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PROCESS SAFETY PROGRESS

ORIGINAL ARTICLE

Human factors influencing the reliability of fire and gas detection system

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Abstract

This paper presents some fundamental factors that influence the reliability of fire and gas (F&G) alarm systems by incorporating human factor's principles. As compared, standard alarm and the safety-related alarm will show two different values of IPF given in process hazard analysis (PHA) studies. In this study, fault tree diagram has been used to calculate the process flow diagram (PFD) value, to identify which alarm type could meet the standard of safety integrity level (SIL1) for F&G system for a single train process. Comparison of both alarms is done for three types of selected detectors; flammable gas detectors, flame detectors, and toxic gas detectors. It has been identified that standard alarm for all type of detectors does not meet the SIL1 requirement. Compared to safety-related alarm, all detectors are able to meet the requirement of SIL1. Since the greater IPF will be given for safety-related alarm, it is crucial to study the holistic factor that could maintain the system with good efficiency and performance. The human factor has been identified as the most critical element for safety-related alarm. A complete coordinated approach is needed to ensure the performance and efficiency of the F&G alarm system can be maintained while process plants are able to be safely operated within as low as reasonably achievable region.

KEYWORDS
alarm system, fire, gas, human factor

1 | INTRODUCTION

In the early stage of fire detection, history has proven that simulating an appropriate emergency alarm is a crucial part of controlling enormous fire losses.

In order to boost the survivability of occupants by using a standard installation and maintenance for fire detection and alarms systems while diminishing overall property losses. Early warning is significant for personnel to be cautious of possible emergency situations in terms of flammable or invisible toxic fire or gases. The aim of early warning is to reduce the consequences of events and risk assessment will be conducted for any likelihood of the event.[1] There are three main functions of fire and gas (F&G) systems as follow:

- Detect - detect releases/building-up of high potency flammable gases and fires;
- Alarm - notify alert to trained personnel with a standard procedure during the hazardous event; and
- Protect - handle activities that are essentially diminishing the impact.

When trained personnel are present at the fire event area, they will likely to have high alertness as a fire detector. Some well fit personnel will be more competent to sense fire characteristics, for example, the odors, flames, heat, and smoke. When a human can detect this situation as mentioned previously, thus, this is the actual reason why the fire alarms system is patterned in a unique way. Additionally, the alarm devices can be manually operated by the first person who discovered the fire. Occasionally, some personnel might trigger panic situations or due to health condition, which leads to lack of confidence during the event of fire and they forget to induce the alarms. Moreover, the possibility for the operator or trained personnel to be absent during the fire event is also high. Therefore, the automatic detector is designed to simulate specific functionalities which imitate the human physical senses of smell, touch, and sight. The thermal detector is fundamentally to sense high temperature while the smoke detector is replicated through the sense of smell, and electronic eyes are designed to detect the presence of flames.[1] In the mitigation of fire and explosion, the installation of detectors is located in the accepted coordinate and it will be analyzed through the F&G detection mapping.

1.1 | Fire alarm systems

To determine the unwanted presence of fires, a fire alarm system is modeled by monitoring any small changes in the surroundings. This system is conventionally categorized into a manual function or an automatically operated or even both at the moment. The installation of automatic fire alarms is to inform the emergency signal for the building occupants to directly leave the building during the fire event or emergencies. This will also trigger the system to notify the emergency services, which at the same time report the off-premises location of the event, plus, the fire services department will construct steps to take over the spreading of fire and smoke. There are a few examples of fire alarm devices such as manual call point or station, smoke detector, and heat detector. The fire alarm system is divided into five parts as below:

1. Power Supply: A device that acts as a power source for operation of the system
2. Fire Alarm Control Panel (FCP): The control and monitoring equipment and parts on all systems. Electronic control panel (FCP) is a light and sound show on the safe and alarm conditions.
3. Initiating Devices: The input device as the origin of the fire alarm. They are divided into two types;
   - Manual Push Station
   - Automatically Signal Devices such as smoke detector, heat detector, flame detector, gas detector.
4. Audible and Visual Signaling Alarm Devices: For examples, bell, siren, and light signal. The residents and the fireman can be noticed that the fire occurred.
5. Auxiliary Devices: A device that connects to other systems involved. The prevention and control of fire alarm systems; fire alarm will be transmitted to other systems.

A fire protection system can be classified into active system and passive system. For active system, the equipment used is spray system and water sprinkler that commonly used in the process plant industries. The performance of the active system is to protect the unit vessels such as loading installations, warehouses, process plant area, and storage units. Domino effect can be avoided by the fire protection system, as it controls the spreading of the exposure or fire by dampening the growth of fire overall. There are other enhanced methods than mentioned above such as application foam pourers or fixed water monitors and some specialization in system for flooding enclosed spaces have been developed, for example. by using inert gases and halogen-based gases.

Another efficacious alternative for active system to prevent vessel failure is by using passive fire protection. Mostly, the passive protection is by applying coatings of fire-resistant insulating media coated to the metallic bare structure. Passive application is commonly utilized when the active protection system is insufficient, for example, in the secluded area or when there is complex solution for fire water system run-off. Besides, there is another passive protection by using firewall, in which, its main advantage is to avert the spreading of fire or any thermal dispersion toward the close by equipment. In resolving the important criterion in order to determine which one has more proper system for fire exposure is by comparing the probable time span for exposure to fire, here the passive is only potent for a short-time exposure (1-2 hours). Below is the outline summary for fire alarm process and the fire protection systems in Figure 1.

