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Fire Risk Index Assessment as an Evaluation Method for Fire Strategies in the Process Industry

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It is increasingly recognised that all complex buildings should be covered by a relevant and up to date fire strategy. This is particularly the case for special infrastructures such as process plant buildings (for e.g. power stations). These buildings contain a number of risk areas, each of which requires an appropriate and specialised level of evaluation. A fire strategy should consider eight key elements (fire safety factors), all of which are relevant to their fire safety and protection.
The fire safety elements are the basis for the determination of a new semi-quantitative methodology of the evaluation of the Fire Risk Index assessment. The methodology contains a number of checks appropriate for different industrial areas, graphical tools and calculation procedures.
The process allows the comparison of an actual fire strategy against a pre-determined baseline strategy. The case study for an exemplar industrial boiler house is used to illustrate the proposed methodology.

1. Introduction

Literature reviews provide numerous examples of engineering approaches for the evaluation of fire and explosion safety in industrial buildings. Many of such buildings require a special risk assessment and adherence to fire safety management criteria, particularly relevant for local fire regulations and code requirements (Vairo et al., 2017; Seay et al. 2017; Siqing, 2017). The most popular risk assessment methods utilise failure statistical data of different safety equipment, which are often difficult to find (Borchiellini et al., 2017; Guanghui, 2017). The presented fire risk index method has been developed from a method proposed by Swiss engineer Max Gretener (Gretener, 1973; Watts, 2016). The main advantage of the method is that there is no need to use statistical failure data. Instead of this, the user creates their own data, based on the building fire strategy evaluation (Brzezinska and Bryant, 2018).
A strategic approach is to take into account all the conditions that exist in the facility being analysed, and which can have a significant impact on the conditions that occur during a fire (PAS 911, 2007; Bryant, 2013). It requires a holistic assessment of the fire protection and provides guidance in the determination of the best possible results in terms of overall fire protection. It is important to take into consideration the four main objectives of the Fire Strategy in the prepared fire strategy: safety of life, property protection, business protection and continuity, and protection of the environment. Each of these objectives can be further subdivided into four sub-objectives (Figure 1).

1.1 Regulations and engineering solutions

There are two basic options for creating a Fire Strategy (PAS 911, 2007; Bryant, 2013; Brzezinska and Bryant, 2018). One option is to make use of regulatory requirements which can be typically highly prescriptive. The other is to utilise performance-based fire-engineered solutions.
Prescriptive codes typically work on the basis that the fire strategy either complies with the imposed requirements, or it does not. This approach can have pitfalls in that it often cannot allow for the intricacies of complex industrial buildings. The alternative is to use engineering methods and solutions based upon the assessment of functional performance objectives of the building and occupancy profile. The engineering approach to fire protection design involves analysing representative fire scenarios and evaluating various

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technical and organizational solutions, using tools and engineering methodologies based upon previously determined objectives. This definition identifies three components of the engineering approach to fire protection, which are (Brzezinska and Bryant, 2018):

- Identification of design objectives what includes a description of the expected level of fire risk for the building which is the subject of the analysis
- Identification of design assumptions and parameters such as fire development scenarios and evacuation requirements
- Engineering analysis of proposed solutions

The aim of the fire engineering approach is to achieve a level of equivalence, or better, to the level required by local regulations, standards or the requirements of special interest groups such as insurers. However, the approach also introduces a high level of complexity in the problem solving stages of an effective fire engineering based fire strategy. This may involve calculus, fire and evacuation modelling, etc. This inevitably can lead to issues for those tasked with the verification and approval of the fire strategy. Whereas a prescriptive based solution is relatively easy to audit, the performance approach requires a more in-depth understanding of the assumptions and decisions made, as well as an appreciation of the methodologies adopted.

One solution to this dilemma is based on an idea to provide a consistent and unambiguous approach that can be more easily assessed and approved without the need to a high level of competence in fire engineering for both those preparing the fire strategy as well as those tasked with its approval. The idea was adopted as the basis of a "Fire Strategies" workshop to develop a fire strategy for boiler houses at a Polish power plant in Polaniec (Brzezinska et al., 2017).

