# *Advancing Quantitative Fire and Gas Detection and Suppression Systems Analysis*

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**Introduction**

Fire and Gas detection and suppression systems have long formed an important part of the Loss Prevention toolkit for plants that process highly hazardous chemicals, both flammable and toxic. While every effort is made to prevent loss of containment of flammable and toxic chemicals, history has shown us that not only do these events occur, but those that are not prepared for them suffer major business-wrecking losses from which they may never recover.

Trends in Loss Prevention clearly show a move toward more and more quantitative methods. In general, this is a valuable trend because high risk situations cannot be simply dismissed as not credible due to the presence of safeguards that are qualitatively deemed appropriate. Furthermore, quantitative methods are helping to 'right size' risk reduction measures such as engineered safeguards, applying more resources to higher risk situations where they can provide the most benefit.

Unfortunately, the new methods that being employed are often misunderstood and misapplied to situations where their use is not appropriate. At this time, risk-based fire and gas detection is one of those situations. Using a very basic and very simple tool – such as Layer of Protection Analysis (LOPA) – to make decisions about the design basis for fire and gas detection and suppression systems, can be misleading and erroneously result in the decision not to implement such systems. The reality is much more complex. LOPA fails to correctly analyze risk mitigated by fire and gas systems for three key reasons 1) LOPA is a method that analyzes the frequencies and probability of events where an event happens or does not, it is not suited to analyzing the partial reductions in consequence the fire and gas detection and suppression systems provide; 2) LOPA is scenario-based and requires a priori knowledge of all of the causes of an event, a priori knowledge of the occurrence of leaks and fires is not possible, and as such, statistical methods to determine fire frequencies and locations is required, which LOPA cannot process; and 3) LOPA utilizes probabilities of failure to determine whether or not risk is tolerable – Simple use of probability of failure of a fire and gas detection and suppression system will lead to grossly inaccurate results as the preponderance of failures of these systems is the result of detectors not being located in the path of the release, as opposed to failure of the devices themselves.

In reality, the problem of quantifying the risks mitigated by fire and gas detection and suppression systems is extremely complex, requiring analysis methods and tools that are only in their infancy at the present time. Fortunately, the tools and methods that will be required to perform these analyses correctly are being developed. The Instrumentation, Systems, and Automation society (ISA) is in the process of developing a technical report, that will at a minimum outline the process that should be undertaken to quantitatively analyze fire and gas detection and suppression systems, and the tools that will be required for the recommended analyses are also under development.

In this paper, the authors are presenting a basic analysis framework and proposing nomenclature for the purposes of standardizing analysis methods. The paper will address in some depth, the problem of quantifying optical fire detection system performance, at least in the Geographic Coverage sense, and will allude to the future steps that will be required to extend the analysis to Scenario Coverage for fire detection and then Scenario Coverage for gas detection.

**Defining Optical Fire Detector Performance**

The objective of a quantitative fire and gas detection and suppression system analysis, ultimately, would be to verify that the quantitative level of risk posed by fires and gas releases is below a tolerable level. In order to know this, one would have to know the frequency at which fire and gas release events occur, and the degree of harm caused by these releases. The frequency can be estimated using statistical "leak rates" of common pieces of process equipment. This methodology should be very familiar to practitioners of Quantitative Risk Analysis (QRA) as it has been performed for a significant period of time of a good degree of success. The degree of harm posed by a release, on the other hand is a more complex analysis. It requires knowledge of the effects and consequences of a release event (which again can be estimated using traditional QRA techniques such as dispersion modeling and fire and explosion modeling) and also the ability of a fire and gas detection and suppression system to identify and act on the incident. This is where the shortfall in tools and techniques evidences itself. This is also where this paper endeavors to advance the state of the art by proposing terms of analysis and a general framework for analysis.

Quantifying the performance of a fire detector requires one to have two general categories of information. Specifically, information is required with respect to the detectors 1) capabilities and 2) positioning. Information regarding the capabilities of a fire detector should include the magnitude of fire that can be detected, and the distance(s) at which a fire can be detected with respect to the device. Information regarding the positioning should include not only the location of the device but also how it is oriented with respect to the room or other fire analysis area in which the detector is contained.

