INCORPORATING THE EVACUATION DECISION MODEL INTO AN EGRESS SIMULATION PROGRAM AND ASSESSMENT OF NEW ZEALAND PRE-TRAVEL SCENARIOS

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Abstract. *Pre-evacuation time can be defined as the time between the first cue and when the population starts evacuating. The Evacuation Decision Model (EDM) considers the evacuation decision process over time and predicts the evolution of the decision to take protective action based on risk perception.*

The parameters that affect the decision-making process of an individual have been defined, and incorporated into the properties of the EvacuatioNZ agent-based egress model to quantify the risk perception level and the response action in consequence to the agent state (i.e., the perceived risk level). Subsequently EDM is assessed to reproduce pre-travel activities times from C/VM2 and formulate a consistent set of parameters that may characterize a specific building use category. The incorporation of the EDM into an egress simulation program allows a focused approach to more realistic evacuation times based on the actual characteristics of the occupants and the building.

NOMENCLATURE

C_E	R_E/R_I.
i	i^{th} agent.
k_i	Prior knowledge constant for agent *i*.
$N_{E(t)}$	Number of agents in evacuation state that the agent i can 'see' at time *t*.
$N_{I(t)}$	Number of agents in investigating state that the agent i can 'see' at time *t*.
$N_{N(t)}$	Number of agents in normal state that the agent i can 'see' at time *t*.
q_a	Alarm cue variable: standard alarm, $q_{a,s}$; voice alarm, $q_{a,v}$.
q_s	Smoke cue variable.
R_E	Minimum level of perceived risk for an agent to be in its evacuating state.
R_I	Minimum level of perceived risk for an agent to be in its investigating state.
R_N	Level of perceived risk for an agent in its normal state.
$R(t)$	Perceived risk for agent *i* at time *t*.
$\dot{R}(t)$	Rate of change of perceived risk for agent *i* at time *t*.
s_i	Increase in perceived risk cause by a social influence cue.
t_E	Time agent *i* enters evacuating state
t_I	Time for agent i to reach investigating state considering external and interpreted cues.
Δt_E	$t_E - t_I$.
$t_{I,a}$	Time for agent i to reach investigating state when the agent receives an alarm alert.
$t_{I,s}$	Time for agent i to reach investigating state when the agent sees smoke.
t_a	Time when alarm first alerts agent i.
t_s	Time when smoke is first visible to agent i.

1. INTRODUCTION

Performance-based fire engineering often requires design calculations that include an evacuation analysis of the occupants of a building, however evacuation time is relatively complex, and is difficult to control and predict [1]. Methods to calculate evacuation times from buildings may range from a simple hand calculation to complex computational models. Currently there are a number of evacuation models available and used internationally by fire engineers to evaluate buildings and compute the required evacuation time for occupants to exit the buildings safely [2].

The evacuation process can be divided into several stages: fire detection, occupant alert, pre-evacuation, travelling time and evacuation (when occupants reach a safe place). The total evacuation time contains two major components: the delay time to start evacuation movement and the time needed to travel to a place of safety [1]. While detection time and occupant alert may be determined from the fire design and the travel time is proportional to the starting location of the occupant, the time the occupant spent in a queue and/or the distance to the safe place, pre-evacuation time is more difficult to calculate.

1.1. Pre-evacuation time

Pre-evacuation time can be defined as the "time between the first alarm or other initial cue until the population starts evacuating" [3] and depends on occupant behaviour. Human behaviour may depend on various factors such as the location of the fire event, the training occupants, mobility capabilities, the time of the day, etc. The current approach to define pre-evacuation is to use values provided in the literature. Values can be pre-defined numbers or selected from distributions; this makes it difficult to tailor inputs to specific buildings, populations and fire scenarios.

