Occupant Response Model: A Sub-Model for the NRCC Risk-Cost Assessment Model

GUYLENE PROULX and GEORGE HADJISOPHOCLEOUS
National Fire Laboratory
Institute for Research in Construction
National Research Council of Canada
Ottawa, Canada, K1A 0R6

ABSTRACT

The Occupant Response Model is a sub-model of the Risk-Cost Assessment Model for apartment building being developed at the National Fire Laboratory of the National Research Council of Canada. The Occupant Response Model simulates human response to information indicating the presence of a fire. The perception of the information, interpretation and resulting action is called the PIA process. The PIA process is performed at each state of fire growth obtained from the Fire Growth Model. Interpretation levels have been defined according to the information sources reaching the occupants in the building. Further, the interpretation level introduces a time delay to interpret information and to take actions before the occupants start evacuation.

The probabilities of perception of the various types of information depend on the state of fire growth, the occupant location and the actions of other occupants. Calculations are made from the nearest location to the fire to the furthest for three interpretation levels. Each interpretation level determines the delay time before the occupants start to evacuate the building. The model outputs are the probabilities of occupants starting to evacuate at six timeframes before flashover. These values will be used by the Occupant Evacuation Model and the Fire Brigade Action Model, which are parts of the Risk-Cost Assessment Model.

KEYWORDS : Human Behaviour, Response Time, Fire Model, Evacuation.

INTRODUCTION

The response of building occupants to a fire represents a complex interaction between the occupant behaviour, the physical environment and the development of the fire. Traditionally, it has been assumed that people evacuate a building immediately upon hearing an alarm bell or seeing smoke [1]. These explanations of occupant evacuation motivation were based on stimulus and response theory. Recent psychological studies, however, illustrate that motivation is not produced by discrete factors but is derived from information processing and decision making [2, 3, 4]. Occupants are alerted by a variety of auditory, visual, olfactory and tactual cues. They then become involved in the process of information search, interpretation and appraisal, and decision making from which evacuation may emerge as the coping strategy [5, 6]. Although human behaviour supposes complex processes difficult to predict with certainty, the Occupant Response Model presents an attempt to illustrate human response to fire.

The Occupant Response Model does not pretend to take into account the complete diversity of human reactions in fire situations. Clearly, the purpose of this response model is not to model all the subtleties of human reactions or to research human behaviour in fire as such. The basic processes of human response are modelled in a simplified way to form a frame of reference to be used in a more general model. The Occupant Response Model is a sub-model of the Risk-Cost Assessment Model being developed at the National Fire Laboratory of the National Research Council of Canada. The Risk-Cost Assessment Model is a tool to assess the expected risk to the life of occupants, and also the costs due to fires in buildings.

The probabilities used within the Occupant Response Model are provided for the different parameters but the model user is free to change these data to study the consequences of different alternative probabilities on the model and on other sub-models. This flexibility allows for constant improvement of the model which can follow future research findings.

MODEL ASSUMPTIONS

The Occupant Response Model is used to estimate the probability of occurrence of events which cause occupants to decide to evacuate a building. The results generated from this model are used in conjunction with results from other models of the Risk-Cost Assessment Model. In recognition of the difficulties associated with modelling human response to fire, as discussed above, it was decided to develop a simple model for occupant response to fire. The decision by occupants to evacuate a building is assumed to be directly related to the occurrence of the various states of fire growth in the compartment of fire origin. Fire growth is computed by a model called the Fire Growth Model [7]. The different states of fire growth allow occupants to either perceive directly the event, receive a warning from other occupants, or receive a cue from the activation of alarm devices.

The Occupant Response Model is based on the general assumption that, in order for occupants to decide to respond to the presence of fire by evacuating the building, the successful achievement of three consecutive processes is needed. These three processes consist of the perception of information related to the event, the interpretation of this information, and actions to execute decisions resulting from the two first processes.

These processes of perception, interpretation and action are called the PIA process. It is considered that the PIA process evolves in dynamic loops in that the processes of perception, interpretation and action interact with each other, resulting eventually in the response of evacuating the building .

