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Optimizing Fire & Gas Detection Coverage and Layout using 3D mapping tools

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Abstract

A Fire & Gas Detection System enables detection of a gas release or a fire scenario and raises alarms and/or initiates appropriate control action (system isolation, deluge, facility shutdown, etc.). This serves to minimize the potential for escalation of events that could lead to a catastrophic damage. To achieve this objective, the coverage of fire and gas detectors should be sufficient to detect gas leaks and fires and this should be set as a performance requirement. Risk assessments which take credit for successful detection of a release activating isolation and blowdown must be required to demonstrate the assumed performance can be achieved. Relying on conventional approaches based on experience and engineering judgement for developing fire and gas detector layout may not be sufficient. A 3D evaluation of the process unit helps to improve the coverage and demonstrate performance, taking into account detector specifications (technology, sensitivity, detection range, etc.), voting logic and reliability.

This paper examines various aspects of fire and gas detection, identifying the gaps and inconsistencies that exist in the detector layout developed based on conventional approaches. Using case studies, the paper demonstrates the necessity to refine these approaches to ensure all hazard sources are covered sufficiently. Furthermore, this paper presents the benefits of adopting a 3D assessment for fire and gas detector coverage using appropriate software tools and the aspects to be considered when such 3D calculations are used to determine coverage. Using case studies, the paper demonstrates how such 3D techniques can optimize the number and location of detectors. It also presents a brief overview of how advanced modelling using Computational Fluid Dynamics (CFD) can be used to supplement the 3D mapping tools.

Introduction

The Fire & Gas Detection System (FGS) plays an important role in preventing escalation of gas leak or fire scenarios in both onshore and offshore oil and gas facilities. Similarly, early detection of toxic releases is also necessary for personnel protection. Ensuring the optimal reliability and performance of the FGS is therefore important. Successful detection helps limit the consequence footprint of hazardous events either through automatic action or through operator response to alarms. To achieve this objective, the detection coverage of fire and gas detectors should be adequate to cover the areas identified with hazard / potential. Also, the desired system performance has to be demonstrated based on the voting logic adopted by the facility (e.g. 1ooN for alarms, 2ooN for executive actions, etc.).

The conventional approaches for developing detector layouts based on operating experience and rule-of-thumb practices may not ensure sufficient detection coverage and desired system performance. There exists a wide variation in the philosophies adopted for FGS implementation. This paper aims to identify the gaps and inconsistencies in traditional approaches for implementation of the FGS. It also aims to demonstrate how 3D Fire & Gas mapping software tools can be effective in optimizing the numbers and locations of fire and gas detectors to achieve optimal FGS performance and desired coverage.

Linkage to Quantitative Risk Assessment (QRA)

A high probability (typically 90%) of successful fire and gas detection is usually assumed in QRAs. This assumption, however, is normally not verified against the actual FGS performance and detection coverage achieved for the relevant areas. In reality, aspects such as provision of detectors only for limited equipment, practical limitations in terms of coverage achieved due to high degree of congestion etc. may tend to increase the gap between the assumptions on probability of successful detection in QRA and the actual achievable detector performance. Therefore, without a systematic verification process to ensure that the FGS performance can meet the assumptions used in the QRAs, the risks associated with a facility may be underestimated. Although there are some guidelines which require the effectiveness of detection and detector reliability to be assessed to ensure the residual risk is within acceptable limits [1], these are not uniformly adopted. Gaps in system performance may therefore continue to propagate from the design phase to the operational phase of facilities. This aspect is also further substantiated by historical data [2], which shows that only about 50% of the major leaks were actually detected by detectors. This number is significantly lower than the assumptions in QRA. This reinforces the necessity to refine the existing approaches to ensure FGS performance meets the required level. It also calls for deeper insight into the other relevant aspects of FGS design which are discussed in this paper. A risk based approach may eventually prove to be one of the best ways forward.

Are all hazards covered?

Prior to establishing the FGS performance, the design must determine which equipment require detection. This step forms the basis for the provision of detectors and hence, caution must be exercised to ensure that all hazard sources are identified. In the authors’ experience, this is an area where inconsistencies are observed. There are various philosophies adopted both in terms of locations of detectors and equipment to be protected, with some approaches resulting in minimal detection.

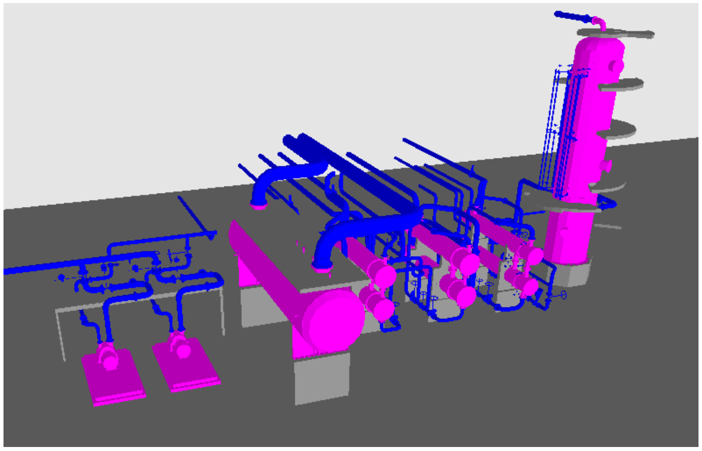
The authors have seen similar facilities with significant differences in terms of provision of detectors owing only to differences in considerations. In some projects (especially onshore) only rotating equipment are provided with detection while others have considered all hydrocarbon handling equipment (rotating, static) as credible hazard sources. Even for rotating equipment, depending on capacity, composition, process parameters, etc., it is often the case that not all hydrocarbon handling rotating equipment are provided with detection. For example, pumps handling flammable materials other than LPG may not be protected with detectors although they handle hydrocarbon liquid at elevated temperatures or close to boiling point.

