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Building Fire Risk Assessment Methods: A hierarchical classification

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Abstract

Fire risk is a key element in architecture: sometimes it derives from human action at the time of construction, sometimes from factors over which man has no control. Prevention is frequently the most effective measure to afford it, even when it is known that zero risk is not an achievable goal and we can only reduce it to acceptable levels. One of the prevention tools that architects and engineers can use are the Fire Risk Assessment (FRA) methods. Over the last years, many techniques or approaches of FRA have been developed, and it is possible that the excessive information makes the analyst´s task difficult. This research tries to be a simple and useful review of the main Risk Assessment Methods, ranking them according to their complexity, which will allow the architect or engineer to select the best technique depending on the specific building needs.

Keywords

Fire Risk Assessment Methods; building fire risk analysis; simplified methods; complex qualitative methods, complex quantitative methods.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

1. Introduction

Risk prevention is our best tool in order to minimize the consequences that accidents can produce in buildings, even more in case of fire, which involves some unpredictable factors, such as human behavior or the intervention time of the rescue services. That prevention becomes an obligation when there is a possibility of human lives loss.

Recent events, as the Grenfell Tower fire in London last June, demonstrate the importance of prevention. In addition to avoiding the initiation of a fire, it is essential to have an action plan in the case it occurs: how the development of the fire will be, its interior and exterior spread, its detection, the evacuation of occupants and the fire department operation. The failure of these elements has catastrophic consequences: 71 fatal victims in Grenfell Tower.

FRA Methods are a good prevention tool for architects and engineers, in order to evaluate the risk of fire, its possible consequences and the safety measures needed. This paper is a review of the most used methods, and a classification of them according to their complexity. It is a task for the analyst to decide what method is the appropriate in each situation.

2. Definitions and existing classifications

The first problem we face when considering FRA is the different terminology used for each of the phases involved in the process. The terms vary depending on the bibliography consulted, the method selected or even the language used. For example, Assessment and Evaluation do not have the same meaning in English, but they are translated by the same word in many languages such as Spanish: "Evaluación".

Therefore, this study begins with the definition of each of the localized terms, from the most global; "Risk Management"; to the most specific. Risk Management is a concept that involves risk assessment and risk treatment, that is, it includes the elaboration of corrective measures against hazards, in addition to the knowledge of their magnitude.

The SFPE (Society of Fire Protection Engineers) Handbook defines Risk Assessment as "the process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society or environment". In this study, Risk Assessment is considered to be composed by two stages: Risk Analysis and Risk Evaluation.

Risk Analysis is the process of identification of the possible hazards, and the estimation of the consequences and probabilities of the adverse effects that could arise from them. Results are presented in a qualitative, quantitative or mixed way. Risk Evaluation consists in making decisions about the level of acceptable risk, based on the results obtained.

Risk Treatment is the process of improving the existing fire safety measures or adopting new ones, that is, the implementation of the assessment result.

Once the terminology is established, the same difficulty is found in the classifications of the different used methods: they differ depending on the consulted bibliography. NFPA 551 divides the methods into: qualitative, semi-quantitative likelihood, semi-quantitative consequences, quantitative and cost-benefit.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

John Watts, in the SFPE Handbook, divides the FRA Methods into four categories according to their form: checklists, narratives, indexing and probabilistic methods.

There are many other authors who propose classifications, such as Frantzich, who also makes a distinction between qualitative and quantitative methods, or Fraser-Mitchell, who establishes three categories: Point-Schemes, State Transition Models and Simulation Models. The Spanish engineer J.C. Rubio Romero divides FRA Methods into two large subgroups: Simplified methods and Complex methods, which are subdivided into qualitative and quantitative.

Therefore, according to the different references, FRA Methods can be classified into multiple ways, depending on the chosen criteria. These classification are not mutually exclusive, but they form a complex network, in which the same method may belong to several categories according to the selected criterion. Some of the possible classifications are:

<table>
<tr><th>CRITERION</th><th>Scenario</th><th>Data source</th><th>Methodology</th><th>Complexity</th><th>Factor Analyzed</th></tr>
<tr><td rowspan="4">CATEGORIES</td><td rowspan="2">Single scenario</td><td>Qualitative</td><td>Checklists</td><td rowspan="2">Simplified</td><td rowspan="2">Consequence</td></tr>
<tr><td rowspan="2">Semi-quantitative</td><td>Narratives</td></tr>
<tr><td rowspan="2">Multiscenario</td><td>Indexing</td><td rowspan="2">Complex</td><td rowspan="2">Hazard</td></tr>
<tr><td>Quantitative</td><td>Probabilistic</td></tr>
</table>

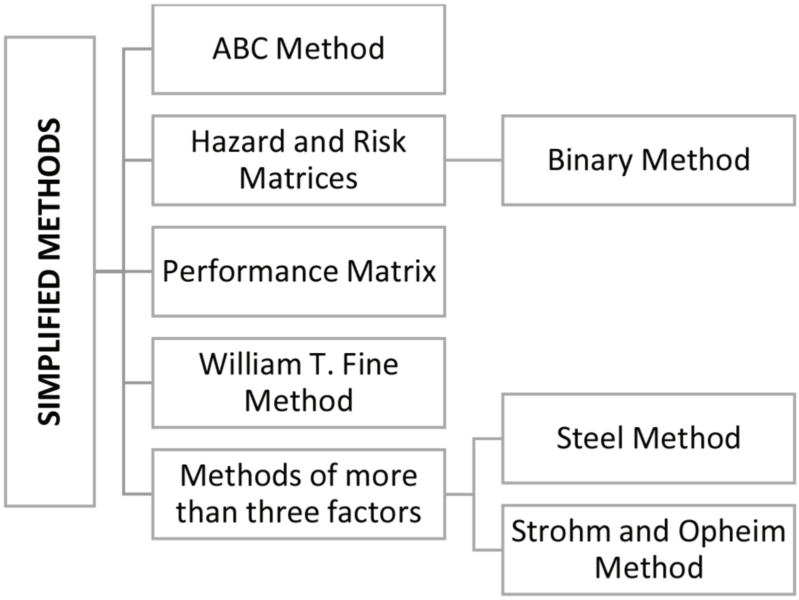
Table 1.
Different classifications for FRA Methods.

