A Review: As-built Data Acquisition Techniques and Developing 3D Model to Effectively Design Fire and Gas System (FGS)

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Abstract

This research investigates the concept of the Fire and Gas Mapping approach by performing as-built drawings, the steps involved, and the problems encountered while executing Fire and Gas Mapping. The methods used to gather information are the existing process data, questionnaires survey, and site observation. Facility management can be effectively improved by keeping as-built documentation in form of records, structure drawings, piping drawings, specifications, and location of equipment. This study also compares the alternate techniques (Laser scanning, Photogrammetry, Videogrammetry, 3D range camera, and the importance of physical measurement (Along with the Camera)) in the oil & gas industry to generate the 3D model for old installations. The oil & gas industry is dynamic in nature, and it frequently undergoes revamping work to enhance production capacity or to maintain/replace existing equipment. This study will help old installations without having the latest plant documentation in making technically reliable and cost-effective decisions to design FGS, with the developed set of guidelines. The Fire and Gas Mapping study is typically based on client-specific gas detection design philosophy, performance-based approach as specified in ISA-TR.84.00.07-2018 (Technical Report – Guidance on the Evaluation of Fire, Combustible Gas, and Toxic Gas System Effectiveness) and OISD 116 (Fire Protection Facilities for Petroleum Refineries & Oil/Gas Processing Plants) to effectively design FGS. Detector coverage assessment tool is used to achieve the required coverage targets.

Keywords: As-Built Drawing, Detection, Fire and Gas Mapping, Oil and Gas Industry, Safety

I. INTRODUCTION

The process equipment used in the refining and processing plant is critical in terms of its operation to produce a product. The protection of equipment, asset, humans, and environment is required from the hazard posed by process plants. Identification of hazards is an essential phase in the risk assessment study as it leads to the engendering of accidental scenarios. In the process plant, the 3D model plays an important role to identify the exact location of process equipment involving hazardous substances. As-built of process facilities need to perform wherever the 3D model is not available. Several works of literature are based on as-built of civil/infrastructure to develop a 3D model, in the current research as-built of the process plant is discussed to effectively design FGS.

The precise and speedy 3D models of site facilities can be adapted to perform efficient layout planning of a construction site to optimize facility running cost and/or time [[7]]. Digital three-dimensional (3D) models are useful at various stages of the infrastructure life cycle. The existing defects in construction can be identified by a detailed and accurate model of the built environment by comparing the measurements taken from the as-built model and the measurements taken from the design [5]. Infrastructure modeling is the process of generating 3D models of civil infrastructure. As the first step in the process of modeling, spatial data collection plays an important role. The quality e.g., resolution and accuracy of the retrieved spatial data undoubtedly relates to the quality e.g., resolution and accuracy of the final output.

ISA-TR84.00.07-2018 is intended for use in evaluating the effectiveness of FGS in process industry applications. It addresses the implementation of FGS to reduce the risk of hazardous releases involving safety impact [[1]], [9],[[15]]. The FGSs are a subset of instrumented safeguards that detect hazardous conditions, provide early warning, and take appropriate mitigation actions to safeguard people and assets [1]. Process plants often contain a much wider array of hazards which include hydrocarbon fires, combustible gas releases, and the possibility of acute toxic gas hazards. FGS reduces the magnitude and severity of the consequence which essentially plays an important role to prevent the severe consequences from the primary event [[2]]. The risk may considerably reduce to As Low as Reasonably Practicable (ALARP) level with the installation of Flame and Hydrocarbon Gas Detection System.

This paper (1) reviews the-state-of-the-art optical spatial data collection technologies and (2) examines the accuracy of physical measurement (Along with the Camera) for developing as-built 3D models. An off-the-shelf, detector coverage assessment software package is used to suggest fire and gas detectors.

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II. BACKGROUND

When Physical measurement as-built technique is a reliable option for the Installations which are established in the twentieth century. In such plants/facilities, the latest techniques such as laser photogrammetry may prove troublesome to an extent as in some cases there are operational, accessibility issues, or they are exorbitant. Limiting conditions at these facilities such as the need for the spark-proof device, complex structure of plants, unavailability of relevant documents lead to the need for a concrete solution to prepare the 3D model to conduct FGS. The installations which are established in the twenty-first century may use the latest techniques for as-built modeling due to its integrity and robust design, however, it may not be true for all such facilities as well.

