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Safety Report Updating for Aged Seveso Plants

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Seveso Directive requires the operator of major-hazard establishments to draw up a Safety Report, which has to be updated after relevant changes and at least every five years. This paper discusses a guideline aiming at the inclusion of the ageing issue in the updated Safety Reports. Such guideline exploits the potential of the short-cut method, adopted by the Italian Competent Authorities for the assessment of the adequacy of ageing management plans, to update the likelihood of top-events by using the calculated *overall adequacy index*. To adequately manage ageing, regulators should promote the implementation of Risk Based Inspection approach (RBI) even in major-hazard small sites. Risk analysis is a pillar of both the Seveso Directive (i.e. Safety Report) and the RBI approach, in this context, the guideline gives suggestions to avoid inconsistencies and promote synergies between the documents.

1. Introduction

Since a few years, equipment ageing has been a major concern for the prevention of major accidents in many Seveso sites in Europe, due to the lack of large investments facing the problem in oil and allied industries. In 2015, when the Italian legislation implemented the new Seveso III European Directive, ageing and corrosion management plans have become a requirement for the Safety Management System (SMS). Equipment ageing is relevant also in risk assessment, even if this is not explicitly mentioned by the legislation. Accordingly, the Competent Authority (CA) requires the operator of upper-tier establishments to update the Safety Report (SR) after changes and, at least, every five years. Risk assessment is the core of the SR and includes the calculation of the likelihood of top-events by means of the Fault Tree Analysis (FTA). The CA sets a cut-off threshold for the likelihood of events (typically 10^{-6} year $^{-1}$ in Italy) to discriminate credible events and develop accidental scenarios for them. In the current practice, risk analysts make use of generic failure rates, derived by proprietary (OREDA or EXIDA) and public (FRED and TNO Purple Book) databases. The limits of generic frequencies of failure are discussed by Pittiglio et al. (2012), the main basic assumption is their independence over the time. Such assumption may be questioned for equipment that exceeded the expected lifetime or are close to reach it. The periodical updating of the SR for upper-tier Seveso establishments gives the CA the opportunity to make a few specific requests for the improvement of the safety levels of aged plants. The Seveso III Directive addressed this issue within the management system and, in 2018, the Italian regulator responded to the challenge by proposing the adoption of a short-cut method supporting the ageing assessment during Seveso inspections. A working group, which represented various stakeholders, developed the method starting from a research idea of Bragatto & Milazzo (2016). Even though the SR updating is out of the scope of the short-cut method, a few concepts could be useful also for this purpose. The method, basically, provides two synthetic indicators related to the equipment integrity, i.e. the *ageing index* associated with the actual deterioration mechanisms and the *longevity index* associated with technical and organisational measures used to control mechanisms. These indicators could be valuable for updating the generic frequencies of failure, as the adequacy of safety measures affects the actual frequency of failures (Papazoglou & Aneziris, 1999). As discussed by OECD (2008), the SR has to be an alive document and a valuable tool to be used every day in the SMS. The tuning of the failure rates is the first step in this direction. The new pervasive sensors for integrity control, the wireless connection systems and the resulting big data are

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the keystone for a dynamic approach in process safety assessment. Oil and allied industries are mature and already accumulated a huge knowledge about deterioration mechanisms. This knowledge is valuable to exploit the data provided by the new enabling technologies and provide trustable predictions on the Remaining Useful Life (RUL) of process equipment; these predictions in turn could be valuable to revive the SR of aged establishments. This paper is organised as follow: Section 2 presents the objectives of the work; Section 3 discusses the structure of the guideline for ageing assessment and the proposed method to update and improve the SR; Section 4 demonstrates the applicability of the method in a use-case; Section 5 gives a few conclusive remarks.

2. Objectives

The goal of this paper is to outline a method to keep updated the SR of Seveso establishments, even when these are approaching the end of their lifecycle. The basic elements of the method are: (i) the awareness about the ageing issue; (ii) the role of failure rate in risk assessment and the need of updating them in all phases of the equipment lifecycle; (iii) the potential of data provided by enabling technologies to improve prognostic; (iv) the importance of the knowledge on deterioration mechanisms and RUL for the prevention of major accidents.

