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Modelling Approach of fire spreading in Building and Its Integration in a Support System tool

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Abstract— In this paper, we propose to study the phenomenon of building's fire spreading in presence of some increasing elements. First, we give an overview of the propagation phenomenon and its human life's impact. Then, we show how to develop a predictive model, with some identified perspectives, in order to improve the knowledge base of a decision tool as an expert system.

Keywords— Fire, Spreading, Bayesian network, Event tree, Probability.

I. 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.

In the article [1] published previously, a method has been proposed for a predictive management of fire risk in a building by applying Bayesian Networks. This method is based on an exhaustive identification of different parameters that can cause a fire in a building. In order de calculate by using the Bayes equation as it is mentioned in the equation (1). The probability of fire ignition in presence of some parameters increasing this phenomenon and others reducing it.

$$P(Ei|X) = \frac{Ci * P(Ei)P(X|Ei)}{\sum_{i=1}^{n} Ci * P(Ei)P(X|Ei)}$$

With :

- $Ci = 0$ if $\alpha i = 0$ or $1 - \sum_{1}^{n} \beta i \leq 0$
- $Ci \neq 0$ if $1 - \sum_{1}^{n} \beta i > 0$

- X : The event « Fire ignition »
- Ei : The event « Existence of an event trigger »
- P(X) : The fire ignition probability
- P(Ei) : The triggering event probability.
- P(X|Ei) is the probability of X after taking into account the effect of Ei.
- P(Ei|X) is the probability of the event Ei if we suppose that the event X is true.

Furthermore

αi is a coefficient which indicates the existence of a triggering event with the following values:

- $\alpha i \neq 0$ if the trigger exists
- $\alpha i = 0$ if not

P(Ei) becomes αi * P(Ei) (A)

ßi is the factor that can reduce the induced effect of the trigger using the following relationship:

P (Ei) becomes $(1 - \sum_{1}^{n} \beta i)$* P (Ei) (B)

By grouping (A) and (B), we obtain the following result:

P(Ei) becomes Ci * P(Ei)

Replacing P(Ei) in the equation's Bayes, we obtain the equation (1)

To enrich this first approach, we study in this article the fire spreading phenomenon [2][3] in building taking account factors affecting his flow, such as:

- 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).

We propose a method to develop an equation that can help us to calculate the probability associated to the fire spreading in the presence of some increasing elements. This equation will be applied on the basis of realistic hypothesis to calculate a fire victim's number.

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II. PROPOSED METHOD

To model the fire spreading in building, we propose to follow the sequence below:

- Identify the increasing parameters for the fire spreading phenomenon in building.
- Representation of these parameters as an event tree.
- Attribute probability coefficients for each parameter.
- Calculation of the fire spreading probability using probabilistic relations
- Results analysis
- Identify the impact of the fire spreading on human life.

We would like to clarify that we have limited in this study to some elements that influence the fire spreading [4][5]. This study will be rich taking account elements that can block this phenomenon.

This study will be used to develop a software tool able to audit existing buildings (or building project) to predict potential risks and to facilitate decision making in order to preserve human life.

A. Parameters identification

The study of different parameters that can increase the risk of the fire spreading in a building, has led us to the following classification:

- Factors related to the construction of the structure, source of fire:
  - i. Presence or absence of open doors and windows;
  - ii. Presence of flammable building materials;
  - iii. Presence of fire resistant walls.
- Factors related to products and equipments present in the building:
  - i. Presence or absence of combustible products;

B. Representation of the event tree parameters increasing the fire spreading phenomenon

After observing different scenarios of fire spreading, we could represent this phenomenon as the following structure:

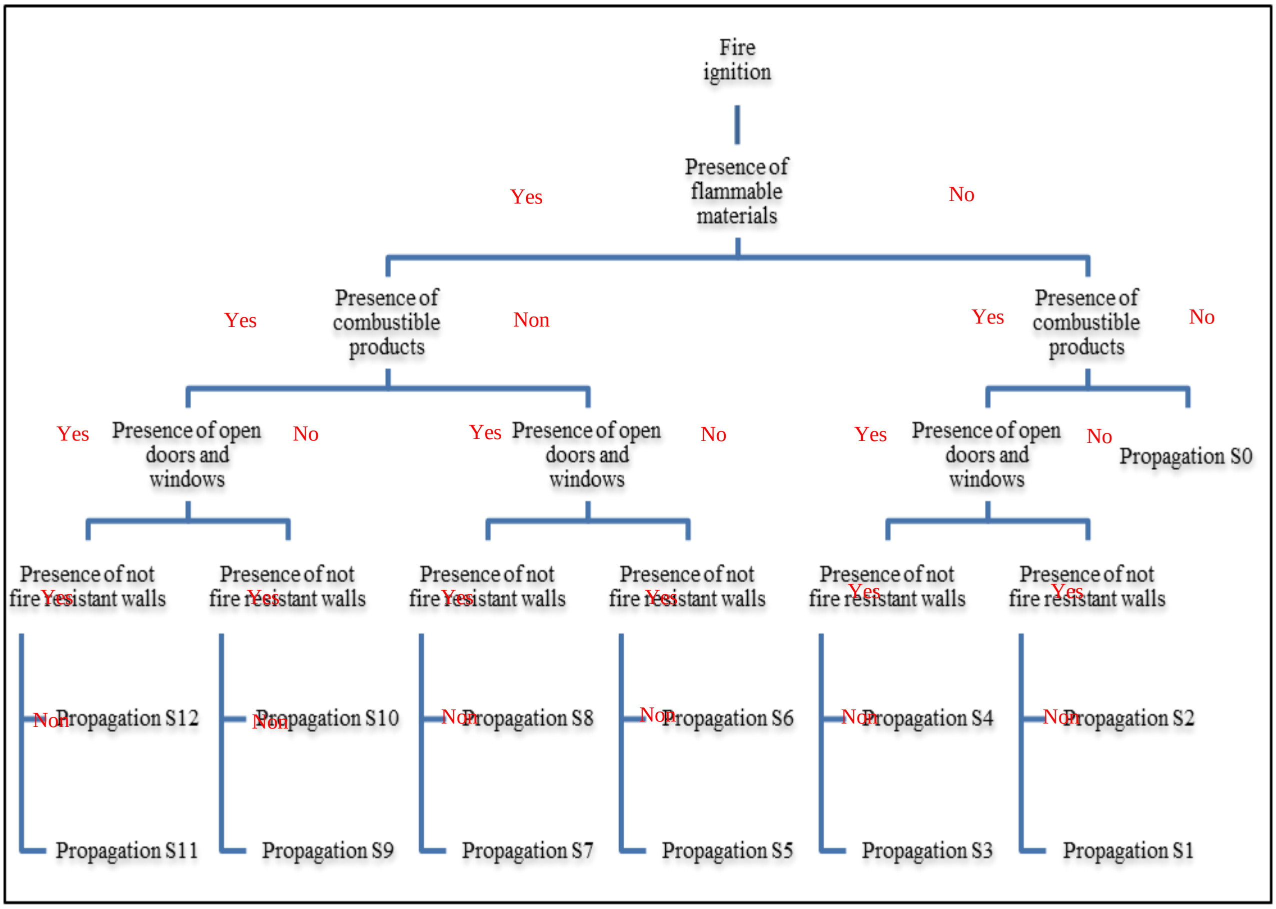

Fig. 1: Event tree describing all cases of fire spreading in a building

C. Formal representation of parameters

In first time, we give a symbolic structure to the previous event tree using the following symbols

- F.I: Fire ignition
- F.M: Presence of flammable materials
- C.P: Presence of combustible products
- O.D.W: Presence of open doors and windows
- N.R.W: Presence of not fire resistant walls
- S0, S1, …, S12 : Different degrees of fire spreading

