How do we define good practice for Fire and Gas Detector Mapping?

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As part of a structured process safety management system, fire and gas detection plays an important role in the protection of people, the environment, assets and corporate reputation.. Detection is dependent on both the hardware's ability to function on demand and detectors being located in the 'right' place. Historically, there has been a significant effort invested in ensuring detectors function on demand and less focus given to their positioning (termed fire and gas detector mapping). This is evidenced by data from the HSE Offshore Release Database which indicates that a large proportion of releases go undetected – 36% of major and 69% of significant gas releases [1]. Should these releases ignite or be toxic the consequences can be devastating.

At present there is limited guidance on how many detectors you need and where they should go. ISA-TR84.00.07 gives detailed guidance on a fully quantitative method but limited guidance for toxics. So why is there such little guidance available? The answer is that the locating of detectors is not trivial and can be influenced by many factors such as ventilation conditions (both forced and natural), nature of the gas being released, congestion, confinement, amongst others.

The Industry is addressing this issue through the development of a British Standard [2] that is to be released this year. The aim of the British Standard is to bring consistency to fire and gas mapping and give guidance on the key points to consider for the hazard against which you are trying to protect. The guidance will also cover toxic gases, a topic which is even less documented than flammable gas and fire detection.

This paper takes guidance from the British Standard and presents the authors views on both good and bad practice for Fire and Gas Detector Mapping and how it can differ dependent on the application and hazard you are protecting against. A methodology is presented to try and ensure a consistent approach is applied to fire and gas mapping going forward.

Keywords: fire and gas detection, CFD, consequence modelling, fire, explosion

Introduction

The use of fire and gas detection dates back to the coal industry in the 1800's. Since this time, fire and gas detector technology has evolved extensively with significant effort put into ensuring detectors function on demand. Despite this investment in technology and reliability, the location of detectors remain critical, if detectors are not located correctly they may not provide any risk reduction.

Formal fire and gas detector mapping started in the late 1980's, with Oil and Gas Majors Shell and BP developing their own internal guidance in the around the turn of the century. At this time, assessment tended to be on a consequence basis (e.g. a system should detect a fire or gas cloud of certain size) and mapping tended to be conducted by Control and Instrumentation engineers. During the late 1990's and early 2000's more quantitative risk analysis techniques were being employed, especially in the Major Hazards industries such as Oil and Gas and Chemicals. Examples include:

- Quantitative Risk Analysis (QRA).
- Occupied Building Risk Analysis (OBRA).
- Computational Fluid Dynamics (CFD) dispersion and explosion modelling.
- Probabilistic explosion analysis.

  This calculated a Design Accident Load (DAL) for critical structures based on an explosion that occurred at a given frequency. This is hence a risk based approach rather than a consequence based approach.

The use of these more sophisticated quantitative techniques led to the generation of data that could be used to aid fire and gas mapping e.g. the release frequencies from a QRA, size of a flammable cloud following a release, explosion overpressure following ignition. This data, and the techniques that were developed, led to more quantitative risk based methodologies being applied in fire and gas mapping and the potential for systems to detect individual scenarios for a particular plant were assessed (termed scenario mapping). The risk based techniques differed to the consequence based assessments; rather than detecting all scenarios, performance was based on trying to detect scenarios with an agreed frequency of occurrence.

In the 2000's, these techniques were implemented using in-house tools developed internally before significant investment in the 2010's led to several commercial software packages being brought to market offering mapping solutions. Moving forward to the present day, and the development of Artificial Intelligence, the use of Big Data and parallel computing, software solutions for fire and gas mapping are continuing to evolve and layouts can now be optimised using techniques such as genetic algorithms. The evolution of the techniques that have been employed have led to fire and gas mapping now being a much more multi-disciplinary function with input required from Safety Engineers, Control & instrumentation Engineers, Operators, Computational Fluid Dynamics (CFD) Analysts and Emergency Response Teams. The requirement for multi-disciplinary teams has brought competence to the fore as input is now required from a much wider group.