The transition probability model for an occupant to respond and decide to evacuate is defined as:

$$P[Resp] = P\ [PIA] \quad (1)$$

or

$$P[Resp]_g = P[Per]_g \times P[Int]_g \times P[Act]_g \quad (2)$$

where,

$P[Resp]_g$ Probability of occupant to decide to evacuate at State g of fire;
$P[Per]_g$ Probability of perceiving a fire cue;
$P[Int]_g$ Probability of interpreting this cue as a fire;
$P[Act]_g$ Probability of choosing the action to evacuate the building, once interpretation of the situation has taken place.

The model assumes that the PIA process is dependent of three specific variables: 1- the state of fire growth; 2- the occupant location in the building; and 3- the warning received by the occupant.

STATES OF FIRE GROWTH

The model uses the states of fire growth illustrated in the Fire Growth Model [7]. These fire states are characterized by the type of fire and detection capacity. Table 1 presents the four states. Occupant will go through the PIA process simultaneously during the three first fire states only. It is assumed that the remaining occupants located in the compartment of fire or on the level of fire who have not received any information at State IV of fire growth, can no longer start to evacuate, they are assumed trapped in the building.

TABLE 1: States of fire growth

Fire Growth	Fire Characteristics
State I	Fire cues
State II	Smoke detector activation
State III	Sprinkler activation
State IV	Flashover

OCCUPANT LOCATION

At the beginning of the fire, all occupants are assumed to be located in one of three different places: 1- occupants in the compartment of fire origin (OCF); 2- occupants on the level of fire origin (OLF); or 3- occupants in any compartment on other levels in the building (OOL). Figure 1 shows the occupant locations considered in the model.

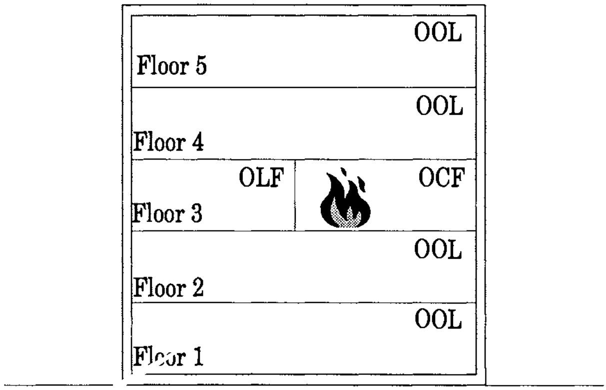

FIGURE 1: Occupant locations

WARNING RECEIVED BY OCCUPANTS

It is assumed that there are six major modes for occupants to receive a warning: 1- the human direct perception of the fire by occupants through visual, olfactory, auditory or skin perception; 2- receiving warnings from other occupants; 3- receiving a warning by the firefighters arriving on site; 4- receiving warnings given by a local alarm; 5- receiving warnings given by a central alarm; and 6- receiving warnings by a central alarm with voice communication. The alarm can be triggered automatically by detection devices, if installed, such as smoke detectors, sprinklers, or heat detectors, or by an occupant activating a manual pull station.

The fire warning received by occupants depends on the fire growth, the location of the occupants and the available means of fire detection. Table 2, presents the possible warnings received by occupants at different fire states depending on their location. It should be noted that, at State 1 of fire growth, occupants can receive a warning by the central alarm system only if the person who perceived the fire decides to activate the pull station. Further, it is assumed that it is too late for occupants of a compartment of fire (OCF) to receive a warning at State-III of fire growth since the fire involves the whole compartment and occupants are assumed trapped.

TABLE 2: Possible warnings received by occupants.

States of Fire Growth	Warnings Received		
	OCF	**OLF**	**OOL**
State I **Fire cues**	Direct perception Warning by other OCF Local alarm Central alarm bell, voice	Warning by other OCF Central alarm bell, voice	Central alarm bell, voice
State II **Smoke detector activation**	Direct perception Warning by other OCF Local alarm Central alarm bell, voice	Direct perception Warning by other OCF Central alarm bell, voice	Central alarm bell, voice
State III **Sprinkler activation**	**Too late**	Direct perception Warning by other OLF Local alarm Central alarm bell, voice Warning by FF	Warning by other OOL Central alarm bell, voice Warning by FF
State IV **Flashover**	**Too late**	**Too late**	Evacuation possible if stairs are tenable

THE PIA PROCESS

It is recognized that the Occupant Response Model, based on the assumptions described above, is a simplification of reality. The model is considered, however, to be both reflective of and sensitive to the general actualization of human response to fire.

