# Methodology for Fire Risk Assessment in Industrial Facilities

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## ABSTRACT

It is known that the occurrence of a fire in a building or an industrial plant is a big problem when referring safety. If out of control the consequences of a fire can have impact on human lives, on business or even on environment. Some strategies rely on hard preventive measures, trying to avoid this type of event, while other include protective means, just to minimize or mitigate the consequences of it.

In the present work it is proposed a methodology to assess fire risk in industrial facilities, and in particular on complex and high risky ones. This methodology has the objective to determine the so-called Fire Risk Measure for specific areas in the industrial facility. The proposed methodology includes the analysis of the negative attributes of the area under consideration (or hazard factors) and the positive attributes of the referred area (or protection factors). The first include the identification of fuel type and fuel load, the existence of ignition sources or the space occupancy, while the later ones consider detection and alarm systems, extinguishing systems and passive protection.

Apart of these attributes it is also considered some influencing factors as maintenance and training of the people onsite and the relative importance of the analyzed area for the organization. At the end of this assessment process, it will be determined a Fire Risk Measure that allows to understand what are the more and less risky areas in the all facility. Based on this it is possible to work on the negative attributes in order to eliminate or reduce their contribution as well as improve some positive attributes just to decrease the risk on the most problematic areas.

The methodology has great potential to be applied to all type of facilities, regardless of the type of activity or process developed on them, contributing to a reduction in the risk of fire in these facilities.

## 1. INTRODUCTION

It is not surprising that the occurrence of a fire is usually an undesirable event. In fact, this is one of the most important topics when referring and analyzing safety whatever the context, infrastructure and the activity developed in a specific place. The reason for such concern is that usually this type of event, if not controlled, result in catastrophic consequences for human lives, business loss and business continuity or even resulting on environmental damage.

According to the National Fire Protection Association (NFPA) Report [1] about fires in industrial and manufacturing properties during the period of 2011-2015 there were an estimated 37,910 fires at industrial or manufacturing properties reported each year, representing annual losses of 16 civilian deaths, 273 civilian injuries, and 1.2 billion dollars (USD) in direct property damage. The same report states that the vast majority of these fires (71%) occurred in outside or unclassified locations, with another 20% taking place in structures and 9% of the fires in vehicles. The 20% of fires taking place in structures accounted for the largest shares of losses in all categories, representing about 49% of civilian deaths, 80% of civilian injuries, and 67% of direct property damage. Almost 65% of the combined industrial or manufacturing facility structure fires occurred specifically in manufacturing properties.

Stewart et al. [2] point out several studies related to fire occurrences. For instance, it is reported that the financial losses associated with large-scale industrial fires can be substantial, giving the example of four of the five largest process industry losses recorded in the year 2016–2017, involved fire events responsible for property losses that represent more than 1.7 billion dollars (USD). A single event in 2009 at the Indian Oil Corporation (IOC) terminal in Jaipur led to the death of 12 people and injuries to 200 more as well as loss of the entire fuel inventory on site over a two-week period of burning. Kumar et al. [3] confirms that such incidents can lead to considerable human harm and extensive damage to plant and the environment.

The statistics for industrial accidents show that around 60% of petrochemical storage tank accidents involve fire [4]. Also, regarding the worldwide domino-effect accident data indicate that fire is the primary event in around 40 to 55% of cases and that of those events initiated by fire and 80% began with pool fire incidents [5]. These studies and the reported numbers presented on them clearly highlight the importance of fire occurrences when assessing the risk in industrial installations.

Some works try to understand the behavior of a fire in a compartment, as for example discussing the energy balance equation taking into account the mutual influence between compartment pressure and ventilation behavior [6], investigating flame ejected from opening at different elevations on the facade wall of a fire compartment by varying the height of the opening and at different heat release rates [7], observing the fire dynamics in compartments made with timber boundaries [8, 9] or investigating the heat conduction pattern of a pool fire and the effect of interlayer thickness in a two-dimensional Finite Element model [10], among other specific studies concerning several topics related to a fire event.

