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Integration of HOFs into ATEX Risk Assessment Methodology

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The current ATEX (Explosive Atmosphere) risk assessment methodology relies on a semi-quantitative approach based on the following indexes: probability of an explosive atmosphere formation, probability of the presence of an effective ignition source and consequences. The whole risk assessment procedure can be separated into four steps ---- area classification, ignition sources identification, consequence analysis, and risk evaluation. However, when reviewing the whole ATEX risk assessment procedures and their results, despite many operations on plant and equipment containing dangerous substances are performed by operators, the human and organizational influences are neglected.
The study proposed in this paper is to develop an ATEX risk assessment methodology with the integration of human and organizational factors (HOFs), in order to provide an advanced methodology able to analyse the HOFs influences on ATEX hazards.
The developed ATEX risk assessment methodology introduces in the procedure the Technique for Human Error Rate Prediction (THERP) to identify human and organizational weaknesses, and also provides a tool for calculating the human error probability (HEP) in the first two risk steps ---- area classification and ignition sources identification. During the risk evaluation procedure, human risk level, based on the results of HEP, has been introduced into the original ATEX risk assessment methodology.

1. Introduction

In the early years of aviation, the aircraft killed the pilot. That is, the aircraft were mechanically unsafe. However, the modern era of aviation, literatures indicate that between 70 and 80 percent of aviation accidents at least in part, can be contributed by human errors (Shappell and Wiegmann, 1996). The same situation in mechanical industries, many techniques within risk assessment are mainly concerning machine functional failure itself. However, nowadays, more and more safety managers and researchers realize that the system of mechanical industry is a complex human-machine system, which is composed of humans, machines, and the interaction between them (Marhavilas et. al, 2011).
ATEX (explosive atmosphere) risk assessment is required when any equipment or protective systems are intended for use in potentially explosive atmospheres. An explosive atmosphere is a mixture of flammable substances with air, in the form of gas, vapour, dust or fibres under atmospheric conditions, which, after ignition, permits self-sustaining propagation (CEI EN 60079-10-1, 2010). This potential hazard associated with explosive atmosphere is released by an effective ignition source (UNI EN 1127-1, 2007). As a safety principle suggested by CEI EN 60079-10-1 (2010), equipment in which flammable materials is handled or stored should be designed, operated and maintained, in order to guarantee any releases of flammable material are kept to a minimum level, with regard to frequency, duration and quantity. The technical standard UNI EN1127-1 also specifies methods for identifying and analysing potential explosion hazards by using hazard identification, risk assessment, reduction of risk, and information for use. However, the influences of HOFs are strongly neglected by doing this traditional ATEX risk assessment, although many operations are performed by operators. This study aims to propose a developed methodology by integrating HOFs inside, in order to better face the potential risk related to explosive atmospheres.

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2. Human Reliability Analysis and THERP

Evans (1976) explained that human reliability is a probability that a person correctly performs some system-required activities in a required time period, and performs no extraneous activity that can degrade the system. Human reliability analysis (HRA) is a method that human reliability is estimated. Several HRA techniques were developed like HEART, CREAM, NARA, THERP during these years (HSL, 2009; Nespoli and Ditali, 2010). THERP, as one of the HRA techniques, although it is not a very recent method, was proved to be still valid and efficient to well represent human error rate range, if a quantitative estimate is required (NASA, 2010).
According to the Handbook of THERP developed by Swain and Guttmann (1983), human can be considered as a closed-loop system component that can receive the information from external environment (such as working environment, documentation materials, displays, etc.), and transfer those external inputs into the internal inputs of human component inside. Inside, human receives internal inputs via sensing, discrimination, and perceiving; then, processes internal inputs based on cognitions; and, responses as human outputs to system outside; finally, external results are obtained. During the internal inputs processing, three human behaviors would influence the performance of human: skill-based behavior, rule-based behavior, and knowledge-based behavior. As a result, those influences may cause incorrect outputs as human errors considering omissions and commissions.
For quantifying the human error probability (HEP), the basic tool of THERP is a form of event tree as human error tree. The branches of the human error tree represent a binary decision process which the correct or incorrect performance are the only choices. For each choice, HEP could be estimated by referring to the 27 tables from the THERP handbook. Thus, the final HEP of the whole tree can be obtained based on the Bayesian method.