A common assumption is that static equipment are not a credible leak source or have a low frequency for external releases. However, clusters of static equipment located in a congested layout or in a modular structure when considered along with their connections and instrumentation may result in a leak frequency as high as rotating equipment, if not higher. Without verifying the provision of detectors in such areas, credit for successful detection and subsequent isolation may also have been assumed in the QRA or Fire Risk Analysis (FRA) to reduce the risk associated with these equipment. Some references [3] do consider that a cluster of valves and flanges will constitute a hazardous area by themselves, but again these are not uniformly adopted. Another example observed in the many designs is to provide detectors for pumps / equipment handling liquid at auto-ignition temperature but no consideration applied for pumps handling liquid close to boiling point. Even in the upstream sector (i.e. fixed platforms, FPSOs), where a more stringent detection requirement is expected, often sufficient detection is not provided citing reasons such as higher maintenance costs, especially when reviewing the detection requirements for normally unmanned installations.

In most cases highlighted above, no clear justification is provided for not providing detectors for all the hazard sources. To some extent, the reason for above inconsistencies is the lack of clear guidelines regarding which equipment should be protected. Each operating company or the design consultant is basing the detection requirements on their operation experience, engineering judgement and past practices. To ensure that all hazards are covered adequately, it is therefore necessary to develop a minimum standard to determine the requirements for detection for process equipment. The most effective way to undertake this exercise is to evaluate the nature of the hazards (jet fire, pool fire, flammable gas release, toxic gas release) associated with each equipment or cluster of equipment including valve assemblies in an area depending on the process stream composition and fluids (e.g. pressurized gas, heavy liquid, flashing liquid, liquefied gases, etc.) handled. This information can then be used to determine the type of detectors (fire and/or gas) required at an equipment or area level. For equipment handling toxic materials, concentration above IDLH [4] in the process stream can be an appropriate threshold for determining the requirements for detection. In addition to equipment, even areas with clusters of leak sources, such as PSV platforms or valve manifolds may need a thorough review to determine the requirement of detection.

For instance, a pump handling LPG will require both fire and gas detection where as a pump handling Diesel or Kerosene may only require fire detection (unless operating at elevated temperature). Even while defining the area for protection (grading), consideration must be given to the process parameters and components. For example, will the release be buoyant or heavy, will it result in a pool fire or a jet fire or both, etc. Such considerations will enable the development of a sound basis for provision of detectors. Although the area (grading) considered for protection may vary based on the operating company, applicable guidelines, etc., it is essential to capture the hazards correctly to ensure that the effectiveness of the FGS will be enhanced.

As an example, a sample geometry with typical processing equipment as shown in Figure 1 was developed to demonstrate the considerations highlighted in this paper. Assuming the service conditions for the equipment as presented in Table 1, the requirements for detection have been summarized. Ideally, an appropriate justification should be provided for considering or not considering the provision of detectors for each equipment.



Note: The sample geometry was generated using IRESC's proprietary in-house 3D fire & gas mapping software tool.

Figure 1. Sample Area 1

Table 1: Detection Requirements for Sample Area 1

Equipment Tag	Equipment Name	Hazardous Components#	Flame Detection	Flammable Gas Detection	Toxic Gas Detection
P-100A/B	Process Pumps 1	6% H_2S, 16% C2 to C4, 17% C5 to C6, 61% C7+	Y	Y	Y
V-100	Process Vessel 1	6% H_2S, 2% H_2, 9% C1 to C4, 2% C5 to C6, 81% C7+	Y	Y	Y
E-100 A/B	Heat Exchangers 1	12% C3 to C4, 27% C5 to C6, 61% C7+	Y	Y	N
E-200 A/B	Heat Exchangers 2	2% H_2S, 1% CO, 1% SO_2, 2% H_2, 40% H_2O, 54% N_2	N	N	Y
E-300 A/B	Heat Exchangers 3	5% H_2S, 71.5% C1 to C4, 23% C7+, 0.5% NH_3	Y	Y	Y
C-100	Column 1	48% H_2, 52% C1 to C4	Y	Y	N

Note:
Components with molar fraction ≥ 1% for hydrocarbon, or concentration ≥ IDLH value for toxic gas (i.e. 100 ppm for H_2S, 300 ppm for NH_3, etc.) are listed for reference.

What types of detectors are required?

Following the requirements for detection, the type of detectors required also need to be determined. While undertaking this exercise based on the process stream composition, some refinement can be applied to this step using engineering judgement. For example, if a process stream handled by any equipment comprises both flammable and toxic materials, would both types of detectors be required? Provision of only one type of detector (flammable or toxic) may be sufficient, depending on whichever will alarm first considering dilution to the desired set point after a release, while taking cross credit for detecting the secondary hazard. A similar consideration may also be adopted when a process stream contains more than one toxic material (e.g. H_2S, NH_3, CO, etc.). In this case, dilution calculations must be performed using the process stream composition and individual detection set points to verify which type of detection will provide an earlier alarm. However, the authors would like to point out that care must be taken to ensure that these cross credit considerations are applicable to all operating modes and all streams handled by the equipment. Separate detection may otherwise be required. There is also a lack of clear guidelines for determining the type of detection and threshold to be considered when the process stream contains both H_2 and hydrocarbons. This is an area that warrants further in-depth assessment to provide clear guidance that can be uniformly implemented in the industry.