In India, more than 1435 no. of factories handles hazardous chemicals in various sectors like gas processing plant, refineries, gas gathering centers, gas compressor stations, bottling plants, wellheads, chemical plants, oil storage & handling, depots, terminals, pipeline installation, lube-oil installations, jetty pipelines, drilling rigs, petroleum laboratories etc. The Oil & Gas sector is facing difficult challenges for automation and safety technology. To protect personnel, assets, and the environment; critical devices like tank farms, storage areas, and loading/unloading operations require FGS and other safety systems. The consequences of incidents like an explosion, jet fire, flash fire, pool fire, etc. at oil and gas stations can be massive. Major incidents in the Hydrocarbon Industry are depicted in *Table* - 1.

Table - 1
Major Losses in the Hydrocarbon Industry (Domestic)

Date	*Event*	*Location*	*Casualties*
29-10-2009	*Fire*	*IOCL, Jaipur*	*Fatalities-11, Injured-135*
07-01-2020	*Fire/Explosion*	*IOCL, Mathura*	*Fatalities-none, Injured-43*
14-09-1997	*Fire/Explosion*	*HPCL Vizag*	*Fatalities-56*
03-09-2019	*Fire/Explosion*	*ONGC, Uran*	*Fatalities-4, Injured-3*
24-09-2020	*Fire/Explosion*	*ONGC, Hazira*	*No casualty*
01-01-2015	*Fire/Explosion*	*IOCL, Madurai*	*Injured-7*
02-01-2018	*Explosion*	*IOCL, Panipat*	*Fatalities-1, Injured-2*
23-08-2013	*Fire*	*HPCL Vizag*	*Fatalities-1, Injured-39*

Disasters caused by hydrocarbon industry, either by accident, negligence, or incompetence overseas as specified in Table - 2.

Table - 2
Major Losses in the Hydrocarbon Industry (International)

Event	*Location*	*Casualties*
Fire	*Lanzhou Petrochemical Company*	*Fatalities-1, Injured-10*
Explosion	*Repsol-YPF refinery*	*Fatalities-8*
Explosion	*BP's Texas City Refinery*	*Fatalities-5, Injured-170*
VCE	*La Mede, France*	*Fatalities-6, Injured-39*
Explosion	*Falcon State, Venezuela*	*Fatalities-48, Injured-80*
Fire	*Mazeikiu, Lithuania*	*Fatalities-1, Injured-1*
Fire/Explosion	*Buncefield fuel terminal*	*Injured 43*

The accidents considered are mostly representative of the types of high-risk scenarios which are typically associated with petroleum refineries. *Fig.* 1 describes most of the events based on their impacts (very high, high, medium, low, none) in terms of effects on the human health or the environment or significant cost either to the operator or in terms of offsite property damage or disruption [16].

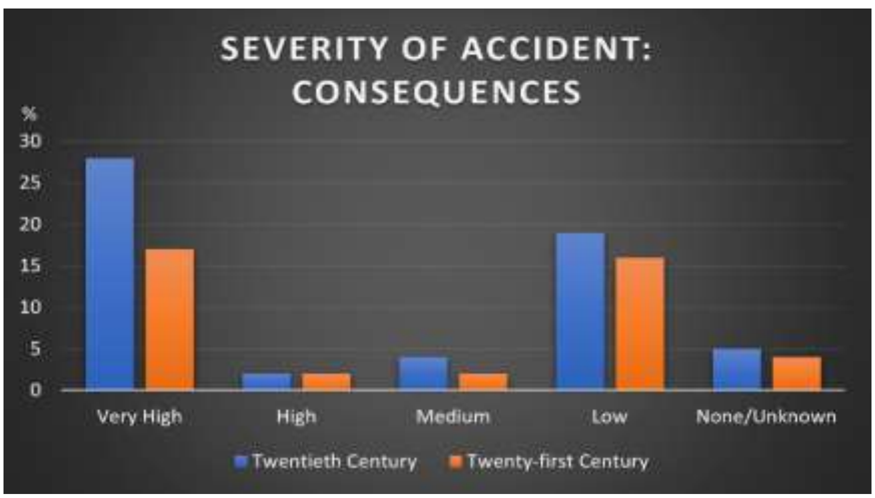

Fig. 1: Severity of Accident: Consequences

Incidents like above illustrate the potential threats to the world's oil and gas supply chain. Most of the incidents/cases happened due to non-provision for auto shut down of plant or non-activation of the fire protection/suppression system.

