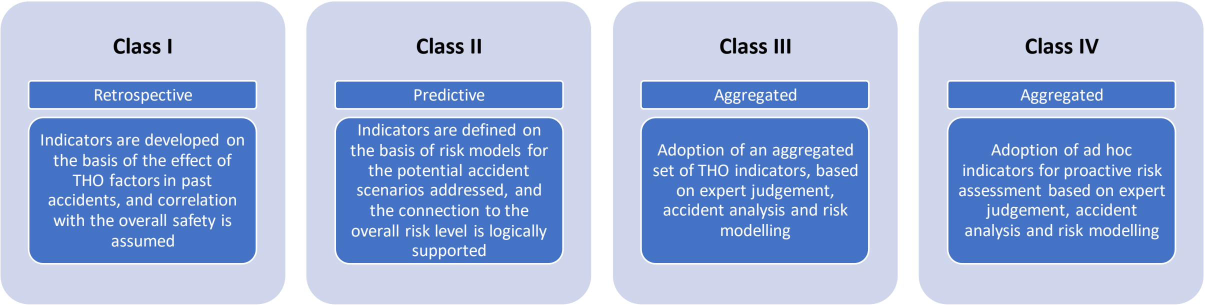

Figure 1. Classes of approaches and related perspective for dynamic risk assessment through monitoring of Technical, Human and Organizational (THO) factors.

Class I and II approaches are limited to the monitoring of indicators in a retrospective and predictive perspective, respectively. Consequently, correlation with the overall risk of the system is only assumed.

In order to accurately assess variations of the overall risk level, which may be expressed with different risk metrics (Johansen and Rausand, 2014), specific techniques aggregating the information provided by the indicators have been defined. Classes III and IV in Figure 1 group the previous approaches, allowing for a more reliable evaluation of risk on a real-time basis. The main difference between classes III and IV in terms of risk evaluation is in the development and use of indicators. In class III, limited sets of risk indicators may not allow comprehensive coverage of THO factors, while the class IV approach employs ad hoc indicators for proactive risk assessment.

A methodology for the evaluation and update of expected release frequencies is hereby taken as example of last generation techniques.

2.2 Frequency modification as example of indicators aggregation

Quantitative risk assessment in O&G facilities (both onshore and offshore) is usually aimed at representing the initial risk status of the facility under analysis, both in terms of likelihood (F) and expected consequence severity (M, namely “magnitude”). According to (Crowl and Louvar, 2002), the risk may be expressed as follows:

$$R = F \times M \tag{1}$$

While the term M is associated to a potentiality of damage that is intrinsic in the facility under consideration (neglecting the variation in the release scenario severity and assuming constant offshore platform population), the term F may undergo relevant variation due to ageing, corrosion, fatigue, poor safety culture and other dynamic elements. In this way, the dynamic feature of the risk is only associated to the frequency term, as follows:

$$R(t) = F(t) \times M_0 \tag{2}$$

where M_0 is the constant damage potentiality, while F(t) represents the possible frequency variation in time (t). Quite clearly, in this simplified risk perspective, the role of safety barriers is not explicitly taken into account. The damage level M_0 is usually reduced considering the effect of possible mitigation systems (e.g., firefighting systems, emergency depressurization, blast walls, firewalls, etc.) that may deteriorate in time, thus leading to the maximum potential damage M_0. Moreover, even in the definition of the frequency term F, the prevention systems limiting the occurrence of the accidents should be taken into account.

However, adopting the considered schematization, at the initial time of operation (t=0) we obtain the initial risk level (R_0) as follows:

$$R_0 = F(t=0) \times M_0 = F_0 \times M_0 \tag{3}$$

Combining Eq.s (2) and (3), we obtain:

$$R(t)/R_0 \cong F(t)/F_0 \equiv \Omega(t) \tag{4}$$

Hence, the relative variation of risk level is associated to the modification of the initial frequency value F_0 through a frequency modification factor $\Omega(t)$ that changes during the lifetime of the plant. The initial frequency value is usually indicated as "baseline frequency" and it is usually derived from standard literature databases (Beerens et al., 2006; Uijt de Haag and Ale, 1999) or obtained through "parts count" (Pitblado et al., 2011; Spouge, 2005).