3. Integration of HOFs into ATEX Risk Assessment Procedures

Figure 1 shows the ATEX risk assessment procedures with the integration of human and organizational factors (HOFs). Four steps that area classification, ignition sources identification, consequence analysis, and risk evaluation were involved in the traditional procedures. For each step, a semi-quantitative approach was introduced for the risk analysis based on the following indexes: probability of an explosive atmosphere formation, probability of the presence of an effective ignition source and consequences. For the previous ATEX risk assessment, the procedures only focus on the function analysis, and the results are trying to assume that additional HOF conditions (AHCs) are always under the correct situations. In the developed ATEX risk assessment, human reliability analysis is introduced in each step, in order to analyse the human error probability (HEP) and consequence considering the failure situation of AHCs. As the result, risk evaluation with considering HOFs will be obtained.

4. Case Study

4.1 Description of Case Study

This case study is originated from the explosion risk evaluation of a food manufacture plant. This plant produces food stabilizers, ingredients, starches and gums. The production plant can be divided into three lines, and each line involves three stations: raw material loading station, raw material mixing station, and product packaging station. Within the 44 of identified emission sources, only the GV5 is analysed in the following parts: a dust cartridge filter, which needs to be replaced regularly according to the frequency mentioned in the instruction manual of the equipment each year. Without doing so, full of dust inside the GV5 filter could break and cause explosive atmospheres on the other machines if continuing doing the operations; on the other hand, without correctly doing the replacement of GV5, it will cause the explosive atmosphere itself (e.g. open the cap incorrectly). These consequences are mainly contributed by human errors. If operators are doing the incorrect operations, the risk evaluation results and consequence analysis will probably be influenced significantly.

4.2 Risk Identification for the Area Classification of Problem 1 - Failure to replace GV5 in the correct way

In this case study, because human errors analysed will have a potential influence on the area classification, the results of original and revised area classification with and without considering HOFs are taken into account.