Despite fire and gas mapping having been around for over 30 years, there is limited written industry guidance on the topic unlike the other quantitative risk assessment techniques mentioned above which have documentation spanning hundreds of pages [2] [3] [4]. BS EN 60079-29-2 [5] provides general guidance on a process to follow when locating gas detectors. It states that the determination should consider:

1. The combination of sources of release with propagation effects.
2. Whether the sources of release can be inside or outside confining structures, buildings etc.
3. What can happen at access points such as doorways, windows, tunnels, trenches etc.
4. Local environmental conditions.
5. Occupational health and safety.
6. Access for maintenance including calibration and verification, and protection of the system against operational hazards of the plant.

The Health and Safety Executive (HSE) also provides guidance on their Control of Major Accidents and Hazards (COMAH) website [6] but like BS EN 60079-29-2 the guidance is quite general with the main detailed below,

The Safety Report should address the following points:

- The effectiveness of using the detectors in terms of their positioning relative to the possible leak sources, taking account of dispersion and dilution of the released gases/vapours;
- The effectiveness of the detectors for the types of substances to be detected (flammable substances, acid gases, smoke, explosive substances, toxic substances) at the concentrations required. Detectors may be chosen to react to more than one substance;
- The types of protective devices linked to the detection systems (alarms, warning lights, reaction quenching systems, isolation systems, fire retardant systems, plant shutdown systems, trip devices, emergency services);
- The detectors can be clearly seen, heard and understood, (appropriate warning signs, lighting, noise recognition), on plant, in the control room and off-site (if appropriate);
- The procedures to respond to alarms, as a result of a leak/gas being detected (emergency evacuation plans, fire drills, risk assessing existing emergency evacuation plans), to confirm that the release has actually occurred and to record and investigate false alarms and take action to change the system to maintain the confidence of operators;
- The level of risk associated with each potential leak source (risk assessments, risk-rating systems) and the reduction in that assessed risk value achieved by the use of detectors;

ISA-TR84.00.07 provides a fully quantitative method for fire and gas detection [7]. This provides a framework similar to that provided in IEC 61511 [8] for identifying Safety Integrity Level (SILs). As acknowledged in the document, fire and gas detection systems are different to other safety systems as they reduce risk rather than eliminating it and the quantification of the reduction in the risk is dependent on many factors which can be hard to quantify. The methods described in ISA-TR84.00.07 are the most prevalent in industry but the feedback is that it can be difficult to apply.

The lack of detailed written guidance on the topic has led to two main problems.

- The first is that it is difficult to justify that fire and gas layouts have reduced risks to As Low As Reasonably Practicable (ALARP) as there is no relevant good practice that can be referenced. Furthermore, end clients commissioning fire and gas mapping studies have no benchmark to assess methodologies and designs against to ensure that individuals are competent.
- The second is consistency in the application of fire and gas mapping. The lack of consistency, in part, is due to risk based techniques being employed which are inherently more complex and require a greater number of inputs. Without written guidance, it is left to the individual conducting the mapping exercise to apply judgement to select appropriate input data which can lead to inconsistencies even within the same business.

The requirement for written guidance is further backed up by historical data. Fires and gas releases go undetected with the Offshore industry providing the best statistics. The Health and Safety Executive (HSE) collates information on hydrocarbon releases and analysis of the data (2001-2008) reveals that approximately 36% of major gas releases and 69% of significant gas releases were undetected [1]. The most recent incident sited on the HSE website is from 2015 where a release on the Kittiwake Platform went undetected for 84 minutes releasing 1,670 kg of flammable material. To quote the HSE regarding the incident, “Your flammable gas detection system failed”.

