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A quantitative assessment on the placement practices of gas detectors in the process industries

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ABSTRACT

Gas detection is an important safety system with interfaces to several other safety safeguards. However, the generality of the regulations, standards and recommended practices in conjunction with the inherent challenges of the gas detector placement problem, has resulted in a widespread use of prescriptive and qualitative detector placement strategies. In order to take advantage of the quantitative information provided by dispersion simulations, a stochastic programming formulation (SP-UV) was previously proposed, developed and validated by the authors. This formulation identifies the gas detector layout that minimizes the expected value of an overall damage coefficient (i.e., the minimization of a risk metric) given a set of dispersion scenarios. Results demonstrated the potential and suitability of numerical optimization to solve the gas detector placement problem while rigorously considering its inherent uncertainties. In this work, four existing approaches for gas detector placement were implemented and compared with the previously proposed quantitative optimization-based approach using three different performance metrics in accordance to the objectives of gas detection systems. Results provide evidence on the effectiveness of the use of dispersion simulations, and mathematical programming, to supplement the gas detector placement problem.

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1. Introduction

Gas detection is an important safety system with interfaces to several other safety safeguards. Incidents like the Buncefield fire are tangible and harsh reminders of the need for proper detection and mitigation. The Buncefield fire (Buncefield Major Incident Investigation Board, 2008a, b) was a major conflagration caused by a series of explosions at the Hertfordshire Oil Storage Terminal, an oil storage facility. As part of the conclusions and recommendations, the investigation report (Buncefield Major Incident Investigation Board, 2008a, b) that followed this incident stated that improvements were necessary in the design and detector placement of the flammable gas mitigation system.

Despite receiving widespread media and general public attention due to third party damages, the property damage value of the Buncefield incident was small compared to other catastrophic incidents experienced by the hydrocarbon industry. From a review of the 100 largest property damage losses, around 70 are attributed to fires, explosions, and/or vapor cloud explosions (Marsh, 2012). These are all incidents where the fire and gas detection system played, or could have played, an important role in preventing further damages after loss of containment. The number of incidents remains high, and the data do not indicate a decreasing trend. BSEE (2012) data for the US outer continental shelf attributed a total of 1612 incidents to fires and explosions from 1996 to 2011 (Not including 2006), 649 of them in the period from 2007–2011. HSE (2007) data from 1980 to 2005 for floating offshore units attributed a total of 296 incidents to fires and explosions, 235 of them in the period from 1990–2005. The Petroleum Safety Authority (2012) reported that there is not significant statistical evidence to support the idea that there has been a reduction in the number of leaks *per* facility year in the Norwegian continental shelf. This conclusion was obtained for leak rates greater than 0.1 kg/s, and compared data from 2011 against the average for the period 2003–2010. Furthermore, the HSE (1997, 2003) reported that less than 50% of the known releases in offshore facilities are detected by the facility's gas detection system. If unknown releases are considered, the actual fraction of releases detected is even lower.

Most detector placement strategies for gas detection systems are prescriptive approaches supported by qualitative

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considerations and rules of thumb rather than quantitative metrics based on the dispersion behavior of the possible leak scenarios. The acknowledgment of this fact by the industry has increased interest regarding the opportunities provided by formal quantitative approaches supplemented by dispersion simulations (IEC, 2007; NORSOK, 2008; ISA, 2010). More recently, the use of stochastic programming formulations was proposed, developed and validated by Legg et al. (2012a, b, 2013) and Benavides-Serrano et al. (2014) in order to take further advantage of the quantitative information provided by dispersion simulations. These formulations identify the gas detector layout that minimizes the expected value of an overall damage coefficient (i.e., the minimization of a risk metric) given a set of dispersion scenarios. Results demonstrated the potential and suitability of numerical optimization to approach the gas detector placement problem while rigorously considering its inherent uncertainties.

Motivated by this evidence, this work strives to answer the following questions: Are current practices effective at designing gas detection systems? What is the value of dispersion data and numerical optimization techniques in terms of detection system performance? The rest of this paper is organized as follows. Section 2 presents a review of the current placement practices. In section 3 we describe our assumptions, and develop implementations of the placement approaches described in 2. In section 4 we outline our data set generation process. Each of the approaches in section 3 is then applied to the generated data sets, their performance is analyzed, and conclusions are presented.