Table 2 revisits the requirements for detection for the Sample Area 1 with the application of the principles of cross credit. It is again stressed that such cross credit consideration can only be applied to equipment which handle streams containing both types of materials (e.g. flammable and toxic) and at all operating modes. Individual types of detection may still be required for other equipment with streams which only pose one of the two hazards.

Table 2: Modified Detection Requirements for Sample Area 1

Equipment Tag	Equipment Name	Hazardous Components[#]	Flame Mapping	Flammable Gas Mapping	Toxic Gas Mapping
P-100A/B	Process Pumps 1	6% H_2S, 16% C2 to C4, 17% C5 to C6, 61% C7+	Y (HC)	Y (HC)	‡
V-100	Process Vessel 1	6% H_2S, 2% H_2, 9% C1 to C4, 2% C5 to C6, 81% C7+	Y (HC)	Y (HC)	‡
E-100 A/B	Heat Exchangers 1	12% C3 to C4, 27% C5 to C6, 61% C7+	Y (HC)	Y (HC)	N
E-200 A/B	Heat Exchangers 2	2% H_2S, 1% CO, 1% SO_2, 2% H_2, 40% H_2O, 54% N_2	N	N	Y (H_2S)[^]
E-300 A/B	Heat Exchangers 3	5% H_2S, 71.5% C1 to C4, 23% C7+, 0.5% NH_3	Y (HC)	*	Y (H_2S)[++]
C-100	Column 1	48% H_2, 52% C1 to C4	Y (HC)	Y (HC)	N

Note:

Components with molar fraction ≥ 1% for hydrocarbon, or concentration ≥ IDLH value for toxic gas (i.e. 100 ppm for H_2S, 300 ppm for NH_3, etc.) are listed for reference.

* Flammable gas detection is inferred by toxic (H_2S) gas detectors. Based on stream composition, toxic (H_2S) gas detectors will alarm first considering the alarm set point and dilution factor.

‡ Toxic gas detection is inferred by flammable gas detectors. Based on stream composition, flammable gas detectors will alarm first considering the alarm set point and dilution factor.

^ CO is inferred by toxic (H_2S) gas detectors. Based on stream composition, toxic (H_2S) gas detectors will alarm first considering the alarm set point and dilution factor.
++ NH_3 is inferred by toxic (H_2S) gas detectors. Based on stream composition, toxic (H_2S) gas detectors will alarm first considering the alarm set point and dilution factor.

Current Industry Practices / Conventional Approaches

Traditional rule-of-thumb approaches for locating fire and gas detectors are typically based on 2D equipment layouts and are mainly developed using operational experience, engineering judgement and based on past practices adopted by the respective facilities. Direct implementation of these approaches often lead to too many detectors and / or inadequate coverage. Too many detectors result in increased capital expenditure and maintenance costs, while fewer than required detectors lead to less coverage. The traditional 2D approaches may also not accurately account for and/or benefit from the detector parameters (sensitivity, range / target gas cloud size, etc.). Additionally, a 2D assessment may also not be sufficient to adequately capture considerations related to voting logic for both fire & gas detection, cross deck / cross elevation coverage for gas detection, combination of point type and open path type gas detectors, etc. Furthermore, a 2D assessment can also lead to issues during installation and commissioning phase especially for flame detectors since it is difficult to provide appropriate elevation and view angle or minimize line of sight obstructions for flame detectors without taking into account the actual physical environment.

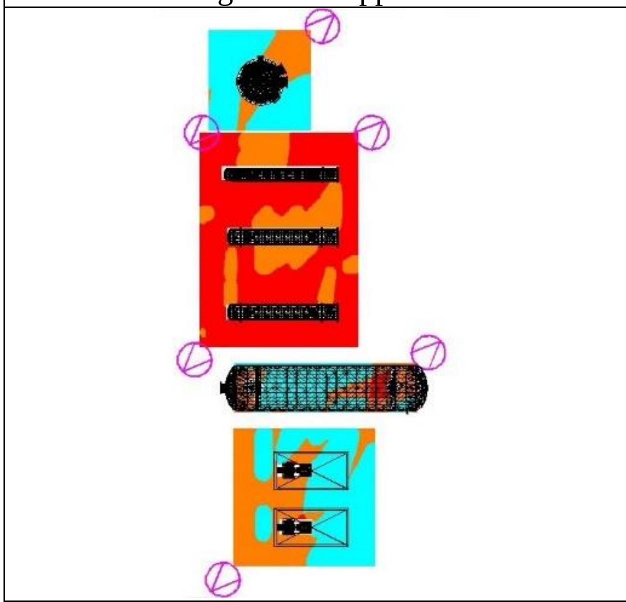
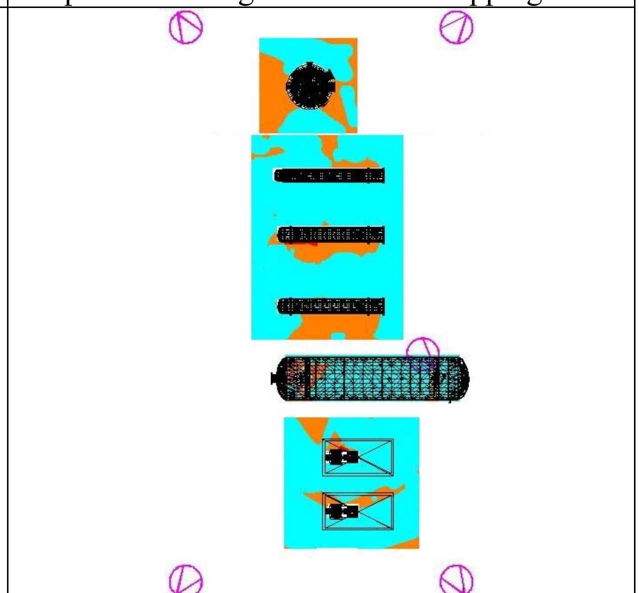
A 3D Fire & Gas Mapping software tool provides a way forward that can address these concerns. There is a trend in the industry to move towards using a 3D fire & gas mapping software tool to optimize the number and location of fire and gas detectors. A detailed discussion on the benefits of using a 3D tool and the requirements set forth for such 3D tools to deliver on their potential is provided later in this paper. The following subsections provide a brief comparison of the typical conventional approaches for locating fire and gas detectors versus 3D mapping tools.