2 | ALARM SYSTEM IN FIRE AND GAS SYSTEM

2.1 | Independent protection layer (IPL) in PHA

According to the IEC 61511,[2] process safety standards, the process risk must be reduced to a tolerable level as set by the process owner. This is done using multiple layers of protection including the basic process control system (BPCS), alarms, operator intervention, mechanical relief systems, and (if necessary) a safety instrumented system (SIS). Each protective function reduces the risk by a certain order of magnitude and acts as an independent protection layer (IPL). Layers of protection analysis (LOPA) is one of the most widely used semi-quantitative methods of analyzing and documenting protective functions. It is a technique best used at preliminary design stage to assist in decision-making process.[3] An important outcome of LOPA is the identification of instrumented protective functions (IPF) essential for required risk reduction. An IPF must be designed to meet the requirements of ISA84[2] to be an IPL. The required safety integrity level (SIL) of each IPF is also determined during LOPA. SIL defines the target performance level of an IPF in terms of range of probability of failure on demand (PFD).

The more risk that can be reduced by the alarm system and the operator, the less risk reduction must be provided by the SIS. The higher the SIL level, the more complicated and expensive is the SIS. Additionally, a higher SIL will require more frequent proof testing, which adds cost and can be burdensome in many plants. Unfortunately, human performance factors provide constraints on the level of risk reduction that an operator can actually provide. By “getting the

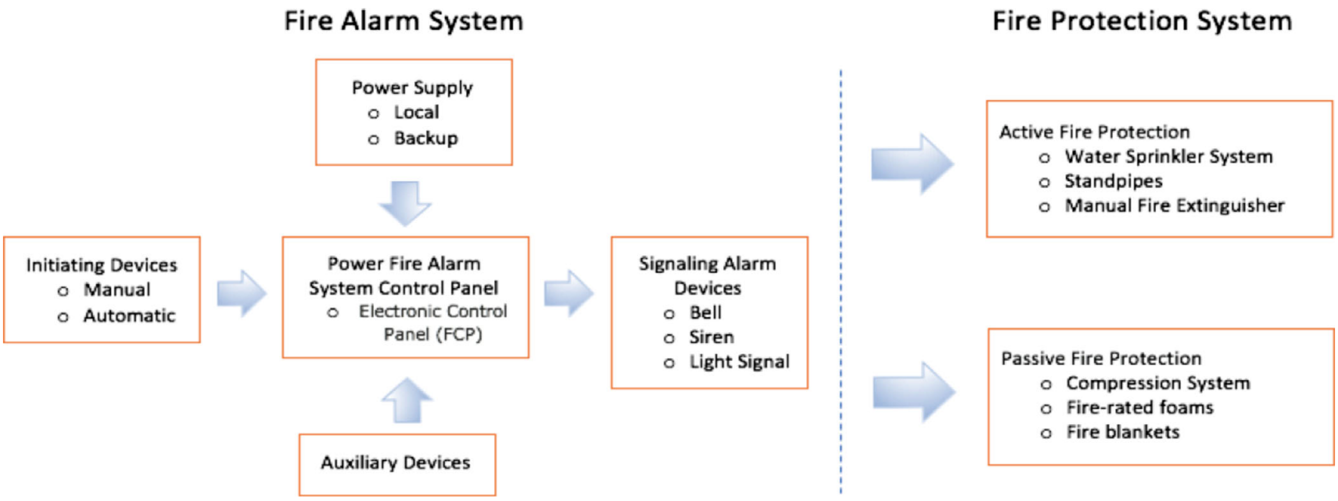

FIGURE 1 Fire alarm system and fire protection system [Color figure can be viewed at wileyonlinelibrary.com]