Thus, it is important to develop methodologies just to understand the risk that a fire induces, knowing that there are not two identical events. For assessing the fire risk of a specific zone of an industrial site it must be taken into consideration what are the existing conditions that promote a fire (negative attributes) and the existing means to face such event (positive attributes). The main objective of the present work is to show a proposal for a methodology that precisely permits to include all these attributes and other influencing factors, allowing to reach an indicator (Fire Risk Measure) that can be used to assess the fire risk in a specific area of an industrial facility or site.

The paper is structured into five sections. The second one refers to fire risk in a wide-ranging vision, referring this type of event and some methods usually used to understand this type of occurrence. Section 3 presents a methodology that is proposed to perform a fire risk assessment in industrial facilities, describing all factors thar can influence the inherent risk, including the negative attributes of the area under consideration (or hazard factors) and the positive attributes of the referred area (or protection factors). Section 4 refers to the discussion on the results obtained for a demonstrative example of the methodology. Finally, section 4 presents some conclusions and future works on the follow-up of the present paper.

## 2. FIRE RISK

When referring to risk in industrial facilities or industrial installations one of the biggest concerns of those responsible for the installations is related to the occurrence of a catastrophic fire. An event like that is most of time something unpredictable and with uncertain consequences. Thus, fire safety is undoubtedly a big issue for buildings, assets and people. Strong regulation must be imposed to owners and the ones who have responsibility for the installation’s safety.

As stated by Sobral [11] the occurrence of a fire is one of the major concerns when analyzing the potential risks on installations. This is the reason why regulations oblige to have technical installations specifically dedicated to face this type of risk, including fire safety systems in a way to prevent fire occurrence or to protect against such events.

There are many standards and regulations that have been developed to assure a proper design, installation, maintenance and operation of such systems just to avoid, limit or mitigate fire events. Some of these standards were published by the National Fire Protection Association (NFPA), that has been for more than a century the leader on research and development of devices and on the publication of standards and regulation about fire safety. For European countries the regulations about this issue are published by the Comité Européenne des Assurances (CEA).

Fire risk assessment and fire safety have been studied in many countries from decades. Developed countries have invested a lot of money on the research for finding solutions, most of them with emphasis in issues related to performance-based fire design [12].

Although the significant amount of human and financial resources invested in preventive measures, it is common to observe a huge number of losses related to human lives, assets and infrastructures, and sometimes the existence of environmental damages. Based on this, it is fundamental to complement prevention with protection in a way to fulfill the objectives of obtaining the lower achievable and controlled risk.

There are several tools and methodologies that are used for fire safety assessment. Some of them are considered as qualitative, some as semi-quantitative and others referred as quantitative. On the qualitative methods one can include the Hazard and Operability Analysis (HAZOP), the Preliminary Hazard Analysis (PHA), the DOW Fire and Explosion Index, the What-If method and the MOND Index, among others. Related to semi-quantitative methods it can be referred the NFPA 101M fire assessment system, the Gretener method (SIA81 method), Fire Risk Index method or the Gustave method. When dealing with quantitative methods, the most known are the L-curve, CrispII, FIRECAMTM, CESRE-Risk, Event Tree Analysis (ETA), Fault Tree Analysis (FTA) and some Fuzzy math methods [12 - 17].

Fire risk analysis can be a part of fire risk management. In this scope Xin and Huang [18] build scenario clusters in the process of fire risk analysis for buildings and create fire risk indexes. Based on these indexes fire risk management measures could be taken aiming to improve fire safety grading and reduce fire risk levels and subsequent damage on those buildings.

In another work developed by Sakenaite [19] the problem of fire safety assurance is considered by means of fire risk indexing and fire risk assessment, giving special attention on the comparison of these two principal approaches and the possibilities of applying them in a combined set. The author stated that fire risk indexing is more practicable than formal risk assessment.

Hosseini et al. [20] assess the risk of fire in a gas processing plant using a fault tree analysis (FTA) and event tree analysis (ETA). The major causes of fire accident were determined through a process hazard analysis (PHA) and the fuzzy logic has been employed to derive likelihood of basic events in FTA from uncertain opinion of experts. By the other side the outcome events in the ETA were simulated by computer model to evaluate their severity.