Fire Detection

A "*target based approach*" is perhaps the most common approach adopted for determining the location of flame detectors. Individual sets of flame detectors (or a single flame detector depending on philosophy) are provided for each set of equipment requiring flame detection. This approach may lead to a high number of detectors since the analysis does not take credit of the detector sensitivity and range considering the target fire size. Furthermore, using only a 2D equipment layout to place detectors at opposite ends (refer to Figure 2) may not be sufficient. Without considering the actual physical environment in the area of concern, it is not possible to ascertain whether the flame detectors have a clear line of sight to the target or in other cases that the clear line of sight is maximized. Also, it may not be possible to accurately determine whether the required coverage target has been achieved especially where detector voting exceeds 1ooN.

Typically, for fire detection, a similar target fire size is selected for the entire facility (although it is important to note that given the higher risk and asset loss potential, offshore facilities generally tend to use a smaller target fire size as compared to onshore facilities). Hence, a 3D fire mapping software tool which considers the target fire size, flame detector sensitivity, range, field of view (from datasheet) and other associated parameters can allow for optimizing the number and location of flame detectors for groups of equipment located in the same area, while ensuring the coverage target is also achieved considering the required voting logic (1ooN, 2ooN, etc.). There are however a number of additional aspects including fire grading (area to be protected), detector yee and yaw angles, etc. which need to be defined in a three dimensional analysis.

A brief comparison of the number of flame detectors and coverage achieved considering the target based approach and optimization using IRESC's proprietary in-house 3D Fire & Gas Mapping software tool is provided in Figure 2. As seen from the figure, a three dimensional analysis can help optimize number of detectors and ensure coverage target is achieved while capturing different voting logics. It also demonstrates that the performance target can be achieved with optimized detector locations (and fewer detectors for this case) without compromising safety.

Target based approach						Optimized using IRESC's 3D mapping tool					
											
No. of Detectors			6			No. of Detectors			5		
0ooN	34.5	1ooN	31.1	2ooN	34.4	0ooN	0.2	1ooN	17.6	2ooN	82.2

Note: Detector range assumed to be 40 m which is typical for onshore facilities.

Figure 2: Flame Detection for Sample Area 1

Gas Detection

"*Leak source based approach*" is the most common approach adopted for locating gas detectors in the authors' experience. In this approach, point type gas detectors are placed close to the leak sources identified which may include pump seals, flanges, valves, etc. Since the selection of likely leak sources is based on experience and engineering judgement, there is a wide variation in the identification of potential leak sources. The authors have seen projects where only rotating equipment seals are considered as a leak source while others consider all flanges, valves, etc. as leak sources. Gas leaks at valve manifolds or clusters of status equipment, if left undetected, may also accumulate and result in an explosion. The above differences in consideration results in high variation in the number of detectors provided for similar facilities.

Another approach, namely the "*grid / spacing based approach*" is a prescriptive form of locating gas detectors. Gas detectors are located at a fixed spacing / fixed distance (representing the target gas cloud size) based on prescriptive guidelines. The typical spacing used in this approach is 10 m for an open area corresponding to onshore facilities. Offshore facilities lie either in the open domain or a partially enclosed domain (spacing for partially enclosed volumes is between 5 to 7 m). The actual spacing adopted may vary with operator, but typically the upper bound in this approach is about 10 m. For toxic gas detection, this approach intends to provide general area coverage to alert operators and limit migration. In this approach, the detector locations are entirely based on even distribution across the area of concern without taking into account leak source locations, prevailing wind direction or impact of physical environment on the footprint of the gas clouds. This approach is on the conservative side and likely to result in a large number of detectors, which may not necessarily improve the probability of successful detection but will definitely increase the likelihood of spurious trips and life cycle maintenance costs. Also, this approach tends to provide detection at grade level and thereby leak sources at higher elevations such as valve manifolds, elevated platforms, column top connections, etc. may go unprotected, unless the same approach is adopted at higher elevation as well.

