

# Vulnerability Analysis of Fire Spreading in a Building using Fuzzy Logic and its Integration in a Decision Support System

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## ABSTRACT

In this paper, a new method is proposed to analyze the vulnerability of fire spreading in building. This study is based on the application of the artificial intelligence using fuzzy logic.

After an overview of the phenomenon of spreading [1] [2], an identification of the various parameters that may influence this phenomenon has been achieved and by applying fuzzy logic technique, the vulnerability analysis has been established.

This study represents an important step for modeling a decision support system in order to optimize the fire risk in a building.

## General Terms

Making decision, artificial intelligence, fire security.

## Keywords

Artificial intelligence, fuzzy set, vulnerability, spreading, fire risk.

## 1. INTRODUCTION

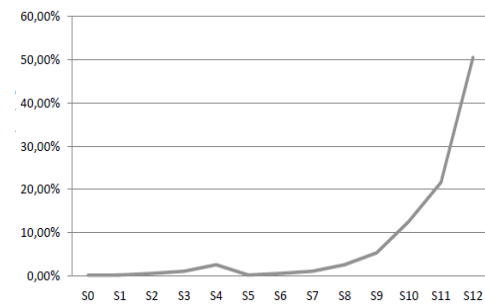
The fire is considered as one of the critical problems that can disrupt human life. It can be violent and destructive for human activities and nature. In fact, it is an uncontrolled reaction in space and time [3].

In the article [4] published previously, a method has been proposed for a predictive management of fire spreading risk in a building, this predictive management will be integrated into a decision support system. This study was based on decision trees. Furthermore, fire spreading impact on human life has been identified by applying Bayesian Networks [5][6][7]. This method is based on an exhaustive identification of different parameters that increase or reduce the risk:

- The presence or absence of flammable materials;
- The presence or absence of combustible components;
- The state of the doors and the windows (open or closed);
- The nature of the building walls (fire resistance).

The obtained results show clearly the probability increase of fire spreading as a function of some parameters presence favoring this phenomenon (Figure 1).

Fire spreading probability

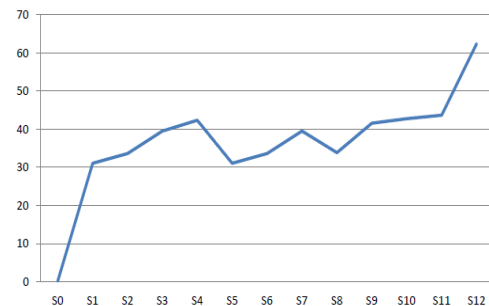


Fire spreading degree (Presence of parameters)

**Fig.1: Probability variation of fire spreading as a function of the favoring parameters presence**

For the second obtained result, the number of humans injured increases gradually as a function of the degree of fire spreading (figure 2).

Number of human injury



Fire spreading degree (Presence of parameters)

**Fig.2: Variation of injured people number as a function of the fire spreading degree**

## 2. FIRE AND ITS PROBLEMATIQUE

### 2.1 General description

Fire is an exothermic phenomenon which needs three parameters:

- Fuel (solid, liquid or gaseous);
- Oxygen;
- Heat source.

This reaction can be represented as a schema called fire triangle:

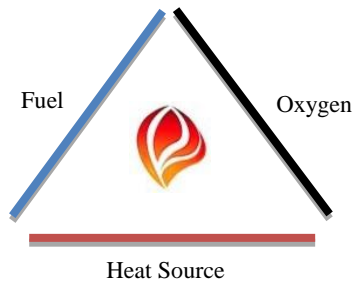


Fig.3: Fire triangle [8]

### 2.2 Steps of fire development

After many studies done about the fire security in building [9][10], we found that the development process of the fire can be divided into four phases [11]:

- Startup of fire: during this phase, the fuel begins to burn, the temperature is located at the point of ignition and the first gas and smoke appear.
- Outbreak: the flames radiation achieves the proximate materials and the hot gases are released and fill out all the volume.
- Flashover: during this step, the fuel achieves its ignition temperature, the volume is embarrassed and fire reaches its maximum.
- Fallen fire: the fuel disappears gradually and the temperature drops.