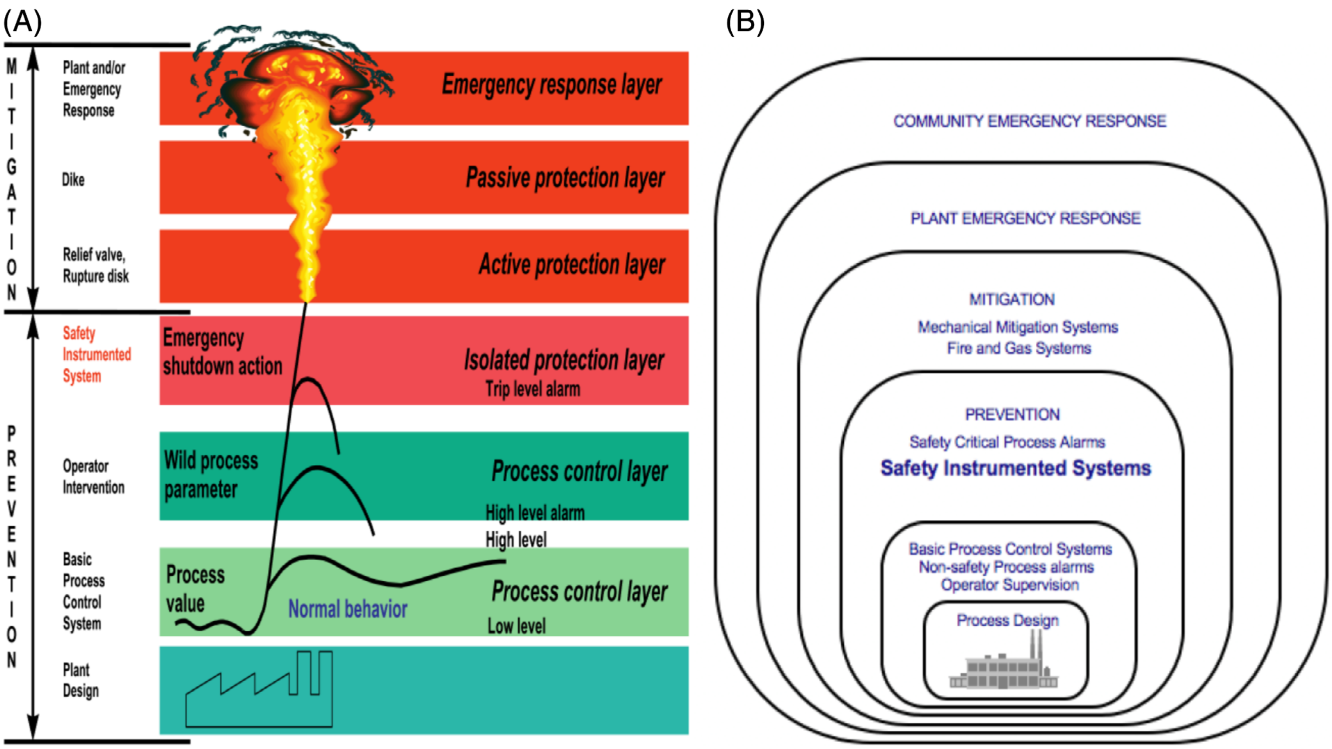

FIGURE 2 Mitigation and prevention layers of protection determined in process hazard analysis (PHA) studies[1] [Color figure can be viewed at wileyonlinelibrary.com]

most" from the operator, the demands on the SIS are reduced, which in turn reduces its chance of failure.

In functional safety lifecycle, the next step after LOPA is a conceptual design of the IPS. In most cases, multiple IPFs and control functions require the same process value. For example, an alarm, a trip, and a PID control loop may require the same process measurement.

In LOPA, some IPLs are used to prevent the consequence from occurring; these are known as preventive IPLs. An example of a preventive IPL is a high-level switch that stops the flow to the tank and prevents an overflow. Other IPLs are used to reduce the severity of the consequence; known as mitigative IPLs. Examples of mitigative IPLs include a dyke that minimizes the environmental impact or an excess flow check valve that reduces the quantity of material released to the surroundings upon loss of containment. The visual layers of protection are as shown in Figure 2.

Preventive IPFs prevent the top event (loss of containment, overpressure, backflow, etc.) to occur, whereas mitigative IPFs try to reduce the consequences of an event that already happened (a loss of containment, leak, fire etc.).

2.2 | Highly Managed Alarms

As described in the ANSI/ISA84.91.01 standard,[4] the process alarm can be grouped into interlock (SCAI) and safety control alarms. This diagram is used to aid in identifying all variation safeguards that "might" be stated by the operator/owner as a protective barrier in order to minimize the risk. In the PHA process, all these safeguards shall be determined. There is another option by applying ANSI.ISA-18.2 that describes as a safety alarm by acting as an alarm which categorized as analytically as critical to process safety or for the security of human life.

A supplementary requirement in the standard for safety alarms is located in a highly managed alarm (HMA) class as shown in Figure 3. On top of that, the alarms are served to inform operators during the equipment crashes or if there were abnormalities process conditions, which are clearly stated by the standard. The BPCS and SIS both utilized analytical logic and process surrounding conditions in creating alarms. Hence, an alarm following the ANSI.ISA-18.2 is also defined as a "safety alarm," which can also be viewed as SCAI based on ANSI/ISA84.91.01.[4]

An alarm system should be considered to be safety related if it is claimed as part of the facilities for reducing the risk from safety or environmental hazards by a factor of 10 or more. In such cases, the average probability of failure on demand (PFD_{avg}) of the overall safety function must be lower than 0.1 and must comply with the requirements of IEC 61508. The overall safety function is defined as the means required to detect and rectify the potentially hazardous event and is implicit that both the equipment delivering the alarm and the operator response are part of the safety-related system and hence, they both should be considered within the scope of IEC 61508.[5]

A safety-related alarm (as a part of HMAs) should not be used for risk reduction factors above 100 (PFD_{avg} of less than 0.01). Therefore, a safety-related alarm would normally fall into the category of a SIL1 function.

As shown in Table 1, SIL1 requirement criteria have a PFDavg of >0.01 to <0.1, which can be expressed as an RRF of >10 to <100 or in more practical terms availability and reliability of between 90% and 99%. This means that at a minimum availability of 90%, for every 10 alarm initiating events, there should not be more than 1 failure of the system to respond correctly. For a maximum availability requirement of 99%, this rises to 1 failure in 100. From a human reliability point of view, this SIL1 target is difficult to achieve. It can only be achieved with a high level of process team and management commitment to maintenance as will be discussed in the following subchapter. The various mandatory requirements for HMAs are spread over several sections throughout ISA-18.2.