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Nonfulfillment of FGS can be hazardous to people, process equipment, and/or structures due to intense fire or toxic gas exposure when flammable or toxic hydrocarbon liquids are released from the process, accumulate, and are subsequently ignited, the result is a turbulent diffusion fire. The extent of a pool fire hazard is governed by the size of the pool, the burning intensity of the fuel, and to a lesser extent, meteorological conditions. When pressurized gas (or liquid/two-phase) is released and ignited immediately upon release, the result is a momentum-driven, turbulent jet fire. The extent of a jet fire hazard is governed by the rate of release, the shape of the flame, the flame orientation, and the burning intensity of the fuel. Both pool fires and jet fires emit thermal radiation, which can be hazardous to people within seconds of exposure. Process equipment or structures can be damaged within minutes of intense fire exposure, especially if fireproofing is not provided or ineffective. Fires can produce heavy smoke, which is hazardous if introduced in an occupied building. Personnel can be harmed either by the direct effect of the ignition of the hydrocarbon release or by exposure to an ongoing fire if the ability to safely evacuate is impaired. Fire detection can be beneficial in the latter case, by detecting an incipient fire in time before further exposure to personnel or impairment of evacuation routes can occur [1].

The actions that are most effective in the early (incipient) stage of fire are:

- Early detection of gas/smoke/fire (FGS System)
- Alarms and evacuation/sheltering of personnel [12]
- Automatic emergency shutdown (ESD) with the isolation of fuel and depressurizing
- Activation of deluge systems/foam systems to suppress burning, cool surrounding equipment, or, in some cases extinguish the fire.

Whereas the effective FGS can detect fire or hydrocarbon vapor as early as practical to reduce the possibility of escalation, minimize impact to the asset, and allow personnel to take appropriate protective actions. FGSs typically reduce the magnitude and severity of the consequence instead of eliminating it [[1]].

III. REVIEW SELECTION OF CRITICAL CRITERIA'S TO EFFECTIVELY DESIGN FGS

A. *3D Models*

The exact 3D models of site facilities are required to conduct the 3D Fire and Gas Mapping study (safety studies) as well as to execute well-organized layout planning of a required site to optimize facility running cost and/or time. Three-dimensional (3D) models are useful at various stages of the infrastructure life cycle. For example, an accurate and detailed 3D model of the built environment can be used to identify existing defects in construction if the designed model is not available.

B. *As-Built*

Modeling is the process of generating 3D models of equipment, piping, valves, pipe rack, column, protective devices, cable arrangement, junction box, hoses, etc. in the facility. As the first step in the process of modeling, spatial data collection plays a significant role. The quality (e.g., accuracy and resolution) of the retrieved spatial data directly relates to the quality (e.g., accuracy and resolution) of the final output. Considering site facilities established before the twentieth century, physical measurement (Along with the Camera) technique is selected among the photogrammetry, Videogrammetry, 3D range camera, Laser scanning technique.

1) *Limiting Conditions*

To ensure coverage of the FGS system, plant information plays a prominent role. The 3D Model, 2D Layout, and piping and instrumentation drawings of site facilities are required as input along with the process parameters to conduct the 3D Fire and Gas Mapping study. The P&ID, 2D layouts, and 3D models play an important role to identify locations or hazardous areas associated with the equipment, piping, etc. in the process industry. A piping and instrumentation diagram is required in the process industry to show the piping and process equipment together with the instrumentation and control devices. The many old refineries may not have updated CAD drawings or native files, generally, they refer to scanned drawings or ammonia print drawings for assessment. Considering the above aspects, the need to develop 2D layouts and 3D models arises to overcome obstacles.

C. *Fire and Gas Mapping*

FGS is required to reduce the possibility of an escalation in case of fire or to detect hydrocarbon vapor as early as practical, minimize impact to the asset, and allow personnel to take appropriate protective actions.