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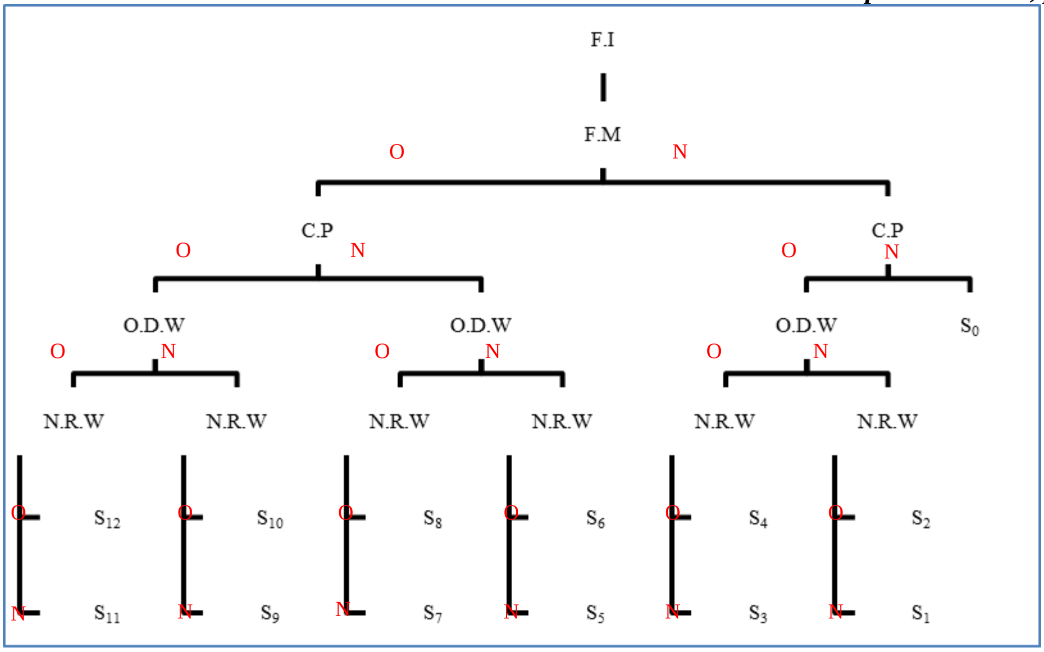

Fig. 2: Simplified diagram of fire spread process

The course of this tree is used to generate multiple paths represented qualitatively by 'n' and 'o'. These characterize the presence or absence of various parameters influencing the flow of fire spreading.

The generated paths correspond to different degrees of fire spreading probability from S0 to S12 as shown in the following table;

Table 1: List of fire spreading probabilities

Probability	**Path**
S_0	n-n
S_1	n-o-n-n
S_2	n-o-n-o
S_3	n-o-o-n
S_4	n-o-o-o
S_5	o-n-n-n
S_6	o-n-n-o
S_7	o-n-o-n
S_8	o-n-o-o
S_9	o-o-n-n
S_{10}	o-o-n-o
S_{11}	o-o-o-n
S_{12}	o-o-o-o

In the next step, we will take the example of a building with specific characteristics as shown in the following table:

Table 2: Attribution of probabilities for the building specifications

Index	**Specifications**	**Initial probability***
E_1	Presence of flammable materials	95%
E_2	Presence of combustible products	95%
E_3	Presence of open doors and windows	80%
E_4	Presence of not fire resistant walls	70%
No E_1	Absence of flammable materials	5%
No E_2	Absence of combustible products	5%
No E_3	Absence of open doors and windows	20%
No E_4	Presence of fire resistant walls	30%

*The values attributed initially arise from voluntarily disproportionate averages to expect the worst. These values will be regulated by using the techniques of learning according to the category, the architecture and the nature of the activity spatiotemporal of a building.

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D. Calculation of fire spreading probability

Based on the present data in the figure 2, we notice that every degree of fire spreading depends from 2 to 4 parameters. Thus every probability of propagation will be calculated using the following method:

$P(S_n) = P(E_1 \cap E_2 \cap E_3 \cap E_4) = P(E_1) * P(E_2) * P(E_3) * P(E_4)$ for $n \in \{1,12\}$ (2)

$P(S_0) = P(E_1 \cap E_2) = P(E_1) * P(E_2)$

Generally:

$$P(S_n) = \begin{cases} P(\cap_1^4 E_i) & n \in \{1,12\} \\ P(\cap_1^2 E_i) & n = 0 \end{cases} \quad (3)$$

As events Ei are independent of each other, we can write:

$P(S_n) = \prod_1^m P(Ei)$ with $m \in \{1,4\}$ (4)

(Where m is the number of events affecting the flow of the fire spreading)

Numerical application:

Table 3: List of values of the fire spreading probability

	P(E1)	P(E2)	P(E3)	P(E4)	P(Sn)
S0	0,05	0,05			0,0025
S1	0,05	0,95	0,2	0,3	0,00285
S2	0,05	0,95	0,2	0,7	0,00665
S3	0,05	0,95	0,8	0,3	0,0114
S4	0,05	0,95	0,8	0,7	0,0266
S5	0,95	0,05	0,2	0,3	0,00285
S6	0,95	0,05	0,2	0,7	0,00665
S7	0,95	0,05	0,8	0,3	0,0114
S8	0,95	0,05	0,8	0,7	0,0266
S9	0,95	0,95	0,2	0,3	0,05415
S10	0,95	0,95	0,2	0,7	0,12635
S11	0,95	0,95	0,8	0,3	0,2166
S12	0,95	0,95	0,8	0,7	0,5054

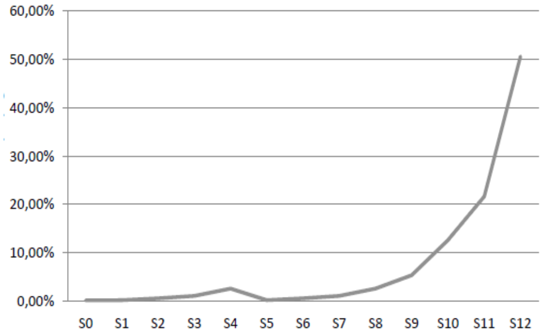
E. Results analysis

The obtained results (Table 4) shows the variation of fire spreading probability, these results appears in the form of an increasing function (which is coherent because by increasing the probability of different parameters, the probability of this propagation also increases)

Table 4: Probability of fire propagation in presence of some increasing parameters

Probability (P)	Value
S0	0,25 %
S1	0,29 %
S2	0,67 %
S3	1,14 %
S4	2,66 %
S5	0,29 %
S6	0,67 %
S7	1,14 %
S8	2,66 %
S9	5,42 %
S10	12,64 %
S11	21,66 %
S12	50,54 %

Fire spreading probabilty



Fire spreading degree (presence of increasing parameters)

Fig. 3: Probability variation of fire spreading as a function of the presence of increasing parameters

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F. Expected risk

1) Application of Bayesian network

To identify the impact of different degrees of fire spreading on human life, we will apply the Bayesian networks technique [6]-[9] according to the following organization:

- Step 1: Identification of parameters affecting human life
- Step 2: Representation of these parameters as a causal graph
- Step 3: Attribution of probabilistic coefficients for each type of parameter
- Step 4: Application of Bayes equation
- Step 5: Results Analysis

We consider the following data:

N: the number of people may be present in a building at the moment of fire ignition.

X: the number of persons who may be victims of a fire (here we take into account the number and not the degree of victimization).

This number depends on the fire spreading degree

We can then write

P (X) = X / N: Probability of fire injury.

P (X) is between 0 and 1: 0 (no victim) and 1 (the total of population has suffered)

Given that the probability that there will be 0% or 100% of victims is very low, we hypothesize that 50% of people presents may be victims. This default value will be corrected by performing various simulations and the principles of self-learning. However, this value is consistent because it cans shows, with realistic data, the impact and influence of propagation induced by elements that promote fire.

In our case, the probability of victimization depends on the probability of fire spreading; this relationship can be described by the following causal graph:

Fig.5: Cause and effect relationship between the fire spreading and possible victimization

By applying the Bayes equation, we can write:

$$P(X|Sn)=\frac{P(X)*P(Sn|X)}{P(Sn)}=\frac{\frac{X}{N}*P(Sn|X)}{P(Sn)} \quad (5)$$

With

N: number of people in a building during a fire ignition.

P (X) = X / N: probability of people may be victims of fire

P (Sn): probability of the fire spreading Sn

P (X | Sn): probability of persons who may be victims according to the degree of fire spreading Sn

P (Sn | X): probability of the fire spreading Sn if we suppose that we have X victims.