Jafari et al. [21] developed a work about the evaluation of the reliability and performance of fire alarms in emergency situations. In this study the authors also used a fault tree analysis (FTA) to determine the root causes involved in the failure of fire alarm systems, the fuzzy set theory and expert elicitation to determine relative probabilities, and dynamic Bayesian networks (BNs) to evaluate the reliability of a fire alarm system. The results show that the system reliability could be increased by providing preventive and control measures to reduce the probability of critical events.

Several other approaches, methods, methodologies and tools can be found on literature about fire safety or fire risk. Whatever the method, it refers most of time to the comprehensive evaluation of two main areas, namely the probability of occurrence of a fire and the severity of the consequences of such event.

## 3. METHODOLOGY PROPOSED

In this paper it is proposed a methodology to assess fire risk in industrial sites, and namely in specific high-risk industrial confined areas. The methodology proposed was adapted to industrial facilities from a previous work developed to assess fire risk in ship compartments [22]. This methodology is also based in standards and regulations such as the Fire Risk Assessment Method for Engineering (FRAME) or Gretener method, usually used for residential and industrial buildings, on the National Fire Protection Association (NFPA) standards, as the NFPA 12 and NFPA 750 and on several papers published on the topic. The methodology includes Positive Attributes, related to protection factors, and Negative Attributes, related to hazard factors. All these attributes should be analyzed for each industrial risky area or confined zone under study, resulting in a zonal risk map whose risk values can be compared inside an industrial facility according to the fire risk category achieved.

In this proposal were considered as Negative Attributes (NA):

- Fuel Type;
- Fuel Load;
- Ignition Sources;
- Space Occupation.

And were considered as Positive Attributes (PA):

- Detection & Alarm Systems;
- Extinguishing Systems;
- Space Boundaries.

Other attributes could be addressed but these were considered by the author of the present proposal to be the ones that better describe the most influencing factors of a fire in a confined area and thus the best set of attributes to be assessed concerning the objective. A description of each one of the attributes above mentioned is given in the following paragraphs as well as an explanation on how to determine the corresponding attribute level to be assumed in the methodology. Figure 1 shows graphically the proposed methodology.

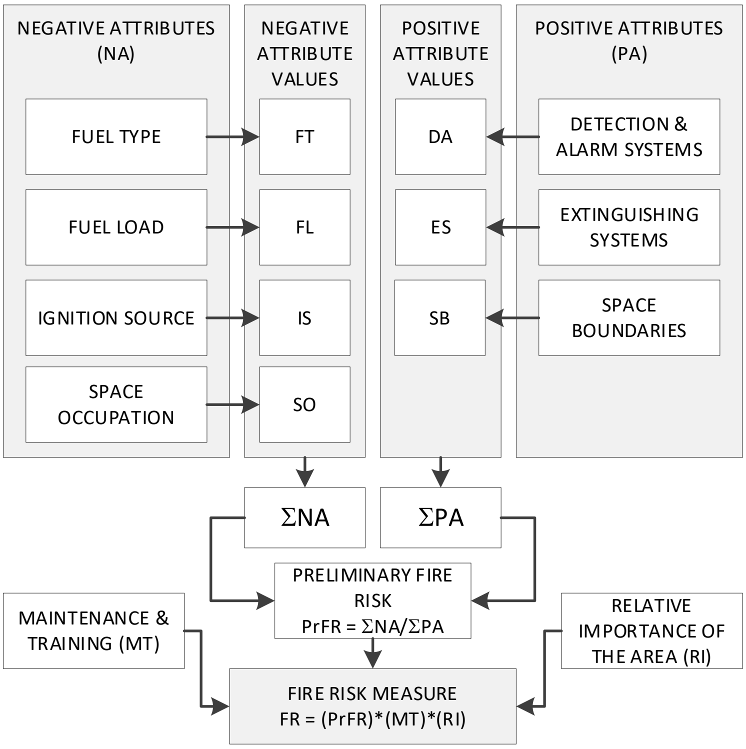


**Fig.1** - Fire risk assessment methodology for industrial facilities

It is assumed that all the attributes have the same weight in terms of contribution to the preliminary fire risk assessment (PrFR) and the influence of Maintenance & Training (MT) and the Relative Importance of the area (RI) factors have also equal weight for the determination of Fire Risk Measure (FR). All attributes and factors are assumed to be independent.