The modification factor $\Omega(t)$ should be considered as a parameter updated in time and aimed at considering both technical and managerial aspects that are related to the increment or decrement of failure likelihood. Several examples of frequency modification factors are available in the literature, as discussed in Section 2.3. However, in these methods, the time-evolving perspective is not emphasised, without clear indications on how to achieve a dynamic frequency evaluation.

2.3 Background on frequency modification factors

Frequency modification factors are aimed at "tailorizing", e.g., introducing a modification to the generic baseline frequency, F_0 (see Eq. (4)). 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 the baseline frequency value.

Several methods are available in the technical and scientific literature. In the following, a brief review of some methods is reported, in order to capture relevant aspect for the development of a novel method specific for O&G upstream sector. A list of the more relevant methods developed in the last thirty years is reported in Table 1; a summary is reported in the following.

Table 1– Overview of literature methods for frequency modification.

ID	*Methodology*	*References*
1	*CCPS*	(CCPS - Center of Chemical Process Safety, 2000)
2	*API 581*	(American Petroleum Institute, 2000)
3	*MANAGER*	(Pitblado et al., 1990)
4	-	(Haugen et al., 1997; Hokstad and Frøvig, 1996)
6	*BORA-Release*	(Aven et al., 2006; Sklet et al., 2006)
7	*ARAMIS*	(Delvosalle et al., 2006)
8	-	(Acikalin, 2009)
9	-	(Vinnem, 2012; Vinnem et al., 2010)
10	-	(Pitblado et al., 2011)
11	*RISK_OMT*	(Gran et al., 2012)
12	-	(Vinnem and Røed, 2015)

The CCPS method is a simple method for variation of baseline frequency data based on generic concepts and expert judgment. An example of application is provided in (CCPS - Center of Chemical Process Safety, 2000) and is dedicated to transport pipelines in a country. Thus, this method may lead to relevant uncertainties if applied for operating process facilities, where local practices can be quite different, as remarked in (Pitblado et al., 2011).

The API 581 method was primarily intended for supporting Risk Based Inspection programs in refineries, e.g. prioritizing the inspections on the basis of the risk associated to each piece of equipment (American Petroleum Institute, 2000). According to this method, baseline frequency data (F_0) gathered from onshore refining and chemical processing equipment databases are modified as follows:

$$F = F_0 \times EF_1 \times MF_1 \tag{5}$$

where F is the modified frequency value, EF_1 is the equipment modification factor and MF_1 is the management system modification factor. The EF_1 factor is based on technical aspects affecting the likelihood of failure, thus related to equipment features and the environment in which the equipment operates. The MF_1 factor adjusts for the influence of the facility management system on the mechanical integrity of the plant. The evaluation of MF_1 is based on interviews with personnel and plant conditions monitoring. As remarked in (Pitblado et al., 2011), the management evaluation questionnaire is static and was never updated. Thus, what deemed as a "good performance" was relative to the context of 2000, and nowadays it is only in the "average". This leads to a non-conservative estimation of the tailored frequencies. Hence, even if a specific distinction among technical and managerial aspects is foreseen in the method, it is not suitable for application, since not updated.

The MANAGER (MANagement Assessment Guidelines in the Evaluation of Risk) method is aimed at determining a site specific failure frequency based on the generic average failure frequency corrected by a Management Factor (MF_2) derived from a site assessment procedure (Pitblado et al., 1990). The procedure is based on a questionnaire covering several managerial aspects (procedures, safety culture, incident investigation, organizational factors, etc.). To each aspect, a qualitative score is assigned, namely Average, Good and Bad. Based on the proportion among the scores, the final MF_2 factor is evaluated in order that 100% Average, Good and Bad have respective FM_2 scores of 1.0, 0.1 and 100. Hence, the tailored frequency is calculated as follows:

$$F = F_0 \times MF_2 \tag{6}$$

It is worth to notice that a more sound and updated evaluation of the management system can be achieved with this method, that appears less static with respect to API 581, but the technical aspects are not explicitly considered.