1.2. Evacuation Decision Model

In 2013 Kuligowski presented a model for occupant decision-making during emergencies; this decision-making model can provide the foundation for a predictive behavioural model for computer modelling techniques [4]. Reneke describes the development of the Evacuation Decision Model (EDM) [3] from Kuligowski's qualitative model of pre-evacuation behaviour and a description of how to implement it as a sub-model in an agent-based evacuation model.

EDM is based on seven assumptions that relate to agent risk perception:

1. The purpose of the model is to predict the point in time when the decision to take protective action is made.
2. Risk perception is the key factor to simulate when predicting the timing of the evacuation decision.
3. Each agent's level of risk perception determines the agent's state, which determines the agent's actions.
4. Agents have three states: normal, investigating and evacuating (discussed in more detail below).
5. An agent's change in risk perception is proportional to the intensity of the cues the agent receives as well as the agent's current level of perceived risk.
6. Agent's perspective and memories of previous experiences can increase or decrease the rate of change of an agent's risk perception when processing external cues.
7. The observed state of other agents can increase or reduce the risk perception of an agent.

1.3. EvacuatioNZ

EvacuatioNZ is a fire egress model currently under development at the University of Canterbury that uses a coarse network approach to simulate occupant behaviour as well as evacuation times to exit during an evacuation process. In a coarse network approach, spaces are represented as single nodes and the nodes are connected by arcs with defined distances within the structure. The program incorporates the Monte Carlo approach with unlimited simulations that generate probability distributions for risk assessment [5].

The occupants in each node can be populated either in a fixed number or in a distribution and several types of occupancies within a single node can be defined. Occupants behaviour can be implicit (movement throughout the evacuation is affected by an user-defined pre-evacuation distribution or an occupant characteristic as movement speed and route choice making options), conditional (occupants evacuation response is affected by assign structural or environmental conditions) or probabilistic [6].

This paper describes the process to incorporate EDM into EvacuatioNZ, as well as the process to determine appropriate values for the EDM parameters. EvacuatioNZ was updated to include the EDM equations and assignment of EDM parameters to the agents.

1.4. Verification Method C/VM2

New Zealand adopted a performance-based building code with the introduction of the New Zealand Building Act 1991 with the intention of allowing for innovation and producing more cost effective designs [7]. The New Zealand Building Code (NZBC) requirements for protection from fire (clauses C1 - C6) aim to protect people in buildings, limit fire spreading to other buildings, assist with firefighting and rescue operations, and protect the environment from adverse effects of fire with specific minimum functional requirements and performance objectives. Compliance with the NZBC can be achieved in any one of three different ways: Verification Method, Acceptable Solution and Alternative Solution.

The "Verification Method: Framework for Fire Safety Design", C/VM2 [8], consists of well-established codes of practice for design [9] and was first release in 2010. This document was developed to facilitate fire engineering designs through explicit guidance on ten different scenarios, design fire inputs, evacuation parameters and performance criteria to be met [5].

2. RISK PERCEPTION

EDM considers the decision process over time and predicts the evolution of the decision to take protective action based on a measure of risk perception. Risk perception depends on human behaviour and environmental cues. The change in risk perception as a result of the external cues impact will have an exponential growth and is defined by three states (i.e. levels of perceived risk) as shown in Figure 1. Each change of state is the result of the sum of the cues received.

- Normal state: agent continues previous actions. At this stage the agent is questioning whether there is any threat.
- Investigating state: agent is seeking additional information. At this stage the agent is questioning whether protective action is required.
- Evacuating state: At this stage the agent decides to take protective action and evacuate the building. The time difference between the first cue the agent receives and the start of the evacuating state is the pre-evacuation time.

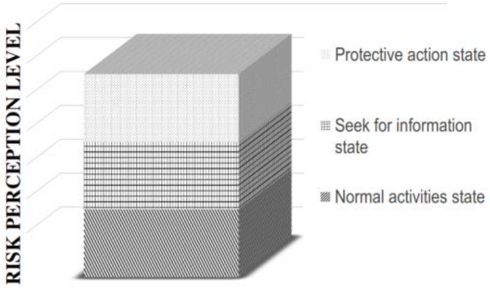

Figure 1. Agent's levels of risk perception.