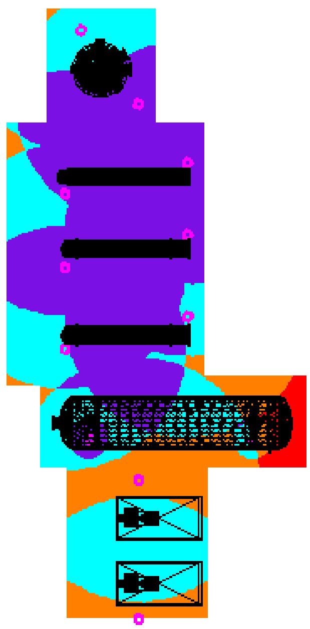
A "*congestion/consequence based approach*" is proposed in guidelines developed by some operating companies where flammable gas detectors are placed considering the potential for explosion to occur (i.e. inside congested areas where leak sources are located). In this approach, the typical target gas cloud size lies in the range of 5 m to 10 m diameter depending on the area characteristics (level of congestion, confinement, fuel, etc.). Since the direct application of default target gas cloud size may be conservative, the guidelines allow for further refinement of cloud size using either dispersion and/or explosion modelling (a damaging overpressure threshold of 150 mbar is typically adopted [5]). This is an important step to keep the assessment practical. The selected cloud size can then be used to determine the coverage achieved using specialized 3D software tools, also taking into account detector voting logic etc. This is a consequence based assessment where the selected gas clouds are modelled as idealised spheres. In this approach, usually dispersion modelling is also conducted for determining the cloud size for toxic gas detection. This approach is suitable for congested areas in onshore or typical offshore facilities. However, for open areas, a direct implementation may result in excessive detectors. In this regard, the authors have also discussed a "*Minimum Requirements Approach*" in another paper [6] which uses a combination of congestion based and leak source based approaches to arrive at a practical number of detectors without compromising safety.

There are also some less common approaches such as the "*likely accumulation approach*" which places detector in the area where accumulation of gas cloud is likely. This approach is intended to utilize the density difference between process fluids and ambient air. So for dense gases, they are assumed to sink and location of detectors will therefore be limited to grade level while buoyant gases are assumed to accumulate under a roof where detectors may be located. However, pressurized releases will tend to mix rapidly with air to form flammable mixtures whose location is not limited by elevation and these mixtures can get ignited resulting in an explosion. Such considerations are not accounted for in this approach.

Other approaches such as “*dispersion based approach*” utilize CFD dispersion simulations to optimize gas detector locations based on rate of successful detection and the time required for detection. This approach is discussed further in later sections of this paper.

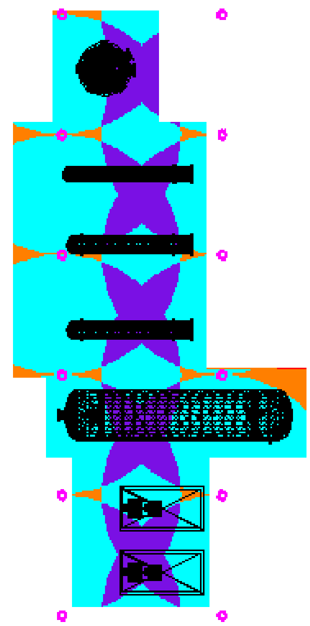
A brief comparison of the coverage achieved considering the various approaches discussed above is provided in Figure 3. The geographical coverage provided by different detector layouts was assessed using IRESC’s proprietary in-house 3D Fire & Gas mapping software tool.

(a) Leak Source Based



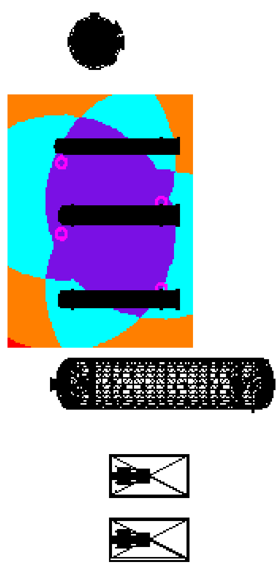
No. of Detectors		12	
0ooN	0.4	1ooN	17.2
2ooN	39.4	≥3ooN	43.0

(b) Grid Based

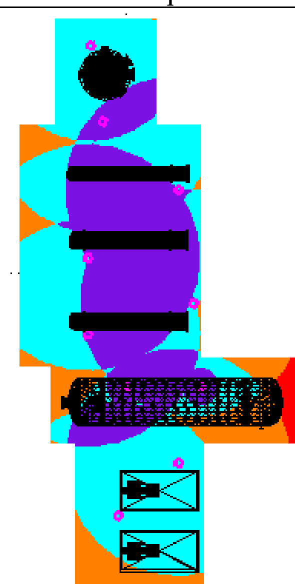


No. of Detectors		12	
0ooN	5.9	1ooN	25.8
2ooN	56.9	≥3ooN	11.4

(c) Consequence Based



(b) Minimum Requirements Based



No. of Detectors		4		No. of Detectors		10	
0ooN	4.2	1ooN	31.5	0ooN	1.5	1ooN	18.4
2ooN	36.4	≥3ooN	27.9	2ooN	43.1	≥3ooN	37.0

Note: Target Cloud Size: 15 m

Figure 3: Volumetric Coverage of Typical Conventional Approaches and 3D F&G Mapping