Not all methods can be classified into one of the above categories, and all categories are interrelated. In addition, sometimes the name of the category is a method itself (as in the case of checklists or indexing).

Some of the methods will be explained and classified below, with the complexity criterion based on the categories used by J.C. Rubio. The following schemes include the most common FRA Methods at international level, and some methods with a widespread use in Spain. Some of them are briefly described, but those specific methods for industrial buildings have not been deeply developed, due to the difficulty on its application.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

3. Simplified Fire Risk Assessment Methods



Scheme 1.
Simplified Fire Risk Assessment Methods classification.

3.1. Hazard and risk matrices

The hazard and risk matrices quantify the consequence of possible events for each type of loss (human lives, property, environmental damage…) along one dimension of the matrix, and relative likelihood or frequency along the other. Then, an approximate risk estimate is obtained. In the case of performance matrices, performance groups (building typologies grouped by their use expectation) are compared with the magnitude of designed events.

Each hazard is located in one of three levels, from the lowest to the highest frequency. These hazards are ranked in a second estimate according to the expected negative impact on people, property and environment, and then they are placed in one of three severity levels. Finally, by a comparative matrix, the arithmetic product of probability multiplied by severity is obtained, and the level of risk is determined.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

RISK		Consequences		
		Low	Medium	High
Probability	Low	Negligible	Tolerable	Moderate
	Medium	Tolerable	Moderate	Severe
	High	Moderate	Severe	Intolerable

Figure 1.
Example of a Risk Matrix.

	Probability	Consequences	Risk (PxC)
Human Lives	Medium	High	Severe
Property	Medium	Medium	Moderate
Environmental Damages	Medium	Low	Tolerable

Figure 2.
Example of a Risk Matrix applied to a Residential Building.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

3.2. William T. Fine Method

The William T. Fine Method, developed in 1971, decomposes frequency or "probability of occurrence" into two factors: the Exposure or frequency of the initiating events, and the Probability that the accident occurring, once the risk event has been started.

Exposure = Risk events / Time

Probability = Expected accidents / Risk events

Cost and effectiveness of Fire Protection Measures can be estimated as of these factors, through the following equation:

Consequences = Expected damage / Expected accidents

Therefore, the risk magnitude can be calculated by combining the above equations:

Risk = Expected damage / Time

*Risk = C * E * P = (Expected damage / Expected accident) * (Risk events / Time) * (Expected accidents / Risk events)*

These equations are completed with numerical values, which are available in different sources and tables. Finally, a numerical result will be obtained in order to estimate the severity of the possible hazards.

The collection of all risk situations, ranked according to the severity of their hazards, provides the elaboration of a priorities list, starting with the higher risk. Another aspect added by the Fine Method to the Risk Assessment is the introduction of a factor that determines if the proposed protection actions are justified, according to their cost and effectiveness.

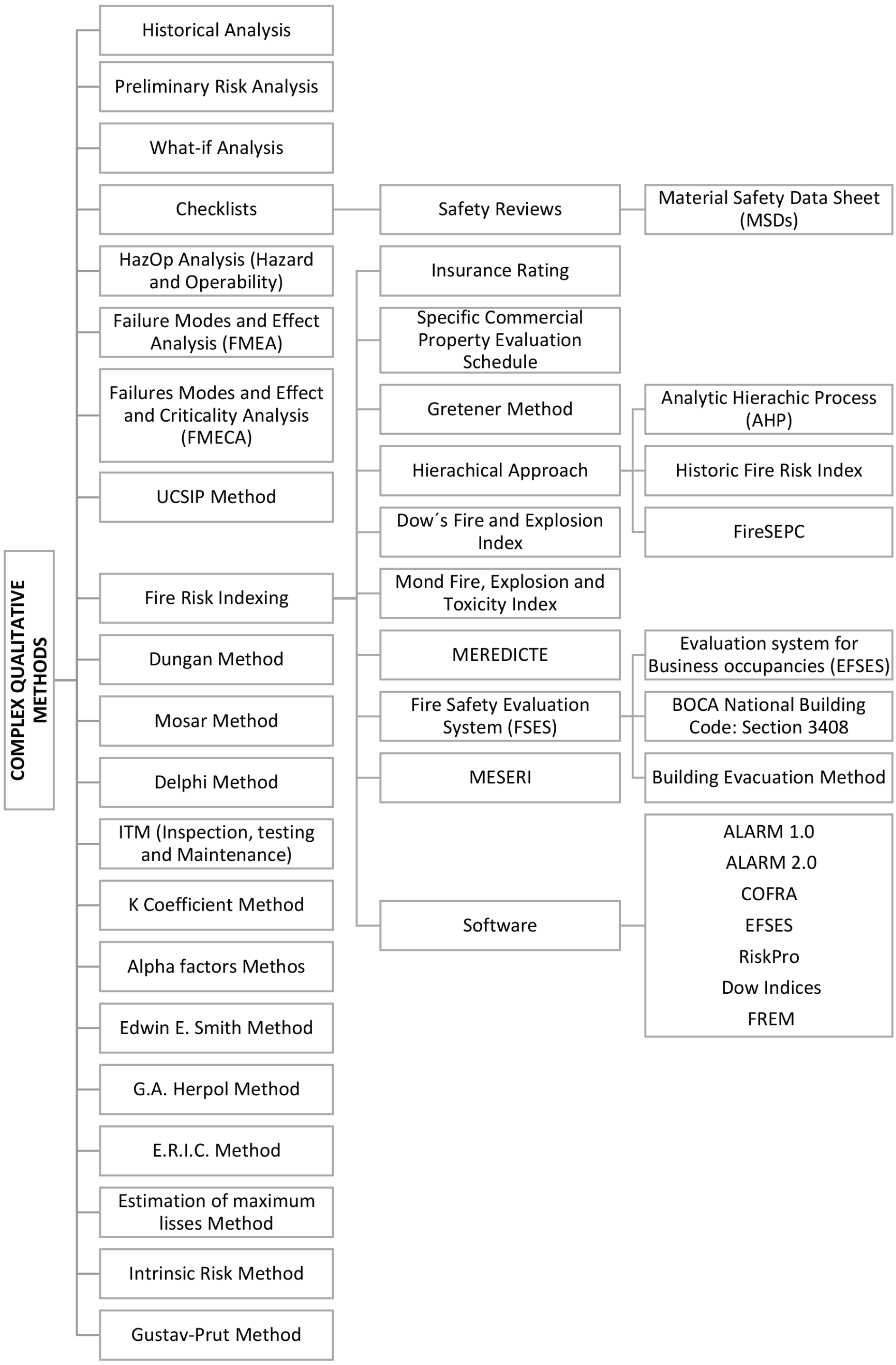
ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