Finally, the Barrier method, presented in (Pitblado et al., 2011), is based on the scoring of safety barriers aimed at reducing the frequency of failures. This methodology requires gathering specific information related to safety barriers and is explicitly devoted to the assessment of technical issues with no direct consideration of managerial factors. Even if the method is complex and detailed, a more focused analysis of operational and organizational aspects should be a key issue in the perspective of dynamic risk assessment (Bea, 2002; Ren et al., 2008; Weber et al., 2012).

3. Methodology for frequency modification

3.1 Overview

In order to provide an example of advanced indicators aggregation, an alternative approach for the determination of a frequency modification factor Ω is shown. The output of the methodology is thus a factor Ω that allows updating the baseline accident frequency associated to a critical release event of a piece of equipment, as follows:

$$F(t) = F_0 \times \Omega(t) \tag{7}$$

Besides obtaining an updated accident frequency value, the benefit of this type of approach is that the factor Ω may be seen as directly correlated with the dynamic risk variation (according to the approach shown in Section 2.2). The frequency modification factor Ω is structured following the definition of API 581 (American Petroleum Institute, 2000) but it features relevant updates: i) the introduction of a dynamic risk perspective; ii) the possibility of revising/updating the scores and factors.

The frequency modification factor is subdivided into two main factors, named TMF and MMF:

$$\Omega = TMF \times MMF \tag{8}$$

TMF is the technical modification factor, and is associated with equipment features and process aspects. MMF is the management modification factor and is related to the evaluation of the management system, both in terms of operations and organizational aspects. The method is named TEC2O, since it integrates TEChnical and managerial aspects, both Operational and Organizational.

It is worth remarking that the method is applied to each piece of equipment in the industrial facility under consideration (equipment-specific modification factors are thus obtained for the critical release events). However, some issues that influence the modification factor are referred to the Company or the installation as a whole.

The methodology is based on the quantification of technical, operational and organizational aspects, through the adoption of a set of indicators. Technical indicators (see Section 3.2) are adapted from the ones reported in API 581 (American Petroleum Institute, 2000), taking into account the lifecycle and features of the equipment under analysis, ageing, erosion/corrosion phenomena, external factors (environmental issues, seismic, extreme weather, etc.). Operational and organizational indicators (see Section 3.3) are based on the Resilience based Early Warning Indicator (REWI) method, developed by SINTEF (Øien et al., 2010a).

The advantage of considering such indicators is the sound quantification of input parameters based on observable quantities. In fact, as mentioned in Section 2.3, subjective evaluation associated with common literature methods may alter the outcomes of the frequency modification factors evaluation.

In order to have a homogenous evaluation of the indicators, a qualitative score is assigned to each indicator ranging from 1 (good) to 6 (bad), in accordance with a previously developed method for dynamic risk assessment (e.g., the Risk Barometer, see (Paltrinieri and Hokstad, 2015; Paltrinieri and Khan, 2016) for more details). Scores are based on an arbitrary scale and are tuned to obtain results comparable with other literature models for frequency modification (see Section 2.3). In case an indicator is not available, qualitative scores may be directly assigned in order to consider the specific technical, organizational or operational aspect. Then, following the quantitative framework of Risk Barometer (Bucelli et al., 2017; Paltrinieri and Hokstad, 2015), weights are then associated to each score in order to estimate the frequency modification factors TMF and MMF. If the Workshop considers that one indicator is not relevant, clearly enough a null weight may be assigned to exclude it.

Dynamic frequency assessment is then achieved monitoring and updating the set of indicators and by periodically recalculating the frequency modification factors. This allows obtaining i) a possible update to the initial Quantitative Risk Assessment (QRA) results and ii) early warning signals of the deterioration of an installation risk profile.

3.2 Technical modification factor

The TMF aims at synthetically accounting 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.