Use of 3D Mapping for Optimization of F&G Detector Layout

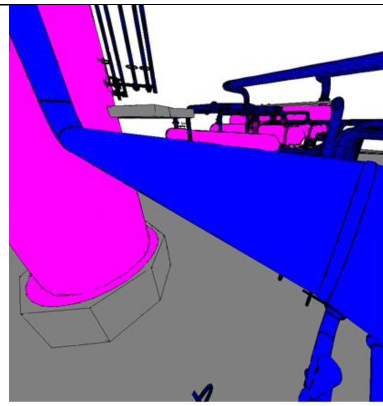
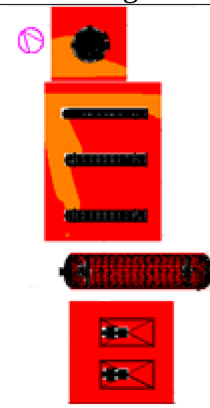
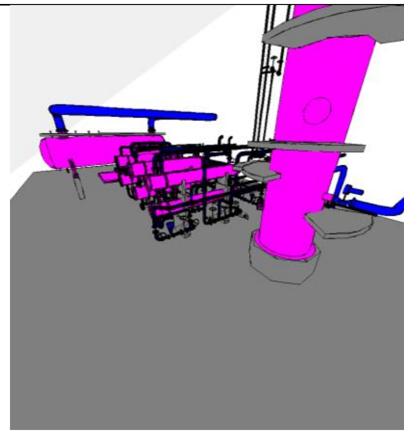
As described in earlier sections, direct application of rule-of-thumb approaches to locating detectors and inconsistencies in the identification of hazardous areas nature of hazards and/or equipment covered for detection leads to either too many detectors and/or inadequate coverage. The further refinement of these practices coupled with a fully three dimensional assessment is definitely the way forward for the assessment of FGS performance. 3D mapping software tools will allow for quantitative optimization of fire and gas detection coverage taking into account the actual physical environment and the detector parameters. It presents the user with a clear picture to locate detectors in more practical, easy to access locations without compromising coverage or safety. It is not desirable to find out during installation at site that a proposed detector location is impractical. Hence, it is important that the right 3D model at the right stage is used as it forms the core of the assessment. A 3D fire & gas mapping software tool can be customized to predict the coverage achieved using the same detector configuration for different voting logics and also providing information on contribution to overall coverage from individual detectors. In general, the 3D tools enable designers to assess at what point and with how many detectors is a practical limit reached, after which the provision of additional detectors does not justify their cost.

Noting all the above considerations, to some extent, it is safe to say that such 3D tools coupled with some refinement in hazard identification can help achieve a balance between safety, cost and reliability. The authors would also like to highlight some finer aspects of 3D mapping as discussed below.

<u>3D Flame Detection</u>

3D tools for flame mapping enable the visualization of actual obstructions by equipment, structures and piping to the flame detector line-of-sight which cannot be accounted in a 2D assessment. These obstructions are typically accounted for in a 3D coverage calculation. With optimization in a 3D environment, flame detection coverage can be improved significantly by placing detectors at locations with optimal view angles. A 3D assessment also enables to ascertain with confidence the elevation and yee and yaw angles to be used for individual flame detectors, which are parameters left for the team at site to decide in a 2D assessment. The parameters used for the assessment also tend to differ based on project philosophy, type of facility and the specifications. A 3D tool with customizable input parameters provides the right amount of flexibility to allow users to define detection range, target fire size, horizontal & vertical Field Of View (FOV) based on detector datasheet and project specifications. A sample comparison is provided in Figure 4. As shown in this figure, what seems as an appropriate location for flame detector based on a 2D assessment results in an obstructed line of sight and poor coverage. With 3D optimization, the coverage is improved significantly with the same detector. Other aspects such as solid angle corrections can also be accounted for.

2D Detector Placement

Layout	Detector View		Coverage	
				
No. of Detectors: 1	0ooN	83.3	1ooN	16.7
3D Detector Optimization				
Layout	Detector View		Coverage	
				
No. of Detectors: 1	0ooN	51.1	1ooN	48.9

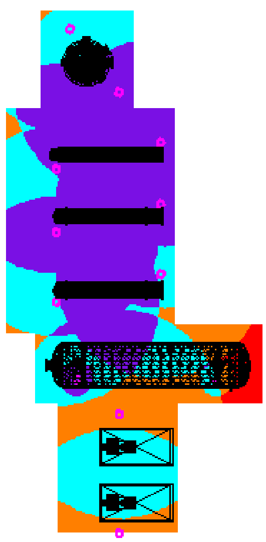
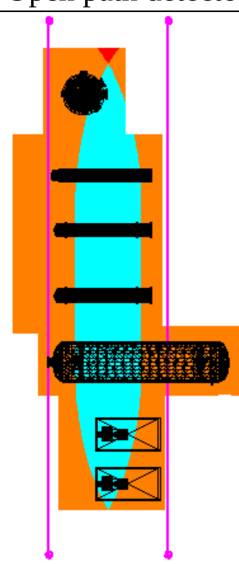
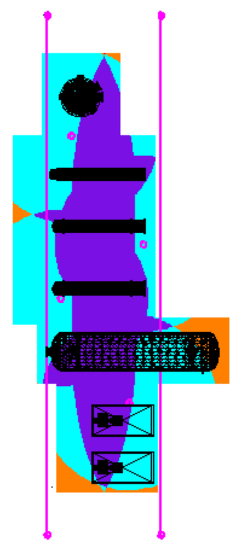
Note: Detector range assumed to be 40 m which is typical for onshore facilities.

Figure 4: Flame Detection - 2D vs 3D

<u>3D Gas Detection</u>

Similar to fire detection, 3D tools provide benefits for gas detection as well. The open path detectors are based on clear line of sight between source and transmitter (also referenced as receiver) and hence, a 3D assessment using open path gas detectors shares some of the benefits as those already discussed for flame detection. Additionally, a 3D tool for gas detection can provide accurate coverage calculations for a selected volume considering the desired target gas cloud size and voting logic. Factors such as cross credit between different types of gas detectors can also be accounted for in the calculations.

