A DECISION MAKING METHOD FOR FIRE SAFETY LEVEL ASSESSMENT IN BUILDINGS

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Abstract

We develop a method for helping building inspectors or engineers reach a given safety level in a building through a better assessment of fire risks towards the building itself (structure, furniture, equipment) and people. The fire risk evaluation method is based on the use of Petri nets and simplified evaluation models of physical parameters related to fire (temperature, height without smoke). Evaluation of injury to people and damage to the building is simulated and begins with expert identification of the sources of danger. Various safety improvements can be compared in order to retain the most effective measures.

KEY WORDS

fire scenarios, risk assessment, Petri nets

Introduction

Our study aims to develop the means to help building managers in fire risk diagnosis and decision making for the protection of buildings and its occupants (maintenance, repair, reinforcement, demolition). This step is integrated within the framework of the national ISI (Engineering of Fire protection) project of which we are member with the CSTB (Centre Scientifique et Technique du Bâtiment – France), an organization that supports this research task. The diagnosis must propose a possible evaluation of buildings with respect to fire risk, then provide a choice between various proposals for fire safety improvement, and distribute a budget allocated to safety. Our study was carried out on various types of buildings, excluding industrial buildings where dangers are too specific. It should also provide a structured approach to effectively communicating with safety commissions and other concerned players.

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Risk assessment method

The method is broken down into four stages presented in Figure 1.

- The first stage defines the objectives related to fire protection in buildings; this stage must be implemented with persons in charge of the building. The objectives will be different for each building type: tertiary, school or housing.
- The system is described through a visit of the building to obtain the information necessary to the study: surface areas, occupations, safety equipment, etc.
- The principal danger situations are then listed. They represent the basis of various scenarios that become the object of digital simulations.
- The consequences of each scenario with respect to our objectives are finally evaluated.

If the objectives are met, the study is finished. In the contrary case—a frequent occurrence—interventions for improving safety are considered and new simulations are carried out.

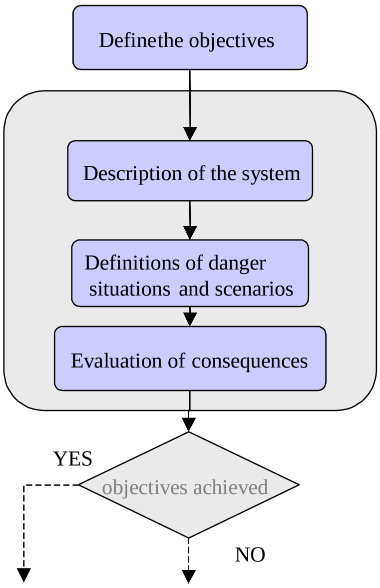


Figure 1 : Diagram of the risk assessment method

Definitions of objectives

It is first necessary to define objectives using "gravity–probability" grids (Figure 2). They are built for the four types of safety objectives: people, assets, the structure and the environment. A first level of negotiation relates to the definition of the axes of the grid. In theory, the axes are constructed with an even number to avoid the tendency of being located at a median level. In our study, we chose axes with four levels. A second level of negotiation consists in locating the border between acceptable and unacceptable zones in the grid.

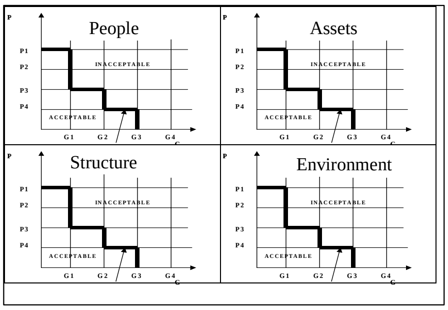


Figure 2 : negotiation relates to the definition of the axes of "gravity-probability" grids

Description of the building system

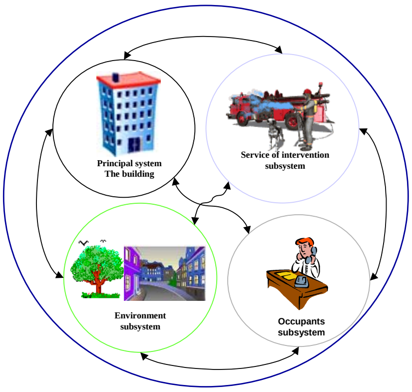


Figure 3 : Decomposition of the building system

The system is described based on a building inspection guide. This makes it possible to identify the users' practices and to define how the building is used and organized. Then the system can be modeled and studied through various subsystems (Figure 3). The principal system, the building, is broken down into two interacting systems: the spread of the fume (propagation subsystem) and the effects of the various facilities concerned with safety units (subsystem for alert/detection/protection).