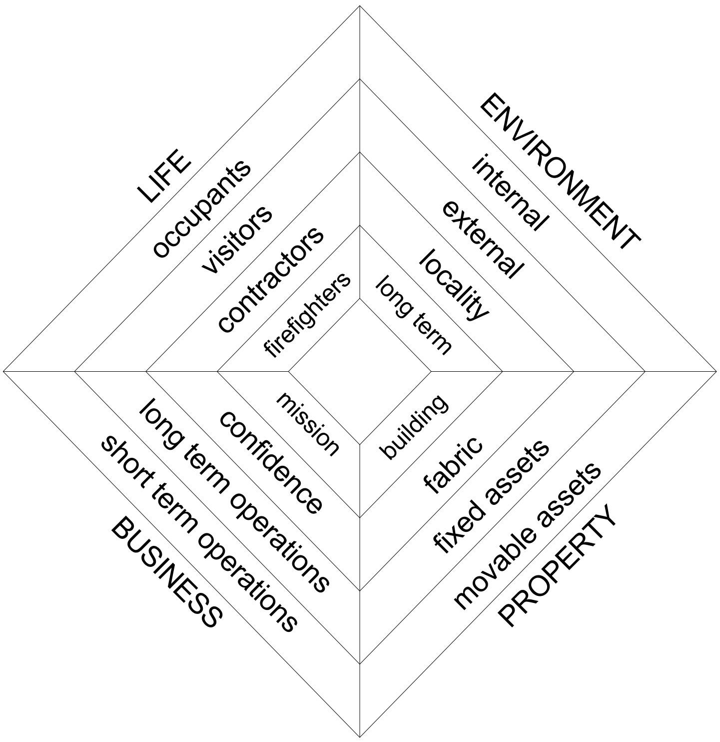

Figure 1: Matrix of Fire Strategy Objectives (PAS 911, 2007; Bryant, 2013; Brzezinska and Bryant, 2018).

1.2 Evaluation of the Fire Strategy

The aim of any fire strategy is to provide a single solution making use of a range of fire prevention, protection and firefighting measures to meet with national regulations and standards, as well as additional requirements and objectives set out by stakeholders and insurers. The fire strategy is constructed of eight fire safety factors representing three fundamental protective layers as prevention and the limitation of fire spread, the use fire protection measures and systems, and the involvement of professional fire fighters. The evaluation of the fire strategy uses a scoring system of each fire safety factor from zero to twenty-five (Brzezinska and Bryant, 2018). The fire safety factors representing three layers of fire protection are presented in Table 1.

Table 1: Fire safety factors in a fire strategy

Layer of fire protection	Fire safety factor (FSF)
Fire prevention and fire spread limitation	1. Organisation and Management (ORG) 2. Control of ignition sources and combustible materials (LIM)
Fire protection measures	3. Fire and smoke spread limitation - passive systems (PAS) 4. Detection and alarm communication (DET) 5. Fire suppression (SUP) 6. Smoke control and evacuation (SC) 7. Availability of fire protection means and devices (MAI)
Fire fighting	8. Fire services intervention (FB)

1.3 Detailed questions for the fire strategy safety factors

In order to formulate the fire strategy evaluation tool, a special list of detailed protective functions for each of the eight fire safety factors were prepared. Note that it is anticipated that every building type will make use of specially adapted question list. The question list relevant to power stations buildings was created in collaboration with representatives of Polish ENEA Polaniec S.A and insurance company PZU during the technical workshop in Polaniec Power Station (Brzezinska et al., 2017). Table 2 shows a fragment of the question list, representing the first of fire safety factors - Organisation and Management.