FACTOR	SELECTED CATEGORY / FORMULA	VALUE
Exposure	Rarely (the risk does not occur frequently)	0,5
Probability	If the fire occurs it is possible the catastrophic consequences	3
Consequences	Disastrous (Several deaths)	40
Risk	$Risk = C * E * P$ If risk is between 20 and 70, the risk is possible: it should be corrected, but it is not urgent	60

Figure 3.
Example of the Fine Method applied to a Residential Building.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

4. Complex qualitative methods



Scheme 2.
Complex qualitative methods classification.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

4.1. Historical analysis

The historical analysis should be integrated in any Fire Risk Assessment. This technique consists in the research about all the accidents recorded in similar buildings or industries. The analysis reliability depends on the size of the available sample.

As the hypotheses are based on real cases, sometimes the extrapolation of data in not possible, if the fire safety facilities are different than those of the studied building, or if there has not been collected enough information. This analysis is useful in order to make a first approximation to the frequency of occurrence of accidents, and to the possible hazards.

4.2. What-if analysis

The what-if analysis is a "Risk Identification" method, based on a conceptual thinking process. It is a preliminary analysis, which consists in the *"What-if…?"* Question concerning potential undesirable events or scenarios that could happen. It is normally used informally, as a basis for more detailed analysis, and it should be performed by specialists (two or three). The possible triggers of risk situations may be identified from detailed information about the building (and if it is an industrial plant, the materials involved), as well as their consequences and their possible solutions.

What-if analysis can be applied at any stage of the building life; from design, construction and operation until later modifications or even when it ceases its functioning. It is a qualitative method.

4.3. Check lists

Checklists are often used as a quick method for verifying if a building meets the standards requirements. They can be as simple or as complex as the analyst may need, and they can be applied at any stage of the project. This analysis should be performed only by expert personnel, and it shall be based on knowledge of the regulations and codes.

Although the open-ended questions are preferable in order to be valued, checklists usually require a "yes" or "no" response, which does not evaluate the risk, but only identifies it in order to give recommendations.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

FIRE SAFETY CHECKLIST		
IN GENERAL	YES	NO
Fire extinguishers are present and charged Smoke detectors are installed and working		
Carbon monoxide detectors are installed and working		
Fire alarms and exit signs are visible There are two exits from any room. All cables, plugs etc, are damage-free		
EXITS AND EXTERIORS	YES	NO
All means of escape are clear and available		
The building exterior and adjacent properties are clean and well maintained		
All doors, stairs and fire escapes are unobstructed and in good condition There are at least two ways out from any level or floor of the building The building address is visible and clearly marked		
Outdoor areas are free of flammable debris and furniture designed for interior use		
Flammable liquids are not stored in building		
Exit signs and emergency lights are in place and working properly		
LIVING ROOM AND COMMON AREAS	YES	NO
All furniture, linens, and draperies are made of fire-resistant material All interior walls and ceilings are in good condition		
All exit doors are unobstructed and providing sufficient means of egress		
Electric outlets on each wall have covers and are in good condition		
All wall electrical switches work easily and light fixtures work properly Hallways and common areas are illuminated Windows operate easily and without bars or barriers		
Exit doors free of locking devices that may interfere with exiting		
Dryers, chimneys, wood stoves and all home heating systems are professionally inspected and cleaned annually		
Smoke detectors are in each hallway leading to bedrooms		
KITCHEN	YES	NO
Electric outlets on each wall have covers and are in good condition		
All wall electrical switches work easily and light fixtures work properly		
Appliances provided appear to be clean and in good working condition		
Appliance electrical cords are in good condition		
Kitchen exhaust and kitchen surfaces are free of grease Hot and cold water turns on and off without leaks		
Windows operate easily, exit route is clear, doors work freely		
BEDROOM	YES	NO
Mattress, furniture, linens, and drapery is made of fire-resistant material Interior walls, ceiling and floor are in good condition Outlets have covers and are in good condition All wall electrical switches work easily and light fixtures work properly		
Smoke detector is present near bedroom and operating		
At least one window operates easily and is not obstructed by bars Door works freely, latches and locks are functional		

Figure 4.
Example of a checklist for the fire safety evaluation of a residential building.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