The total increase in the perceived risk caused by external cues is defined as proportional to the intensity and time of the cues received by the agent as per assumption 5. The model considers that the cues received by the agent could be an alarm cue (q_a), a smoke cue (q_s) and/or a social influence cue (s_i). EDM also takes into account the information an agent receives or remembers in response to some interaction or trigger and this is defined as prior knowledge (k_i). This parameter could be considered as unique characteristic of each agent but for the purpose of the model is being considered here it is used as a global positive or negative value.

EDM is based on the Likert scale which is a commonly used approach for scaling responses in survey research [10], a value of 7 is assigned for the highest level of risk perception ($R_E = 7.0$). Risk perception scale is arbitrary therefore Reneke defined the normal state as 1.0 ($R_N = 1.0$). These values define the model: risk perception level cannot be less than 1.0 and the agent will evacuate when the level risk perception reach 7.0. As per assumption 4 a value for the investigating state of the agent is also required to be defined in the model. This value will depend of the intensity of the cues that the agent receives, therefore the model is defined by an associated time in which the agent will change from normal state to investigating state as a result of each cue.

3. INCORPORATING THE EDM

3.1. EDM Interpretation

Reneke's EDM model has been simplified for one agent in the following form:

$$\dot{R}(t) = \frac{ln(R_I)}{t_I} \cdot \left(k_i + q_j + s_i\right) \cdot R(t) \qquad (\text{if } R(t) < R_I) \qquad (1)$$

$$\dot{R}(t) = \frac{ln(CE)}{\Delta t_E} \cdot \left(k_i + q_j + s_i\right) \cdot R(t) \qquad (\text{if } R_I < R(t) \leq R_E) \qquad (2)$$

where $k_i = 0$ if there is no previous knowledge, otherwise $k_i \neq 0$; $q_j = 0$ if the j^{th} cue is inactive, otherwise $q_j \neq 0$; and $s_i = 0$ if there is no social influence, otherwise $s_i \neq 0$.

EDM model considers alarm and smoke cue as constant values relative to each other, however the social influence (s_i) is a dynamic function defined by Equation 3. The social influence is defined such as if the agent i sees other agents in evacuating state or in investigating state the agent is more likely to start investigating, likewise the social influence can dilute the risk perception level of the agent i if other agents are in normal state, and if the agent i does not see any other agents then the social influence is 0.

$$s_i = \begin{cases} 2\dfrac{N_{E(t)} + N_{I(t)} - N_{N(t)}}{N_{E(t)} + N_{I(t)} + N_{N(t)}} & EDM_i < R_I \\ 2\dfrac{N_{E(t)} - N_{N(t)}}{N_{E(t)} + N_{I(t)} + N_{N(t)}} & EDM_i \geq R_I \end{cases} \qquad (3)$$

According to Reneke's model, t_I, Δt_E, k_i, as well as the parameters required to estimate s_i are *user defined* (in addition to the risk perception levels R_I, and R_E). Therefore, it does not provide any other information more than how the risk perception level evolves over time.

Here, besides some changes to the original Reneke's formulation, the model is further modified so that the user has to define "base-line" t_I values (i.e., independently for an alarm cue only or smoke cue only, without considering the influence of interpreted cues), as well as relative values of k_i and s_i. It is assumed that these values can be obtained or derived from existing literature (e.g., C/VM2) as will be discussed later on. With this information, the model estimates a new t_I considering the effect of all active cues, and then Δt_E (and consequently t_E) are automatically computed.