Table 2: Detailed questions for the fire strategy safety factors

Organisation and Management	Score scale
1. Have internal procedures/instructions been fully implemented, which take into account the specifics of the power plant facilities and nature of activities? For example: general instructions in the scope of the organisation with regard to fire safety, procedure for fire-hazardous work, fire safety instructions, explosion protection document, the rules concerning the operation of equipment and installations in case of fire,	0 ÷ 5
2. Are emergency and evacuation drills regularly conducted in line with emergency plans prepared? Do fire and rescue service operatives participate in the exercises? How often are fire scenario drills conducted?	0 ÷ 4
3. Are systematic periodic and documented fire safety inspections carried out on facilities / grounds / areas as well as on the fire protection equipment, installations and fire safety and protection infrastructure and safeguards?	0 ÷ 4
4. Is their provision of round the clock monitoring of the power plant facilities and operations that will communicate with fire and rescue services? Additionally, or alternatively, is there an on-site professional fire and rescue presence?	0 ÷ 6
5. Has an integrated system of coordination of all fire and explosion protection activities been implemented as well as the formulation of procedures to be taken against emergencies/ disasters?	0 ÷ 4
6. Is there a firefighting (ATEX) training program systematically in place for the company's staff? Have work conditions been established for external contractors with respect to fire protection and ATEX?	0 ÷ 2

The first stage of this fire strategy evaluation process is to define a baseline fire strategy. This may be based on the requirements of the applicable regulations and standards and/or requirements of stakeholders such as insurers company, and the specific conditions associated with the facility. The baseline strategy is determined by adopting the appropriate score on a scale of 0 ÷ 25 for each of the fire strategy safety factors analysed. When an appropriate assessment is made for each of the eight fire safety factors, it is marked on the strategy value grid shown in Figure 2. Each point is connected with lines to form a pattern. This is the basis of the fire strategy evaluation grid.

Once the baseline strategy is plotted, then the evaluation of the actual fire strategy can commence. This represents the actual level of fire safety and protection of the processing plant as designed (in the case of newly built plants) or in service (in the case of existing plants). The idea is to allow each of the eight fire safety factors to be considered separately and ultimately evaluated by scoring from zero to twenty five. The purpose of the method is to enable the user to determine how each of the listed Fire Safety Factors affects the whole of the fire strategy. This diagram allows both the visualization of the strategy as well as the analysis of its development and can be used both in the design of new buildings and the evaluation of existing buildings.

The example of the diagram is shown in Figure 2 where fire strategy evaluation for the boiler houses of the Polaniec Power Plant is shown.

1.4 Fire risk index calculation

The last step of fire strategy evaluation is calculation of a fire risk index (FRI). The presented method of calculation has been developed from a method proposed by Swiss engineer Marc Gretener (BVD 1973; Wats, 2016). In his original method, fire risk was assumed as a product of hazard severity (fire hazard) and loss expectation represented by fire frequency of ignition. In the presented method, the fire risk and fire hazard terms are replaced respectively by the fire (strategy) risk index - FRI and fire hazard index – FHI, but the general assumptions stay the same and are covered in formula (1) (Brzezinska and Bryant, 2018).

$$\text{Fire risk index (FRI)} = \text{Fire hazard index (FHI)} \cdot \text{Frequency of ignition (Fi)} \tag{1}$$

The hazard severity, referred to as the fire hazard index in equation (1) is proportional to the potential hazard, reduced by protective measures, shown in formula (2).

$$\text{Fire Hazard Index (FHI)} = \frac{\text{Potential Hazard (PH)}}{\text{Protective Measures (PM)}} \tag{2}$$

The original Gretener formula expressed empirically derived numerical factors for fire initiation and spread, with factors for fire protection (Gretener, 1973). The idea used in the method presented here is based upon the values achieved from scoring of each fire safety factor in accordance with Table 1 and Table 2 for the baseline and actual strategies, respectively. Additionally, appropriate weighting factors for FRI and FHI calculations are applied.
A total scoring for protective measures (PM) is obtained from the formula (3) by aggregating the points obtained from the assessment of each fire safety factor adjusted by the appropriate weighting factor.