Figure 2 shows the hierarchical structure of TMF definition. TMF is divided into four main subfactors, according to the framework proposed by API 581 (American Petroleum Institute, 2000). Each subfactor accounts for technical issues affecting the likelihood of failure during the life cycle of the plant. In particular:

- Ageing subfactor (TM): ageing of equipment due to erosion/corrosion phenomena.
- Environmental subfactor (U): natural hazards, extreme weather conditions and features of the plant layout (workplace quality).
- Construction subfactor (M): features of the mechanical aspects of the piece of equipment under analysis and design complexity
- Process subfactor (P): stability of the process and status of protection systems

Each subfactor is then specified through a specific set of indicators, which constitute the input data for the analysis. The complete set of indicators is explained in details elsewhere (Landucci and Paltrinieri, 2016). 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.

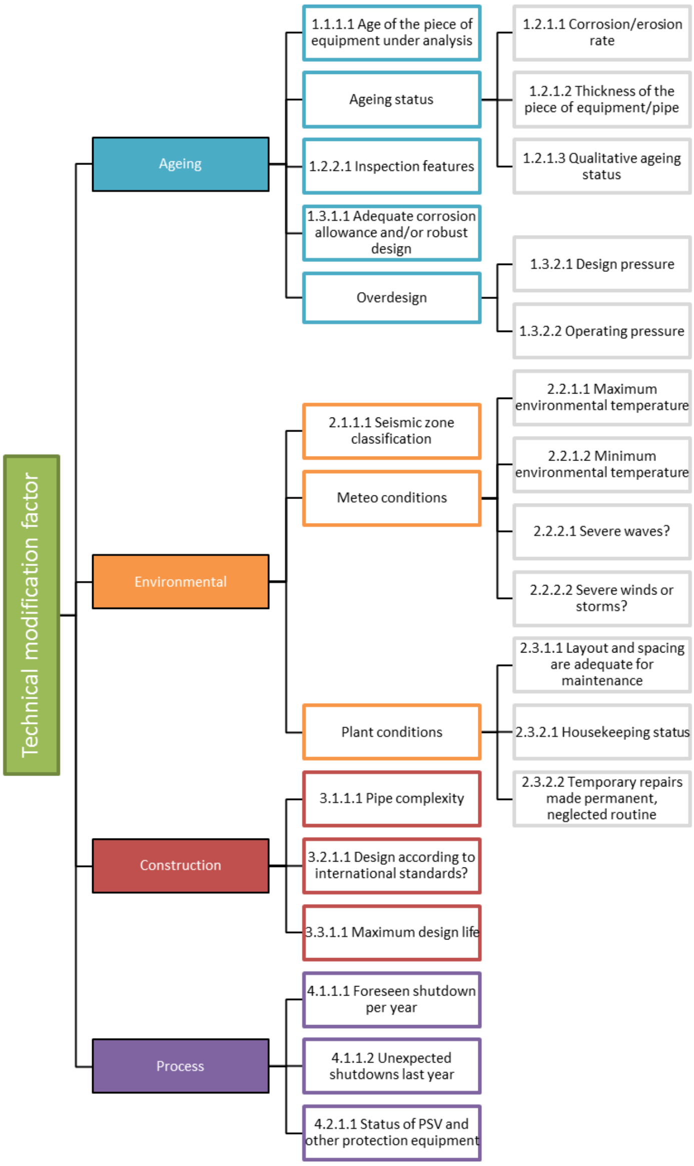

Figure 2 – Hierarchical structure of the technical modification factor (TMF).

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). The combination of the scores using weights ($wt_{,i}$) leads to the calculation of the overall technical score ε:

$$\varepsilon = \sum_{i=1}^{n} S_{t,i} wt_i \tag{9}$$

In the present work, an 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 3.