For each one of the inputs were established levels with the corresponding values assigned in accordance to the literature review regarding fire risk assessment methods and in some standards and regulation about fire risk assessment (mostly about fire safety in buildings). These attributes and inherent levels and values will be presented in the following tables.

### *3.1 Fuel Type*

Fuel Type (FT) attribute is related to the type of material that exist in the area under analysis. Each type of material has a different reaction to fire and it determines how easy a fire can breakout and spread through the area under study. Table 1 shows different levels and respective FT value. In the presence of several fuel types, it must be assumed the worst-case concerning material fuel type, unless its quantity is considered as insignificant.

**Tab.1 -** Fuel Type

| Fuel Type | FT Value |
|---|---|
| Incombustible Materials | 0 |
| Difficult to Ignite (self-extinguishing) | 1 |
| Slow Burning Materials | 3 |
| Combustible Materials | 5 |
| Flammable Materials | 7 |
| Highly Flammable Materials | 10 |

### *3.2 Fuel Load*

Fuel Load (FL) attribute corresponds to the potential hazard related to the total fuel load in the area under study and is defined as the ratio between the materials total heat of combustion and the total area of the space floor. For this case it was used the scale developed by Kenneth et al. [23], with the necessary adjustment (levels and correspondent values), as presented in Table 2. It is widely recognized that fuel loads below 180 MJ/m² are insufficient to maintain a fire and flashover and complete combustion does not occur for fuel loads under 350 MJ/m². Fuel loads above 900 MJ/m² are suitable to maintain a fire for a long period.

**Tab.2 -** Fuel Load

| Fuel Load [MJ/m²] | FL Value |
|---|---|
| Below 180 | 0 |
| 180 – 350 | 1 |
| 350 – 600 | 3 |
| 600 – 900 | 5 |
| 900 – 1500 | 6 |
| 1500 – 3000 | 7 |
| 3000 – 6000 | 8 |
| 6000 – 10000 | 9 |
| Above 10000 | 10 |

### *3.3 Ignition Sources*

Another negative attribute that must be taken into account refers to the existence of potential sources of ignition in the area under consideration. Ignition sources are related to fonts of heat that can become hot enough to ignite the fuel load inside the area. These Ignition Sources could be related to mechanical parts, electrical sockets and appliances, hot surfaces, product combustion or any activity that involve hot work as welding, cooking, incinerators, boilers and others.

Table 3 shows some classes for Ignition Sources and their contributing value. The Sum of Ignition Sources (SIS) value is achieved by the arithmetic sum of all IS contributions. Then, according to Table 4 the final Ignition Sources (IS) value is determined.

**Tab.3 -** Ignition Sources contribution

| Ignition Source | IS contribution |
|---|---|
| No sources of ignition | 0 |
| Electrical (equipment and wire installation) | 6 |
| Naked flames (smoking, pilot lights, etc.) | 8 |
| Mechanical machinery | 4 |
| Hot work (cutting, welding or grinding) | 8 |
| Hot surfaces (heaters, engines, boilers, etc.) | 6 |
| Cooking activities | 8 |
| Chemical reaction / storage incompatibility | 4 |
| Other | 4/6/8 |

**Tab.4 -** Ignition Sources

| Sum of Ignition Sources | IS value |
|---|---|
| SIS < 5 – Low | 0 |
| 5 ≤ SIS < 10 – Medium Low | 5 |
| 10 ≤ SIS < 15 – Medium High | 7 |
| SIS ≥ 15 – High | 10 |

### *3.4 Space Occupation*

It is known that if a confined area is usually occupied by people the corresponding probability of a rapid detection is higher and thus faster the alarm and the efficiency of the potential actuation (e.g. the use of manual extinguishers). This situation usually led to the avoidance of the escalation of the initial fire. Table 5 shows the Space Occupation (SO) level and related value.