Reneke defined the relative value of the smoke cue as:

$$q_s = \frac{t_{I,a}}{t_{I,s}} \qquad (4)$$

In EDM, the time is referenced to the activation of the first cue and not from the start of the simulation. In this study, the above formulation holds true for the case when both continuous cues (i.e., alarm and smoke) start at the same time. When the agent first hears the alarm ($t_a = 0$) and after some period of time t_s sees smoke, for instance, then the relative value of the smoke cue is computed as follows:

$$q_s = \frac{t_{I,a}}{t_s + t_{I,s}}; \text{and } q_a = 1.0 \tag{5}$$

The same applies for the case when the agent first sees smoke ($t_s = 0$) and after some period of time t_a hears the alarm:

$$q_a = \frac{t_{I,s}}{t_a + t_{I,a}}; \text{and } q_s = 1.0 \tag{6}$$

The above formulation has an additional difference when compared to Reneke's EDM. Both alarm and smoke cues are treated in the same way, meaning that whichever starts first its relative value will be $q_j = 1.0$. In Reneke's EDM model, q_a is always 1.0 and q_s is then estimated.

3.2. Estimation of the time to reach investigating state (t_I)

To estimate the time t_I it takes the agent i to reach R_I considering external and interpreted cues, Reneke's equation was solved for $R(t) < R_I$:

$$R(t) = R_N \cdot exp\left\{\frac{t \cdot ln(R_I) \cdot (k_i + q_j + s_i)}{t_{I,a}}\right\} \tag{7}$$

For the case when one single alarm cue and interpreted cues are present, the above equation can solved for t (since $R_N = R(t=0) = 1$). When $R(t = t_I) = R_I$:

$$t_I = \frac{t_{I,a}}{(k_i + q_a + s_i)} \tag{8}$$

which means that for one single alarm only ($k_i = s_i = 0$, and $q_a = 1$,), the time to reach investigating state t_I is equal to the time to reach investigating state with one constant and continuous single alarm cue $t_{I,a}$ (i.e., as originally proposed by Reneke). However, when interpreted cues are also present, the time t_I has to be adjusted accordingly in order to be consistent with the proposed model.

For the case when the smoke is visible, the solution of the differential equation is not appropriate and a distinction has to be made whether if the time t being considered occurs before or after t_s:

$$\dot{R}(t) = \frac{ln(R_I)}{t_{I,a}} \cdot (k_i + q_a + s_i) \cdot R(t) \qquad (\text{for } t_s < t_I) \tag{9}$$

$$\dot{R}(t) = \frac{ln(R_I)}{t_{I,a}} \cdot (k_i + q_a + q_s + s_i) \cdot R(t) \qquad (\text{for } t \geq t_s) \tag{10}$$

As aforementioned, this approach holds true (with the respective change of variables) also for the case when the agent first sees smoke ($t_s = 0$) and after some period of time t_a hears the alarm.

3.3. Estimation of time to transition from the investigating state to the evacuating state (Δt_E)

Reneke proposed the following relationship between t_I and Δt_E, for a single alarm cue without interpreted cues:

$$\frac{ln(CE)}{ln(RI)} \cdot t_I = \Delta t_E \tag{11}$$

Following the same approach but when $(k_i + q_a + s_i) \neq 1.0$ (i.e., considering interpreted cues and one single alarm acting at the same time), then the formulation becomes:

$$R_E = C_E \cdot R_I = exp\left\{\frac{ln(R_I)}{t_I} \cdot (k_i + q_a + s_i) \cdot t_E\right\} \tag{12}$$