4.4. Fire risk indexing

Fire Risk Indexing is an assessment method for fire safety. On the one hand, it consists in the analysis and assessment of the building hazards, in order to produce a simple result that estimates the relative risk of fire. On the other hand, values are assigned to positive and negative safety measures. Then, the analyst operates with arithmetic functions until a simple value, which is compared to other evaluations. It is a simple, effective, semi-quantitative method. It may be appropriate in several situations: When a high level of sophistication is not required, when the analysis is required to be economically effective, and when there is a need to communicate the level of risk. This type of methodology is also known as rating schedules, point schemes, ranking, numerical grading and scoring.
There are several indexing techniques. Some of them have been developed for the evaluation of industrial buildings; there are indices for specific national regulations (i.e. MEREDICTE and MESERI in Spain); there are international indices…

The Gretener Method is widely used in Europe. It is a risk index developed between 1960 and 1965 by the Swiss engineer Max Gretener. The process consists in numerically expressing the factors for fire initiation, and the factors of protection: fire risk is measured as the ratio of negative features that increase risk and positive features that decrease risk. A Potential Fire Risk is calculated and compared to an Admissible Potential Risk. It is a very complete method in terms of the number of factors it evaluates, but it should be performed by an experienced operator.

The calculation is based on:

$$R = B * A = (P / M) * A$$

Where:

B = Fire Hazard (P/M)
A = Probability of ignition. This factor is left open to the subjectivity of the analyst.
P = Potential hazard
M = Protection measures.

"P" is composed by the product of all dangerous factors, both content (fuel load density, combustibility, smoke formation, corrosion or toxicity) and continent (fuel load density, height or floor level and amplitude of fire compartments). Therefore, it evaluates the intrinsic risk conditions for the developed activity and the construction characteristics of the building.

"M" is the product of all protection factors: normal measures (portable fire extinguishers, hydrants and hose...), special measures (detection and alarm systems, fire intervention, automatic extinguisher systems and smoke control...) and fire resistance of the building (structural elements, facades, firewall cells...).

Once the value of the Effective Fire Risk (R) is calculated, an Accepted Fire Risk (Ru) value is set; such value is obtained from a Normal Risk value (Rn = 1.3), which is corrected by a factor that takes into account the danger to people (PHE). This factor is calculated with the capacity of the floor, its height with respect to the level of the ground and the people exposure to the risk, (which is determined by the ease or difficulty of evacuation).

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

$$Ru = Rn * P_{HE}$$

From the comparison between Effective Fire Risk and Accepted Fire Risk, we can deduce whether or not fire safety is sufficient. For this purpose, the Fire Safety Factor (γ) is used:

$$\gamma = Ru / R$$

If $\gamma < 1$, the fire safety of the building or compartment is insufficient and corrective measures must be taken.

In summary, Gretener Method is a specific FRA Method, which is very useful for the evaluation of fire risk in high-occupancy buildings or those with specific evacuation problems (hospitals, hotels, etc.)

This index is the most used and there are a lot of variations of it, in order to create specific index according to the different national regulations. For example, in the Spanish Building Code there is an official document for the evaluation of the fire risk in non-industrial buildings, by the use of an index. The method is called MEREDICTE, and it is based on the Gretener Method for its application in Spanish buildings.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

FACTOR	DEFINITION	SELECTED CATEGORY / FORMULA	VALUE
NRG	Global Risk	$NRG = \frac{PP}{NPG}$	0,67
NRE	Building Risk	$NRE = \frac{PP}{NPE}$	0,67
PP	Potential Hazards	$PP = AS * (0{,}4 * T + 0{,}3 * CO + 0{,}3 * CA)$	1,90
AS	Number of people in the compartment	0 < people < 65	0,80
T	Fire tetrahedron	$T = TC * TCM * TEA * TRC$	2,66
TC	Combustible	$TC = c1 * c2 * c3 * c4 * c5 * c6$	2,02
c1	Content Fuel load density	Housing Residential	1,40
c2	Continent Fuel Load density	Non-combustible facades and structure	1,00
c3	Combustibility	Housing Residential	1,20
c4	Smoke	Housing Residential	1,00
c5	Corrosion and toxicity	Housing Residential	1,00
c6	Fire development	Housing Residential	1,20
TCM	Comburent	Normal Atmosphere	1,00
TEA	Activation Energy	$TEA = ea1 * ea2 * ea3 * ea4 * ea5$	1,10
ea1	Activation Danger Coefficient	Housing Residential	1,00
ea2	Special Hazards	There is a protected Low Risk Local	1,10
ea3	Reparation	There are not reparations	1,00
ea4	Electrical installation	It complies with the regulations	1,00
ea5	Heat systems and Decorative elements	There are not	1,00
TRC	Chain reaction	The fire compartment allows the vertical spread	1,20
CO	Occupants characteristics	$CO = co1*co2*co3*co4*co5*co6*co7$	1,04
co1	Vulnerability	Normal occupants	1,00
co2	Familiarity	The occupants are familiar to the building	0,80
co3	Sleeping occupants	Occupants may be sleeping	1,45
co4	Obstacles	There are not obstacles	1,00
co5	Occupation Load	Low Occupation Load (10-20 m2/person)	0,90
co6	Panic	It is not expected a panic situation	1,00
co7	Orientation	There is no risk of disorientation	1,00
CA	Building Characteristics	$CA = ca1*ca2*ca3*ca4*ca5*ca6*ca7$	3,34
ca1	Fire Compartment Area	1000 m2 < Sc < 1500 m2	1,10
ca2	Evacuation Height	18 < Ev. Height < 28	2,20
ca3	Underground floors	There are not underground floors	1,00
ca4	Ceiling Height	2,78 < h < 3,34	1,15
ca5	Facade accesibility	One accesible facade	1,20
ca6	Facade absorptivity	720 < B < 2500	1,00
ca7	Facade ventilation		1,00

Figure 5.
Example of MEREDICTE Index applied to a residential building (Risk factors).