**Tab.5 -** Space Occupation

| Space Occupation [daily] | SO value |
|---|---|
| 100% of time occupied | 0 |
| 75% - 100% of time occupied | 1 |
| 50% - 75% of time occupied | 3 |
| 25% - 50% of time occupied | 5 |
| 0% - 25% of time occupied | 7 |
| Never occupied (or incipient) | 10 |

### *3.5 Detection and Alarm Systems*

The existence of manual or automatic devices that give an alarm in case of fire is extremely important. It is essential to ensure that this type of devices is maintained and operational. In those conditions will be given a fast response and alert for an ongoing undesirable event. In the present methodology this is assumed as a Positive Attribute for the fire risk assessment on the area under study. The impact of existence of such measures is shown in Table 6.

**Tab.6 -** Detection & Alarm Systems

| Detection & Alarm Systems | DA value |
|---|---|
| Space without automatic detectors | 0 |
| Manual detection and manual alarm signal | 3 |
| Space partially covered by automatic detectors | 5 |
| Space fully covered by automatic detectors but no external alarm signal (visual/audible) | 7 |
| Space fully covered by automatic detectors and external alarm signal (visual/audible) | 10 |

### *3.6 Extinguishing Systems*

Similarly, the existence and operability of Extinguishing Systems (ES) will also act as safety barriers. This type of equipment is also considered as a Positive Attribute on the fire risk assessment for an industrial facility. In accordance with the existence and type of these systems there is a probability of success on the mitigation of a fire. Table 7 presents some types of Extinguishing Systems and their contribution value.

For the proposed methodology, when more than one extinguishing system is installed in the area under study, the Sum of Extinguishing Systems value (SES) corresponds to the arithmetic sum of all ES contributions. Then, according to Table 8 the final Extinguishing Systems value (ES) is determined.

**Tab.7 -** Extinguishing Systems contribution

| Extinguishing System | ES contribution |
|---|---|
| No extinguishing system | 0 |
| Portable extinguisher (<15 meters) | 4 |
| Hose and Hydrant (<15 meters) | 6 |
| Fixed CO2 / other gas flood system | 8 |
| Fixed water sprinkler system (traditional) | 8 |
| Fixed high expansion foam system | 8 |
| Fixed water spray system (water mist) | 8 |
| Other | 4/6/8 |

**Tab.8 -** Extinguishing Systems

| Sum of Extinguishing Systems | ES value |
|---|---|
| SES < 5 - Low | 0 |
| 5 ≤ SES < 10 – Medium Low | 5 |
| 10 ≤ SES < 15 – Medium High | 7 |
| SES ≥ 15 - High | 10 |

### *3.7 Space Boundaries*

Regarding this attribute one must look up to the area under study and observe the passive protection of its boundaries in a way to protect the referred area from the spread of a fire coming from the outside. That is assumed as the analysis of the “quality” of the boundaries regarding a fire event, and thus also observed as a Positive Attribute.

Table 9 shows the several types for the space boundaries and the corresponding contribution value. The Sum of Space Boundaries value (SSB) corresponds to the arithmetic sum of the usual six boundaries of the area. Then, according to Table 10 the final Space Boundaries value (SB) is achieved.

**Tab.9 -** Space Boundaries contribution

| Space Boundaries | SB contribution |
|---|---|
| Permanently open | 0 |
| Wood | 3 |
| Wood with fire retardant coating | 4 |
| Plasterboard | 5 |
| Plasterboard with fire retardant coating | 6 |
| Brick or Steel | 7 |
| Brick or Steel with fire retardant coating | 8 |
| Concrete | 10 |

**Tab.10 -** Space Boundaries

| Sum of Space Boundaries | SB value |
|---|---|
| SSB < 20 - Low | 0 |
| 20 ≤ SSB < 30 – Medium Low | 5 |
| 30 ≤ SSB < 40 – Medium High | 7 |
| SSB ≥ 40 - High | 10 |

### *3.8 Fire Risk Assessment*

The next step refers to de determination of a Preliminary Fire Risk value (PrFR) that is achieved based on all considered values for Positive Attributes (PA) and Negative Attributes (NA). This PrFR value represents the measure of how big are the Negative Attributes in order to Positive Attributes in a specific area of the industrial facility. The methodology does not finish at this point because it also considers the influence of two extrinsic important factors that are not related to the area under study itself.