Propagation Subsystem

The propagation subsystem is used to analyze the progression of the fire from its release to the end of the scenario, which could be either a definite time (a study of a 20-min fire scenario, for instance) or an event (generalized fire, multiple deaths).

A great deal of information is required for this study:

- Starting place of the fire;
- Characteristics of the seat of the fire (intensity, law of evolution);
- Conditions of fire spread from one room to another.

Alert/detection/protection subsystem

The alert/detection /protection subsystem must take the various safety features of the building into account (fire-stop doors, sprinklers, alarms, etc.).

Occupant subsystem

The occupant subsystem represents the flow of people who are present in the building and their survival conditions. This subsystem mainly involves the evacuation of people: sheltering employees or other occupants from an imminent danger by directing them towards a safety zone, often outside. Evacuation has as its main objective the safety of people. In case of fire, the evacuation time from the beginning of the fire until the end of evacuation must be lower than the survival time of the occupants in the building. The architectural design of corridors, protective measures and means already in place and the organization of safety influence these two times.

Intervention subsystem

The intervention subsystem contains all the elements of the rescue intervention procedure, from the initial call to the intervention itself. The intervention service will be informed at a specific moment called the alarm time and will be able to intervene within 10–20 minutes.

Environment subsystem

The environment subsystem contains elements outside the system that have an influence on the fire or are influenced by it: roads, car parks, housing estates, railways, rivers, etc. and the constraints related to these elements.

Danger situations and scenario definitions

The complexity of the system studied requires representation methods and analysis techniques that can follow the progression of the various subsystems and their interactions over time. Petri nets are used and have many advantages. They are graphs that are plotted according to successive markings of their vertices (nodes), called places (Figure 4). Tokens, which materialize the state of the network at a given moment, can pass from one place to another by crossing transitions under certain conditions (e.g., Grolleau 1999).

This is why Petri nets are widely used for the analysis of systems with discrete events. In our case, the building, the energy and smoke mass exchanges between the various rooms as well as the openings (doors and windows that can be open or closed) can be easily represented with Petri nets. It is also possible to follow the main indicators (temperature and height of smoke) over time, providing a correct evaluation of material damage and human injury. It is thus possible to evaluate various potential actions for safety improvement and to facilitate the choice of one or more of these measures by a decision maker.

The transition moments in Petri nets are managed by the two values of the smoke temperature zone (high zone: TZH) and the zone's height (height of discontinuity ZD) evaluated at every moment in each room. Existing models cannot be used to simulate the development of a fire in a building (Fisba software) or the movement of the fume (Cifi software), nor to evaluate the stability of the structure (Nat software), because the number of scenarios to be modeled is large. So as not to forget scenarios with important consequences, simplified models have been elaborated with simplifying assumptions that make it possible to determine the physical parameters very quickly and to evaluate material damage and physical injury.

MOCA-RP V12 Software

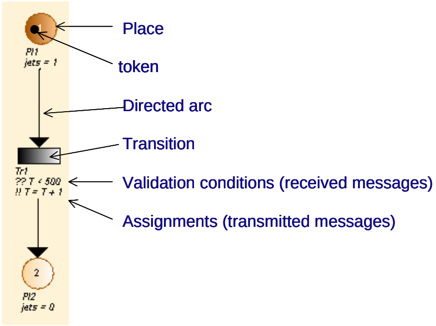
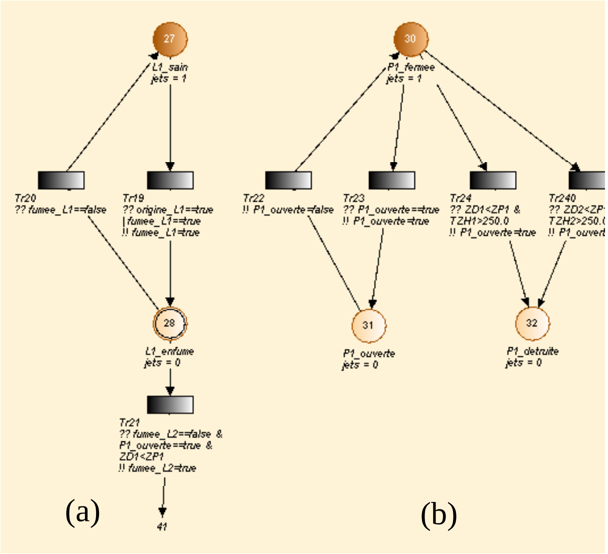


Figure 4 : Representation of the Petri net

MOCA-RP (MOnte-CArlo based on the Petri nets) is software designed to simulate the behavior of complex dynamic systems to statistically analyze reliability, availability, productivity and probabilistic parameters. The system studied is modeled in the form of an interpreted stochastic Petri net that is used with a traditional Monte-Carlo simulation.