### 2.3 Parameters affecting the fire spreading

The vulnerability of fire spreading in a building may depend on two types of factors [12] [13][14][15]:

#### 2.3.1 Factors related to the construction of the structure, source of fire:

- Volume of the space (height and area);
- Oxygen flow in the space;
- Area and number of open doors and windows;
- Type of doors and windows (fire doors or normal);
- Thickness of walls;
- Flammability of building materials;
- Flammability degree of building materials.

#### 2.3.2 Factors related to products and equipments present in the building:

- Quantity of the products;
- Combustion speed of the products;
- Flammability of the products.
- Flammability degree of the products.

## 3. PROPOSED METHOD

### 3.1 General principle

The fire spreading is a phenomenon which depends on many factors, the most important ones are: the amount of oxygen existing in the construction, source of fire and the combustion speed of existing combustible materials.

Therefore, the disappearance of fuel or oxygen can stop immediately the fire.

The method proposed in this article is to model the fire spreading time in a building as a function of the oxygen quantity and the combustion speed of combustible materials present therein.

This study is based on the application of fuzzy logic technique [16][17] which is one of most used decision making methods.

The choice of this technique is justified by the nature of variables to be modeled. They are linguistic variables which vary in a set of intervals and which take different values according to the building to be studied.

### 3.2 Application process

To apply the proposed method, the steps below must be followed:

- Identification of linguistic variables of the system (input and output variables);
- Specification of the universes of discourse variables;
- Identification of the membership functions for each variable;
- Definition of the system operating rules;
- Computation of the membership functions for the output variables;
- Selection and application of an inference method;
- Application of a method of defuzzification;
- Results analysis.

## 4. OVERVIEW ON FUZZY LOGIC

Fuzzy logic is a technique of artificial intelligence based on fuzzy set theory [18][19].

It is a tool for decision making in situations of uncertainty where there is a lack of accurate and reliable mathematical probabilities. Thereby, it is an adaptive technique for evolutive situations.

Fuzzy logic is used to guide the control systems and to model the variation of some variables as a function of others.

The operation of this technique is described by the following diagram:

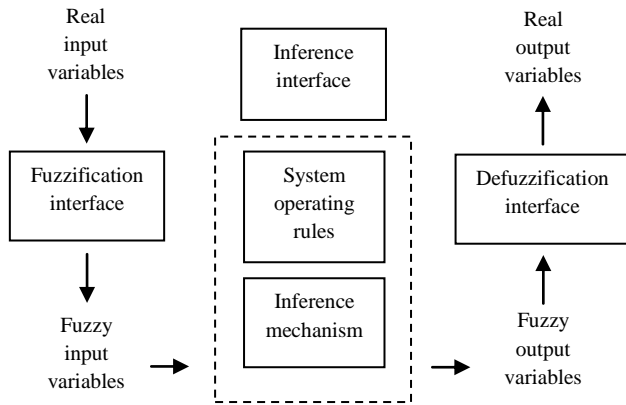


Fig.4: Process of fuzzy logic technique [18]

There are many libraries which implement the fuzzy set technique as C++, java, python, Matla, in this paper, we choose the fuzzy logic toolbox in Matlab [20].

## 5. CASE STUDY

### 5.1 Identification of linguistic variables and their values

#### 5.1.1 Input variables:

According to questionnaires proposed to some experts in fire safety domain as well as to those of the fuzzy logic domain, the determination of the various fuzzy variables is established in the following way:

**OxygenVolume** to indicate the oxygen quantity present in the construction, source of fire.

The volume of oxygen (**OxygenVolume**) possesses as linguistic values: Low, Medium and High distributed on a universe of discourse varying between 0 and 10 m<sup>3</sup>.

**CombustionSpeed** to designate the combustion speed of combustible materials present in the construction at time of fire ignition.

The combustion speed (**CombustionSpeed**) has as linguistic values: Slow, Medium and Fast which are distributed on a universe of discourse going from 0 to 2 mm/min.