Fire and Gas Detection Systems in Context

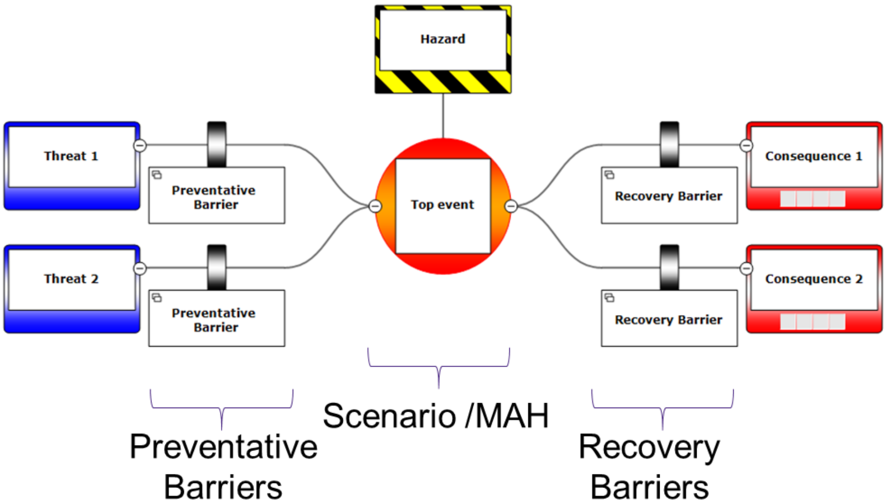
To define good practice it is first necessary to understand where fire and gas detection sits in terms of the barriers that are in place to prevent the end consequence i.e. fire, explosion or toxic harm. This is best illustrated via the use of a BowTie diagram as show in Figure 1. An *effective* barrier is made of three components:

- a sensor.

- a response.
- an action.

It is only when all three components act together that an independent barrier can be claimed. Fire and gas detection is the sensor component of a recovery (or mitigative) barrier (i.e. lies to the right of a BowTie). In terms of the hierarchy of control it is towards the bottom and only when combined with the response and action (e.g. isolation, alarms, blowdown, deluge) are risks lowered as the potential for escalation and chance of escape and evacuation are reduced. It is therefore imperative when considering gas detection that the decision and action on gas detection is understood. The other point to note is that unlike other barriers, fire and gas detectors do not eliminate the risk and only reduce it as even if an event is detected there is a finite time before response and action. For example, a gas release could be detected, all valves closed to limit the inventory and all adjacent inventories blowdown but the release could still ignite and the consequence still realised.

Figure 1 - Illustrative BowTie Diagram



Current State of Practice and Potential Learnings

There are currently three different methodologies that are employed in fire and gas mapping:

- Engineering judgement.

  This describes approaches where quantitative assessment is not applied. Examples include:

  - Open geometries for fire detection. In these instances appropriate coverage may be achieved by simply placing detectors at the boundaries of the area.
  - "Simple systems" e.g. a single short pipe run through a facility may not require fully quantitative analysis and based on the nature of the fluids being released an appropriate judgement could be made on appropriate locations for gas detectors.
  - Where proven design has previously shown to be adequate.
  - Engineering experience from previous projects.

- Volumetric mapping.

  This assesses the capability of a system to detect a target gas cloud and presents the results in terms of the coverage of a given volume i.e. 80% coverage. In its most simplistic form, volumetric mapping assumes a gas cloud size can originate at any point within the three dimensional space being analysed.

- Scenario based mapping.

  Scenario based mapping requires information specific to the operation. A number of scenarios are postulated and the results presented in terms of either the % of scenarios detected or the frequency of releases that are not detected.

Parallels can be drawn between the above and different risk assessment methods (e.g. qualitative, semi-quantitative and quantitative), as illustrated in Figure 2. Each technique has its place and the most appropriate one should be chosen for the application in question. Examples of the advantages and disadvantages of each are summarised in XX.