For most of the F&G system in refineries or process industries, F&G detection mapping study will conclude the number of detectors needed and the location of the detectors. Detectors will sense the presence of hazardous gas or the presence of flame due to liquid leak from the source. Once detected, an automated control system will take the corrective action in the process area. Most of the F&G studies are done with this configuration of automated control system. It has been assumed for this study that key F&G alarm actions are initiated manually by an operator from the F&G control panel and/or from other safe locations. It is assumed there will be no automatic

TABLE 1 Relation between PFDavg and RRF according to SIL level[4]

Safety integrity level (SIL)	Safety availability	Probability of failure on demand (PFD_{avg})	Risk reduction factor (RRF)
SIL4	>99.99%	>0.00001 to <0.0001	>10 000 to <100 000
SIL3	99.90%–99.99%	>0.0001 to <0.001	>1000 to <10 000
SIL2	99.00%–99.90%	>0.001 to <0.01	>100 to <1000
SIL1	90%–99.00%	>0.01 to <0.1	>10 to <100

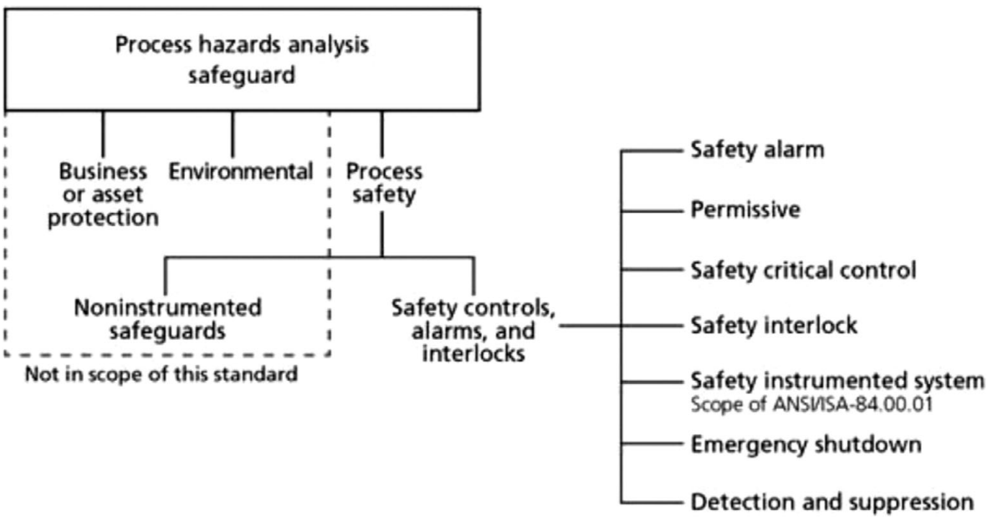

FIGURE 3 Safety controls, alarms, and interlocks relationship to the process hazard analysis (PHA)[2]

control actions in the process areas of refinery. The configuration in this study (with manual action by operators) by considering the function refinery with single train or process line, the impact from F&G false alarms/spurious trips as part of an automatic system would be significant and likely reduce the overall availability of the plant. F&G systems that generate unwanted shutdowns will reduce operator confidence in the system and such systems tend to be inhibited or ignored. This will, in turn, reduce the effectiveness of the F&G system as effective mitigation against undesirable events.

To facilitate an effective F&G system, an alarm only system will be studied; allowing protective functions to be initiated by the operator. Hence, there must be a very important study to manage the alarm system to prevent alarms to be missed by the operators. This places the importance of the capabilities not only on the operators but the management of alarm system influenced by human factors should also be studied and maintained with the highest efficiency. This study will present the difference of standard alarm and safety-related alarm to meet the minimum requirement of SIL for F&G system. The most important factor, that is, human factor contributing to the effectiveness of the F&G alarm system will be discussed.

Festag in 2015[7] studied the false alarm ratio of fire detection and fire alarm systems. The highly sensitive sensors in fire detectors make the identification of fires in an early stage possible, but this also makes the system susceptible to false alarms. In that study, they stated that human behaviors play a vital role when the alarms with good intent are triggered by human activities. In the event of malicious alarms, for example, persons triggered manual call points or light matches underneath fire detectors with the intention of damaging them. In the event of false alarms due to good intent, the persons alert the fire brigade in an act of good faith (mistake) although, here as well, there is no fire. Instead, human behavior plays a decisive role. The difference between malicious and good intent activities lies in a person's particular intention.

A very recent study by Lucke[8] in 2019 studied about alarm flooding and structures the field of alarm data analysis and suggests a distinction between methods applied to alarm sequences and methods applied to alarm series. The study also shows by means of a case study how a binary series approach can address a gap in online alarm flood classification in the industry.

The latest study by McNay in 2019[9] focused on the current approach and effectiveness to fire safety in machinery spaces. Taking a closer look at incident prevention, they studied about the bias toward direct causal factors that may be attributed to the widespread application of linear, event-based models to accident analysis. In general, human errors at the sharp and blunt ends are symptomatic of deeper underlying problems in the control of safety rather than the direct cause of accidents. Hence, they have suggested that the term human error should be replaced by considering such events as human-task mismatches instead.

Wang[10] proposed a probability analysis model of offshore fire using the method of converting the fault tree into Bayesian Network to incorporate the effect of human and organizational factor. The three basic events they have identified related to alarm is not hearing the alarm, not properly identifying the alarm and alarm panic; in which all of them are due to human factors. On the other hand, they have also discussed that not obeying the provided standards and not complying with instructions generally contribute mostly to the occurrence of fire scenarios. Hence, controlling these crucial events would reduce the probability of a fire accident.