IV. METHODOLOGY

As-built drawings recognized in the industry to illustrate the drawings (2D/3D) prepared from on-site measurements of an existing building or space. Nowadays, the accuracy and time to take on-site measurements can be reduced by taking photographs of equipment or areas that are covered in the scope along with the physical measurement with the flameproof camera.

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A. *Optical Spatial Data Collection Techniques*

Numerous noncontact spatial data collection techniques are available to facilitate process plant modeling. Optical spatial data collection techniques are one typical branch of them. Several combinations of optical-based acquisition techniques with the traditional acquisition techniques can be proposed to achieve higher performance. The weakness of one technique can be overcome from the strength of the other techniques hence, the maximum potential of both techniques can be achieved through their combination [3].
The technique based on sensors adopted can be classified into two categories, passive, and active [[4]].

1) Passive Sensor-Based Technique

Passive Sensor-Based Technique generally measures the naturally occurring light e.g., sunlight. Passive sensors based on the spatial data collection techniques use the present light energy of the scene to obtain its 3D information, they do not transmit any form of energy, like an infrared light or laser, into a scene. Example – Photogrammetry, Videogrammetry, and Physical Measurement (Along with the Camera) also part of this technique.

2) Active Sensor-Based Techniques

Active Sensor-Based Technique measures the naturally occurring light e.g., sunlight, emitted laser, or infrared light. The spatial data collection techniques based on active sensors provide their own energy e.g., emitted laser or infrared light for spatial information retrieval. Active sensors transmit some form of energy e.g., infrared light or laser into a scene. When the transmitted energy meets an object, it is reflected, and the return energy signal is used to determine the object's spatial information in the scene [[4]]. Example - Laser scanning and 3D camera ranging.

The design and implementation of FGSs are in line with the underlying principles of both ANSI/ISA-84.00.01-2018 and IEC TR 61511-0:2018. *Figure 2* describes the steps involved in Fire and Gas Mapping techniques.

Fire and Gas Mapping methodology includes data collection, categorization of areas of concerns in the process industries to identify hazards associated with leaks, hazard/risk scenarios identifications based on FGS philosophy, analyzation of the consequence to identify the physical extend of hazard. The undetected hazards such as combustible gas hazards or toxic gas hazards lead to a potential escalation in the facility. The performance target is identified to recognize the severity of specific equipment associated with the facility. The coverage of the detector is verified according to respective voting logic to provide an alarm to give control action or to maintain safety concern [1].