Figure 2 - Fire and Gas Mapping Techniques

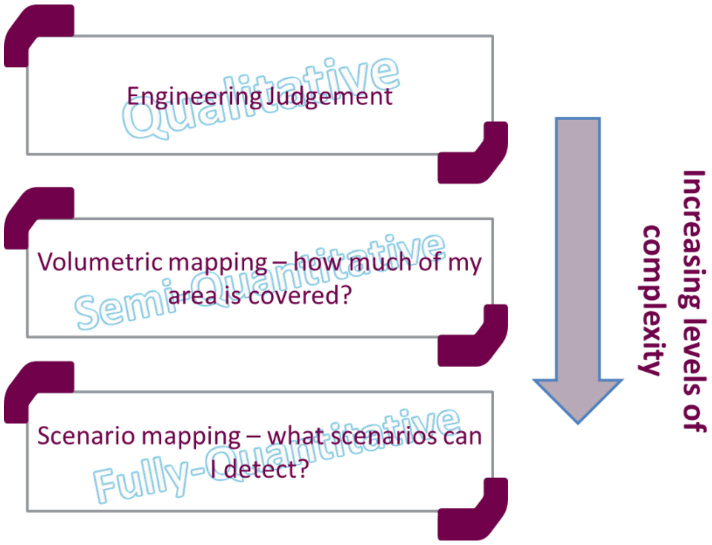


Table 1 - Advantages/Disadvantages of Different Mapping Techniques

Method	**Advantages**	**Disadvantages**
Judgement	Fast	Subjective
	In many instances appropriate given the uncertainty in the parameters that can affect placement.	
	No 3D model required	
Volumetric Mapping	Detailed information on process not required e.g. heat and mass balance data	Results can be influenced by the volume assessed
	Consistent Design	Percentage coverage does not relate directly to probability of detection.
	Fast	Simplistically assumes that gas can originate at any point
	Easily audited	
Scenario Mapping	More thorough consideration of the risk	Time consuming and expensive
	More optimised detector coverage	Can be dependent on the number of scenarios analysed.
		Greater level of competency required
		More open to interpretation

Although in some instances the above techniques are applied appropriately this cannot be said unilaterally. Table 2 presents examples of bad practice seen in industry and presents potential learnings from others areas of engineering that can be drawn upon to define good practice for fire and gas mapping. Below the table are further examples of bad practice and recommendations on how these can be avoided.

Table 2 - Examples of Bad Practice

Examples of Bad Practice	**Potential Learnings**
No philosophy for the fire/gas detection system i.e. what is the system trying to detect and why.	In fire engineering, a fire strategy/philosophy document (see British Standard Document PAS 911 [9]) is developed for each project at the design stage. This details the protection measures to be employed that align with the risk levels for the building and the acceptance criteria for the company. Learnings should be taken from the fire engineering community and a similar document should be produced for fire and gas mapping.
Lack of justification or insufficient number of scenarios considered.	Probabilistic Explosion Analysis or Explosion Risk Analysis (ERA) defines blast loads based on a number of simulated scenarios and Norsok Z-013 [4] provides guidance on the selection of scenarios. This guidance should be used as a starting point if

	conducting scenario based gas detection mapping.
Lack of multi-disciplinary input.	Fire and gas mapping should learn from the approaches taken in Hazard Studies where a multi-disciplinary team is assembled. Although it may not be practical to conduct fire and gas mapping as a group exercise, a kick-off meeting should be held to ensure that all stake holders buy into the philosophy the system being designed or reviewed.
Change management	Over time there may be modifications to the plant or detectors may be in fault leading to reduced coverage. Learning from the DSEAR regulations [10] and associated Approved Code of Practice [11] can be taken on this topic as stated below. *Regulation 5(3)(b)* *There has been a significant change in the matters to which the risk assessment relates including when the workplace, work processes, or organisation of the work undergoes significant changes, extensions or conversions* *L138 page 93 onwards* *If changes to workplace activities necessitate a revised risk assessment, then it may be necessary for employers to provide updated information, instruction or training to employees.* It is therefore recommended that a procedure is put in place that ensures that a management of change review is carried out should detectors go into fault or if there are changes to operations.
Lack of documentation	On many projects the only documentation associated with fire and gas detectors is a layout indicating the positions; no justification for the number and the position is provided. As a deliverable, a fire and gas layout is very similar to a Hazardous Area Classification (HAC) drawing. The difference being that a HAC drawing would be accompanied by a List of Equipment for Area Classification (LEAC) which documents the materials being handled and the reason for the zone size. It is recommended that fire and gas mapping learns from this and similar documentation is produced to accompany layout drawings and document the basis and justification for the number and position of detectors.