The first factor is the Maintenance & Training (MT) related to the maintenance activities and technicians' competences concerning fire equipment and fire events and the second factor is the Relative Importance of the area (RI) regarding its individual importance to the entire facility. Next paragraphs give a brief description of these two factors and how they can influence the fire risk assessment for a specific area in an industrial facility. The MT and RI values are a proposal and can be adjusted considering organizational objectives. However, once established, they should not be changed due to the necessity of having coherent comparable results.

#### *3.8.1 Maintenance & Training*

The Maintenance & Training (MT) is a very important factor to be taken into consideration. Depending on that, the way how devices and equipment are maintained and the personal behavior of the technicians when facing a fire event will influence the evolution of such fire. In the present methodology the evaluation of technician's competences and the devices and equipment operational condition is performed using a questionnaire, as the one shown in Table 11.

**Tab.11 -** Maintenance & Training requirements

| Maintenance & Training requirements | Y / N |
|---|---|
| There is a maintenance and testing plan for detection and alarm systems? | |
| There is a maintenance and testing plan for extinguishing systems? | |
| Maintenance technicians have periodic training activities about detection and alarm systems? | |
| Maintenance technicians have periodic training activities about extinguishing systems? | |
| Regular inspections are made to detection and alarm systems? | |
| Regular inspections are made to extinguishing systems? | |
| There are instructions for operators/others on what to do in case of fire? | |
| The confined areas are well ventilated? | |
| The areas are kept clean regularly (fuel load)? | |
| Are fire drills carried out regularly? | |
| Fire regulations are followed? | |
| Insurance recommendations/requirements are followed? | |
| Is there an internal firefighting department? | |
| Are firefighting devices visible and accessible? | |
| Do firefighting devices have adequate and visible signage? | |

The definition on how to obtain such answers must be discussed in a way to gather true information and credible responses (supported by evidences). Based on the answers given to the questions stated in Table 11, the Maintenance & Training factor assumes the following values shown in Table 12.

**Tab.12 -** Maintenance & Training factor

| Quantity of negative answers | MT factor |
|---|---|
| Negative answers ≥ 2 | 1.15 |
| Negative answers = 1 | 1.00 |
| Negative answers = 0 | 0.90 |

### *3.8.2 Relative Importance of the Area*

Similar to Maintenance & Training factor, the Relative Importance of the area (RI) can be seen as a factor that represents the perspective on how a fire in a specific area will affect the work developed in the whole facility. It refers to the importance measure that the area under study represents to the organization objectives and could be used to prioritize the firefighting when fire incidents occur in multiple areas. The values for the Relative Importance of the area are shown in Table 13.

**Tab.13** – Relative Importance of the area factor

| Importance | RI factor |
|---|---|
| Critical to the facility (high impact) | 1.15 |
| Critical to a process (medium impact) | 1.00 |
| Not critical (no impact) | 0.90 |

## 4. RESULTS AND DISCUSSION

Based on the proposed methodology presented in the previous sections, a spreadsheet tool was developed allowing the automation of the entire process and to determine the quantification of the risk associated with a fire in a given area of the industrial facility. This spreadsheet tool is a very simple way to materialize the methodology and simplify the assessment. It is automated just to make the calculations easier and give error messages if something is wrong on the fulfillment of the required fields.

In a way to demonstrate the methodology proposed, it was tested in a real industrial facility belonging to an organization on the pharmaceutical field. There were two areas under consideration for the fire risk assessment:

- Area A = purified water pump room
- Area B = chemical warehouse

Following all the steps of the methodology the values achieved for the positive and negative attributes, as well as the MT and RI factors and the Fire Risk Measure for the two areas are presented in Table 14.

**Tab.14** – Fire Risk Measure of the areas A and B

| | Item | Area A | Area B |
|---|---|---|---|
| NA | FT | 0 | 7 |
| | FL | 1 | 5 |
| | IS | 7 | 7 |
| | SO | 7 | 5 |
| PA | DA | 3 | 7 |
| | ES | 7 | 7 |
| | SB | 10 | 10 |
| PrFR | | 0.75 | 1.00 |
| | MT | 1.00 | 1.00 |
| | RI | 1.15 | 1.00 |
| FR | | **0.86** | **1.00** |

The Fire Risk Measure value by itself does not have significance neither is possible to be compared with other else values given by other method or a different industrial facility. In this case it should only be understood in comparison to other areas of the same installation and using the methodology proposed in this work.