After this information is known, fire detector performance then becomes a tortured exercise in analytical geometry. At the elevation of interest, the area that is covered by the detector is the conic section that represents the intersection of the 'cone of vision' of the detector device and the plane formed by the elevation of interest. As a result, the projection can be an ellipse, parabola, or hyperbola. This analysis simply yields the 'unobstructed' coverage of a detector, the analysis is then further complicated by the fact that any obstructions to the line of sight of a detector need to be considered in the analysis. This is performed by projecting the shape of the obstruction as a shadow onto the plane of the elevation of interest. Finally, the viewable areas and the obstruction shadow projections from all of the potentially many detectors that form a specific detector array need to be aggregated to determine their overall effectiveness.

**Fire Detector Properties**

In order to quantify the performance of a fire detection system, the performance of the detector itself should be known. Fire detector vendors typically define performance in one of two ways (or both). Some vendors provide drawings that show a 'cone of vision'. This drawing visually displays the extents at which a 'typical fire' (usually a 1ft x 1ft pan of heptane) can be seen. Other times, only the ultimate distance at which the fire can be seen is presented in addition to angles away from the line at sight at which a fire is detectable.

The authors suggest that the following parameters should be utilized to study the performance of fire detectors.

DF Detection Distance (Far Field)

DN Detection Distance (Near Field)

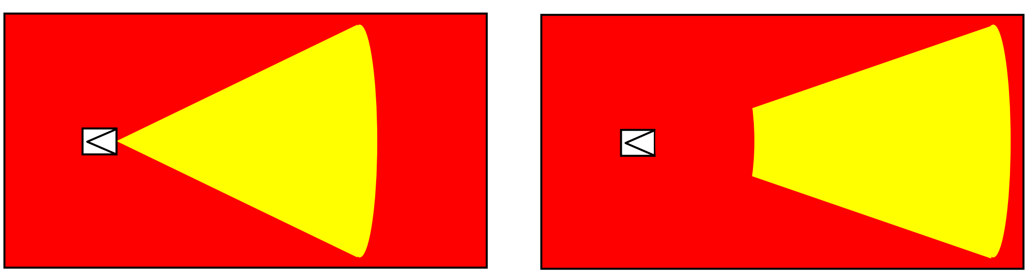
ϕH Sweep Angle, Horizontal Plane

ϕV Sweep Angle, Vertical Plane

The first parameter of interest, is the distance at which a fire can be detected. DF, or detection distance in the far field, represents the furthest distance at which a fire of interest can be detected. It is important to note that the fire must be larger than a certain threshold size before it is detectable. The distance will vary depending on the specific detector and the sensitivity settings implemented on the detector. The near field detection distance (DN) is also important. This parameter represents the nearest that a fire can be detected. If a fire is too close to a detector, some detector models can not accurately determine that it is a fire because too large of a fraction of its field of view is engulfed in the fire, preventing its detection algorithms from making the correct assessment.

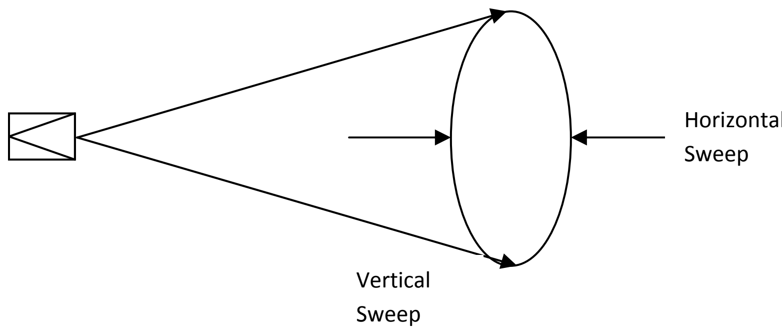
*Figure 1* presents two fire detector coverages. The first has a DF of 75 ft and a DN of 0 ft, and the second has a DF of 100 ft and a DN of 25 ft.