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

FACTOR	DEFINITION	SELECTED CATEGORY / FORMULA	VALUE
NPG	Global Protection Level	$NPG = NPA*NPE$	2,85
NPA	Self-Protection Plan	Not required	1,00
NPE	Building Protection level	$NPE = RFE*(0{,}24*P + 0{,}4*EO + 0{,}24*IPCI + 0{,}12*IB)$	2,85
RFE	Fire Resistance of the Structure	It complies with the regulations	1,15
P	Fire Spread	$P = PI*PE$	1,26
PI	Interior Spread	$PI = PI1*P12$	1,20
PI1	Fire Compartments	$PI1 = pi1.1*pi1.2*pi1.3*pi1.4*pi1.5$	1,20
pi1.1	Fire Resistance of floors and ceilings	EI 90	1,00
pi1.2	Fire Resistance of doors	Half Resistance of ceilings and walls	1,00
pi1.3	Compartmentalization of elevators	There are not elevators between sectors	1,00
pi1.4	Doors between compartments	It complies with the regulations	1,00
pi1.5	Pass of systems	They are compartmentalized	1,20
PI2	Fire Reaction	$PI2 = pi2.1*pi2.2*pi2.3$	1,00
pi2.1	Reaction to fire of construction elements	It complies with the regulations	1,00
pi2.2	Reaction to fire of textile elements	There are not textile elements	1,00
pi2.3	Reaction to fire of decorative elements	There are not decorative elements	1,00
PE	Exterior Spread	$PE = pe1*pe2$	1,05
pe1	Fire Spread: Facades and Roofs	It complies with the regulations	1,00
pe2	Reaction to fire of facades and roofs	It complies with the regulations	1,05
EO	Evacuation of Occupants	$EO = EO1*EO2*EO3*EO4*EO5*EO6*EO7*EO8$	4,72
EO1	Number of exits	Only one exit is required	0,90
EO2	Evacuation routes Lenght	There is one exit, and the distance is less than 15 meters	1,60
EO3	Dimensioning of the means ef egress	It complies with the regulations	1,00
EO4	Evacuation Routes Protection	$EO4 = eo4.1*eo4.2*eo4.3*eo4.4*eo4.5$	2,40
eo4.1	Type of Evacuation	Vertical egress	1,00
eo4.2	Type of horizontal Egress	Vertical egress	1,00
eo4.3	Type of vertical Egress	Protected stair	2,00
eo4.4	Stairs Continuity	The stair lead to a minimum risk compartment	1,20
eo4.5	Stairs ventilation	Passive systems (windows)	1,00
EO5	Doors in evacuation routes	$EO5 = eo5.1*eo5.2*eo5.3*eo5.4$	1,05
eo5.1	Opening direction of the door	Doors open in the evacuation direction, if they will be used for more than 100 people	1,00
eo5.2	Opening System of the doors	It complies with the regulations	1,00
eo5.3	Type of doors	Vertical rotation axis	1,05
eo 5.4	Automatic doors	There are not	1,00
EO6	Signaling of the means of egress	It complies with the regulations	1,00
EO7	Smoke Control	It is not required	1,00
EO8	Disabled People Evacuation	There are refuge areas in the protected stairs	1,30
IPCI	Fire Safety Systems	$IPCI = IPCI1*IPCI2*IPCI3*IPCI4$	0,63
IPCI1	Detection and Alarm	$IPCI1 = ipci1.1*ipci1.2*ipci1.3*ipci1.4*ipci1.5*ipci1.6$	0,70
ipci1.1	Detection system	There is not detection system	0,70
ipci 1.2	Types of detectors	There is not detection system	1,00
ipci1.3	Detectors Identification	There is not detection system	1,00
ipci 1.4	Alarm System	There is not detection system	1,00
ipci 1.5	Detection Central	There is not detection system	1,00
ipci 1.6	Alarm Communication to the Fire Department	There is not detection system	1,00
IPCI 2	Extinción manual	$IPCI2 = ipci2.1*ipci2.2*ipci2.3*ipci2.4$	0,90
ipci 2.1	Extinguishers	There are extinguishers	1,00
ipci 2.2	Dry Column	There is not Dry Column	1,00
ipci 2.3	Hydrants	There is not Hydrant	1,00
ipci 2.4	Hoses	There are not hoses	0,90
IPCI 3	Suppression System	$IPCI3 = ipci3.1*ipci3.2$	1,00
ipci 3.1	Suppression System Disponibility	There is not Suppression System	1,00
ipci 3.2	Suppression System Objective	There is not Suppression System	1,00
IPCI4	Complementary security systems	$IPCI4 = ipci4.1*ipci4.2*ipci4.3$	1,00
ipci 4.1	Means of escape Signage	Yes	1,00
ipci 4.2	Emergency elevator	No	1,00
ipci 4.3	Emergency Lighting	Yes	1,00
IB	Fire Department Operation	$IB = ib1*ib2*ib3$	1,12
ib 1	Accesibility for firefighters	4 fachadas accesibles	1,40
ib 2	Distance from the fire department	10 km < d < 25 km	0,80
ib 3	Private Firefigthers	No	1,00

Figure 6.
Example of MEREDICTE Index applied to a residential building (Protection factors).

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

4.5. Maximum Loss Estimation Method

The Maximum Loss Estimation Method (or PML-EML) is a semi-quantitative quantification of fire risk, by estimating the economic losses under three possible scenarios: the most pessimistic, the most probable and the most optimistic. For each scenario the assets are valued and the economic loss is calculated. This model is widely used by insurance companies, as their approach is strictly economic. It is used for the evaluation of hypothetical fire situations, although it could be applied in more scenarios predicting all types of economic losses.