Studies above show that there is a significant need to study human factors affecting the efficiency and effectiveness of F&G detection system. Most of the studies above do not discuss the type of alarm that is needed to be installed in a process plant in order to achieve the target SIL. Hence, this study will discuss the comparison of a standard alarm and safety-related alarm and the SIL achieved for both. To further analyze the system, the most influencing factor affecting the effectiveness of the safety-related alarm will be identified and discussed.

3 | METHODOLOGY

A fault tree analysis has been done by using two types of alarms, that is, standard alarm and safety-related alarm. The result will identify which alarms are able to meet the requirement of SIL for F&G systems. The results will also identify the weak links within the F&G system and provide a basis for as low as reasonably achievable (ALARP) recommendations. Three types of detectors (detectors are of 1ooN voting) will be studied and the results will be compared, that is, flammable gas detector, flame gas detector, and toxic gas detector. Some typical vendor data has been adopted for this study.

Besides, the beta factor is assumed as follows based on IEC 61508[5]:

- 5% between identical devices
- 2% between diverse devices (like a different make and type of pressure transmitters or two pressure transmitters on different lines).

Typical vendor data has been used for the fire loops & gas loops, that is, detectors, logic solvers, and final elements, to build the fault trees. The data has been utilized to determine the SIL, or more accurately the safety availability, of the F&G system hardware.

3.1 | Overall PFD assumptions

The PFD for the F&G system is calculated using the fault tree analysis methodology as shown and summarized in Table 2. All data obtained has done an annual test interval.

4 | RESULTS AND DISCUSSION

Three Fault Tree Diagram has been constructed to assist the calculation of PFD for each detector type, that is, flame detector, flammable

TABLE 2 Input failure rates to fault trees

Equipment type	PFD	Data source
Flame detector failure	$2.19 \times ^{-3}$	5
Flame detector common causefailure	$5.72 \times ^{-5}$	2% as per IEC 61508
Flammable gas detector failure	$2.50 \times ^{-3}$	6
Flammable gas detector common cause failure	$1.25 \times ^{-4}$	5% as per IEC 61508
Toxic gas detector failure	$1.56 \times ^{-3}$	6
Toxic gas detector common cause failure	$7.80 \times ^{-5}$	5% as per IEC 61508
ESDV failure	$9.28 \times ^{-5}$	Typical data
ESDV failure common cause failure	$4.64 \times ^{-6}$	5% as per IEC 61508
Fire and gas panel failure	$1.00 \times ^{-3}$	Typical data
Operator action (standard alarm)	$1.00 \times ^{-1}$	IEC 61508
Operator action (aafety-related alarm)	$1.00 \times ^{-2}$	IEC 61508

gas detector, and toxic gas detector. The diagrams are as shown in Figures 4–6. Whereas the results of PFD achieved by each detector type are shown in Table 3.

As presented in Table 3, standard alarm achieved PFD that is higher compared to safety-related alarm. Technically, standard alarm for all detectors does not meet the SIL1 requirement. Hence, credit should not be given to this standard alarm in PHA studies. Compared to safety-related alarm, all of the detectors are able to meet the requirement of SIL1. The safety-related alarm that able to meet SIL1 would result in increased order of magnitude in the reliability of the overall F&G systems.

Although HF has been well understood for years, it is very hard to predict or measure HF; thus, the best way is only to estimate it. Various studies conducted by the American Institute of Chemical Engineers (AIChE), American Petroleum Institute (API), and other similar organizations have concluded that almost 80% of industrial incidents are linked to human errors.[11] When it comes to human–machine interaction (HMI), human is required to react or operate with the presence of an alarm. During this process, there are variables that cannot be precisely measured in operating environments. However, there are certain