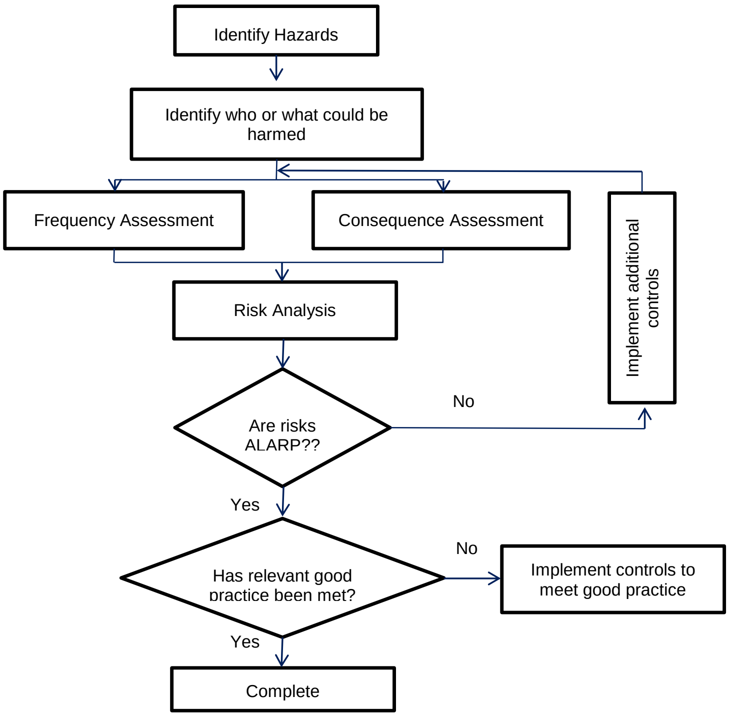
Other examples of bad practice include:

- **Approach that you *must* have fire and gas detection.**
  - If handling or storing flammable or toxic materials, there is no legislative requirement to install fire or gas detection. The requirement for fire or detection should be based on a risk assessment of the operation being considered as shown in Figure 3. The risk assessment should not solely focus on personnel. The requirement for fire and gas detection to protect against the environment, business continuity and corporate reputation should also be considered.

    Often risk assessment is not carried out, and irrespective of frequency, consequence or other controls, detectors are installed. Examples that the author has seen where detection would offer limited risk reduction include,

    - Installation of gas detectors for a deodorant can storage facility where the potential for release is no greater than in a supermarket. The consequence of a release would be minimal due to the limited inventory and it is unlikely that the detectors would have seen sufficient concentration to alarm.
    - Installation of gas detectors on a facility where flammable liquids were handled below their flash point. In this instance there was a lack of understanding of the mechanisms by which a hazard material forms a flammable liquid.

Figure 3 - Risk Assessment Process



- **Lack of understanding of the hazard and consequences.**

  The hazard and consequence for both fires and gas varies significantly depending on a number of factors including:

  - Fires:
    - Fluid State: Dependent on the fluid state a jet fire, two-phase or pool fire can arise.
    - Pressure: This governs both the size and momentum of a jet or two-phase fire.
    - Geometry: In congested geometries high pressure gas and two-phase fire are likely to impinge on equipment resulting in fire shapes that are more akin to a fireball than a jet;
    - Inventory size: This should be considered to understand the fire duration. If the inventory is limited then it may not be necessary to detect the leak as the potential for escalation to a secondary fire may not be possible.
  - Gas release:

    In order to increase the potential for detection, detectors should be located in areas where gas is likely to accumulate. This is not trivial and depends on the factors below and in many instances effects compete against each other e.g. the momentum of a release may be reduced due to impinging on geometry in some areas of the plant but increased in others due to e.g. forced ventilation.

    - Fluid state: Where gas accumulates is dependent on both the state when stored and when released to atmosphere. As an example, methane is a gas at ambient conditions and can be stored as a pressurised gas or at low temperatures as a liquid. Despite being the same material, gas would accumulate differently hence it would not be appropriate to have the same detector layout for both.
    - Pressure: If a release is unchoked it will results in a plume that will be highly influenced by the wind. If choked then it will be a jet with higher momentum and less likely to be influenced by the wind.
    - Geometry: Is the release likely to impinge on geometry hence reducing momentum and changing the gas cloud size?
    - Density/Buoyancy: Is the release lighter or heavier than air?
    - Ventilation: Forced and/or natural?

Both at the risk assessment stage and before detailed quantitative analysis is performed an understanding of the above factors should be considered to at least inform the most appropriate location for detectors. An example of a lack of understanding of the above is locating detectors in close proximity to leak sources. In most cases this will results in poor coverage as high pressure releases tend to form jets, if not impinging on geometry, which are thin at the point of release and expand as they entrain air in the far field. Locating detectors in close proximity to releases of this kind would result in gas passing between detectors and not being detected.