A Fire Risk Measure of 1 means that the Positive Attributes have the same weight of the Negative ones and the factors of Maintenance & Training and Relative Importance of the areas do not affect the intrinsic Fire Risk. This is the average situation and acceptable for the common industrial areas based on several simulations that were performed and allowed to refine the methodology as it is.

If the PrFR has a value more than 1 it means that the Negative Attributes are higher than the Positive ones, which represents a concern for this type of event. Something should be done do decrease such risk to values close to 1 or less. Nevertheless, the consideration of the Maintenance & Training and Relative Importance of the areas must be included, once these factors can affect the final result for the Fire Risk Measure of the area under study.

## 5. CONCLUSIONS

In the present work it is proposed a methodology to assess fire risk in industrial facilities, based on the individual study of specific areas. It will allow to understand the risk of a fire occurrence in those areas and further establishment of adequate preventive and protective measures. This type of assessment is based upon the specific attributes of each area under study, making possible to distinguish several areas in the industrial facility in the fire risk perspective.

Regarding all the attributes required to be analyzed on the methodology, perhaps the Fuel Load estimation is one of the most difficult one due to the difficulty on the determination of the heat combustion of the materials in the area under analysis. Despite fire literature, tables with thermal and thermodynamic material properties or other source of information regarding these elements it is not a direct and fast method and requires some time and expertise to gather the necessary information. It is being analyzed the possibility of replacing the estimation of Fuel Load in the area upon deterministic calculation based on quantities and quality of materials by a probabilistic estimation based on statistics about the type of area and typical load existing in it.

Concerning the Space Boundaries, it is being evaluated the inclusion of the fire resistance classification of both structural and non-structural elements, in accordance to international standards, instead of an assessment only based on the nature of the materials in each one of the six boundaries.

The next steps for this work must include the application of the proposed methodology in more real examples of industrial facilities and to perform a sensitivity analysis to verify how it responds to single variations of area attributes and adjust some parameters, if necessary.

Based on the proposed methodology it is possible to distinguish several areas in the industrial facility at the fire risk point of view. Then, a zonal fire risk map can be done allowing a better understanding of the higher risk zones and lower risk ones concerning a fire event. The application of the present methodology is a valuable tool to enhance the knowledge of every single area allowing to adjust the adequacy of preventive and protective measures, promote the necessary improvements to reduce fire risk and meet legal requirements in the field of safety.

## 6. REFERENCES:

[1] RICHARD CAMPBELL, Fires in Industrial and Manufacturing Properties, NFPA Research, Data and Analytics Division, US (2018);

[2] JAMES R. STEWART, HERODOTOS N. PHYLAKTOU, GORDON E. ANDREWS and ALAN D. BURNS, "Evaluation of CFD simulations of transient pool fire burning rates". *Journal of Loss Prevention in the Process Industries*, Vol 71, pp. 104495 (2021);

[3] VIPIN KUMAR, S.K. PANDEY, S.M. TAUSEEF, TASNEEM ABBASI and S.A. ABBASI, "Pool Fires in Chemical Process Industries: Occurrence, Mechanism, Management". *Journal of Failure Analysis and Prevention*, Vol 18, pp. 1224–1261 (2018);

[4] JAMES I. CHANG, CHENG-CHUNG LIN, "A study of storage tank accidents". *Journal of Loss Prevention in the Process Industries*, Vol 19, Issue 1, pp. 51-59 (2006);

[5] BAHMAN ABDOLHAMIDZADEH, TASNEEM ABBASI, D. RASHTCHIAN and S.A. ABBASI, "Domino effect in process-industry accidents – An inventory of past events and identification of some patterns". *Journal of Loss Prevention in the Process Industries*, Vol 24, Issue 5, pp. 575-593 (2011);

[6] JUNYI LI, HUGUES PRÉTEL, SYLVAIN SUARD, TAREK BEJI and BART MERCI, "Energy balance equation for pressure in air-tight compartment fires: detailed discussion and experimental validation". *Fire Safety Journal*, Vol 122, pp. 103362 (2021);