4.6. Gustav-Purt Method

The main aim of the Gustav-Purt Method is to objectively determine what type of risks requires the installation of special security measures. The Purt Method assumes that the destructive action of fire takes place in two distinct areas: the building and its contents. Therefore, two independent coefficients, for the building and for the content, are calculated.

The risk of the building (GR) lies in its possibility of the destruction, depending on two factors:

- The intensity and duration of the fire.

- The resistance of the construction.

GR depends on: the fuel load of the contents and of the building, the combustibility of the materials, the area and situation of the fire compartment, the time lapsed until the intervention begins, the fire resistance of the structure and a reduction coefficient to be applied in some cases.

The risk of the content (IR) is constituted by:

- Harm to people

- Damage to the material assets inside the building.

For GR calculation, it is important not to exceed a specific limit value, but in the case of IR it is stricter, since it refers to people or goods of value. This double meaning is taken into account in a graph (the Measurement Diagram). GR is represented in ordinates (in the example, 1.41), and IR is represented in abscissa (in the example 3.0), so that each combination of both values corresponds to a point in a two-dimensional plane. The position in this plane allows the determination of an overall risk level and an assessment based on it, translated to a level of requirements of the fire safety measures: : in this case, we are in the region "3", so the recommended measures is the installation of a detection and alarm system. A first orientation on the appropriateness of the preventive measures is then obtained, but it should be later examined in more detail.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

FACTOR	DEFINITION	SELECTED CATEGORY / FORMULA	VALUE
GR	Risk of the building	$GR = \frac{(Qm * C + Qi) * B * L}{W * Ri}$	1,41
Qm	Fuel load of the contents	481-960 Mcal/m2	2,0
C	Comustibility	Medium	1,2
Qi	Fuel load of the building	0-0,80 Mcal/m2 (concrete and bricks)	0,0
B	Fire Compartment Area	Less than 1500 m2	1,0
L	Time until the invtervention begins	Fire department distance: 12 km	1,5
W	Fire resistance of the structure	F-90	1,6
Ri	Reduction coefficient	There are not combustible materials storage	1,6
IR	Risk of the content	$GR = H * D * F$	3,0
H	Harme to people	Tpeople may be impaired or can not evacuate	3,0
D	Damage to the material assets	The assets does not have an important value	1,0
F	Smoke Action	Without a particular danger for smoke or corrosion	1,0

Figure 7.
Example of Purt Method applied to a residential building.

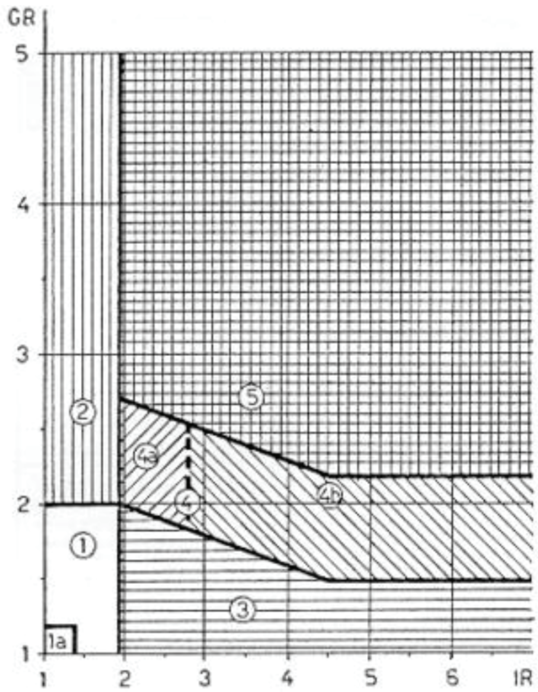


Figure 8.
Measurement diagram of the Gustav-Purt Method.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

5. Complex Quantitative Methods

Quantitative methods answer three questions numerically:

-Frequency of events.

- Severity of damage.

- Total resulting risk.

The first question is answered by applying the probabilistic analysis and by calculating the likelihood of occurrence of an undesired event by using reliable baseline data. The second question is answered by applying methods for the calculation of effects and damages. Finally, the third question is solved by multiplying frequency by severity of the accident, and the evaluation of its acceptance or not.

5.1. Fault Tree Analysis

Fault Tree Analysis (FTA) were conceived in 1962 by H.A. Watson. It has been applied in space, nuclear, chemical, petrochemical and electronic industries.

It is a top-down or "reverse" thinking process, that is, a deductive technique that focuses on a particular event that may occur, and provides a framework for assessing the potential causes of that event, instead of starting from the causes and reaching the consequences. For this purpose, a structure is provided in the form of a graphical representation and the analyst uses it for placing the events, conditions, actions and results. FTA is a series of combinations of initial events that could lead to a failure; and may include components, equipment and operational systems, and / or human actions and errors.

Previously, accidents or "top events" must be identified through the use of other methods such as preliminary risk analysis or historical analysis, and their frequency of occurrence must be quantified. From this "Top Event", the intermediate events will be found, as well as the basic events that cannot be further decomposed.