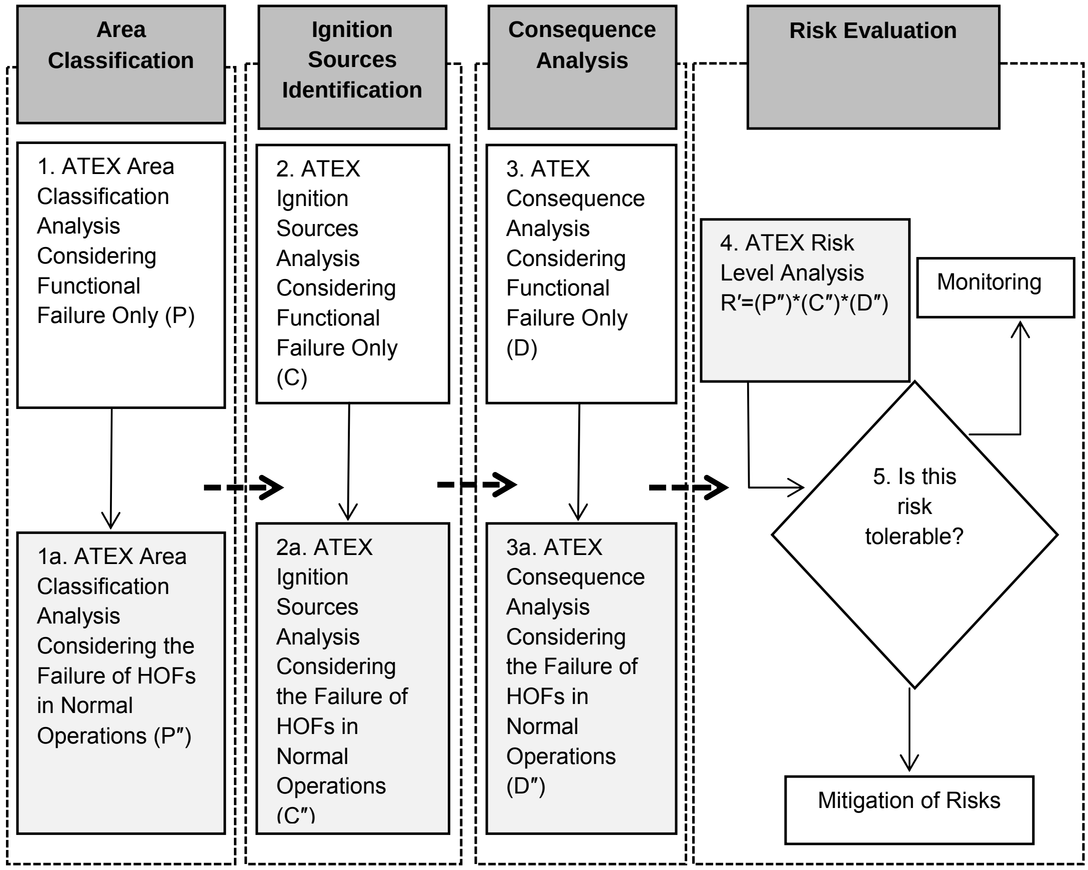

Figure 1. ATEX Risk Assessment Procedure with Integration of HOFs

The original risk evaluation results of area classification are the zone 20 inside and zone 22 outside, and the AHC is trying to be assumed that operators or maintainers are always doing replacement correctly. If considering such AHC fails with a certain probability, task analysis is applied to identify potential risks caused by human errors. The list of human actions is as the following:

Relevant Steps from “Immediate Actions” to guarantee the success of doing replacement:

Step 1. Verify the requirement to replace GV5 based on the frequency.
Step 2. Verify that replacement action is done or not.

Relevant Steps from “Follow-up Action Sections” to guarantee the success of doing replacement:

Step 3. If not doing replacement action, do replacement actions step by step.
Step 3.1 Remove the cartridge cover and suck the dust totally.
Step 3.2 Remove the used cartridges and replace them, reminder that when doing install the cartridges, the copper presented on the same track needs to be connected.
Step 3.3 Check the solenoid firing.
Step 3.4 Check the cleanliness of the cabinet.

4.3 The Human Reliability Analysis

Figure 2 presents the HRA event tree for Problem 1, which is based on the task analysis in the risk identification procedure above. Table 1 explains each symbol in the figure. Of the three failure paths in the HRA event tree, two failure paths (F1 and F2) of immediate actions are clearly dominant. These two failure paths contribute to almost the overall failure probability F_T, of 2.43×10^{-2}. Here, according to the tables to support calculation of HEP in the handbook of THERP (Swain and Guttmann, 1983), supposes that this human error event is possible to be diagnosed at 15 minutes. Thus, four reactor operators and advisors should be available to cope with such abnormal event, which are reactor operator (RO), senior reactor operator (SRO), shift technical advisor (STA), and shift supervisor (SS).