$$\begin{aligned}\text{PM} = {} & \text{W}_{\text{ORG}} \cdot \text{E}_{\text{ORG}} + \text{W}_{\text{LIM}} \cdot \text{E}_{\text{LIM}} + \text{W}_{\text{PAS}} \cdot \text{E}_{\text{PAS}} + \text{W}_{\text{DET}} \cdot \text{E}_{\text{DET}} + \text{W}_{\text{SUP}} \cdot \text{E}_{\text{SUP}} + \text{W}_{\text{SC}} \cdot \text{E}_{\text{SC}} + \\ & + \text{W}_{\text{MAI}} \cdot \text{E}_{\text{MAI}} + \text{W}_{\text{FB}} \cdot \text{E}_{\text{FB}}\end{aligned} \tag{3}$$

where:
E_{ORG}, E_{LIM}, E_{PAS}, E_{DET}, E_{SUP}, E_{SC}, E_{MAI}, E_{FB} – score of each fire safety factor,
W_{ORG}, W_{LIM}, W_{PAS}, W_{DET}, W_{SUP}, W_{SC}, W_{MAI}, W_{FB} - weighting factors taken as 20% of baseline strategy value of each baseline fire strategy safety factor.

By determining the result of the assessment of protective measures (PM), the value of the fire hazard index FHI, for the both baseline and actual fire strategies, can be calculated from the formula (4).

$$\text{FHI} = \frac{\text{PH}}{\text{PM}} \cdot 100 \tag{4}$$

where:
FHI – fire hazard index,
PH – potential hazard factor (determined on the base of assumption that FHI = 1 for the baseline strategy),
PM – protective measures, calculates from the formula (3).
The final step of the fire strategy assessment is the determination of the fire risk index from the formula (5).

$$\text{FRI} = \text{FHI} \cdot \text{Fi} \tag{5}$$

where:
FRI –fire risk index,
FHI – fire hazard index,
Fi - frequency of ignition.
The frequency of ignition value in the equation 5 can be taken from different statistics or standards, as for example the British Publish Document: Application of fire safety engineering principles to the design of buildings, Part 7: Probabilistic risk assessment (PD-7974-7, 2003).

2. The goals of the fire strategy for the boiler house of Polaniec Power Plant

As mentioned in the introduction, the fire strategy for the boiler house of Polaniec Power Plant was developed jointly by a group of experts and other stakeholders. The strategy has been developed in line with the stated fire strategy objectives, based on the matrix described in Figure 1.
As the main objectives of this strategy, life safety and business continuity (of production) were adopted. Next the baseline fire strategy (in accordance with Polish regulations) and actual fire strategy (in accordance to

actual boiler houses fire protection) were evaluated. The results of the evaluation are presented graphicly in Figure 2.