#### 5.1.2 Output variables:

**FireDuration** to indicate the fire spreading duration in the building.

The fire duration (**FireDuration**) has as linguistic values: Short, Meduim and Long.

The universe of discourse of the variable **FireDuration** varies from 0 to 120 min.

### 5.2 Identification of the membership functions

The membership functions used has a trapezoidal form because it is the most appropriate for the variables selected in this study.

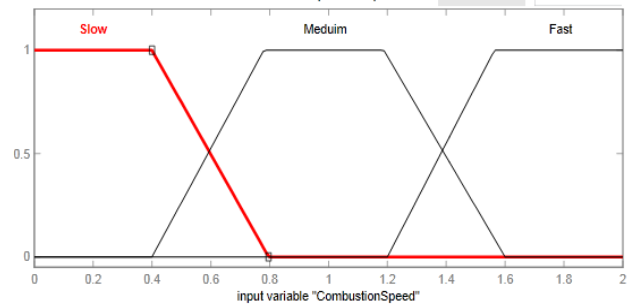


Fig.5: The membership function of the variable CombustionSpeed

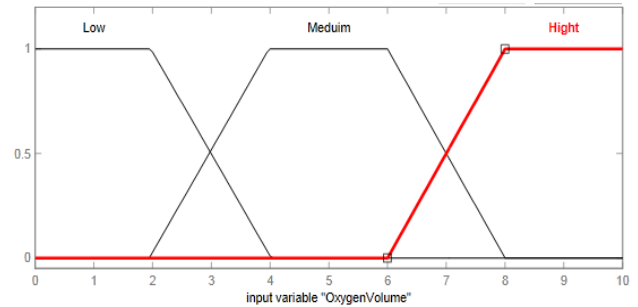


Fig.6: The membership function of the variable OxygenVolume

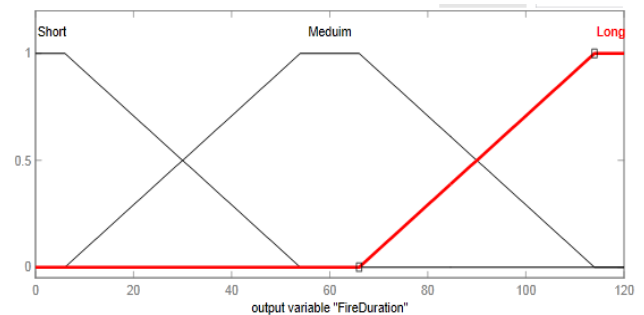


Fig.7: The membership function of the variable FireDuration

### 5.3 Definition of the system operating rules

The basis of rules in this study is attributed by some experts in the fire safety domain and it is presented below:

R1 : If (OxygenVolume is Low) and (CombustionSpeed is Slow) Then (FireDuration is Short)

R2 : If (OxygenVolume is Low) and (CombustionSpeed is Meduim) Then (FireDuration is Short)

R3 : If (OxygenVolume is Low) and (CombustionSpeed is Fast) Then (FireDuration is Meduim)

R4 : If (OxygenVolume is Meduim) and (CombustionSpeed is Slow) Then (FireDuration is Short)

R5 : If (OxygenVolume is Meduim) and (CombustionSpeed is Meduim) Then (FireDuration is Meduim)

R6 : If (OxygenVolume is Meduim) and (CombustionSpeed is Fast) Then (FireDuration is Meduim)

R7 : If (OxygenVolume is High) and (CombustionSpeed is Slow) Then (FireDuration is Short)

R8 : If (OxygenVolume is High) and (CombustionSpeed is Medium) Then (FireDuration is Medium)

R9 : If (OxygenVolume is High) and (CombustionSpeed is Fast) Then (FireDuration is Long)

These bases of rules will be enriched.

### 5.4 Obtained results

The obtained result is based on the application of the Mamdani inference rule. Its principle is:

- In the conditions: « AND » is represented by the function Min and « OR » is represented by the function Max.

- In the conclusion: « OR » is represented by the function Max and « THEN » is represented by the function Min.