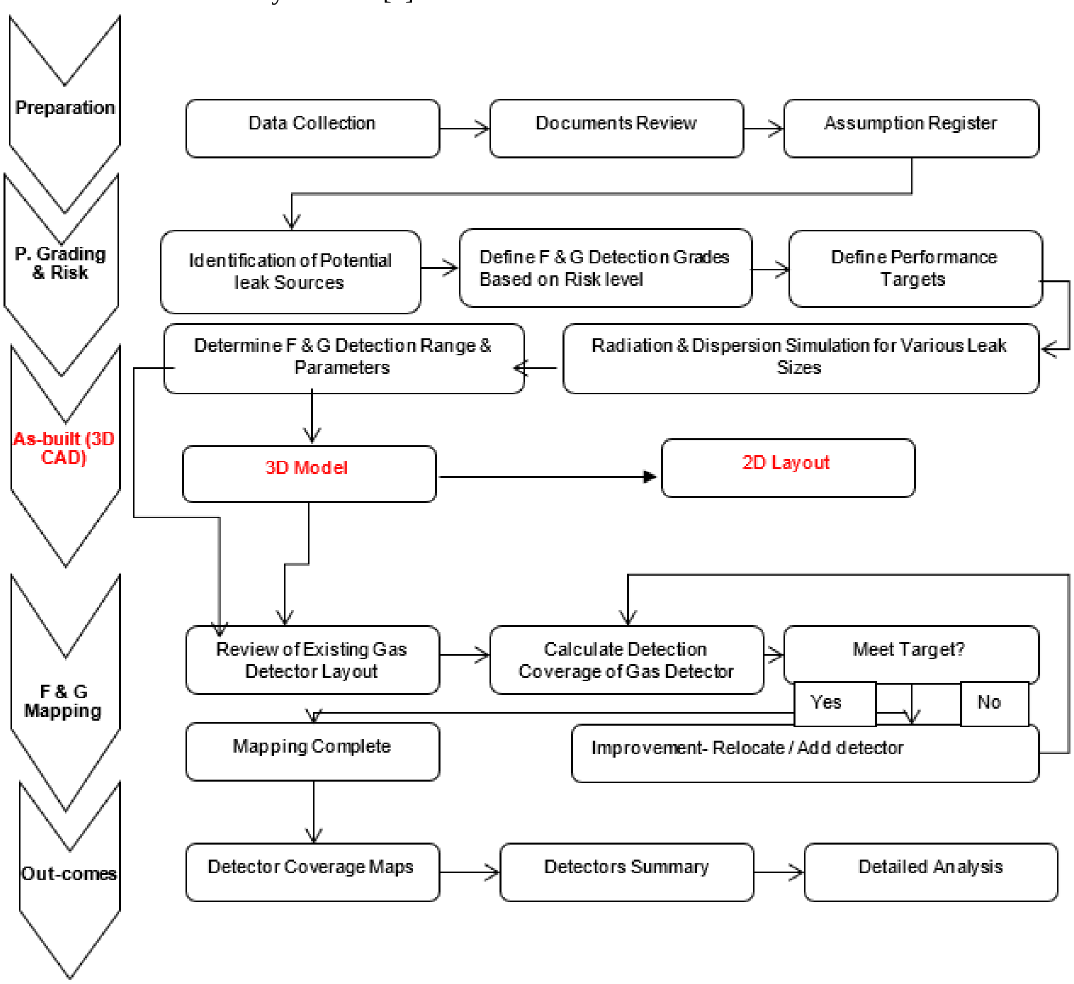

Fig. 2: outline of Fire and Gas mapping Method

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The fundamental approach is to examine the hazard and estimate the risk to establish required FGS performance and specify a design to achieve performance [1]. In this context, the performance includes the safety availability of the FGS equipment, the coverage of the FGS detectors, and the effectiveness of the mitigative actions [1]. A design for FGS mitigation requires input from the end user's fire and gas philosophy in terms of establishing the performance objectives.

Techniques applied to select target FGS performance should consider parameters that affect the hazard and risk. Techniques are often applied on an equipment-item basis to determine if FGS should be considered to protect each equipment item and, if protection is required, then to estimate what degree of performance should be targeted in the design [[1]].

V. DISCUSSION

In this section, the optical-based spatial data collection techniques and their requirements are discussed to select an essential as-built technique to design effective FGS in the process plant.

The updated 2D or 3D drawings for existing/revamping units were unavailable before conducting the Fire and Gas Mapping study. The requirement to develop the 3D model was generated to visualize the actual location of equipment, access routes, structure, etc. in the facility. After plant installation, in the 2D-drawing-based scenario, the chemical, structural, and mechanical engineers reviewed the design drawings in 2D CAD and created a general arrangement drawing. General arrangement drawings include floor plans, elevations, cross-sections, and details. General arrangement drawings contain information for construction such as the list and size of units, installation coordinates, and level. The general arrangement drawings specifically used to install structural steel frames in the field were referred and created the 2D drawings. 2D drawings include process units, control room, administration buildings, main gate, etc in the facility. Separately drawn drawings are cross reviewed to perform integrity checks.

A 3D-model-based scenario is a collaborative approach cantered on 3D models. The master 3D model was created, the 2D layout using the 3D model was generated. The 3D-model-based documentation approach saved time and money by integrating site and factory processes. Also, by utilizing a 3D model with integrity, accuracy and productivity were improved.

As-built drawings recognized in the industry to illustrate the drawings (2D/3D) prepared from on-site measurements of an existing building or space. Nowadays, the accuracy and time to take on-site measurement can reduce by taking photographs of equipment or areas along with the physical measurement with the flameproof camera considering its severity in terms of exposer to hydrocarbon in the oil & gas Industry.

Figure 3 and Figure 4 depict the actual location of the "inlet channel" and the representative image of the "Inlet Channel" built in the 3 - D Model

Fig. 3: Actual image of Inlet channels

Fig. 4: Representative image of Inlet Channel built in the 3D Model

The numerical value of the size which describes the object of measurement is determined by measuring instruments with the complex of operations is called Physical Measurement. The act of deriving quantitative information about a physical object or action by comparison with a reference characterized as physical measurement. The most critical elements of measurement, (i) measurand quantity, i.e., the physical quantity or property like, length, width, height, angle, etc. being measured, (ii) comparison or comparator, i.e., the means of comparing measurand with some reference to deliver a judgment and (iii) reference, i.e., The physical quantity or property to which quantitative comparisons are made.