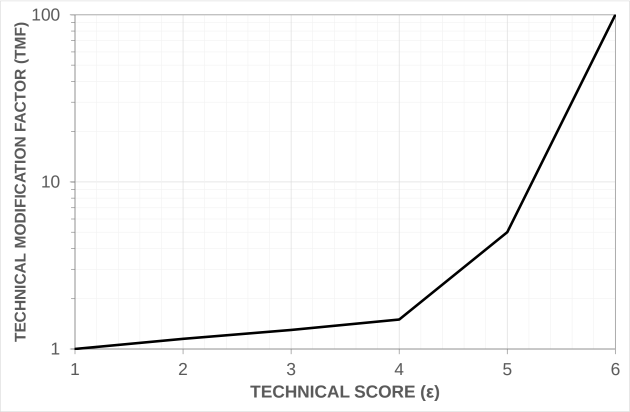

Figure 3 - Determination of the technical modification factor TMF as a function of the technical score ε.

It is worth noticing that the lowest possible value of TMF is unitary (see Figure 3), thus this factor 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.

Average scored equipment (more complex or subjected to insufficient maintenance) are penalized by a 50% increment of the factor respect good scored ones, since it is likely that technical aspects are at high quality levels even in average installations. On the contrary, bad scores are associated to a factor that is two orders of magnitude higher, in order to penalize old plants where insufficient maintenance and conditions may lead to process upsets.

3.3 Management modification factor

The proposed tool for the evaluation of the Management Modification Factor (MMF) is based on the concept of resilience. A classic definition of resilience is given by Woods, which describes resilience as 'the capability of recognizing, adapting to, and coping with the unexpected' (Woods, 2006). This concept was considered in the definition of the REWI methodology, that was adopted for supporting the MMF. The REWI methodology was developed, discussed and applied in several previous works (Øien et al., 2010a, 2010b; Paltrinieri et al., 2012); hereby the main aspects are highlighted in the perspective of TEC2O method development.

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 and, more in general, a metric for the managerial aspects, the REWI method proposes the use of indicators based on the concept of resilience. Indicators are quantitative parameters, so they can be monitored and modified/updated in time.

In the TEC2O method, a selection of relevant indicators provided in REWI method is carried out. The indicators are adapted and associated to a qualitative score. The scores are weighted and converted into a managerial score, which on turn is used for the evaluation of the second frequency modification factor, MMF, based on managerial aspects.

In order to obtain more precise indications, the managerial factor is divided into two main subfactors, also considering the approach shown in (Øien et al., 2010a, 2010b; Paltrinieri et al., 2012):

- Operational subfactor (dealing with personnel training, skills, experience and communication)
- Organizational subfactor (dealing with safety culture and safety procedures)

Each subfactor is evaluated through the definition of specific indicators (OP and OR respectively for operation and organization) and associated score ($S_{op,j}$ and $S_{or,k}$ respectively for operation and organization). A set of provisional indicators is reported in (Landucci and Paltrinieri, 2016) and an example is discussed in the following. However, indicators should be selected and agreed in the Company workshop (as in the case of REWI methodology).

Once an indicator is deemed important by the workshop and thus is selected, it will be monitored for the all lifecycle of the plant, thus leading to a quantitative parameter changing in time. A provisional example of scoring for each indicator (ranging from 1 = GOOD to 6 = BAD) is indicated in (Landucci and Paltrinieri, 2015). Each score can be adjusted by the Company Workshop on the basis of the specific case of concern. Nevertheless, in case a selected 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
- MEDIUM = 4
- BAD = 6

Hence, even in presence of a qualitative good situation, an intrinsic penalty is associated even to “GOOD” indicators since insufficient indicator monitoring was performed (e.g., no sound quantitative data are recoded at that given time even if the indicator was deemed important by the Workshop).

The combination of the scores associated with each indicator 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

$$OP = \sum_{j=1}^{m} S_{op,j} wm_j \tag{10}$$

$$OR = \sum_{k=1}^{p} S_{or,k} wm_k \tag{11}$$

In the present work, an 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:

$$\mu = \psi OP + (1-\psi) OR \tag{12}$$

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 4; MMF is then implemented in Eq. (8) together with TMF for the dynamic frequency evaluation.