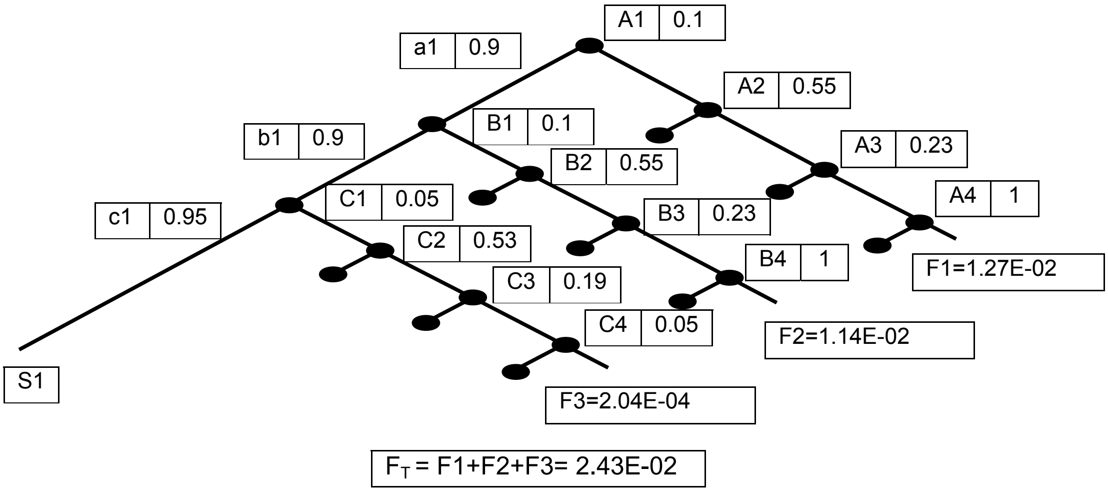

Figure 2. HRA event tree for Problem 1

Table 1: Explanation of terms in HRA event tree for Problem 1

Failure Limb & Person	Estimated HEP and Source	Task Explanation
A1	0.1	RO fails to correctly diagnose the need to replace GV5 based on the frequency.
A2	0.55	SRO fails to correctly diagnose the need to replace GV5 based on the frequency.
A3	0.23	SS fails to correctly diagnose the need to replace GV5 based on the frequency.
A4	1	STA fails to correctly diagnose the need to replace GV5 based on the frequency.
B1	0.1	RO fails to verify that replacement action is doing or not.
B2	0.55	SRO fails to correct RO’s error.
B3	0.23	SS fails to correct RO’s error.
B4	1	STA would not be involved in this procedural detail.
C1	0.05	RO fails to do replacement action step by step correctly.
C2	0.53	SRO fails to correct RO’s error.
C3	0.19	SS fails to correct RO’s error.
C4	0.05	STA is assessed LD to MD for major events.

4.4 Risk Evaluation

ISO/IEC 31010 (2009) is the international standard to explain the risk assessment techniques for the risk management. Risk assessment is the overall process of risk identification, risk analysis and risk evaluation. In ATEX risk evaluation, in general, the risk (R) relies on a semi-quantitative approach based on the following indexes: probability of an explosive atmosphere formation (P), probability of the presence of an effective ignition source (C), consequences (D), and also the other factors (e.g. personnel presence (PL), dust explosion index (Kst), Gas explosion index (KG), Cloud Volume (VZ), Layer Thickness (SS), Confined Dust Cloud (CN)). The Eq (1) can be showed as following:

$$R = P*C*D + (\text{Other Factors}) \quad (1)$$

Table 2 shows the semi-quantitative evaluation criteria of traditional ATEX risk index P, C and D. Table 3 demonstrates the overall risk evaluation criteria of risk analysis and the human risk level evaluation criteria according to U.S. Military Standard. According to Table 4, the area classification is zone 20 inside and zone 22 outside with only considering function analysis. As a result, the result of risk evaluation under normal condition (without considering HOFs) is R ≤ 1, and the risk level is negligible.

Traditionally, the ATEX area classification estimation (calculation procedure) considers as much as possible situations of the normal operation, maintenance, cleaning procedure, and foreseen failure, but the catastrophic failure (CEI EN 60079-10-1, 2010). However, taking AHC into account, human related particular operations during the maintenance activities, like cleaning and replacing the accessory in this case study will have a potential influence on the normal operational working environment. According to the

AHC analysis, the revised result of R', in this case study, will probably be changed that is mainly caused by the P value (P'), the result of the area classification zone. Therefore, the Eq (2) can be introduced to better investigate the difference of the R result with and without considering AHC.