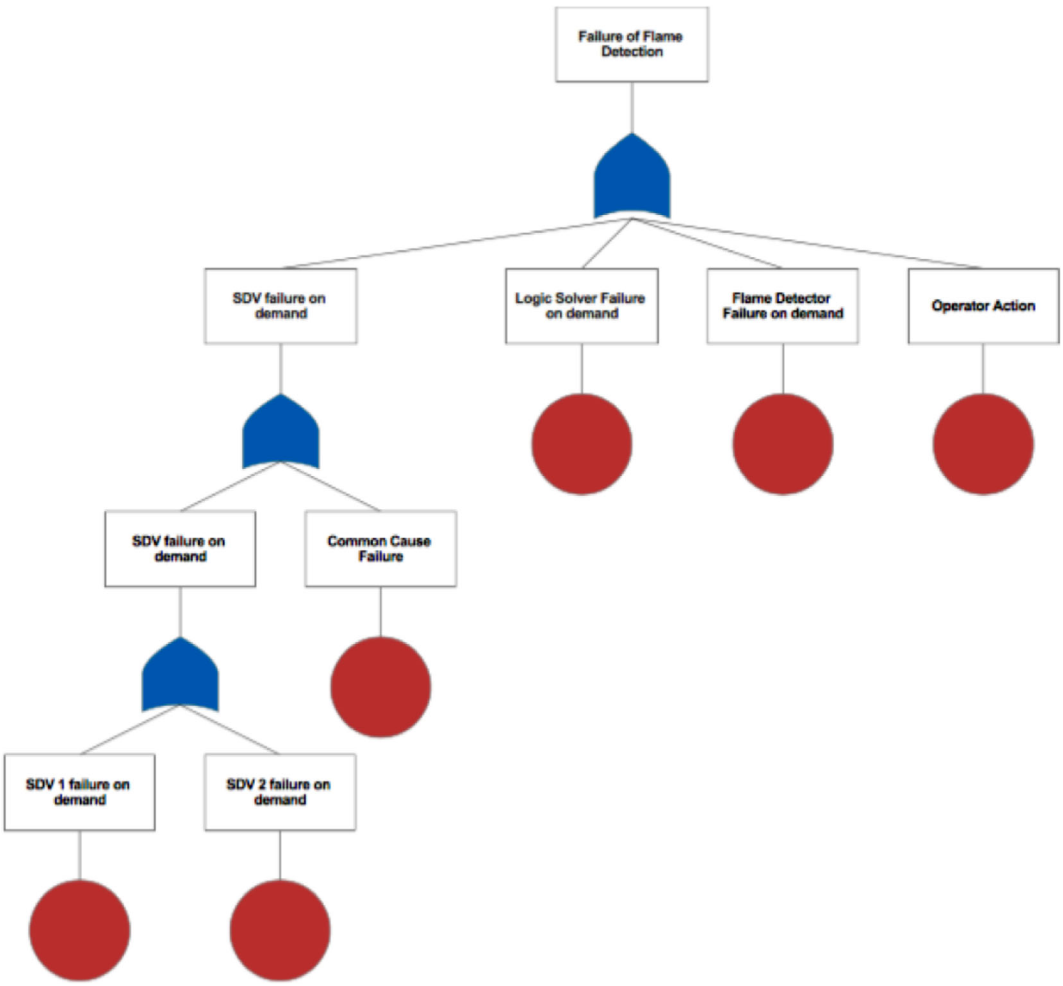

FIGURE 4 Fault tree analysis for flame detection [Color figure can be viewed at wileyonlinelibrary.com]

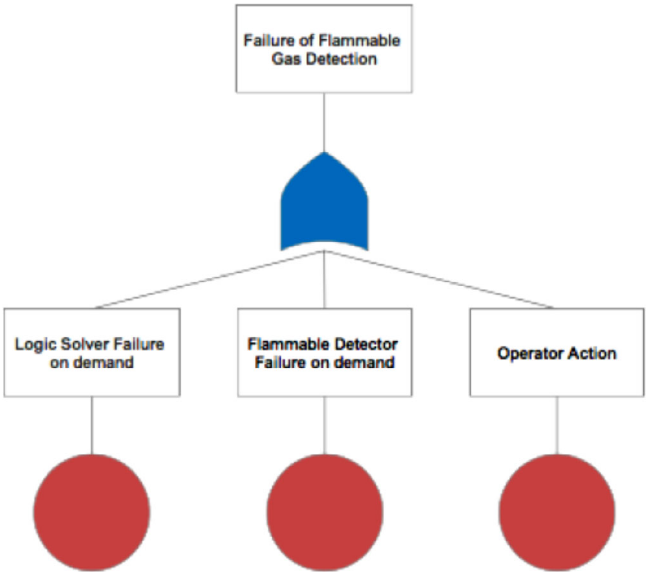

FIGURE 5 Fault tree analysis for flammable gas detection [Color figure can be viewed at wileyonlinelibrary.com]

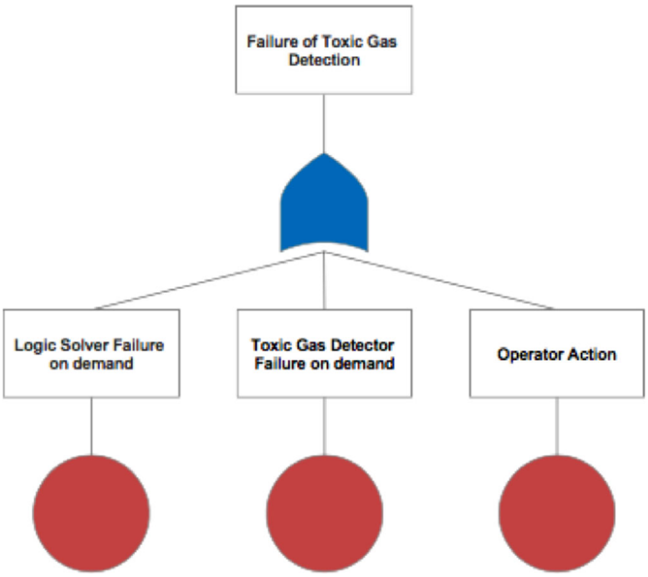

FIGURE 6 Fault tree analysis for toxic gas detection [Color figure can be viewed at wileyonlinelibrary.com]

human reliability requirements to be followed in order to efficiently consider operator intervention in F&G systems. In this section, two types of alarm will be discussed with regard to human reliability requirements. IEC 61511-3 has detailed guidance on claimed levels of performance with respect to alarms (range of PFD_{avg}).

4.1 | Alarm integrated with BPCS

Alarm and final element system may be integrated into process control systems. For such standard alarm, PFD_{avg} claimed can be in the range of 1-0.1. There are no special requirements for this alarm type. However, the alarm system should be operated, engineered, and maintained to the good engineering standards. In order for an operator to respond normally to a dangerous situation, the following criteria should be followed:

- Proper indications provided that there is a condition of process upset and the operator's action is required (ie, process shutdown).
- Proper training has been provided to the operator to react accordingly.
- The operator has enough time (more than 15 minutes) to react to the alarm.
- The operator is present and monitoring the process continuously.