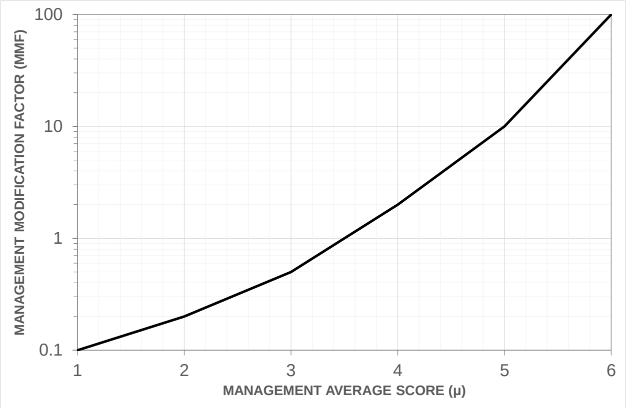

Figure 4 - Determination of the management modification factor as a function of the management score μ.

It is worth to mention that MMF is lower than unity for good management evaluation (see Figure 4). This accounts for possible improvement due to more attention to safety management, rewarding a proactive approach to the safety aspects through the lifecycle of the plant.

However, the lack of management attention to safety, may increase by two orders of magnitude the likelihood of a failure. Relevant case histories such as Bhopal (Kletz, 2004), Texas City (Ferdous et al., 2013), Deepwater Horizon (Kerr et al., 2010) accidents and so forth document the relation between accidents and poor safety culture, insufficient preparedness of operators to emergency situations and scarce management devotion to safety.

4. Definition of a case study

In order to exemplify the methodology application, a sample case study is defined. The analysis focuses on a slug catcher of an offshore platform. A corrosive/erosive service was considered, assuming also a relevant sand content in the multiphase stream flowing in the process lines. The separator is located on a platform in a non-seismic zone, with ambient temperature ranging from -5 to 40 °C; possible severe storms may affect the area.

The case study is aimed at determining the normalized accident frequency (namely, Ω, see Eq. (8)) during 10 years of operations.

Beside the technical indicators and scores, the management indicators, both operational and organizational summarized in Table 2, are also monitored. For the sake of simplicity, a schedule of random events was associated to the separator and to the facility as a whole. Those events are summarized in Table 3 and constitute the input for the evaluation of indicators and the quantification of the case study.

In the analysis of the case studies, the default set of weights was adopted. However, the weights may be changed by the Company workshop in order to penalize or not a given aspect.

Table 2– Summary of management subfactors, indicators and structure of MMF.

Subfactor	**Aspect**	**Reference indicators adopted in the case studies**
OP	Operational	OP1 - Average no. of hours system training last 3 months OP2 - No. of tool-box meetings last month OP3 - Maximum no. of simultaneous operations (SIMOPS) last month OP4 - No. of emergency preparedness exercises last three months
OR	Organizational	OR1 - No. of procedures not up to date OR2 - Number of unscheduled maintenance on safety systems OR3 - No. of process and plant changes/modifications last month OR4 - Amount of overtime worked

Table 3– Schedule of events considered for the case study. The cells marked with an "X" indicate the occurrence of the event during the monitored year of operation.

Event	**Year**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Worsening of inspection quality	X	X			X			X		X
Severe storms and waves			X				X			
Deterioration of seals and gaskets					X		X		X	X
Worsening of safety barriers quality status							X	X	X	X
Unexpected shut down									X	X
Insufficient emergency preparedness exercises		X			X				X	X
Insufficient tool-box meetings			X			X				X
Simultaneous operations SIMOPS		X						X	X	
Turnover with inadequate training									X	X
Procedures not up to date						X				X
Unscheduled maintenance on safety systems			X		X			X	X	
Process plants relevant modifications				X						
Increment of overtime worked		X			X		X	X	X	X

5. Results

On the basis of the events affecting the facility under consideration and defined in Table 3, the relevant indicators were monitored and scored according to the TEC2O procedure summarized in Section 3. The indicators dynamic behaviour is summarized in Figure 5. Due to insufficient inspection quality and deterioration of safety critical components, a worsening of technical indicators was determined in the last three years of operations. Lack of training and ineffective design of operations led also to the worsening of managerial indicators. This constitutes an example of class I and II indicators monitoring (e.g., see Section 2.1 for indicators classification), through the assignment of the scores.