3. Guidelines

3.1 Ageing fishbone method

In 2018, the Italian Ministry of Environment adopted a short-cut method for the evaluation of ageing and corrosion plans during inspections at Seveso sites, so-called *Ageing Fishbone* method (AFB). As discussed in detail by Milazzo & Bragatto (2019), the method scores twelve factors identified to be relevant for equipment ageing, in the sense that they can accelerate or slow-down the phenomenon. Negative or accelerating factors represent the strength of deterioration and include deterioration mechanisms, age or in-service time, failures, accidents/near-misses, damages and stops. Positive or decelerating factors indicate the resistance contrasting the deterioration and include physical protections (e.g. cathodic, lining, cladding), audits, integrity management system (policy and maintenance), adequacy controls (techniques and competences of personnel), inspection results (results of integrity and functionality verifications and inspection scheduling) and the process control. The method analyses each equipment item, classified as “critical” in the risk assessment, based on the occurrence of top-events. Then, a score is assigned to each factor, some are assigned at the establishment level (i.e. integrity management system and audits), and then the *overall adequacy index* is calculated by summing the average score of accelerating factors (*ageing index*) and the average score of decelerating factors (*longevity index*). Usually the result is given at the establishment level as a cumulative index by summing the overall index of all equipment. Seveso inspectors use this index to approve ageing management plans and eventually recommend or prescribe further technical or organisational measures, including the adoption of best available monitoring techniques.
Eq.(1) gives the *overall index* for the establishment ($I_{overall}$):

$$I_{overall} = \sum_{k=1}^{M} w_k S_k \tag{1}$$

where M is the number of factors (namely 12 in the present version of the guideline); S_k is the score for the k^{th} factor at the establishment level; w_k is the weight of the k^{th} factor (– 1 /M for accelerating factors and + 1/M for decelerating factors).
As mentioned above for organisational factors, the score S_k is assigned at the establishment level, whereas physical factors are evaluated for any critical item, according to Eq.(2):

$$S_k = \frac{1}{N} \sum_{i=1}^{N} S_{k,i} \tag{2}$$

where N is the number of critical items; $S_{k,i}$ is the score of the k^{th} factor for the i^{th} critical item.
The AFB was born as a tight method, then, a number of trade-off was accepted to take into account the needs of industrial stakeholders. The value $I_{overall}$ = 0 does not have to be interpreted as a sort of average condition, but as the lowest acceptable condition for the item. The “average condition” is better represented by the value $I_{overall}$ = 0.5. For the purpose of Seveso inspections, an alert range is defined between $I_{overall}$ = 0 and $I_{overall}$ = 0.5, where improvements are recommended. For negative value of $I_{overall}$, but higher than – 0.5, recommendations are preferred to prescriptions, these latter cannot be avoided for $I_{overall}$ < – 0.5.

Even though the scope of the AFB is the assessment of the overall adequacy of the establishment from the point of view of ageing, the application to a single critical item does make sense. The *equipment overall index* or simply *equipment index* (included in the second release of the method) is defined by Eq.(3):

$$I_{eq,i} = \sum_{k=1}^{M} w_k S_{k,i} \tag{3}$$

where $I_{eq,i}$ is the overall index for the equipment i.
For organisational factors, the individual score ($S_{k,i}$), by definition, is the same of the overall score (S_k) and equal for all items. The *overall adequacy index* is the average amongst all equipment indexes, according to Eq.(4):