2. Current approaches: background

Regulations, standards and recommended practices for gas detection systems mostly provide general guidelines regarding the placement of gas detectors. Recommendations and requirements are focused on installation, testing and performance, calibration, detection technologies and the type of actions expected in response to a confirmed gas leak. Most of them do not provide guidelines regarding the number of detectors or the placement strategies that should be used. Examples include: FM (2001), API (2001) (Section C.1.3.2), ISA (2003) (IEC 61779-6 Mod, Section 6), NFPA (2007) (Section 6.5.2.7.1), Canadian Standards Association (2001), HSE (2001) (Section 4), ISO (2003), ISO (1999) (Appendix B.6), GOST (1981), DNV (2008) (Section 4.D), and UKOOA (2003). More recently the use of dispersion studies has gained recognition as a tool to better understand the behavior of the releases, e.g., EC 60079-29-2 (Section 8) (IEC, 2007), and NORSOK STANDARD S-001 (Chapters 12 and 13) (NORSOK, 2008). However, in the abovementioned sources, methods for determining gas detector placement using data provided by dispersion studies are not specified, and common industry practice considers only a limited set of high-impact scenarios.

While effective technology exists for gas detection, several difficulties make the problem of gas detector placement in the process industry challenging. Leak location, size, and duration are unknown, leading to a large uncertainty space and a large number of potential leak scenarios to consider. Second, formal quantification of the risk for any given leak scenario is difficult. The gas leak dispersion development and transport depend on fluid properties, environmental factors, and facility geometry. Reliable gas dispersion simulations are needed to accurately assess leak development. Finally, even if all this data is consolidated with the highest quality, due to the combinatorial aspects of the problem, exhaustive search is not an option. For example, assuming a detector placement study identifies 1000 candidate detector locations, the number of possible placement combinations is approximately $2^{1000} \approx 10^{300}$.

The generality of the regulations and standards, in conjunction with the inherent challenges of the gas detector placement problem, has resulted in a widespread use of prescriptive and qualitative detector placement approaches. CCPS (2009) (Chapter 5) summarizes some of the qualitative placement approaches used in the process industries for gas detectors. The placement strategies outlined include source monitoring, volumetric monitoring, enclosure monitoring, perimeter monitoring, and path of travel and target receptor monitoring. Most of these approaches are based on rules of thumb and simplified placement strategies, surrogate metrics like maximum spherical volume uncovered and distance from leak sources are used instead of real risk metrics.

Although the evaluation of the risk reduction capability of the gas detection systems is the exception rather than the norm, it is possible to find wide agreement regarding the principal objective of the gas detection system: to provide fast and reliable detection of gas accumulations before they reach concentration and sizes which could pose a risk to the facility and it's occupants. That is, identifying accidental releases as fast as possible, so that proper countermeasures can be initiated (IEC, 2007; NORSOK, 2008; ISA, 2010). This point of view is shared by recent performance analyses where gas detection systems effectiveness is commonly evaluated in terms of time to and probability of detection (Kelsey et al., 2002, 2005; Bratteteig et al., 2011). Gas detection systems have interfaces with the Emergency Shut Down (ESD), Blow Down (BD), Ignition Source Control (ISC), ventilation, Public Address (PA) and alarms system, and fire fighting systems (NORSOK, 2008). Minimizing the time to detection and guaranteeing reliable detection allows for effective corrective actions and emergency response, including ignition source control, containment, evacuation of personnel, or other actions appropriate to the specific situation. However, it was not until recently that standardization entities started assessing the use of these metrics in performance-based designs. ISA-TR84.00.07-2010 (ISA, 2010) is the state of the art in this body of literature. Scenario and geographical coverage quantification are proposed as metrics to achieve a desired risk reduction in the design of fire and gas detection systems. Apart from the standardization publications, there is a wide array of performance-based practices and metrics developed by companies, contractors and academics in order to supplement the general recommendations and requirements aforementioned. These new techniques have arisen due to increased capabilities and understanding of leak and dispersion modeling. Examples include: Strøm and Bakke (1999), Dhillon and Chakrabarty (2003), Obenschain et al. (2004), DeFriend et al. (2008), Gencer et al. (2008), and Lee and Kulesz (2008). While these approaches strive for performance-based quantitative designs and they represent improvements over qualitative techniques, they fail to provide a rigorous quantitative framework that provides guaranteed optimality in their design objective while considering the inherent uncertainties and combinatorial characteristics.

3. Models

For this work, four existing approaches for gas detector placement were implemented and compared with two quantitative optimization-based approaches. It was intended to include a broad range of qualitative/semi-quantitative approaches and methodologies being currently used. The four existing approaches studied were the Random Approach (RA), the Volumetric Approach (VA), the minimization of the distance between the detectors and the leak sources, and a greedy scenario coverage approach (GC). These approaches were compared against the previously developed stochastic programming formulation considering unavailability and voting effects (SP-UV, Benavides-Serrano et al. (2014)).

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