The scores of the indicators were then combined into the aggregated frequency modification factors, which are summarized in Figure 6. TMF can only be subjected to an increment to the baseline situation during the lifecycle of the plant (e.g., TMF>1). Relevant increases are following the worsening of inspection and work environment quality, especially at the end of the analysed 10 years. Despite the technical indicators are worsening, the management indicators lead to low value of the MMF, which never exceed the unity in the first 8 years. Nevertheless, mainly due to the worsening of organizational indicators associated to insufficient training and work organization, MMF increases over the unity in the last part of the period considered.

Combining TMF and MMF according to Eq. (8), the resultant modified frequency is evaluated. Figure 6 shows the normalized frequency value Ω. In the considered case, the accident likelihood is severely affected by both technical and managerial issues, which lead to a worsening of accident frequency of about one order of magnitude with respect to the baseline value in the last two years of operation. On the same time, when MMF is kept low due to efficient management system (e.g., mainly during the first 8 years), the accident likelihood is halved with respect the baseline value.

Finally, it is worth to mention that uncertainties and limitations in the method are mainly related to data collection effectiveness, which involves the commitment of the Company, the scoring and weighting process and the translation of scores into frequency values. In the present work, single point experts' estimate was adopted, which stability was tested according to the sensitivity analysis carried out by (Landucci and Paltrinieri, 2016).

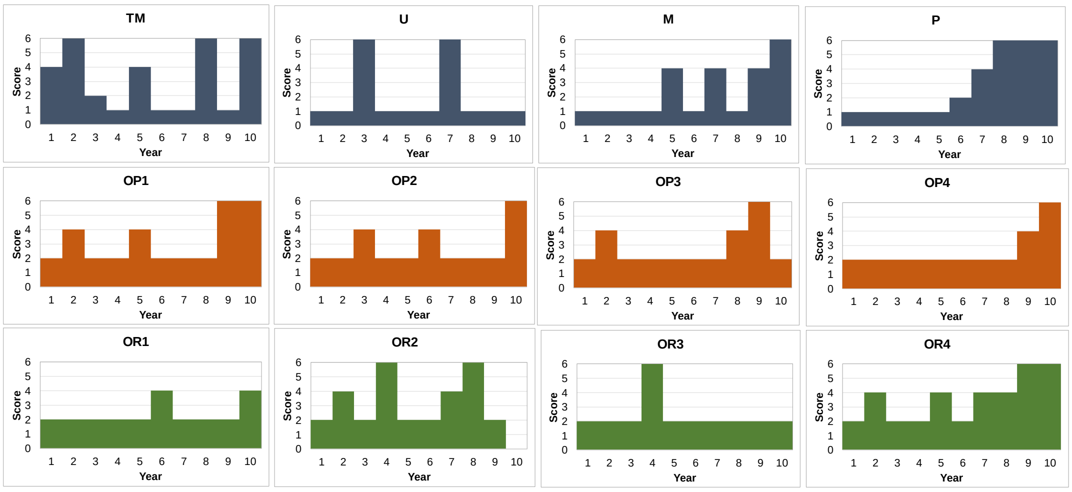

Figure 5: Summary of the indicators scores (ranging between 1 and 6; 1 = good and 6 = bad) assigned on the basis of the monitored indicators in the dynamic case study. Technical indicators are defined in Section 3.2; management indicators are summarized in Table 2.