***Figure 1 – Coverage Effects of DD and DN***



The two sweep angles define the shape of the 'cone of vision'. In reality, the 'cone of vision' is not actually a cone. A cone of vision implies that the cross section perpendicular to the line of sight of the detector would form a circle (i.e., the detected distance in the vertical and horizontal directions would be equal). In reality, this is often not the case. Very frequently, optical fire detectors have different abilities to detect fires in the horizontal and vertical directions. As such, it is important for analysts of fire detection performance to consider a device's abilities in both directions. The authors chose to quantify this phenomena with two variables called horizontal and vertical sweep angles.  A sweep angle is the total angle (in each direction) that the detector is capable of viewing.  See *Figure 2*.

***Figure 2 – Horizontal and Vertical Sweep Angles***




**Fire Detector Location**

Given that the performance parameters of specific fire detector devices are known, the number, location, and orientation of the detectors further defines the abilities of a fire detection system.  In the experience of the authors, the following parameters should be utilized to define each detector in the detector array.

X  Distance from the analysis area origin in the 'x' direction

Y  Distance from the analysis area origin in the 'y' direction

Z  Elevation of the detector (i.e., distance from the analysis origin in the 'z' direction)

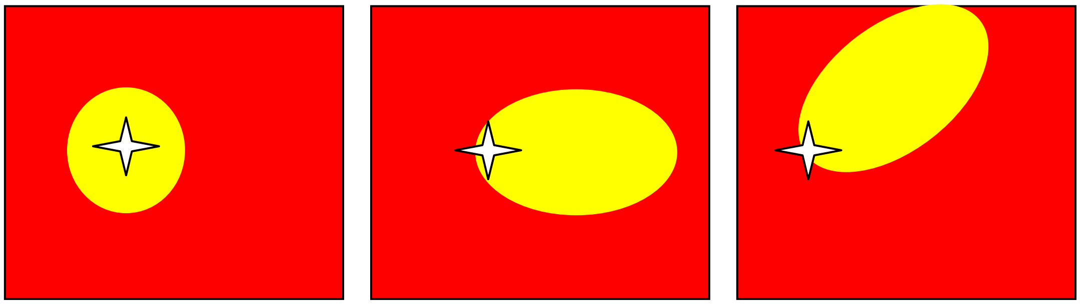
ϕR  Angle of rotation

ϕD  Angle of Declination

When performing the analysis, each detector most first be located.  In order to do this, the analysis area is considered in a Cartesian coordinate system, where one corner of the analysis area is the origin (i.e., the zero point).  After the origin is defined, the location of detectors is defined with three parameters, X, Y, and Z, where X and Y define distance from the origin in the horizontal plane and Z defines the height of the detector from the floor (or more correctly, the distance from the analysis space origin in the vertical direction).

The angle of rotation and the angle of declination determine the detector's orientation, or where the detector is "pointing".  The orientation of the detector ultimately determines the shape and location of its projected area of coverage of the plane formed by the elevation of interest.  Consider *Figure 3*.  This figure includes three areas of coverage that can be made from a single detector location by varying its orientation parameters.  The detector is at a set location, and in this example its vertical and horizontal sweeps are the same magnitude.  The first item shows a declination angle of 90 degrees (i.e., pointing straight down).  The second shows a declination angle of 80 degrees and a rotation angle of 90 degrees.  The last item shows a declination angle of 80 degrees and a rotation angle of 45 degrees.

*Figure 3 – Coverage Effects of Detector Orientation*



**Considering obstructions**

Simply projecting the "cone of vision" of a detector, considering its location, onto the plane of interest (or more correctly, all applicable planes) is not the end of the analysis. The steps presented above will provide an intermediate analysis point that can be referred to as Unobstructed Geographic Coverage. The next analysis step will be to consider the shadows in coverage generated by obstructions. After obstructions are considered, the resulting data is referred to as Geographic Coverage. In practice, geographic coverage is presented in two ways. First, there is a plan view graphic depiction of geographic coverage, this plot is very helpful to fire and gas detection system designers because it visually illustrates what portions of a protected area can and cannot be 'seen' by the existing detector array. The other result of this analysis comes in the form of a numerical coverage figure. The Geographic Coverage figure is essentially the area (at the plane of interest, or the summation of all planes of interest) that can be 'seen' by the given detector array, divided by the total area. This numerical figure can subsequently be used as a design criteria that should be considered during the detector layout process.