Equation 12 is an approximation because it is based on an equation valid for $R(t) < R_I$ but evaluated at $t = t_E$. Assuming the approximation holds true, and given that $t_E = \Delta t_E + t_I$, then the equation can be solved for Δt_E. Moreover, for the case when the smoke is visible a distinction has to be made whether if t_s (i.e., time when the smoke is visible) occurs before or after t_I. Here, it is assumed that the impact of the smoke cue on Δt_E is significant only when the smoke is visible before transition to investigating state:

$$\Delta t_E = t_I \cdot \left[\left(\frac{ln(CE)}{ln(R_I)} + 1\right) \cdot \frac{1}{(k_i + q_a + q_s + s_i)} - 1\right] \qquad (\text{for } t_s < t_I) \tag{13}$$

$$\Delta t_E = t_I \cdot \left[\left(\frac{ln(CE)}{ln(R_I)} + 1\right) \cdot \frac{1}{(k_i + q_a + s_i)} - 1\right] \qquad (\text{for } t_s \geq t_I) \tag{14}$$

Again, this approximation holds true (with the respective change of variables) also for the case when the agent first sees smoke ($t_s = 0$) and after some period of time t_a hears the alarm.

3.4. Time to enter the evacuating state (t_E)

Once t_I and Δt_E have been estimated a verification has to be made to make sure the final solution is consistent with the full procedure. The solution of Reneke's EDM differential equation when $R_I < R(t) \leq R_E$ leads to:

$$R(t) = R_I \cdot exp\left\{\frac{(t - t_I) \cdot ln(CE) \cdot (k_i + q_j + s_i)}{\Delta t_E}\right\} \tag{15}$$

Solving this equation for t and given that at $R(t = t_E) = R_E$, then

$$t_E = \frac{\Delta t_E}{(k_i + q_j + s_i)} + t_I \tag{16}$$

Equation (16) is not consistent with the previous definition of $t_E = \Delta t_E + t_I$. Moreover, the term $(k_i + q_j + s_i)$ is already considered when Δt_E is estimated, suggesting that this term should be removed otherwise it would be double-counted and the final solution will not be consistent with the previous assumptions. Therefore, the following equation is proposed for the case when $R_I < R(t) \leq R_E$:

$$\dot{R}(t) = \frac{ln(CE)}{\Delta t_E} \cdot R(t) \tag{17}$$

3.5. Key differences between original Reneke's formulation and the proposed model

In general, the original Reneke's EDM model does not provide a way to estimate Δt_E, t_E, or to adjust t_I based on all active cues. Therefore, it might be considered as merely descriptive, providing only a measure on how the risk perception level evolves over time.

In the following the main differences between the original Reneke's EDM model and the proposed model are summarised.

1. In the proposed model q_s is computed as a cumulative time $t_s + t_{I,s}$, instead of $t_{I,s}$ only;
2. A new t_I is computed, taking into account all the active cues;
3. An equation to estimate Δt_E is proposed;
4. The rate of change of perceived risk when $R(t) \geq R_I$ is reformulated to make it consistent with the proposed model.

4. C/VM2 PRE-TRAVEL VALUES

"Pre-evacuation time" is denominated as pre-travel activity times in the C/VM2 document and are part of the evacuation parameters provided by the Verification Method to comply with the NZBC. Pre-travel activity times incorporate factors identified in PD7974-6 [11], but also account for parameters that are considered to be country-specific such as the evacuation procedures. New Zealand regulations require evacuation schemes that promote a culture of prompt evacuations [11].

C/VM2 pre-travel activity times are described for seven different building characteristics and behavioural scenarios specified by "building use" categories. The first two categories account for buildings in which users will be awake, the third and fourth categories account for sleeping facilities, the fifth and sixth categories account for health care facilities, and the last category accounts for buildings which have focused activities such as stadiums and cinemas.

As an application of EDM, it is aimed to adapt the model to C/VM2 [8] pre-travel activity times (i.e. to match the inputs parameters with C/VM2). A consistent set of parameters would allow the user to simulate the pre-travel time in any type of building based on the occupant characteristics. EvacuatioNZ allows the user to input an occupant distribution in each node, therefore the pre-travel actions of agents with different types of behaviour in the same space could be assessed.