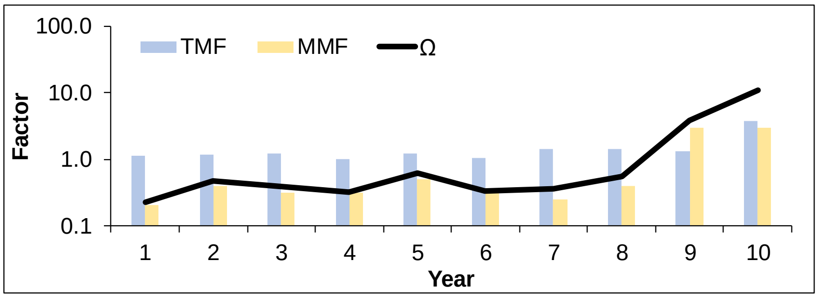

Figure 6: Results of the case study: Technical modification factor (TMF), Management modification factor (MMF), accident frequency value normalized with respect to the baseline frequency adopted in the QRA (Ω).

6. Discussion

The case studies showed an example of the potentialities related to TEC2O application in offshore O&G context. The results obtained may be considered in two different perspectives.

Firstly, the primary purpose of the method is to provide a set of input values aimed to periodically update the detailed risk assessment results. In fact, it is worth to remind that the methodology should be individually applied to tailor accident frequency values associated to each single piece of equipment, despite some indicators are referred to the facility as a whole. However, the update in time of a conventional QRA is not a straightforward task, which may result in excessive costs. It is recommended to screen among process units in order to apply TEC2O for the more critical items.

Secondarily, if dynamic methodologies for risk assessment (e.g., DRA) are applied, the tool is suitable for contributing to the probability update, that is crucial to support both Bayesian or non-Bayesian DRA methodologies (Meel and Seider, 2006; Weber et al., 2012).

Thirdly, in case QRA update or DRA methods are not applied, the constant update of indicators and, consequently, the automatic variation of scores and factors may be eventually used as simplified risk ranking tool. The methodological approach adopted to analyse the dynamic case study showed that worsening of managerial aspects may lead to increment of relative risk level, compared with similar installations. A proactive approach may be thus driven by the assessment of indicators aiming at the improvement of the organizational attribute of resilience, such as suggested by the REWI method (Øien et al., 2010b), which inspired the definition of the management evaluation. The advantage of TEC2O is also to introduce the evaluation of technical aspects, such as environmental issues or design feature, that may play a significant role in the frequency variation; this emerges from the analysis of the case study, considering the last two years of operations.

Finally, it is worth to mention that the case study was only aimed at exemplifying the methodology with a tutorial application, showing the typical results. However, in an actual field, the choice of monitoring specific indicators with higher correspondent weighs may surely lead to continuous control and improvement of the indicator, since deemed critical by the Company. Thus, the application of the method may be key strategy in controlling relevant indicators. This may avoid the situation in which a higher weight is associated to a “bad” indicator, leading to Ω overestimation evaluated in the last two years of operation.

7. Conclusions

This contribution discussed several proactive approaches for dynamic risk assessment. Such approaches are based on safety/risk indicators, which can be regularly collected and assessed to identify variations in the overall plant risk level. Four classes of approaches have been described, representing different levels of connection to the overall risk picture of a facility under analysis. An example of a dynamic aggregation method based on comprehensive sets indicators was shown.

The method, namely TEC2O, was specifically designed to support accident frequency tailorization, accounting for technical, operational, and organizational aspects. The frequency tailorization method was adopted in a dynamic perspective, providing guidelines to the regular update of frequency values during operations, in order to constantly update the risk profile of a facility. In fact, accident likelihood may increase due to both technical aspects (ageing, corrosion, deterioration, etc.) or neglected managerial aspects (poor safety culture, insufficient maintenance organization, etc.). On the contrary, a proactive approach based on effective training, appropriate competence and the capability of the organization to cope with unexpected events in a resilient manner may even reduce accident likelihood. Moreover, it was indicated that frequency modification factors can be seen as a relative risk variation in the framework of offshore operations. The method, together with the likelihood estimation, can thus provide a dynamic evaluation of the relative risk level, associated to an installation.

The method was applied to a sample case study in order to show the potentialities in dynamic analysis. In the case study, the effect of worsening of safety procedures, plant modification and ageing were taken into account determining the progressive frequency update in a slug catcher of an offshore platform during 10 years of operation. The method was proved to be a suitable tool in the framework of integrated operations, 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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