The following result describes the variation of the fire duration in the case of an oxygen volume that equals 7m<sup>3</sup> and a combustion speed that equals 2mm/min.

The fire duration value obtained in this case is 69.1 min.

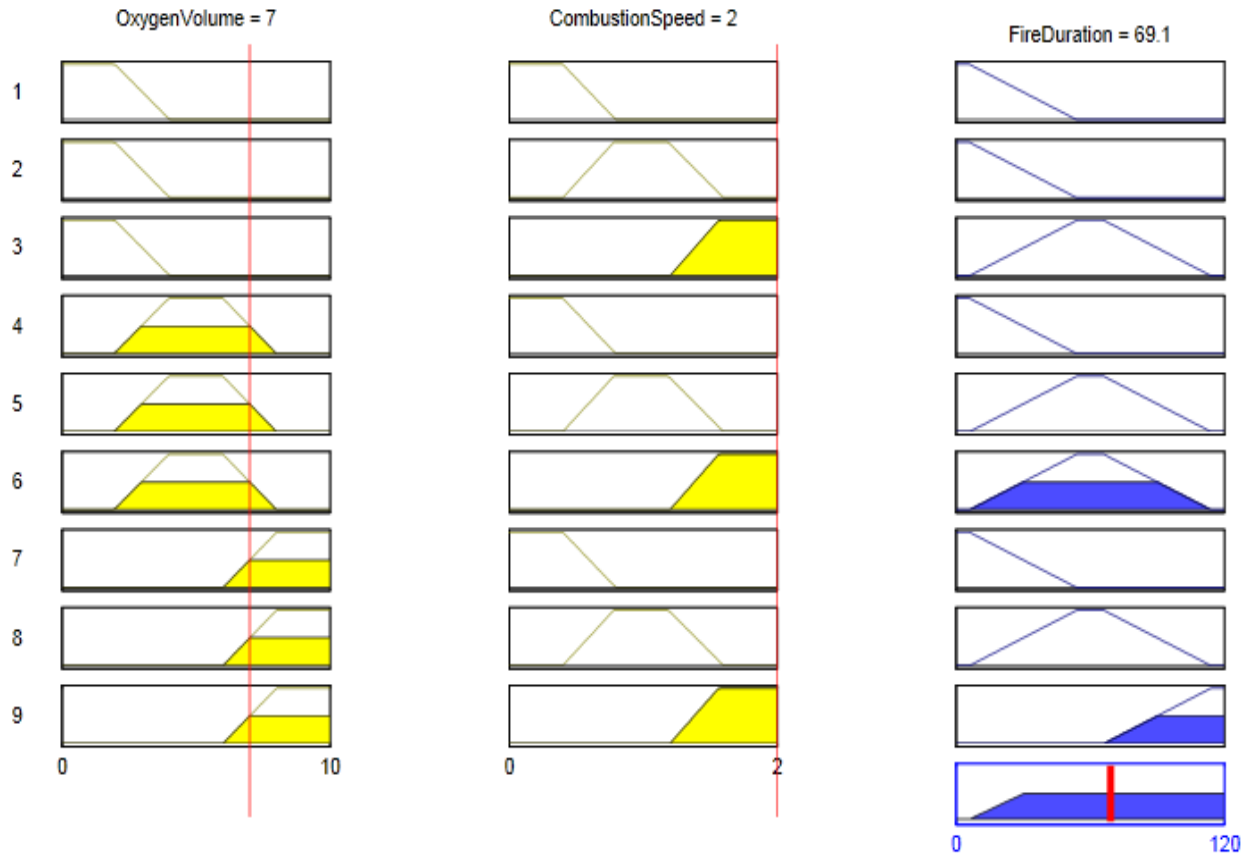


Fig.9: Variation of the fire duration as a function of the oxygen volume and the combustion speed.