The initial state of the system is defined by an initial marking of the places (Figure 4). Some entry places are marked whatever the particular case, other places may or may not contain tokens. It is thus possible to validate different simulation options (detection equipment failures, empty elememnt, etc.). They are validated before launching the simulation.



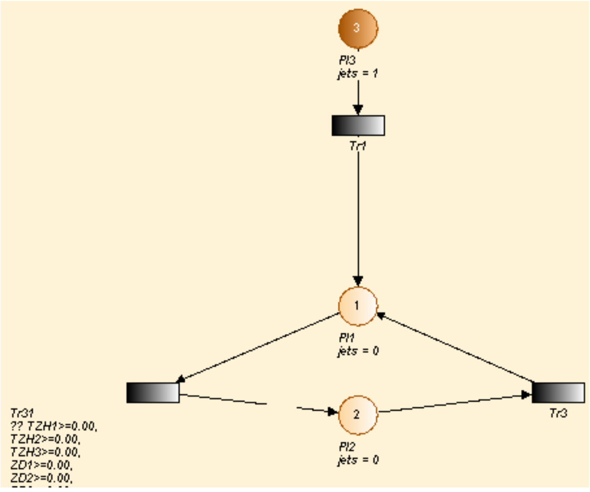


Figure 5 : representation of the Petri nets of the state of the room (a) and the door state (b)

Figure 6 : loop for the physical model

A transition is described through a list of Boolean expressions. They must be checked so that the transition becomes valid. These expressions are separated by commas and represent the validation conditions.

The messages transmitted after validation of a transition give values for the variables generated by the Petri net. It is possible to integrate more complex parameters through special laws defined in a code in C++. In our case, the simplified model of fire propagation is thus introduced into the Petri net. (Figure 6).

The principle of representation by Petri nets is to use networks restricted to each space entity (room, corridor, etc.) and their doors and windows. All these networks are managed by a general network that evaluates the physical parameters and reflects the modifications of the state of each room or subsystem in relation to the messages linked to the validated transitions. Several networks are defined for each room.

A first one is built to represent the state of the room and the propagation of the fume from one room to another (Figure 5 a). Independent networks are used to define the state of the different openings such as doors (Figure 5 b).

The transition Tr24 in this figure explains how door 1 (P1) can pass from the "open" to the "destroyed" state. The validation conditions are ZD1<ZP1 & TZH1>250, which corresponds to a headroom of smoke (ZD1) lower than the height of the door (ZP1) and a temperature of the smoky high zone (TZH1) higher than 250°C. Once these conditions have been established, a shooting time defines the moment at which the transition will be valid. In this example, we took a uniform law of 300–900 seconds. When the transition is valid, a token goes from place 30 to place 32 (P1_destroyed) and the message "P1_open" is transmitted.

A general Petri net (Figure 6) that works as a loop is built to obtain information on the conditions in the buildings at each time step. The Tr1 transition initializes the calculation of the conditions according to the parameters of the study defined in a textual file. Transition Tr 31 reads the messages of the various Petri nets. At each moment, they give the values for the variables in the physical model (Figure 7). In return, the variable values of the physical model are assigned to the different messages; now, in our model, the variables taken into account are only:

- temperature of the high zone per room;
- height without smoke per room;