- **A 5 m target gas cloud size is appropriate for all flammable gas detector applications.**

  A 5 m target gas cloud size is often applied in flammable gas detection without justification. The origins of this gas cloud size are based on work done by the HSE in 1993 [13]. This showed that the flame speed from a 6 m long methane cloud would not exceed 100 m/s and not produce overpressure of more than 150 mbarg. It may be appropriate to apply this criteria but the justification should be documented and the considering the following.

  - If the level of congestion on the plant differs from the experiments in [13] a smaller/larger target gas cloud may be justified.
  - The 5 m spacing is based on a methane explosion. If handling different materials the target gas cloud should be modified accordingly e.g. for hydrogen a smaller target gas cloud may be appropriate.
  - 150 mbarg is the overpressure generally associated with personnel fatalities. If, for example, the philosophy was to protect the environment or for asset protection, rather than personnel, then this magnitude of overpressure may not be appropriate.

  If a 5 m target gas cloud size is not deemed appropriate then either empirical/phenomenological tools or CFD methods should be employed to calculate a more appropriate value.

- **Competency of individuals when using CFD methods.**

  The demonstration of competence is a topic that many industries are currently grappling with. The development of software solutions has meant there is now less of a barrier to entry for the application of CFD methods. Although this may be seen as a step forward, there is the potential that the software 'assumes' competence rather than the user taking the responsibility. In this instance there is a danger that the individual does not have sufficient experience and the age old problem remains of 'garbage in, equals garbage out". In order to guard against this it is imperative that work is peer reviewed and that robust internal checking procedures are in place.

- **Lack of understanding of the practical aspects e.g. detector siting for maintenance and calibration.**

  "Optimised" layouts are often generated using computational techniques and access to detectors is not considered. Detectors are then proposed that would require scaffolding to access hence increasing cost and risk. It is recommended that a ruleset is developed specifying access requirements for detectors and areas where they can/cannot go before mapping is commenced.

- **Consideration of volume rather than concentration for toxics**

  When considering the detection of flammable gas, the premise is to limit the volume of gas and hence the potential consequence (i.e. explosion/flash fire). When considering toxics, it is no longer the volume but the concentration and the duration of exposure that is of concern. This point is often overlooked and the same methodology for both flammable and toxic gas (e.g. I want to detect a cloud size of X m^3) is applied, which is incorrect. The spacing requirements for toxics should be assessed separately to those for flammables as the concern should be to alert operators and allow adequate time to escape.