$$R' = P'*C*D + (Other\ Factors) \quad (2)$$

Supposing P value is the probability of an explosive atmosphere formation in 365 days, based on the influence of AHC, the value of P' should be the sum of HEP in 365 days and P, see Eq (3):

$$R' = (P+HEP)*C*D + (Other\ Factors) \quad (3)$$

In order to estimate the value of P', because of the only reference for the validation of the gas (CEI 31-35, 2012), this P range from the reference is also trying to be provided as the first hypothesis of the validation for the dust. As the result, the P' value equals to the sum of the original P value ($P>10^{-5}$) and HEP (2.43×10^{-2}). Thus, the range of P' is $10^{-1}\geq P>10^{-3}$, and the value of P' is 2. The result means that an area with explosive mixtures is likely to occur in normal operation during a year. The area classification zone will be zone 20 inside and zone 21 outside, and the human reliability risk level is the medium (Table 3), which means that the failure caused by human errors at least happen sometimes during a year. If it happens, the risk R' will be 4, and the risk level goes up to the low level. In this case, risk reducing measures should be implemented in a long period.

Instead of doing nothing for GV5, considering the potential influence of AHC, it is strongly suggested that at least the checklist or tag on the GV5 should be applied, in order to reminder operators or maintainers to replace it regularly and correctly.

Table 2: Semi-quantitative Evaluation Criteria of Traditional ATEX Risk Index

Value of P and D				Value of C	
Area Classification Zone	Probability of Explosive Atmosphere Formation in 365 days *(CEI 31-35, 2012)*	P Value	D Value	Presence	C Value
Zone 0/20	$P>10^{-1}$	3	3	Very Likely	3
Zone 1/21	$10^{-1}\geq P>10^{-3}$	2	2	Likely	2
Zone 2/22	$10^{-3}\geq P>10^{-5}$	1	1	Unlikely	1
Zone NE	$P>10^{-5}$	0	0	Very Unlikely	0

Table 3: Risk Evaluation Criteria

Risk Evaluation under the Normal Condition			Human Risk Level Evaluation		
Risk Level	Degree	Risk Value	Risk Level	Degree	HEP
High	Frequent	$R \geq 18$	High	Frequent	$>10^{-1}$
Medium	Probable	$9 \leq R < 18$	Medium	Probable	10^{-1} to 10^{-3}
Low	Occasional	$1 \leq R <9$	Low	Occasional	$< 10^{-3}$
Negligible	Impossible	$R \leq 1$	Negligible	Impossible	$<10^{-4}$

Table 4: Risk Evaluation Results with Considering AHC

Emission Source	Emission Degree	Generated Zone	Additional HOF Conditions (AHC)	Amended Zone if AHC Failure	HEP	Human Risk Level
GV5	Secondary	Inside: Zone 20 Outside: Zone 22	Replace GV5 in the correct way	Inside: Zone 20 Outside: Zone 21	2.43E-02	Medium

4.5 Discussion of Evaluation Result

The evaluation result shows the influences on the final ATEX risk levels when comparing the results with and without considering HOFs. Before considering HOFs, the risk level of the case study is negligible; however, after considering HOFs, the risk level of the case study goes up to the low level with a certain human error probability. This case study indicates that the influences of human and organizational factors should be considered under certain situations.

5. Conclusion

ATEX, as one of the risk assessment considerations, is required to be done if any equipment or materials generate potential explosive atmosphere. Traditional risk analysis techniques only focus on the functional failure. Despite operators are involved in many operations, the influences of human and organizational factors are neglected. This study proposes a developed methodology with integration of HOFs into ATEX risk assessment. For each procedure, additional human condition (AHC) analysis is introduced inside to identify human actions which may cause potential hazards by using task analysis. THERP, as one of the efficient quantitative analysis techniques for the human reliability analysis, supports the estimation of human error probability of each human action. In the risk evaluation procedure, human reliability evaluation is separated from the original ATEX risk evaluation. As an independent part, stakeholders could see the different risk evaluation results with and without considering HOFs in terms of different requirements. Especially for the situation of many operators are involved, the human error probability and the amended consequence with considering HEP are provided. Thus, the final human risk level can be also obtained by using the semi-quantitative way.

As the limitation of this study, THERP is an efficient HRA technique to calculate the HEP. However, it is not so easier to be applied in the real industries. The human analyst or safety manager should be required or trained, and also it is time consuming method. Furthermore, the technique of risk identification for the interaction between human actions and equipment still need to be improved for the general use in real industries.

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