The major benefits of the Physical Measurement (Along with the Camera) technique are the precision, low equipment cost, and no need for specialized operators/training. The limitations of laser scanning lie in the upfront investment (high equipment cost) and training of operators. Though, due to the presence of explosive material in the plant, the spark-proof camera shall be carefully chosen to avoid further consequences.

The analysis of the point cloud also takes more time when compared to other remote sensing techniques such as photogrammetry [[4]]. The accuracy of laser scans is highly dependent on environmental and object parameters like surface reflectivity, surface

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texture, and weather [[6]]. For example, a building with large windows cannot be accurately captured using laser scanning because the laser beams pass through the structure's window glass [[3]], sharp edges, and corners [[7]].

1) Physical Measurement (Along with the Camera)
2) Photogrammetry
3) Videogrammetry
4) 3D range camera
5) Laser scanning

Pros and cons of optical-based spatial data acquisition techniques described in
Table - 3

Table - 3:
Selection criteria of Optical-based spatial data acquisition technique

Techniques	*Pros*	*Cons*
Physical Measurement (Along with the Camera)	*1) Portable 2) Precise 3) Low equipment cost 4) Specialized operators/training not required*	*1) Direct contact essential 2) Manual Intervention 3) Non-real-time data retrieval 4) Operation at day only*
Photogrammetry (P)	*1) Precise 2) Low equipment cost 3) Movable*	*1) Manual 3D data retrieval 2) Non-real-time data retrieval 3) Operation at day only 4) Low spatial resolution 5) Limited range distance*
Videogrammetry (V)	*1) Precise 2) Low equipment cost 3) Movable 4) High spatial resolution 5) Real-time data retrieval*	*1) Limited automated 3D data retrieval 2) Operation at day only 3) Limited range distance*
3D camera ranging (3DCR)	*1) Automated 3D data retrieval 2) Operation day and night 3) Reasonable equipment cost 4) Movable 5) Real-time data retrieval*	*1) Short-range distance 2) Low spatial resolution 3) Not as precise as photogrammetry and Videogrammetry*
Laser scanning (LS)	*1) Automated 3D data retrieval 2) High spatial resolution 3) Operation day and night 4) Long-range measurement*	*1) High equipment cost 2) No portable 3) Non-real-time data retrieval 4) Not as precise as photogrammetry and Videogrammetry*

Generally, Physical Measurement (Along with the Camera) requires more time to as-built compared to other techniques, considering the complete manual intervention while measuring dimensions as well as modeling the 2D & 3D model/layout in the modeling tools. As per combined (As-built and Fire and Gas Mapping) experience with the efficient utilization of resources and executing as-built modeling and Fire and Gas Mapping study together; the time required to accomplish this study can be minimized significantly.

Numbers of drawings were generated based on the below assumptions which in turn converted to 3D model and 2D Layout with the assistance of modeling tools;

1) *Equipment Modelling:*
   a) All equipment handling hydrocarbon & toxic gas will be modeled with overall outline dimensions.
   b) In the case of Equipment within enclosed buildings/Sheds, Envelopes of the overall building Size shall be modeled.
   c) Dimensions considered for the equipment modeling shall be based on equipment GA drawings and site survey.
   d) For equipment spacing, Rack locations, Roads, etc. overall plot plan/unit plot plans shall be referred.
2) *Piping Modelling:*
   a) Inlet and Outlet Piping for each the equipment will be modeled.
   b) Inlet/Outlet lines are modeled from equipment till the line enters the rack. Entire line routing will not be done.
   c) For control valve manifolds envelopes will be modeled.

Once the site measurements and modeling of all areas or units are complete at the individual level then the next process is to integrate all areas or units to make a consolidated model. FGS can be effectively suggested by reviewing consolidated model or individual unit/area wise model as per requirement and system configurations to minimize computational time and cost.