The processes of perception, interpretation and action have been introduced in the Occupant Response Model to represent recent developments in psychology. In the field of cognitive psychology, the concept of information processing is used as a major approach to study human behaviour [8, 9]. The person is regarded as an active information processor who looks for information to enable decision making and problem solving. Information is gathered in the environment, from other people, from past experiences or acquired knowledge and from intuitive wisdom. Consequently, the building occupant is regarded in the Occupant Response Model as an information processor who will go through the PIA process to solve the problem of facing a fire.

The perception process can be defined as "how an occupant gets information about the occurrence of the fire". This supposes primarily that the fire emits cues detectable in one way or another and which are perceived by the occupant.

The interpretation process is directly related to the perception process. Once information is perceived, the occupant has to interpret this information to make sense out of it. This implies that the meaning of information is not automatically discernible. The interpretation of the information is undertaken according to the occupant's personal background, experience and knowledge. It is impossible to model all the variables that could interfere with the interpretation process, however, for the purposes of the Occupant Response Model, the interpretation process is considered in a simplified way. It is assumed that the interpretation is dependent on the certainty of the information. This means the more the information appears reliable, the more likely the occupant will interpret the information as cues related to a fire.

It is further assumed that the degree of certainty of the information depends on the source of this information. In the model, the perception of information can come from three sources: a) direct perception, b) reception of a warning issued by others, c) reception of a warning issued by technical devices. The model considers each of these sources as providing information with different degrees of certainty for the occupant as presented in Table 3.

TABLE 3: Information sources and interpretation levels

Information sources	Interpretation certainty
Direct perception of fire	Level 1 - reasonable certainty
Warning by firefighter	Level 1 - reasonable certainty
Warning by other occupant	Level 2 - fair certainty
Warning by central alarm with voice	Level 2 - fair certainty
Warning by local alarm	Level 3 - little certainty
Warning by central alarm system	Level 3 - little certainty

The two most reliable sources of information are the direct perception of the fire and receiving a warning by firefighters. These are the most likely conditions that will be quickly interpreted as an actual fire. They have an interpretation of Level 1, reasonable certainty. The second most reliable sources of information are the warnings received directly by another occupant or through a central alarm system with voice communication. These sources of information have an interpretation of Level 2, fair certainty. Finally, receiving information from a local alarm or from the central alarm system are less likely to be interpreted by the occupant as related to an actual fire and have an interpretation of Level 3, little certainty.

Interpretation levels are represented in this model by a time delay, which is needed to execute pre-evacuation actions. The time delay accounts for the extended time occupants spend searching for more information to confirm the warning received or to assess the situation. The response time of occupants can be computed using:

$$t_{resp} = t_{perc} + \Delta t_{interp_i} \tag{3}$$

where t_{resp} time to start evacuation;
t_{perc} time of perception; and
Δt_{interp_i} time required for interpretation of perception
i interpretation level.

The action process is directly related to the interpretation process which is linked to the perception process. Occupants, after perceiving information, interpret it and then decide which action should be taken. The model assumes that, if the occupants directly perceive the fire, an interpretation of Level 1 will be made - leading directly to the response of starting evacuating the building. However, if the occupants received information with interpretation certainty of Levels 2 or 3, it is assumed that these occupants will look for more information and take different actions before deciding to evacuate.

Starting to evacuate the building is regarded as the ultimate action and the response sought in the model. The model considers two pre-evacuation actions; namely, warning others directly and activating the alarm pull station. Probabilities of doing these two actions are taken into account in the model because these actions have a direct impact on the times to start evacuation for other occupants. It is known that other actions such as investigating, trying to fight the fire, rescuing children, gathering valuables, etc., are likely responses in a fire emergency. Although these pre-evacuation actions are not specifically included in the model, they are assumed to take place between the time of perception and the time to start evacuation - namely during the time delay introduced by the interpretation level.

MODEL OPERATION

The model assumes that the PIA process starts at the time of occurrence of each state of fire growth. The time required for the completion of the PIA process, time delay between perception and decision to start evacuation, is measured in timeframes. It is assumed that there are two timeframes between two consecutive states. The duration of each fire growth state is determined by the fire scenario computed by the Fire Growth Model. The duration of a timeframe is half the time of each fire growth state which can have different lenght.