Gas detectors are mainly two types i.e. point type detectors and open path type detectors. 3D mapping tools can help optimize gas detection coverage using only point type detectors, open path type detectors or a combination of both. It is not easy to predict whether the required coverage target has been achieved, especially when using a combination of the two types of gas detectors without the support from a robust 3D mapping tool. For large units and/or complex areas, the use of only point type detectors may result in a large number of detectors, which also increases the overall life cycle cost. For such scenarios, using a combination of detectors may be beneficial which can be effectively evaluated using 3D mapping tools. A comparison of these options is shown in Figure 5.

<table>
<tr><th colspan="4">Point type detectors</th><th colspan="4">Open path detectors</th><th colspan="4">Combination of Both</th></tr>
<tr><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td colspan="2">No. of Detectors</td><td colspan="2">12</td><td colspan="2">No. of Detectors</td><td colspan="2">2</td><td colspan="2">No. of Detectors</td><td colspan="2">6</td></tr>
<tr><td>0ooN</td><td>0.4</td><td>1ooN</td><td>17.2</td><td>0ooN</td><td>4.6</td><td>1ooN</td><td>71.3</td><td>0ooN</td><td>2.8</td><td>1ooN</td><td>16.1</td></tr>
<tr><td>2ooN</td><td>39.4</td><td>>3ooN</td><td>43.0</td><td>2ooN</td><td>24.1</td><td>>3ooN</td><td>0.0</td><td>2ooN</td><td>51.3</td><td>>3ooN</td><td>29.8</td></tr>
</table>

Note: Target Cloud Size selected was 15 m

Figure 5 - Comparison between considering different type of gas detectors

For complex congested modules located in onshore facilities or offshore in FPSOs/FLNGs or multiple congested decks in an offshore platform, gas clouds can migrate through the decks (assuming they are grated and not plated) and accumulation may occur across the entire module / entire platform. Gas detectors may be placed at various elevations in the module / across multiple decks. A 2D assessment cannot capture this feature accurately and it may result in a high number of detectors since the benefit of cross deck / cross elevation contribution remains unutilized. The authors would however, advise caution when considering cross deck contributions since this consideration is also dependent on the density of process fluids. For instance, detectors at the uppermost deck should not be considered to detect heavy gases that will accumulate close to the grade level.

Figure 6 shows a sample modular area (denoted as Sample Area 2) developed for this purpose. Figure 7 below demonstrates the difference in detection coverage between assessment with and without taking credit for cross-deck coverage. The coverage by 2 or more detectors significantly increases after taking credit for cross-deck coverage.

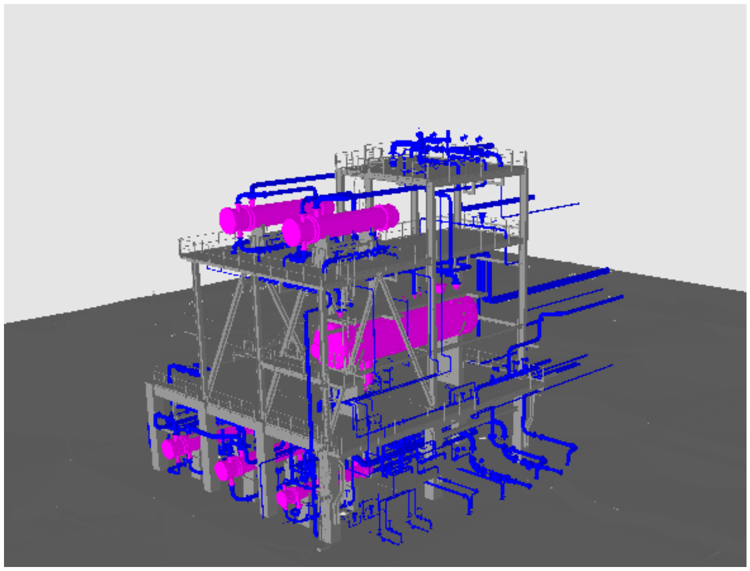
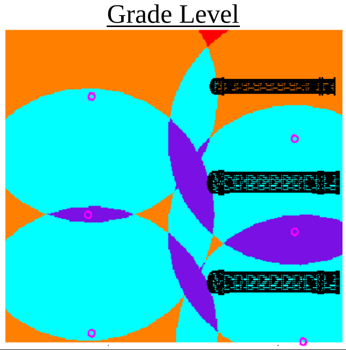
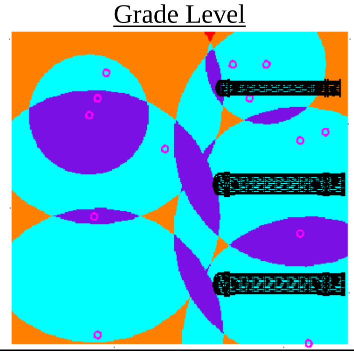
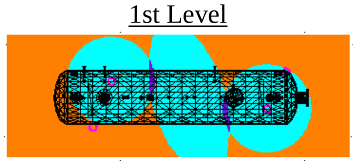
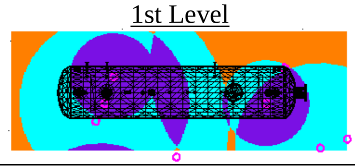
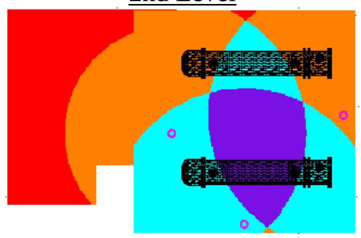
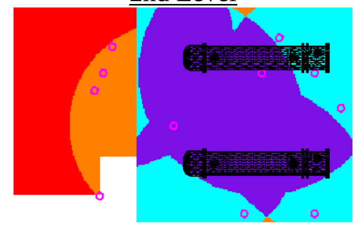