TABLE 3 Comparison of PFD results

	PFD	
Detector type	Standard alarm	Safety-related alarm
Flame detector	$1.18 \times ^{-1}$	$1.45 \times ^{-2}$
Flammable gas detector	$1.12 \times ^{-1}$	$1.35 \times ^{-2}$
Toxic gas detector	$1.11 \times ^{-1}$	$1.15 \times ^{-2}$

4.2 | Safety-related alarm (as a part of HMA)

For this type of alarm, the alarm and final element systems should be designated as safety related and categorized as implementing SIL1 safety functions as defined in IEC 61508. The alarm and the final element system should be independent of the process control system (unless this has also been designated as safety related). In order to have this type of alarm, the standard of human reliability requirements shall be followed (will be discussed in next subchapter). It has been identified that claims for a PFD_{avg} below 0.01 are not made for any safety function, which relies upon operator action even if it is multiple alarmed and very simple.

4.3 | Safety-related alarm in F&G systems: human factors in practice

Human interventions are considered the weakest link in the system of F&G. For safety-related alarm, a PFD of 0.01 can be given, with strict adherence to the standard's requirements. This section will discuss the safety-related alarms recommendations that shall be followed if human reliability requirements are to be achieved and risks to be reduced to ALARP.

Safety alarms will allow credit to be given (in PHA studies) for the operator to take corrective action and ensure the plant operates in a safe condition as stated by ISA-18.2. The consideration of safety alarms to be incorporated (as stated in IEC 61511) safety life cycle as well as in the PHA shall be taken into account. A set of key performance indicators (KPIs) is defined by the Alarm Philosophy. The

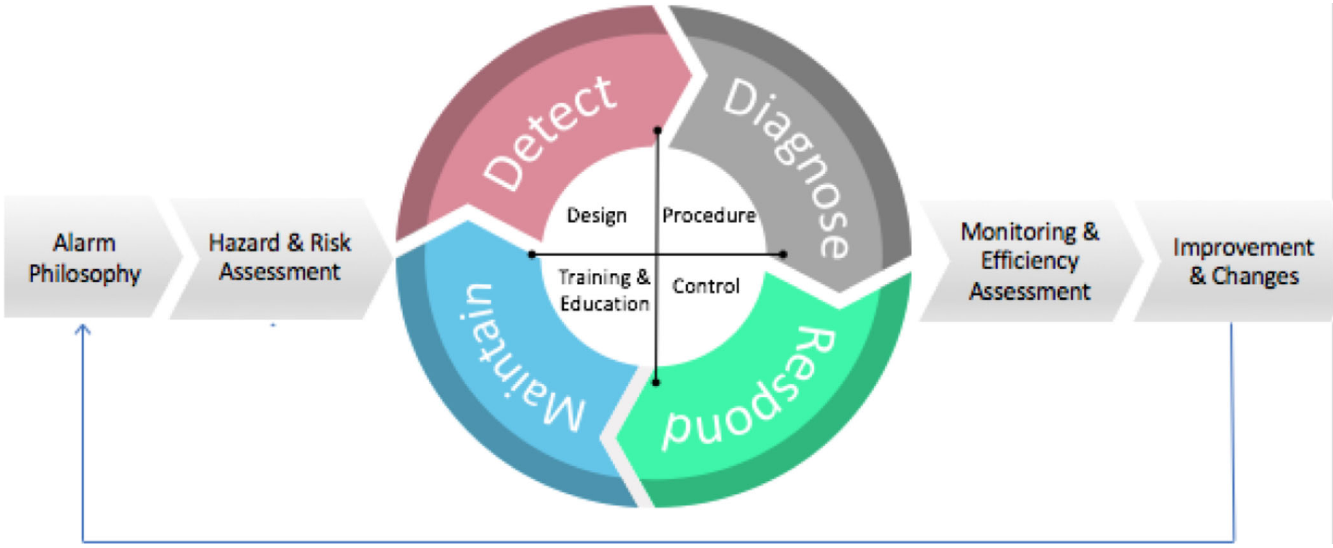

FIGURE 7 Coordinated approach for alarm system management [Color figure can be viewed at wileyonlinelibrary.com]

performance tolerance will be threshold limited while for coherent system performance goals will be identified. The initial state of the approach can be enhanced by routine monitoring, which defines the KPIs and further improvement and changes can be adapted to the initial state of the approach. As shown in Figure 7, the four cyclic processes that trigger human performance within the alarm system management will be discussed as follows.

4.4 | Detection

Annunciating alarm in a way that the operator can monitor and sense the problem by taking corrective action in a short time. The operator performance can be boosted, so, there will be no missed alarm or alarms been accidentally ignored. Below are the criteria discussed for effective alarm detection:

4.4.1 | High-priority alarms

High priority alarm shall be designed with different functionality compared to other alarms. It is suggested to design with 3-4 priorities by ISA-18.2 such as most of 5% of alarms are recognized as a high priority.[11] Since during alarm flooding, the operator tends to be in a stressful situation. This poses them with some additional challenges to make decision[12] when the most critical priority level alarms make the operator believes to be of lower significance. According to ISA-18.2, priority is established based on the immediate consequence of operator inaction and the time requirement for operator to response. ISA-18.2 also requires monitoring of alarm system performance. The standard is provided with metrics to evaluate the stress on the operator due to alarm. If the alarm system performance is not monitored, it might not be appropriate to take any risk reduction for response to alarm by operators making the RRF for safety alarms reduced to 1.