$$I_{overall} = \frac{1}{N}\sum_{i=1}^{N} I_{eq,i} \tag{4}$$

3.2 Updating failure rates and risk assessment

Generic frequencies of failure to be used in the risk assessment are provided by recognised databases that gather worldwide data. These frequencies are representative of equipment assumed to be in an "average" condition with respect to the safety management. By developing the concept introduced by Papazoglou and Aneziris (1999), Milazzo et al. (2010) discussed in the detail how to weight and judge the effects of the safety management, i.e. the different measures adopted by the company to prevent failures. They assumed that the frequencies could range between an order of magnitude, which can be higher or lower than generic values taken from the database. In API 581 (API 2016b), the same range of variability is assumed. As previously discussed, the AFB method aims including factors relevant for ageing management and, consequently, the *overall adequacy index* may be exploited to tune the generic frequencies used in the SR and namely in the FTA. This index may range between a minimum value $I_{eq,\min}$ and maximum $I_{eq,\max}$. These values respectively modify the frequency in the highest and the lowest frequency of failure, whereas the average value ($I_{eq,\text{med}}$) between them does not modify the frequency and makes it equal to the generic frequency of failure. On the basis of the application of the AFB to thousands of items, it can be reasonable assumed that the extreme values for I_{eq} are $I_{eq,\min}$ = – 2.0 and $I_{eq,\max}$ = + 3.0 and, consequently, $I_{eq,\text{med}}$ is equal to 0.5 (mean value of -2.0 and +3.0).
The frequency of failure is modified according to Eq.(5), where f_{mod} is the modified frequency of failure; $f_{generic}$ is the generic frequency of failure from the literature; a_m is the factor modifying the frequency, which, according to Milazzo et al. (2010), takes into account of the safety management and ranges between -1 and 1. The value of a_m may be derived from the actual value of I_{eq} according to Eq.(6):

$$\log f_{\text{mod}} = \log f_{\text{generic}} + a_m \tag{5}$$

$$a_m = \frac{2\left(-I_{eq} + I_{eq,\text{med}}\right)}{\left(I_{eq,\min} - I_{eq,\max}\right)} \tag{6}$$

Finally, the modified frequency will replace the generic frequencies in the FTA, consequently also the frequency of the expected top-event will change. The cut-off threshold (e.g. 10^{-6} events/year), as fixed by the regulators, does not change, but the recalculation of frequency could change a negligible event as a credible one. This means that new accidental scenarios must be considered. Hence, even the emergency plans and eventually also the land-use plan should be reconsidered in the light of the new scenarios (Palazzi et al., 2015).

3.3 Equipment prognostic and health management

The estimation of the *residual useful lifetime* of industrial equipment, based on its actual health conditions, is a need for the establishment operator. The combination of models for equipment prognostic and some innovative technologies (Bragatto et al., 2018) supports in achieving such an estimation. To this scope, a preliminary version of the model above has been already included (as an ageing metric) in a system, which combines technologies for a smart identification of equipment (Gnoni et al., 2016) and cloud computing to store and manage equipment data and outputs deriving from the quantification of the equipment ageing conditions (Milazzo et al. 2018). Further implementations of the model will be part of a system for an advanced prognostic and health management (the so-called virtual sensor).

3.4 Safety report: a proactive approach

To improve the SR, the CA should also require the operator to include detailed information about the deterioration mechanisms, the actual condition and the adopted inspection and maintenance strategies for critical containment systems (namely pipe and vessels). Largest companies easily provide this information as they already apply recognised RBI guidelines or standards, on the contrary, smallest companies usually do not have an organised approach for ageing management. The CA has the duty to examine and eventually approve the SR; during this process, it can require or suggest technical improvements to prevent major accidents. The knowledge of the best available techniques to control the deterioration mechanisms is essential to make adequate decisions and to understand and prescribe the optimal monitoring contrasting the additional risk due to ageing. As discussed by Bragatto et al. (2018), the research in the field of integrity monitoring is promising; a number of technical solutions to continuous control the equipment health is already available in the market and further solutions will be likely ready in near future. The review of the SR should consider the adoption of innovative technologies to assure a safe life extension of aged critical equipment.

Table 1: Check points for the harmonisation of Safety Report and RBI study.