2) case study

Using the following hypothesis:

N = number of people = 90 people

P (X) = 50% probable number of victims (the most consistent hypothesis value)

X = 45 number of victims of the fire

The application of equation (5) on the different possibilities of propagation gives the results shown in Table (5).

Table 4: variation of the number of victims according to the degree of fire spreading.

	P(Sn)	P(Sn|X)	P(X|Sn)	X
S0	0,25%	0,00%	0,20%	0,18
S1	0,29%	0,20%	34,48%	31,03448276
S2	0,67%	0,50%	37,31%	33,58208955
S3	1,14%	1,00%	43,86%	39,47368421
S4	2,66%	2,50%	46,99%	42,29323308
S5	0,29%	0,20%	34,48%	31,03448276
S6	0,67%	0,50%	37,31%	33,58208955
S7	1,14%	1,00%	43,86%	39,47368421
S8	2,66%	2,00%	37,59%	33,83458647
S9	5,42%	5,00%	46,13%	41,51291513
S10	12,64%	12,00%	47,47%	42,72151899
S11	21,66%	21,00%	48,48%	43,62880886
S12	50,54%	70,00%	69,25%	62,32686981

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The analysis of the above table shows the influence of elements that can propagate fire. We find then that the hypothesis of 50% of victims varies according to the presence or absence of these elements and their respective impacts. The first result, which will be developed, reflect a coherent causal relationship between the number of potential victims during the process of the fire (outbreak and spreading).

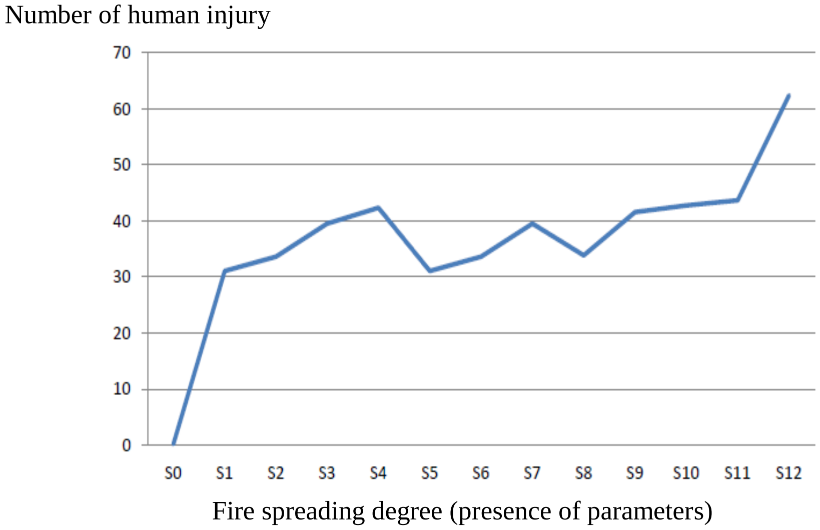

Fig. 5: Variation of injured people number as a function of the fire spreading degree

III. Conclusion & Perspectives

In this paper, we proposed a method for studying the fire spreading in building in the presence of some increasing factors, using the event tree technique, such as:

- The presence of flammable materials
- The presence of combustible products
- The presence of open doors and windows (Amount of oxygen available)
- The nature of walls (Presence of fire resistant wall or normal)

The study done will be completed by interesting perspectives that will include the following elements in order to develop a decisional computer application.

- The building architecture
  - i. Free Volume
  - ii. The use of fire-resistant walls.
  - iii. Details of materials used: volume, quantity and combustion speed.
- Safety equipment installed
  - i. Operationality
  - ii. Monitoring and Maintenance
- Characters of people present in the building during a fire
  - i. Readiness level of permanents occupants
  - ii. Level of vulnerability and dependence: children, elderly or disabled, sick ...
  - iii. The moment of fire ignition.
- Classification of victims: injured, seriously injured, and died.
- Estimated material damage.
- Implementation of a self-learning system that takes into account the following points:
  - i. Nature of the fire: voluntary or involuntary
  - ii. Nature of the trigger and its size
  - iii. The category of the building.

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