**Making the Move to Scenario Coverage**

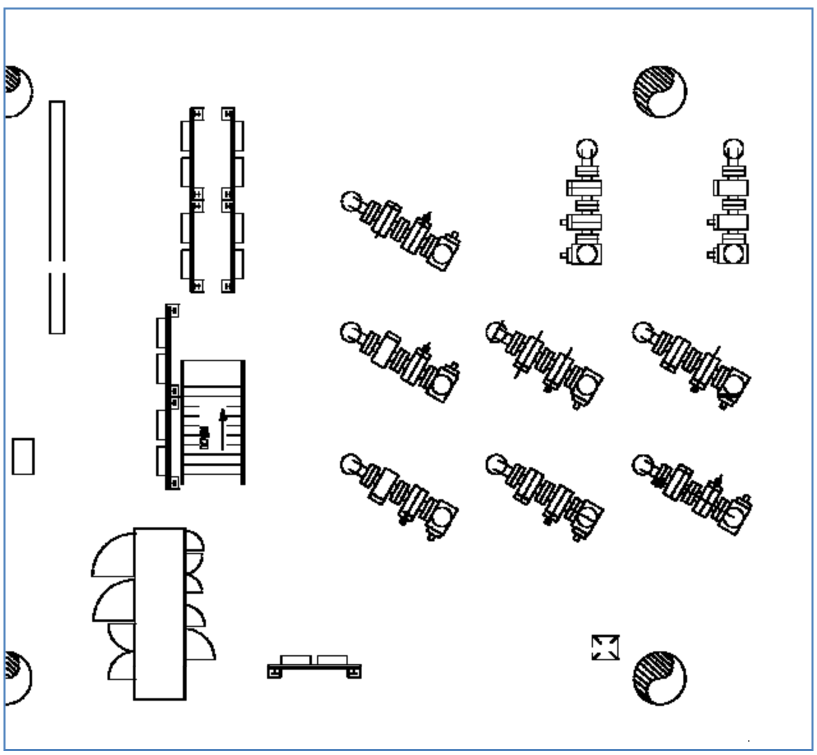
The discussion above talks in great detail about Geographic Coverage, but Geographic Coverage has its limitations. In order to utilize the results quantitatively, the objective must be to determine Scenario Coverage. It is most important to know not what percentage of an area can be "seen" by a fire detector, but what fraction of 'fire scenarios' can be seen. When a Geographic Coverage analysis is performed it reflects the ability of the detector to see 'points' that generate a certain level of thermal radiation. In reality, a fire cannot be a point, which is infinitely small. Real fires have volume. In order for a fire to reach the amount of thermal energy input that can be seen by a typical fire detector, it must usually have a significant volume. As such, even though a portion of a room might be obstructed by a piece of equipment, a 'fire of concern' might result in a projected area to the fire detector that is large enough to spill out either side of the obstruction, allowing the fire case to be seen even though part of the fire was obstructed. Geographic Coverage significantly understates the actual scenario coverage.

**Benefits of Geographic Coverage**

While geographic coverage does not provide a comprehensive quantitative target to measure against and achieve, performing the analysis can be very beneficial even if the only result is quantitatively looking at the graphical results to see if they demonstrate some oversight in the expert judgment layout or possible error in the heuristics that were used for laying out the detector array. Some early attempts at utilizing geographic coverage directly were not well accepted in industry because the analyses were performed by equipment vendors and often resulted in specification of much more equipment than expected and the experts, using their heuristic methods, deemed as necessary. This “over instrumented” specification was typically the result of attempting to reach a very high level of Geographic Coverage, which as described earlier, might not have been necessary because Geographic Coverage is typically so much less than actual scenario coverage.