[7] KAIHUA LU, ZICHANG WANG, YANMING DING, JIE WANG, JIANPING ZHANG, MICHAEL A. DELICHATSIOS and LONGHUA HU, "Flame behavior from an opening at different elevations on the facade wall of a fire compartment". *Proceedings of the Combustion Institute*, Vol 38, Issue 3, pp. 4551-4559 (2021);

[8] CARMEN GORSKA, JUAN P. HIDALGO and JOSE L. TORERO, "Fire dynamics in mass timber compartments". *Fire Safety Journal*, Vol 120, pp. 103098 (2021);

[9] YUCHUN ZHANG, XIAOLONG YANG, YUEYANG LUO, YUNJI GAO, HAIYAN LIU and TAO LO, "Experimental study of compartment fire development and ejected flame thermal behavior for a large-scale light timber frame construction". *Case Studies in Thermal Engineering*, Vol 27, pp. 101133 (2021);

[10] DONG MU, SONG WU, FEI ZENG, FENGJUN WANG and XIN HUANG, "Experimental research in the fire resistance of the double-frame container". *Journal of Loss Prevention in the Process Industries*, Vol 66, pp. 104202 (2020);

[11] SOBRAL, J., "Fire Safety Systems in Buildings - Problems and Concerns beyond the Project". *MOJ Civil* Eng. Vol. 2 (5), pp. 177-178 (2017);

[12] HUANG, Y., HAN, B. and ZHAO, Z., "Research on Assessment Method of Fire Protection System". *Procedia Engineering*, Vol 11, pp. 147–155 (2011);

[13] XUE Z., "Research on FTA of Fire and Explosion in the Crude Oil Gathering Transport Combination Station". *Procedia Engineering*, Vol 11, pp. 575-582 (2011);

[14] CHU G. and WANG J., "Study on probability distribution of fire scenarios in risk assessment to emergency evacuation". *Reliability Engineering & System Safety*, Vol 99, pp. 24-32 (2012);

[15] ISIMITE J. and RUBINI P., "A dynamic HAZOP case study using the Texas City refinery explosion". *Journal of Loss Prevention in the Process Industries*, Vol 40, pp. 496-501 (2016);

[16] GUPTA, J.P., KHEMANI, G. and MANNAN M.S., "Calculation of Fire and Explosion Index (F&EI) value for the Dow Guide taking credit for the loss control measures". *Journal of Loss Prevention in the Process Industries*, Vol 16, Issue 4, pp. 235-241 (2003);

[17] WANG, J. and SONG, W., "Fire and Explosion Index calculation method incorporating classified safety measure credits". *Journal of Loss Prevention in the Process Industries*, Vol 26, Issue 6, pp. 1128-1133 (2013);

[18] XIN, J. and HUANG, C., "Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management". *Fire Safety Journal*, Vol 62, pp. 72–78 (2013);

[19] SAKENAITE, J., “A comparison of methods used for fire safety evaluation”. *Science – Future of Lithuania*, Vol 2, No. 6, pp. 36-42 (2010);

[20] NAVID HOSSEINI, SAEED GIVEHCHI and REZA MAKNOON, “Cost-based fire risk assessment in natural gas industry by means of fuzzy FTA and ETA”. *Journal of Loss Prevention in the Process Industries*, Vol 63, pp. 104025 (2020);

[21] MOHAMMAD JAVAD JAFARI, MOSTAFA POUYAKIAN, ALIREZA KHANTEYMOORI and SABER MORADI HANIFI, “Reliability evaluation of fire alarm systems using dynamic Bayesian networks and fuzzy fault tree analysis”. *Journal of Loss Prevention in the Process Industries*, Vol 67, pp. 104229 (2020);

[22] SOBRAL, J and GUEDES SOARES, C., “Fire Risk Assessment for Ship Compartments”. *Maritime Technology and Engineering III*, Guedes Soares, C. & Santos T. A., (Eds.), Taylor & Francis Group, London, UK, pp. 895-902 (2016);

[23] KENNETH, S., LAMBRINEAS, P., SUENDERMANN, B. and WOODWARD, R., “A Fire Risk Assessment Methodology for Naval Vessels”, *Proceedings of the Fire Safety’91 Conference*, Volume 4, pp. 385-396, Florida, USA (1991).