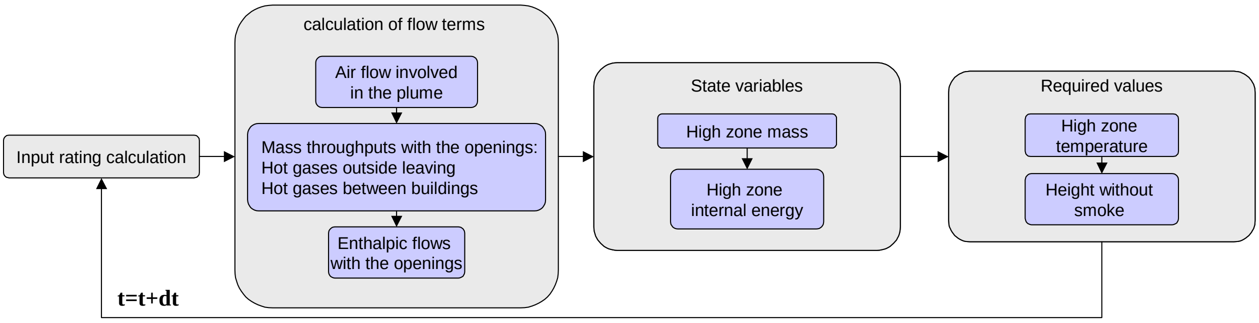
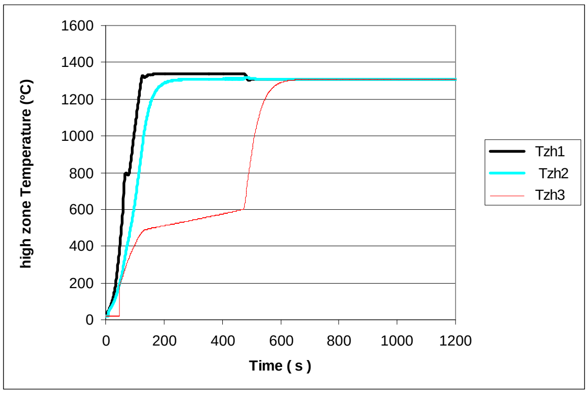


Figure 7: Algorithm of resolution

These two variables must be known at all times. Figure 7 defines the necessary calculation sequence. A number of variables are defined at each time step from the values of these parameters at the previous time step. The different flow terms are determined; the outgoing flows for vertical openings are calculated with Bernoulli’s theorem and with the Navier-Stokes relations (e.g., Curtat 2002). The input rating produced as well as parameters of the seat of the fire enable us to determine the fume flow pulled by the fume plume. Heskestad’s formulas (e.g., Curtat 2002) are used. As the mass of smoke in the high zone and the energy accumulated in this zone have been previously determined, it is possible to evaluate the temperature of the high zone.

Evaluation of consequences



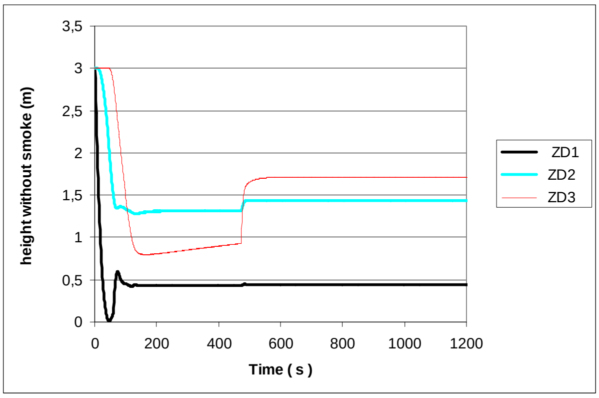
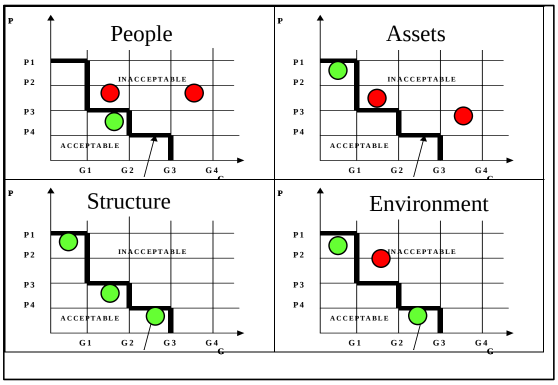


Figure 8 : Changes in temperature in three rooms

Figure 9 : Changes in headroom of smoke in these three rooms



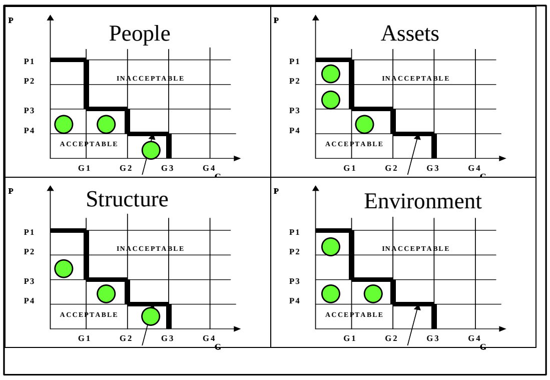


Figure 10 :Unsatisfactory analysis results

Figure 11 : Satisfactory analysis results

The results provided by the model and the simulation provide the values of two parameters:

- the probability of each scenario, according to the probability of occurrence of the initiating event related to the danger situation;
- the consequences of each scenario on the various points analyzed (people, assets, structure, environment). The scenarios considered to be unacceptable (red points in Figure 10) could be analyzed in detail through the temperature curves (Figure 8: temperature change in three rooms, room 1, origin of the fire) and the height without smoke (Figure 9: changes in headroom of smoke in these three same rooms).