Good Practice Methodology

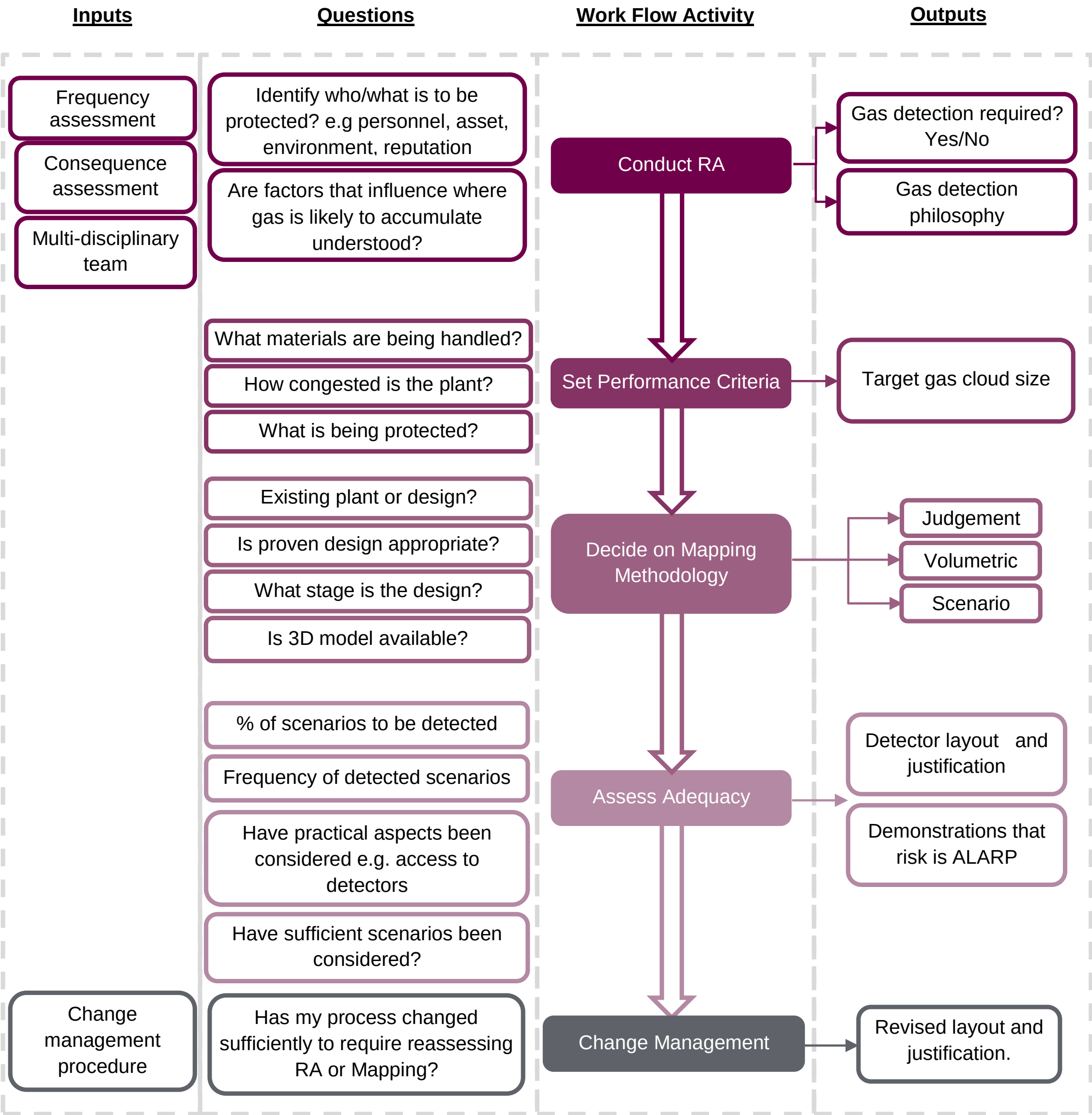
As highlighted previously, the lack of written guidance has led to inconsistencies in the application of fire and gas mapping and examples of bad practice. To address this, Figure 4 presents a recommended methodology for flammable gas detection (a similar methodology would apply for fire and toxic gas detection). The aim of this methodology is to ensure that a structured approach is taken to the process, accompanied with documentation, and that bad practice is avoided.

In the author's experience, the point that is most overlooked is a clear philosophy for the fire and gas detection system. With the increase in computing power and software solutions there is a tendency to jump into analysis without taking a step back and thinking about what is trying to be achieved. This often leads to analysis having to be repeated. As a minimum the philosophy should include.

- What metrics are used to assess the system e.g. percentage coverage, gas cloud of a certain size, gas cloud/fire that could lead to escalation, fire of a certain frequency of occurrence.
- Set points for gas detectors.
- What mapping methods that are to be applied; these could differ as a design progresses. More detailed methods may not be appropriate early on in a design as sufficient information may not be available.

For design projects the philosophy will often be a live document and it will get updated as the design progresses. The development of this document also ensures that a consistent approach can be taken should operations be modified or extended in the future.

Figure 4 - Flammable Gas Detection Good Practice Methodology



Conclusions

This paper has tried to highlight the current state of practice in fire and gas detection. It has hopefully shown that it is non-trivial and requires interpretation, judgement (e.g. risk acceptance criteria), multi-disciplinary input and competency. For a given operation there is no 'right' answer but by following the methodology set out in Figure 4 it should ensure that the position and location of detectors is decided based on a structured process that is justified and fully documented. Due to the size of the topic at hand it is not possible to cover all aspects in this paper and further guidance can be found in the British Standard that is to be released later this year [12].

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