The 3D model of inlet channels was deliberately developed to perform the Fire and Gas Mapping study with the existing available documents & data gathered from the site visits. Maximum data was collected in the manner of dimensions to generate the 3D model from the site visits with the help of various measuring tools & techniques. The number of drawings were generated with the help of hand-drawn sketch data during the site visit to convert to a 3D model with the modeling tools along with the cameras for more clarity and to minimize the modeling time.

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The existing or proposed layouts were reviewed, and the coverage of individual detectors or array of detectors was analyzed. The suitability of detector type and layout, in terms of how much coverage a detector array can achieve, was checked. The detector coverage is analyzed qualitatively with the internal engineering assessment, rather than calculating the numerical coverage provided to individual equipment, it was ensured that equipment is provided with the necessary and suitable type of detection. The detector locations were proposed considering most prevailing wind direction, most stable wind condition, cloud dispersion zone, the height of the cloud from the release location, overlapping of the clouds, and the possibility of civil/infrastructural interference in detector mounting and optimized the number of detectors giving maximum efficiency and covering maximum process area. In house hazard analysis & detector coverage assessment tool was used to analyze flame length, flame diameter, flame areas, radiation level, flammable gas dispersion distance and accordingly to set the required hydrocarbon point gas detectors, hydrocarbon (HC) line of sight gas detectors, hydrogen sulfide (H_2S) point gas detectors and flame detectors [[14]].

A. *Detection Parameters*

The detection criteria applied to determine the most optimized spots for fire and gas detectors allocation are presented in *Table* - 4.

Table - 4
Detection criteria to design FGS

Type	*Hydrocarbon (HC) Point Gas Detector*	*Hydrocarbon (HC) Line of Sight Gas Detector (Open Path Gas Detector)*	*Hydrogen Sulfide (H_2S) Point Gas Detector*	*Flame Detector*
Detection	*0.2 LEL for Low Level;*	*1 LFL/m for Low Level;*	*10 ppm for Low Level;*	*4, 12.5 & 37.5 kW/m2*
	0.4 LEL for High Level	*2 LEL/m for High Level*	*15 ppm for High Level*	*Effective for detecting minimum flame area of 0.1 m2*

Considering the LFL extent for the hole sizes the coverage was checked to ensure the detectors placed would meet the requirement. For example, the 0.2 LFL extent for any scenario (Equipment), it is ensured that this is covered by at least one detector to have immediate alert/indication to the operator for the leak [[13]]. The physical coverage was checked and most of the detectors are placed within 1-5 m from the hazard source or the equipment which means that in case of any leak from that equipment is detected in no time by at least 2 or more detectors. The wind probability in the area suggests that the maximum times the gas would be driven towards the northeast making it more likely to be detected by the detectors. Flame detectors were provided to cover equipment which are operating (i.e., normal condition) above AIT of the handled flammable fluid.

For checking the coverage by a minimum of two detectors in the mapping area the probability may be reduced due to the inter distance between the detectors however it was checked that in any of the mapping areas at least two detectors are available for alarm in case of any leakage.

VI. CONCLUSION

The 3D model can be developed to the accuracy by selecting the required as-built technique to achieve efficient detection coverage of FGS in the process plant. As part of Fire and Gas Mapping, 3D-model and 2D Layouts of revamping units of refineries were developed by Physical Measurement as-built technique with the flameproof camera and utilized as an input to effectively design FGS.

The effects of different detector arrangements or detection technology on detection coverage were quantified and assessed, through the design iterations. Based on the outcomes of consequence analysis & performance grading, Hydrocarbon (HC) Point Gas Detectors, Hydrocarbon (HC) Line of Sight Gas Detectors (Open Path Gas Detectors), Hydrogen Sulfide (H2S) Point Gas Detectors, and Flame Detectors were proposed for the processing units. The approach used was based upon recommendations outlined in ISA-TR.84.00.07-2018, OISD 116, MB Lal Report, etc.

Quantitative Risk Assessment (QRA), Fire and Explosion Risk assessment (FERA), Escape, Evacuation, and Rescue Assessment (EERA), Gas Explosion, Dust Explosion, Gas & Smoke Dispersion Analysis, Flare Radiation & Dispersion study, Vent Dispersion Study, Heating, Ventilation, and Air Conditioning, Dropped Object Study, HVAC, Air Monitoring, Air Modelling, Noise Mapping, etc. studies can be done by utilizing 3D model generated by as-built techniques.

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