4.4.2 | Avoid alarm overload

When each operator is assigned with the overloaded amount of alarms, here the probability to ignore or miss the alarms is high.[8] İn ISA-18.2 stated that the operator should not handle more than 1–2 alarms for every 10 minutes in a steady-state condition.[12] In spite of that, operators still flooded with one alarm every 60 seconds, making the operator be less confidence in handling the alarms and lead to corrective actions might not be taken within the required time during this event.

4.4.3 | Human–machine interface (HMI)

There is a fact stating that around 0.5% of female population and 8% of male population have deficiencies in color vision. This group has deficiency highly in color vision discrimination, but they are not entirely “color-blind” compared to color normal.[11] Another way to differentiate this color when they still see the same hue can be assessed by the brightness area of this color that is different.

4.5 | Diagnose

Diagnosing the cause of alarm requires knowledge on the process and proper corrective actions to be taken. A set of exercises and fundamental in management needs to be equipped for the operators, then they will train to do the corrective steps in a right manner every time there are system malfunctions. For each alarm, hazards assessment and proper documentation of each operator's actions are prepared ahead. Furthermore, alarm response procedure (ARP) and the rationalization of the documents are included in the operator appropriate tools and training's aspect. These steps will help to assist the operators to access and perform the corrective action in the required time.

4.6 | Response

After examining the reason for the alarm, the operators will apply restorative actions. Alarm setpoint and process dynamics both lead to the operator response time.[13] The decision in identifying the alarm priority in order to attend which alarm first dependable on its location and rationality. Apart from that, when the alarms system is not coordinated and rationalized properly, the priority to decide which alarm to attend first will be at failing due to the operator will be puzzled. In this case, the consequences of the event will worsen as the preventive measures cannot be solved due to operators' lack of experiences and, therefore, alarms will be ignored. A significant role by the alarm priority causes the operators to take the right actions at the same time within the acceptable duration of time.

If the operators acted in corrective ways within an adequate time frame, the credit will be awarded for alarms in LOPA. The ability to respond by the operators within the timeframe is particularly why it should be considered a study during LOPA. Even when the operator handles in a controlled action, the undesired event might occur due to the decision making of obtaining the credit is done incorrectly.

4.7 | Maintain

Reliability, examine, maintenance, and failure indication - This section directs the reliability of the alarm system to convince that (a) the alarm notifies the alarm information to the operators in a secured path; (b) component and the alarm functions can be study/test periodically by the crews; (c) Maintenance of the alarm system has less interference, which ensures the alarm messages are easily comprehended and handled by the operators' ability; and (d) alarm system also designates to show any system failures.

4.8 | Monitoring and applying changes

Poor management or mismanaging alarm systems exacerbates the consequence of events, even when the alarms are designed with high technology. Implementation of a management of change (MOC) procedure is an excellent way to control the modifications (such as disabling an alarm, reduce or increase the alarm limit, or even modify its priority). When an alarm is used, a safety layer of protection, modifications for such alarms should not be made without proper analysis and justification. Therefore, an appropriate review by technical managers and board members is needed preceding to the implementations.

The software or system that is used should automatically save a log of all alarms that are generated over time. This will facilitate the auditing process and will give hints for improvement and changes to be done. In other words, on-going alarm rationalization by utilizing this log can determine any inconvenience alarms and conventional alarms (no user involvement). Cut down on obsolete alarms and other alternatives need to be determined to deal with such nuisance alarms. These may include modifying the set point or not raising an alarm until the alarm condition has been detected on two or more sensors.

Current studies show that several conventional methods of human factor assessment are often static, unable to deal with data and model uncertainty, and unable to consider independencies among failure modes.[14] To overcome the above limitations, it is highly recommended to use hybrid dynamic human factor model considering human factor analysis and classification system (HFACS), intuitionistic fuzzy set theory, and Bayesian network into missing human factor found in F&G system during the design stage. Meanwhile, in another report highlighted a proper functioning of the safety system depends on the reliability and the failure probability of the system.[15] In that regard, to determine the integrated system safety and calculation of risk management using bowtie model with an emphasis on LOPA is also recommended.

5 | CONCLUSION

Safety alarms are a highly effective layer of protection, with a higher risk reduction factor compared to standard alarm. The standard alarm can only be given an IPF of 0.1, wherease the safety-related alarm can be given and IPF of 0.01 provided the technical standards from the design stage through the operation and maintenance are strictly followed. Standard alarm for all detectors does not meet the SIL1 requirement. Hence, credit should not be given to these standard alarms in PHA studies. Compared with safety-related alarm, all of the detectors are able to meet the requirement of SIL1. Besides, human factor has been identified as the most critical element for safety-related alarm. Besides, it will be in higher importance to consider, if the actions toward the alarm are done manually by operators. Hence, it has been suggested that a coordinated approach is needed to ensure the performance and efficiency of F&G systems alarm system that can be maintained, whereas process plants are able to be safely operated within ALARP region. The four main key cyclic processes of the coordinated approach that triggers human performance within the alarm system management are detect, diagnose, response, and maintain.

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