Point	RBI study	Safety Report	Reconciliation
Failure Rates and Corrosion Rates	Failure rates, as well as corrosion rates, come from API 581 or from available proprietary resources.	Generic failure rates derived from public or proprietary databases.	A different accuracy is acceptable in RBI and SR, but the values should be harmonised.
Likelihood	Likelihood of failure (LOF) derives from generic failure rates combined with corrective factors.	Likelihood of top-events is calculated by FTA. Regulators set a cut-off threshold to discriminate credible events.	SR should consider also the effect of context on the likelihood of top-events, as RBI. The ageing index could reconcile both approaches.
Consequences	Consequences of failures include both economic-financial effects and impact effects.	Consequence evaluation of top-event is very accurate and includes extension of the impact area with effects for humans and environment.	The consistency of the impact areas for major releases of hazardous materials should be verified in SR and RBI.
Damage mechanisms	RBI trusts in a huge knowledge basis (API 2011), developed for oil industry, but valuable also for process industry.	In the current practice, SR does not mention damage mechanisms.	SR should demonstrate the awareness about ageing (knowledge of damage mechanisms and control techniques). SR should exploit API 571.
Safety management System	The SMS is carefully assessed according to a proprietary API checklist. The obtained score is used to correct generic failure rates.	The SMS is carefully verified according to a regulatory checklist, which gives a score. Seveso inspection is used only to determine the time of next inspection.	RBI study should use the score from the regulatory checklist. SR should quantify the effects of SMS on risk. The use of ageing indexes reconciles the approaches.

To contrast ageing, innovative sensors and communication technologies could not be enough. The adoption of adequate organisational models is surely more important than the use of technological innovation in monitoring. If equipment is approaching the design lifetime or has overcome it, the operator should adopt an RBI approach to manage integrity (Bragatto et al., 2012). The full implementation of API guidelines (API 2016a, API 2016b) is suitable for major companies and larger plants. For small-medium sized ones, the implementation of these guidelines may be difficult because of the required resources, thus, other RBI guidelines are more suitable, including the EEMUA 159 for above ground atmospheric storage tanks (EEMUA 2018) or the European standard EN 16991 (CEN 2018). Operators of small sized Seveso plants often have a limited understanding of deterioration phenomena and the adoption of an RBI strategy is a necessary condition to extend the in-service life of aged equipment, independently on the adopted guideline or code.

It must be underlined that both the Seveso legislation and the RBI approach are based on a risk management approach. While RBI is based on a semi-qualitative risk assessment, the European regulation requires quantitative analysis to be included in SR. The first approach gives a risk classification, based on the probability of the failure and the consequences; the second one consists of the calculation of the probability of credible events and the development of simulations for the release and the impact of scenarios. The scope is different, but the results of the assessments should be consistent with each other; this is not so obvious and, inside largest companies, SR and RBI are managed by different departments, which often do not communicate each other. A complete overlap is not possible, due to the different scopes and approaches: RBI includes even financial losses due to failures and operational interruptions, whilst SR considers major losses on the basis of the impact area. SR is a public document, shared with other stakeholders, whilst RBI is a private document for internal use and, therefore, a less conservative and more agile approach is required. Even though the two documents must be kept independent, a reconciliation is essential to avoid conflicting evaluations. A merge of them does not make sense, but a number of elements should be carefully checked by looking at both documents. Table 1 summarises the main points to check to harmonise SR and RBI. In updating the SR, the operator should verify the existence of an RBI study and, if it does, he/she should follow point by point the suggestions in Table 1 to assure the required “consistency”. In the same way, when a new RBI study is under preparation, the SR should be accessed and, even in this case, the points in Table 1 provide a useful guideline.