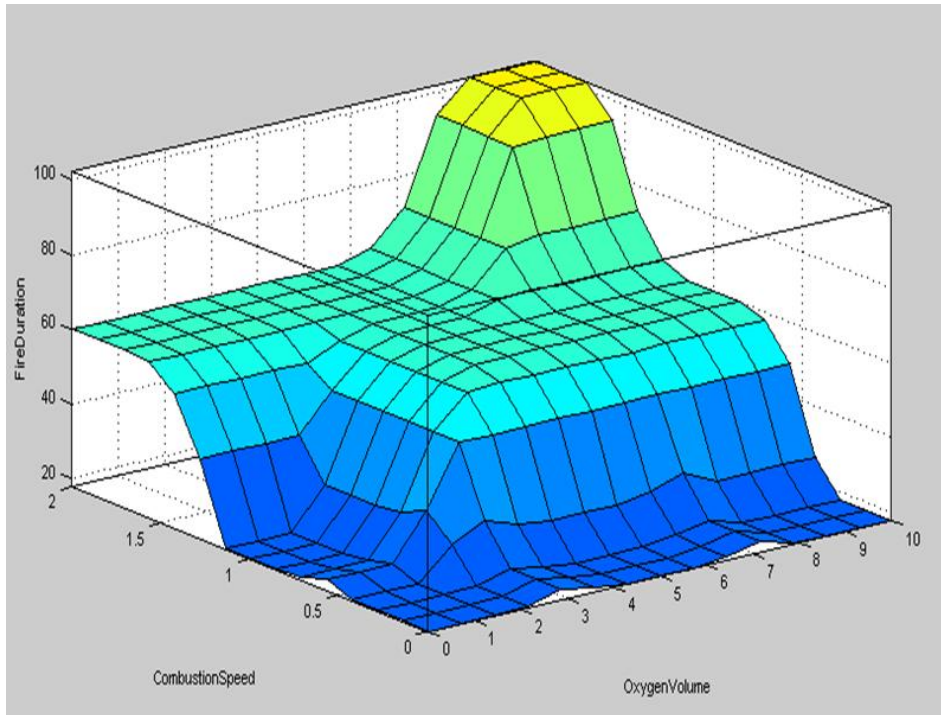


Fig. 10: The surface variation of the fire duration as a function of the oxygen volume and the combustion speed.

### 5.5 Results analysis

The following results allow to specify factors presenting a major interest in the fire spreading phenomenon. This interest will aim for determining the appropriate tool of fire security.

By fixing for example the oxygen volume, and by varying the combustion speed of the present material, the fire duration increases gradually until the total disappearance of fuel as it is mentioned in the following table:

Table 1: Variation of the fire duration as a function of the combustion speed of existing materials in the construction, source of fire.

Volume of oxygen (m3)	Combustion Speed (mm/min)	Fire duration (min)
5	0,3	17,8
5	0,7	57,2
5	1,8	60

Consequently, the proposed tool of security will have for aim to slow down the combustion speed of the present combustible products.

And by fixing the combustion speed, and by varying the oxygen volume, the fire duration increases as it is shown in the following table:

Table 2: Variation of the fire duration as a function of the volume of oxygen present in the construction, source of fire

Volume of oxygen (m3)	Combustion Speed (mm/min)	Fire duration (min)
1	0,9	18,9
4	0,9	59,9
9	0,9	60

As a result, the proposed security equipment must reduce the quantity of the oxygen existing in the building.

The solution proposed then is to use security equipment aiming to minimize the available oxygen, thus the combustion reaction of existing products goes slow, in other words, their speed combustion slows down.

### 6. CONCLUSION & PERSPECTIVES

The study presented in this paper represents another interesting step in the modeling of a decision making system in the fire safety domain. This system will be used by experts to audit existing buildings with the aim of reducing the fire risk.

The proposed decision support tool will have for inputs the descriptive information about the building to audit (volume of rooms, number of the open doors and windows, type and nature of existing equipment, etc...) and as outputs the vulnerability degree of the fire spreading (described by the fire duration as well as the rate of human and material damage).

In the same way, other studies will be realized by taking into account other influencing factors of the phenomenon of the fire spreading in order to complete the reasoning basis of our decision making tool.

Also, a modeling of the fire risk impact in building by the application of the same technique (fuzzy set) will be established.

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