The deductive process of the fault tree is divided into two phases:

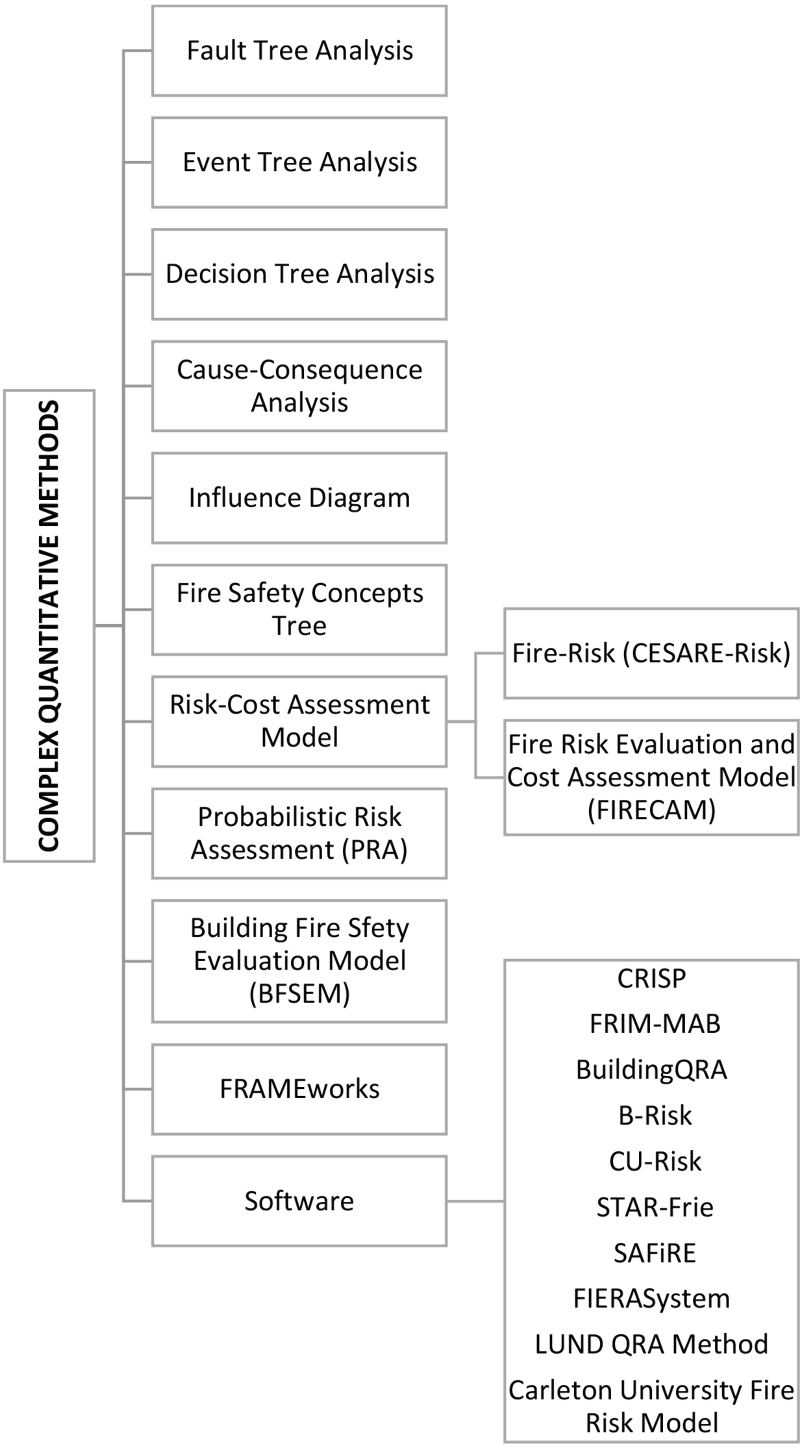
-The development of the tree

-The quantification of the tree

Although it is initially a qualitative method, if probabilities or frequencies are given, it could be used as a quantitative method. For this purpose, the probabilities or frequencies of the initial events are combined using the "AND" and "OR" gates. The use of the "AND" gate implies that all branches derived from the upper event may occur. In contrast, if the "OR" gate is used, only one of the leads can occur. The branches are mutually exclusive.

Assigning a probability or frequency to each event of the tree, and combining them according to "AND" "OR" rules, the probability or frequency of the initial event can be extracted.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018



Scheme 3.
Complex quantitative methods classification.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

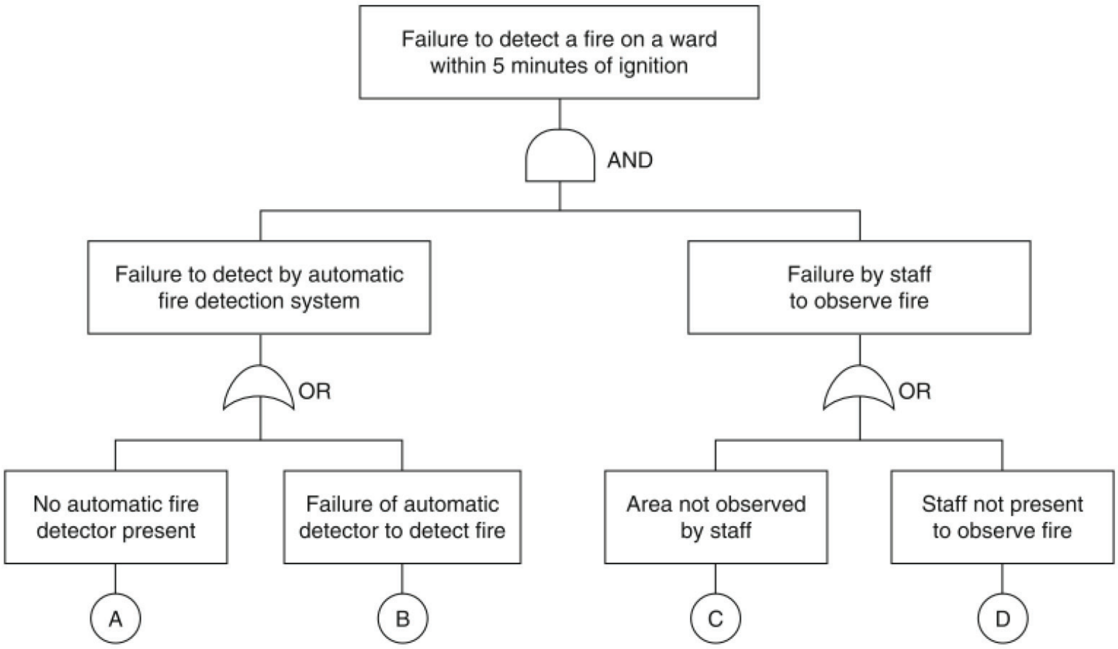


Figure 9.
Simple fault tree-fire detection in a hospital ward (Meacham 2015).