4. Case study

The implementation of the method, discussed in section 3.2, in a real establishment includes the following steps: i) to find out the critical containment systems and get the expected frequencies of accidents; ii) to apply the AFB method and calculate the *equipment overall index* I_{eq_i} for each critical item; iii) to calculate the corrective factor for each item, according to Eq(6); iv) to adjust the frequency of accidents according to Eq(5). The sensitivity of the AFB method, as discussed in a recent paper (Ancione et al. 2020), is low and substantial changes are required to affect the ageing indexes. Thus, even the corrective factors and the frequencies are expected to change significantly, just in the case of major changes (technical or organisational) in ageing management. The selected case study is a medium sized depot, containing five atmospheric tanks for the storage of light products (virgin naphtha or gasoline). Each tank, named TK0n (where n = 1, 2, 3, 4, 6), is equipped by an adduction line (named L10*n*) and an extraction line (L20*n*). Most tanks were built some sixty years ago, as well as the lines. At the depot there are no particular measures for ageing control, such as RBI, best inspection techniques, functional safety policy, physical protections (neither active or passive). Thus, the application of AFB method gives a negative *equipment overall index* for some tanks and lines (see Table 2), due to their age and condition. The SR, issued and approved a few years earlier, provided the frequencies of release of critical equipment, based on generic failure rates derived from the literature. For the tanks, the SR reported a frequency equal to 4.1 10^{-6} event/year for minor release from small holes (up to 20 mm) and 2.5 10^{-7} event/year for catastrophic losses due to tank ruptures. For the extraction and adduction lines, the SR gave 2.0 10^{-3} events/year for small release and 3.1 10^{-7} event/year for ruptures. Then, the frequencies of all events were adjusted, in order to take into account the ageing effects. Table 2 summarises the results of the application of the AFB, including the modified frequencies. The major releases associated with tanks TK03 and TK04, were no-credible (lower than the threshold 10^{-6} events/year) in the original SR, they overcome the credibility threshold due to ageing. Even the releases from lines ID=106 - 206, were no-credible in the SR and become credible because of ageing.

Table 2: Application of Ageing Fishbone Method and modification of frequencies. The criticalities are marked.

	Average score for accelerating factors S_k	*Average score for longevity factors* S_k	*Equipment overall index* I_{eq}	*Corrective factor* 10^{am}	*Frequency of leakage* f_{mod}	*Frequency of rupture* f_{mod}
TANKS			$f_{generic}$ *from the Safety Report* ➔		4.1E-06	2.5E-07
TK01	2.17	2.25	0.08	1.6	6.6E-06	4.1E-07
TK02	2.17	2.25	0.08	1.6	6.6E-06	4.1E-07
TK03	2.83	2.17	✖-0.67	3.8	1.6E-05	★9.7E-07
TK04	3.00	2.17	✖-0.83	4.6	1.9E-05	★1.2E-06
TK06	2.50	2.17	✖-0.33	2.6	1.1E-05	6.6E-07
LINES			$f_{generic}$ *from the Safety Report* ➔		2.0E-03	3.1E-07
L101 - L201	2.22	2.33	0.12	1.5	3.1E-03	4.7E-07
L102 - L202	2.22	2.33	0.12	1.5	3.1E-03	4.7E-07
L103 - L203	2.22	2.33	✖-0.38	2.7	5.5E-03	8.3E-07
L104 - L204	2.72	2.33	✖-0.38	2.7	5.5E-03	8.3E-07
L106 - L206	3.05	2.33	✖-0.72	4.0	8.1E-03	★1.2E-06

5. Conclusions

Aged plants in major-hazard establishments pose additional risks, therefore, a few actions are required to control them. In the framework of Seveso legislation, the AFB method is used during inspections to verify the adequateness of the equipment ageing plan implemented by operator. The periodical update of the SR for upper-tier Seveso establishments is a further opportunity to face the ageing issue. The results of the case study, discussed in Section 4, have demonstrated the potential of the AFB method to evaluate the contribution of ageing management to the likelihood of the top events and, consequently, to update the SR, as required by the Seveso Legislation. The discussed case study showed how a poor ageing management may affect negatively the likelihood of accident; but the use of the AFB method is, of course, adequate also to recognise the positive effects of an adequate management. The best action to the increased likelihood of accident, due to equipment ageing, is the adoption of the best inspection techniques and implementation of RBI policies, harmonised with the SR, as detailed in Section 3.4.

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