Table 4 shows the timeframes and delays according to the interpretation level. To calculate the probabilities of occupants starting to evacuate at each timeframe, the model goes through four different steps. First of all, occupants must perceive the information. It is assumed that this information can be perceived only at the beginning of a state. Once the information is perceived, the second step is to assign an interpretation level related to the information. The third step is to look at the probability of occupants issuing a warning directly to other occupants or activating the alarm pull station before their evacuation. Finally, the fourth step calculates the probability of occupants starting their own evacuation.

The calculation procedure starts by dealing with the occupants of the compartment of fire (OCF). At Timeframe 1, there is a probability of occupants directly perceiving the fire, bringing an interpretation of Level 1, and starting evacuation immediately at the end of Timeframe 1, this is represented in Table 4 by $P[PIA]_{I_1}$

The occupants that have directly perceived the fire may warn other occupants in the same compartment, warn occupants on the same level and activate the alarm pull station. Each of these actions is assigned a probability. These probabilities will have an influence on the information perceived by other occupants. These warnings, if issued, are assumed to be perceived also at Timeframe 1. Consequently, at Timeframe 1, an occupant can receive a direct warning or can perceive the alarm and voice communication system if someone has activated the alarm pull station. These two types of information would bring an interpretation of Level 2 and these occupants would start their evacuation at the end of Timeframe 2, $P[PIA]_{I_2}$ in Table 4. Finally, there is a probability of occupants perceiving an alarm bell only, at Timeframe 1, bringing interpretation of Level 3 and starting evacuation at the end of Timeframe 3, $P[PIA]_{I_3}$ in Table 4.

This approach is also applied to the States 2 and 3 of fire growth, as well as to occupants in other locations in the building.

The probabilities to start evacuation at the various timeframes, shown in Table 4, are computed using the probabilities of the PIA process as follows:

$$P[evac_1] = P[PIA]_{I_1} \quad (4)$$

$$P[evac_2] = P[PIA]_{I_2} \quad (5)$$

$$P[evac_3] = P[PIA]_{II_1} + P[PIA]_{I_3} - P[PIA]_{II_1} * P[PIA]_{I_3} \quad (6)$$

$$P[evac_4] = P[PIA]_{II_2} \quad (7)$$

$$P[evac_5] = P[PIA]_{III_1} + P[PIA]_{II3} - P[PIA]_{III_1} * P[PIA]_{II3} \quad (8)$$

$$P[evac_6] = P[PIA]_{III_2} \quad (9)$$

where $P[evac_i]$ probability to start evacuation at timeframe i, applicable to occupants remaining in the building at timeframe i.

$P[PIA]_{k_j}$ probability of perception, interpretation and action at state k, for information leading to interpretation level j.

These probabilities are applied to the people remaining in the building at each timeframe.

TABLE 4: Timeframes and response delays according to interpretation levels

	State I		State II		State III	
Interpretation levels	Timeframe 1	Timeframe 2	Timeframe 3	Timeframe 4	Timeframe 5	Timeframe 6
Level 1	PIA_{I_1} →		PIA_{II_1} →		PIA_{III_1} →	
Level 2	PIA_{I_2} ———	——→	PIA_{II_2} ———	——→	PIA_{III_2} ———	——→
Level 3	PIA_{I_3} ———	———	——→			
			———	PIA_{II_3} ———	——→	
Probability of evacuation at various timeframes	P[$evac_1$]	P[$evac_2$]	P[$evac_3$]	P[$evac_4$]	P[$evac_5$]	P[$evac_6$]

When there is a probability of occupants receiving a warning, there is also the complementary probability that occupants do not receive this warning and therefore do not respond. During the next timeframe, the probability of response is calculated for the remaining occupants as well as for the occupants that may not have received the warning. All probabilities of perceiving information and warnings at a single location at a specific state add up to the total warnings. When dealing with occupants that are asleep, an extra timeframe is added allowing occupants to wake-up and dress. Occupants who do not start evacuation at Timeframe 6 are assumed to remain trapped in the building.

INPUT DATA

To run the Occupant Response Model, a series of input data have to be introduced. Probabilities are determined from the literature on fire and psychology and from statistical data. As a first step, probabilities are introduced relatively for an occupant to; a) directly perceive the fire (DPer); b) be warned by a local alarm (LAlam); c) be warned by the central alarm (CAlm); d) be warned by the central alarm with voice communication (AlmV); and e) be warned by the firefighters (FF). These probabilities are calculated for the three different states of fire growth and for the three possible locations of occupants. Table 5 shows the probabilities determined for the perception of information relative to the fire for occupants awake in an apartment building with the fire occurring in an apartment.