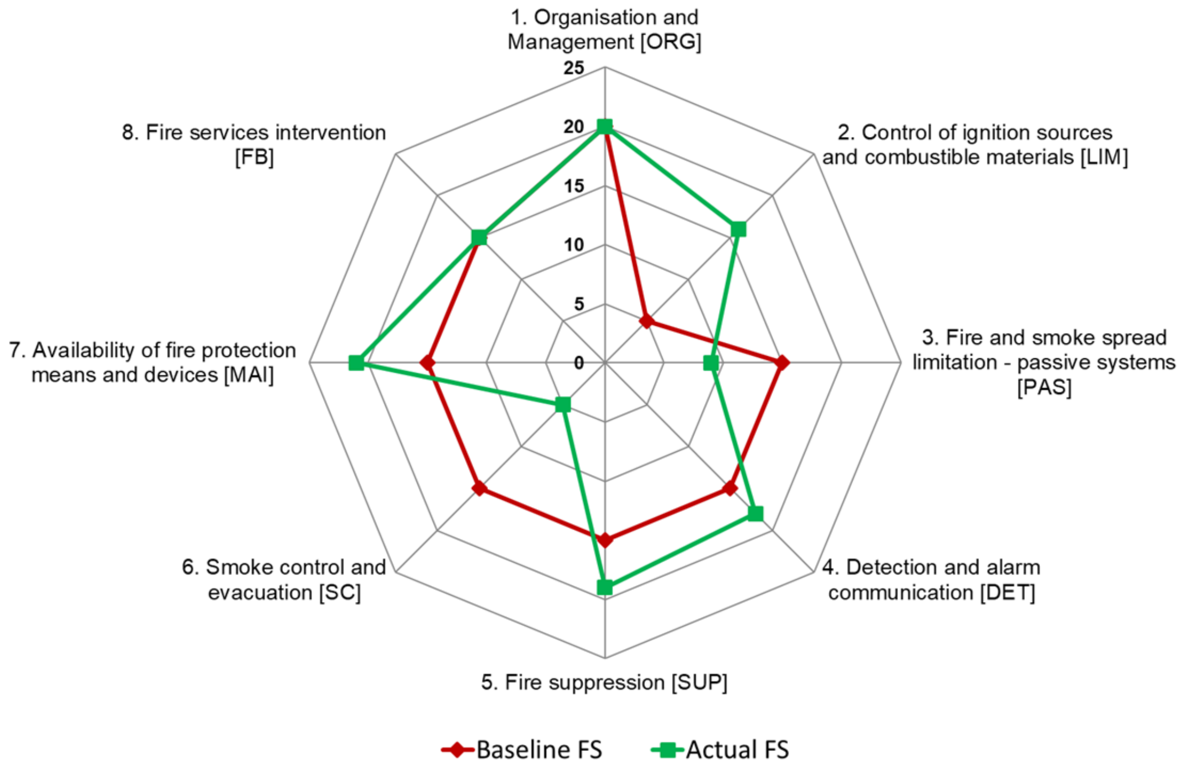

Figure 2: Polaniec Boiler House Fire Strategy Value Grid (Brzezinska et al., 2017)

The fire strategy assessment of the Polaniec Power Station Boiler Houses, as illustrated in Figure 2, shows the differences between their actual and baseline fire safety levels. It is evident that the organization and management of fire protection as carried out in the analysed boiler houses is seen to be satisfactory, in line with the expected level. Likewise, the protection measures utilised for fire detection and fire suppression systems, as well as the availability of protection measures and firefighting equipment, are shown to be fit for purpose. Fire and smoke control is significantly different from the expected level, impacting on the efficacy of evacuation. Attention should be given to the variance od scores for passive fire protection.
The fire strategy evaluation was undertaken in accordance with the presented calculation procedure. In the first step baseline and actual strategy protective measures (PM) in accordance with formula (3) were scored. Then fire hazard indexes (FHI) and finally the fire risk indexes (FRI) were calculated. The values of fire risk indexes were achieved respectively:

FRI_{BAS} =4,02 – fire risk index of the baseline fire strategy,
FRI_{AC} = 3,55 - fire risk index of the actual fire strategy.

The results show that the fire risk index for the actual strategy adopted in the analyzed plant was lower than the baseline strategy ($FRI_{AC} < FRI_{BAS}$). It can therefore be concluded that the measures applied in the plant provide a level of the fire protection in excess of the expected level.

3. Conclusions

The presented method for fire strategy evaluation provides a new, unique, semi-quantitative technique for fire risk index (FRI) assessment for fire strategies. It makes possible to present and evaluate fire strategies prepared for new or existing buildings. The most significant element of the presented methodology is the possibility of determining if a prepared fire strategy is appropriate for a specific building risk profile. It also allows for the comparison of different fire strategy concepts for a building, or other form of infrastructure, as well as comparison of similar fire strategies used in different buildings. The simple rule of the methodology assumes that, where the fire risk index for the actual fire strategy is equal or lower as the baseline fire strategy, then this strategy is deemed to be suitable and fit for purpose. A higher score means that fire strategy should be reviewed, and the elements of the strategy revisited. The methodology given in this article was tested as part of the fire strategy evaluation of the Polaniec Power Station Boiler Houses.

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