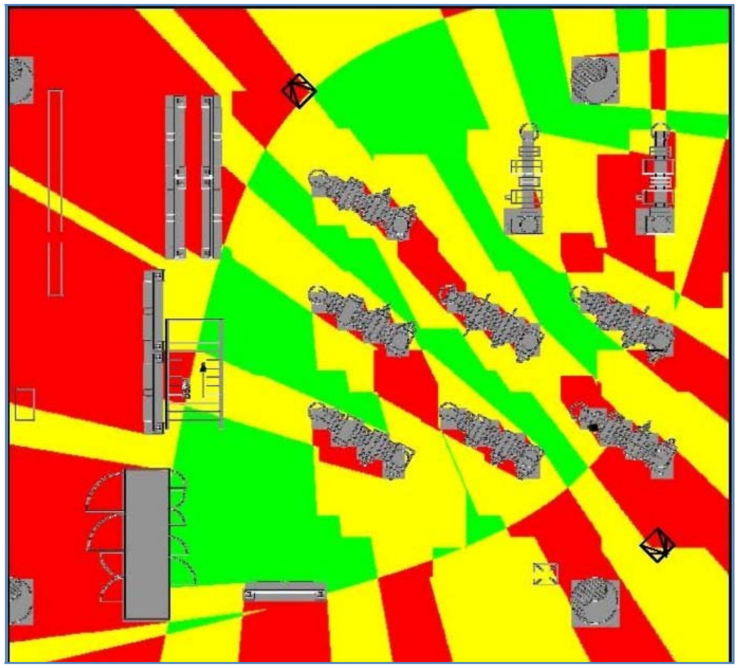
Consider the following example of a well bay that had its fire detectors placed by heuristics. *Figure 4* shows the equipment layout on the deck.

***Figure 4 –Wellbay Example***



A fire detector performance analysis was performed utilizing the approach outlined above, which resulted in the geographic coverage shown in *Figure 5*.

***Figure 5 –Baseline Detector Coverage***



The analysis shows that the geographic coverage is 62% (sum of green and yellow areas, which are covered by at least one detector). Coverage is limited by obstructions including wellheads, piping, cable trays, panels, and junction boxes. In this case, only two optical flame detectors were provided in the analysis based on heuristics. A geographic coverage of 62% is quantitative figure that allows for optimization of the design, but it does not provide the most relevant information. Qualitative inspection of the results shows that the current layout of the detectors results in a gap in coverage on one side of the well bay. This situation is unacceptable for a number of reasons, including being a violation of some qualitative rules of detector placement. As this example clearly demonstrates, even though the absolute value of Geographic Coverage, may have limited value, visual inspection of the results of Geographic Coverage provides significant insights and benefit to the fire and gas detector placement process.

**Extending the Analysis to Gas Detection**

As can be clearly shown in the discussion this far, quantitative analysis of fire risk is not a simple matter. The analysis of gas leaks is at least as difficult, and potentially even more complex due to the difficulty in defining the 'shapes' that are generated by gas leaks, and thus must be intersected by the gas detectors "field of vision". Determining the 'shape' of a gas leak is currently done by utilizing similarity models. As practitioners of QRA know, these models are only accurate when the release is unobstructed and results are only considered for the far field. In the case of fire and gas detection and suppression systems, the release is almost always obstructed and only the near field is relevant to the analysis. Prior to being able to accurately model gas releases, a lot of work will need to be done with regards to dispersion models that fit this particular problem.

**Conclusions**

As demonstrated in this paper, quantitative methods for quantitatively analyzing the performance of fire and gas detection systems are making great strides, but are still in earliest stages of development, and should not be relied on alone, in lieu of traditional expert judgment for making decisions about the design and application of these systems.

While a lot of work is still required to be completed in order to accurately model the abilities of fire and gas detection and suppression systems to mitigate risks, some of the work done to date has established a basic framework for how these types of analyses should be carried out. Furthermore, the results that are currently being achieved, while not perfect or quantitatively definitive, are still provide Loss Prevention specialists more insight and more qualitative information with regards to this complex but important problem.