Figure 6: Sample Area 2: Modular Structure

(a) Without Cross-Deck Credit	(b) With Cross-Deck Credit
Grade Level 	Grade Level 
1st Level 	1st Level 

2nd Level 				2nd Level 			
No. of Detectors		13		No. of Detectors		13	
0ooN	5.8	1ooN	34.9	0ooN	6.7	1ooN	13.3
2ooN	51.0	>3ooN	8.3	2ooN	50.3	>3ooN	29.7

Note: Target Cloud Size selected was 15 m

Figure 7: Effect of Cross-deck Credit on Flammable Gas Detection Coverage

Other Considerations

Detector Reliability

In addition to achieving the target geographical coverage, the FGS performance also depends on the reliability of detectors. For example, if a 1ooN coverage of 90% is achieved by providing a detector whose reliability is 90%, this means that the actual detection probability is only 81%. The detection probability will drop further to 73% in case a 2ooN voting logic is adopted [6]. Detectors may be unavailable due to failures or periodic maintenance activities leading to inadequate coverage. This effect is magnified for facilities that adopt 1ooN voting logic (i.e. coverage by a single detector) where a number of areas may only be provided with a single detector. One way to overcome this issue is to consider "N = M+1" when considering a voting logic of MooN (M out of N detectors). Simply put, this means that a minimum number of detectors required for an area adopting a 1ooN voting logic would be 2. Similarly, for a 2ooN voting logic, the minimum number of detectors would be 3 and so on. This approach would ensure the coverage target is achieved even if one of the detectors is not available. The investment and life cycle cost of additional detectors increases, but has to be evaluated based on a cost-benefit analysis

Applications of CFD Modelling in 3D Fire and Gas Mapping

As discussed earlier in this paper, the typical target cloud sizes suggested by guidelines from some operating companies are refined further using explosion modelling. For this purpose, CFD based explosion modelling can be performed to determine the target cloud size required to limit the explosion overpressure to below 150 mbar [5], which is the threshold for damage to structures/ equipment. The simulations can be conducted for a range of process stream compositions as applicable to the facility and also considering different levels of congestion depending on the characteristics of the areas where they are handled. A "*dispersion based approach*" using CFD simulations may also be adopted for determining the probability for successful detection for a given detector layout. Flammable gas clouds are never perfect spheres, especially those produced from high pressure momentum releases. For example, a narrow elliptical gas cloud may slip through and remain undetected. Since typical consequence modelling software using Gaussian dispersion model do not account for the effect of obstructions in gas dispersion, this results in inaccurate prediction of gas cloud shape, especially in the near-field area. This is where CFD dispersion simulations can help in predicting a more realistic dispersion footprint of flammable gas cloud and thereby, a more realistic detection success probability. Furthermore, CFD based dispersion simulations can also enable prediction of the time required for detection of different leak scenarios. The detector layout can then be optimized to meet the assumptions used in the risk assessments to minimize the potential for escalation.

Although more accurate, CFD techniques are resource and time intensive. Typically, due to these limitations and to maintain a practical timeframe for the assessment, only a limited number of leak scenarios are considered. Furthermore, the selection of leak scenarios is based on experience and engineering judgement only. Hence, it may not be sufficient to use the results from only a limited number of scenarios to decide the detector layout for the entire facility. This is an area which needs further work in order to determine an effective way to combine the assessment of FGS performance with advanced modelling considering time and resources.

Conclusions

This paper has examined various aspects of fire and gas detection, identifying the gaps and inconsistencies that exist in detector layout development using current practices which are based on operational experience, engineering judgement and conventional approaches. The paper has emphasized the necessity to correctly determine the requirements for detection at an equipment level before developing the detector layout such that the the safety of the facility is not compromised. Using case studies, the paper has demonstrated the benefits of adopting a 3D assessment for verifying fire and gas detector coverage using appropriate software tools. CFD based modelling tools can also help in optimizing detector performance.

Through this paper, the authors aim to promote further discussion amongst designers and operators to enhance the performance and effectiveness of the FGS.

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References

1. *Guidance on the Evaluation of Fire, Combustible Gas and Toxic Gas System Effectiveness (ISA-TR 84.00.07)*, The International Society of Automation, 2010
2. *Offshore Hydrocarbon Releases Database (1992 - 2015)*; UK Health and Safety Executive
3. *Area Classification Code for Installations Handling Flammable Fluid (EI15)*, Energy Institute, 2005
4. *Immediate Dangerous To Life or Health (IDLH) Values*, The National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC)
5. *Offshore Gas Detector Siting Criterion Investigation of Detector Spacing (OTO 93 002),* Offshore Technology Report, UK Health and Safety Executive, 1993
6. Dr. Andrew Walton, Akshat Khirwal, Jeff Cheng, *Establishing Minimum Requirements for Gas Detection in Onshore Process Facilities*, 2013, Hazards Australasia, Perth, Australia,

2013.