The knowledge of these parameters enables us to place the scenario in the grids of probability/gravity. If all the scenarios are in the acceptable zone (Figure 11), the safety objectives are achieved and the study is finished. In the contrary case (Figure 10), scenarios are not acceptable and a new phase must begin. Some specific actions on the building must be proposed in order to reduce the risks to achieve our goals.

Safety improvement actions

As we saw previously, if points representing the scenarios are in the unacceptable zone of risk, the system must be modified by including various actions to improve safety (installation of alarms, sprinklers, firebreak doors, etc.).
Various actions can be carried out and their contribution can be evaluated by new simulations of the same scenarios with the modified system. For instance, the building can be modified by introducing firebreak doors (A1) and installing fire detection or sprinklers (A2 or A3, respectively).
For each action, the consequences can be evaluated and if the results match those in Figure 11 (every scenario is acceptable), no further action is studied. But if after adding a safety feature (e.g. A1) the objectives are still not reached, cumulative actions (e.g. A1+A2) must be carried out until the goals are met.

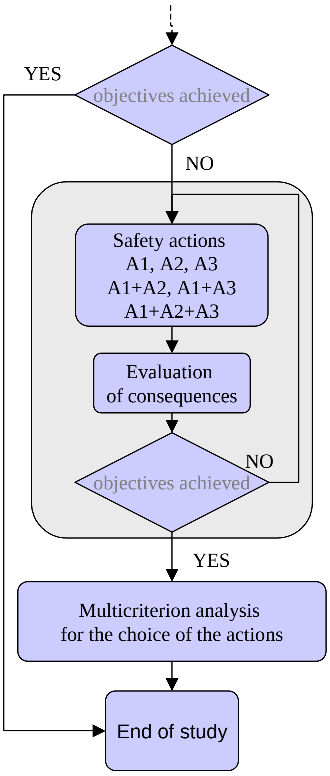


Figure 12: diagram of the method of actions choice

Choosing between different safety improvement actions

The last operation compares actions or cumulative actions that would make the level of safety acceptable according to various criteria (capital cost, operation cost, installation duration, etc.): the decision-making part of the study. Assuming that the building owner has financial limits and solutions to the fire safety problem are available, a multicriteria choice must be made, a well-known problem in decision-making (e.g., Roy 1993). Solutions providing the best compromise or optimizing the safety level of the building require innovative knowledge from several disciplines, which increases the complexity of the problem. In order to clarify the decision, actions need to be compared or assigned to defined classes, making it possible to establish a total or partial ranking (e.g., Mangin 2004).

The multicriteria analysis of the actions is done based on criteria presented in Table 1. This decision matrix is made up of two types of criteria:

- one composed of the percentage of acceptable scenarios related to people, assets, structure and environment;
- the second related to the actions and taking into account three criteria: cost of the action, operational cost per year, and start-up duration.

A decision matrix is obtained, as illustrated in Table 1. The environmental aspect has not yet been studied. We are now able to rank the different actions with the ELECTRE 2 method or to classify these actions with the ELECTRE TRI method. (e.g., Scharlig 1996)

Table 1 : example of a decision matrix

	% acceptable scenarios			Actions		
	People	Assets	Structure	Time of installation (in weeks)	Investment (in €)	cost of operation (in €/year)
Initial situation	80	75	95	-	-	-
A1	80	90	98	0.5	2000	200
A2	100	70	95	4	17000	500
A3	98	85	100	6	24000	1000
A1+A2	100	90	98	4.5	19000	700
A1+A3	98	85	100	6.5	26000	1200

Conclusion

The method has now been validated on simplified cases (three communicating rooms and a small public-use building of six rooms per floor).
The simulation on scenarios requires tools representing the changes and the dynamics of these scenarios. The following results were obtained:

- The use of Petri nets and MOCA-RP software is validated.
- The damage resulting from each scenario is assessed using indicators evaluated at any moment. It is thus necessary to use simplified models.

Integral powerful models have been developed in this study, in particular in the scenario generator using Petri nets (MOCA-RP). This stage makes it possible to automate the research of potential damage in reasonable times. A complementary work on this subject is in progress to:

- Extend the validation of the model to real cases;
- Look further into the principal sources of dangers and/or various potential initiating events of the fire to obtain the most relevant scenarios and to treat them on a hierarchical basis;
- Refine the presentation of the results through a more complete multicriteria analysis.

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