TABLE 5: Probabilities to perceive information for different locations at different fire states

Location	Fire State	DPerc	LAlm	CAlm	AlmV	FF
OCF	1	0.9000	0.1500	0.0300	0.0300	0.0010
OCF	2	0.9000	0.9000	0.4500	0.4500	0.2000
OCF	3	0.9000	0.9000	0.9500	0.9500	0.9500
OLF	1	0.0000	0.0000	0.0300	0.0300	0.0010
OLF	2	0.3500	0.1000	0.4500	0.4500	0.2000
OLF	3	0.8000	0.3500	0.9500	0.9500	0.9500
OOL	1	0.0000	0.0000	0.0300	0.0300	0.0010
OOL	2	0.0000	0.0000	0.4500	0.4500	0.2000
OOL	3	0.2000	0.0000	0.9500	0.9500	0.7500

The probabilities of actions such as receiving a warning from other occupants or from someone deciding to activate the alarm pull station are further calculated in a second step. The probabilities of, a) warning occupants of the compartment of fire (WaOCF); b) warning occupants on the level of fire (WaOLF); c) warning occupants on other levels (WaOOL); and d) warning by activating the alarm pull station (WaPUL), are determined according to the information first perceived by the occupant and the location of the occupant. Table 6 shows these probabilities of action.

TABLE 6: Probabilities of action according to the information perceived and the location of the occupant

Location	Perception	WaOCF	WaOLF	WaOOL	WaPul
OCF	DPerc	0.9500	0.4000	0.1000	0.5000
	ReWa	0.4000	0.0000	0.0000	0.1500
	LAlm	0.5000	0.0000	0.0000	0.1000
	CAlm	0.3000	0.0000	0.0000	0.0000
	AlmV	0.2000	0.0000	0.0000	0.0000
	FF	0.9000	0.1000	0.0000	0.0000
OLF	DPerc	0.7000	0.3000	0.0100	0.5000
	ReWa	0.1500	0.1000	0.0500	0.1500
	LAlm	0.1500	0.1000	0.0000	0.0000
	CAlm	0.0100	0.0000	0.0000	0.0000
	AlmV	0.0000	0.0000	0.0000	0.0000
	FF	0.0000	0.0000	0.0000	0.0000
OOL	DPerc	0.0000	0.1000	0.1500	0.5000
	ReWa	0.0000	0.0000	0.0500	0.1500
	LAlm	0.0000	0.0000	0.0000	0.0000
	CAlm	0.0000	0.0000	0.0000	0.0000
	AlmV	0.0000	0.0000	0.0000	0.0000
	FF	0.0000	0.0000	0.0000	0.0000

OUTPUT DATA

The Occupant Response Model is run with the probabilities presented in Tables 5 and 6. The outputs obtained are the probabilities of occupants starting to evacuate at the six different timeframes (TF 1 to 6) during the fire. The complementary probability of no response is also calculated. Table 7 presents the output probabilities of an occupant starting to evacuate for the three different locations.

TABLE 7: Probabilities of occupant starting to evacuate

Location	TF 1	TF 2	TF 3	TF 4	TF 5	TF 6	No Response
OCF	0.9001	0.0967	0.0029	0.0002	0.0001	0.0000	0.000000
OLF	0.0010	0.6872	0.1497	0.1250	0.0369	0.0003	0.000001
OOL	0.0010	0.5531	0.0892	0.2731	0.0669	0.0167	0.000071

CONCLUSION

The Occupant Response Model will be used in the general Risk-Cost Assessment Model. Although the model is a simplification of the complex reality of human response in fire, it is considered a comprehensive tool to assess the probability of an occupant deciding to evacuate a building at different times during a fire.

The probabilities used in the model will become more and more precise as new data are assembled. For example, research studies on evacuation are presently underway at NRCC and these should bring more accurate data to the model.

Further development of the Occupant Response Model will evaluate specific variables more closely. For example, the actual probabilities might need to be adjusted depending on the type of building. It is well known that occupant responses are different in a hotel compared to a home. Also, the occupant's possible limitations or disabilities will have to be taken into account. The probabilities of perceiving the information and of undertaking different actions are dependent on the characteristics of the occupants involved. These issues will be dealt with in further versions of the model.

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