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

Phase 1: Elaboration of the tree: This phase consists in a deductive process, based on Boolean algebra laws. It starts from the undesired event (Top event) for finding out its origins, decomposing it into intermediate events until the basic events are reached (which cannot be further decomposed) or undeveloped (for lack of information). Both types, basic or not developed events, are independent one from the other, and they have associated a probability of occurrence that can be calculated.

Phase 2: Tree Quantification: In this process, the tree will be reduced until the obtainment of the minimum combination of primary events whose simultaneous occurrence would lead to the occurrence of the Top event. Each of these combinations is a "minimum set of faults". Since the basic events are independent one from the other (that is, the occurrence of one has no influence on the occurrence of the other), the probability of a minimum set of faults is given by the product of the probabilities of the elementary events that conform this set. The Top event will be represented by the logical union of all "n" minimum sets of faults and their probabilities, by applying the theorem of total probabilities.

The technique is quite complex, so there are computer programs that help its resolution.

5.2. Event Tree Analysis

Unlike the FTA, which starts from a fault and looks for causes, the Event Tree Analysis (ETA) provides a structure to postulate an initial event, whose frequency of occurrence is known, and it analyzes the possible consequences. The main tool is a decision tree, with branches that imply success and failure (yes / no or other similar binomial). It consists in the identification of an initiation event, of the systems or strategies used to its mitigation, and the question about the success or failure of each system or strategy. This method allows the analyst to find out the different sequences of accidental events that can be triggered, and to know the possible consequences and probabilities of the different accidents that may occur. From this knowledge it is possible to verify that existing and planned preventive measures are sufficient for the limitation or reduction of undesired effects. As with FTA, ETA is in principle a qualitative tool, which becomes quantitative at the moment in which probabilities or frequencies are assigned to each branch. The probabilities of each factor can be estimated by using a combination of historical data and expert judgment, leading to an estimated probability for a possible consequence (scenario). Data can be obtained from fire statistics or other observations and measurements.

Event Tree Analysis are very useful for the analysis of systems whose components have a sequential relationship. The stages that compose it are generally the following:

A. Construction of the event tree. Starting from the top event on the left, two bifurcations are presented on the right, reflecting in the upper part the success or occurrence of the conditioning event and, in the lower part, the failure or non-occurrence of the conditioning event. 2N combinations or theoretical sequences are obtained, although due to the dependence between the events, it can result that the occurrence or success of one of them, may eliminate the possibility of other events.

B. Quantification of the tree. The initiation event has a frequency "f", as well as the "N" conditioning factors or accidental events, each defined by its probability of occurrence, "p". Complementary events will have associated a probability of 1-p occurrence.

After the construction and quantification of the tree, it could be useful to classify the answers into categories of similar consequences, for the subsequent study of the consequences model.

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

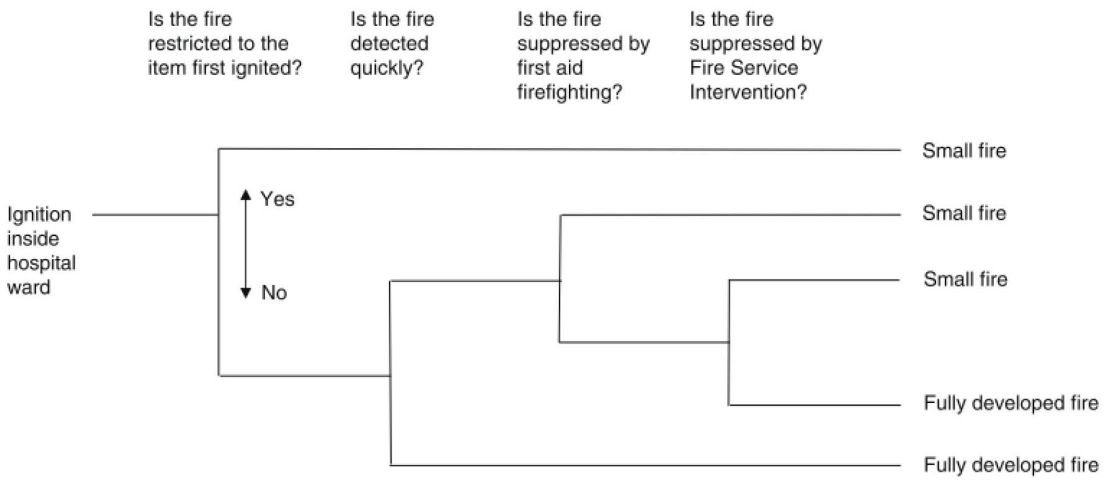


Figure 10.
Simple event tree- fire extinguishment in a hospital ward (Meacham 2015).

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

Conclusions

Risk Assessment Methods are a very useful tool in order to deal with possible hazards that we can face in a building due to its specific characteristics of use, operation, design... Fire is one of the most dangerous potential hazards, as it involves the design of the building, human behavior and the development of the fire itself. Fire in buildings is very difficult to predict. Therefore, FRA Methods are needed in order to propose effective protection actions. The present study aims to show an overview in the field of Fire Risk Assessments, by making a classification, which is susceptible of being extended, by following the complexity of use criterion. The objective has been to provide the analyst with the necessary tools for selecting the most appropriate method to each specific situation. Such choice is not a minor task, since some methods are too complex to be used without previous experience in the matter, and all of them must be used with the knowledge of their limitations.

Acknowledgement

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ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 5 (2) / February 2018

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