The scope of this research only considers the first four "building use" categories to be compared with the EDM. Scenarios in which social influence may affect the decision-making time (like care centres and focus activities as a stadium) are not being analysed. The incorporation of the social influence cue would add a dynamic impact to the risk perceived by any agent in the model.

Table 1 summarises the parameters being considered to adapt the model to the pre-travel times (t_E) recommended by C/VM2 per building use and fire location.

Table 1. Parameters required to adapt EDM to C/VM2 building use categories

Scenario	Building use category	Location	Alarm type	Pre-travel time	EDM parameters					
					$q_{a,s}$	$q_{a,v}$	q_s	K_i	R_N	R_I
1	Occupants are considered awake, alert and familiar with the building.	a. Enclosure of origin	Standard	30	×	×	✓	✓	✓	✓
		b. Remote from enclosure	Standard	60	✓	×	×	✓	✓	✓
2	Occupants are considered awake, alert and unfamiliar with the building.	a. Enclosure of origin	Standard	60	×	×	✓	×	✓	✓
		b. Remote from enclosure	Standard	120	✓	×	×	×	✓	✓
		c. Enclosure of origin	Voice	30	×	✓	✓	×	✓	✓
		d. Remote from enclosure	Voice	60	×	✓	×	×	✓	✓
3	Occupants are considered sleeping and familiar with the building.	a. Enclosure of origin	Standard	60	×	×	✓	✓	×	✓
		b. Remote from enclosure	Standard	300	✓	×	×	✓	×	✓
4	Occupants are considered sleeping and unfamiliar with the building.	a. Enclosure of origin	Standard	60	×	×	✓	×	×	✓
		b. Remote from enclosure	Standard	600	✓	×	×	×	×	✓
		c. Remote from enclosure	Voice	300	×	✓	×	×	×	✓

Despite Reneke proposed values for q_a, q_s and k_i , one of the objectives of this work is to select a set of EDM parameters such that their combination gives the best match to the C/VM2 pre-travel times.

Each EDM parameter needs to correspond to some aspect of the various building use categories in a meaningful way, so for example it is appropriate to match whether an occupant is familiar with a building with the EDM prior knowledge parameter. Similarly the type of alarm corresponds to the q_a parameter (standard alarm signal $q_{a,s}$ or voice alarm signal $q_{a,v}$), whether an occupant is in the enclosure of origin or remote depends on the q_s parameter as this then considers whether fire cues (i.e. smoke) are visible.

Determination of the EDM parameters was done in a systematic process. Once a parameter has been set then it remains fixed while other parameters are then varied in sequence to get the complete set for the 11 scenarios. Some EDM parameters are not applicable to some building use categories and so are not assessed in the solution to the relevant equations.

Table 2 summarises the resultant set of parameters to model C/VM2 values with the EDM. These results are based on initial assumption of $R_I = 2.5$. The purpose of this assumption was to get always a value $t_{I,a}$ less than 60 s, otherwise the agent reaches the evacuating state immediately after receiving a cue. However, the same procedure can be followed for different R_I values if required.

Likewise, it is assumed that for these cases either the smoke is visible at 0.0 s or the alarm activates at 0.0 s. However EvacuatioNZ allows these times to be set to a value other than 0.0 s. For the case when the agent first sees smoke ($t_s = 0$) it was supposed a period or 30.0 s for the alarm t_a to sound.

Table 2. EDM adapted values to C/VM2

Scenario	$t_{E,VM2}$	EDM Results									$t_{E,EDM}$
		R_I	$t_{I,a}$	$t_{I,s}$	t_s	t_a	$q_{a,s}$	$q_{a,v}$	q_s	k_i	
1a	30	2.5	57	57	0.0	30.0	0.3	0.0	1.0	0.4	30.0
1b	60	2.5	57	n/a	n/a	0.0	1.0	0.0	0.0	0.4	62
2a	60	2.5	57	57	0.0	30.0	0.3	0.0	1.0	0.0	46.5
2b	120	2.5	57	n/a	n/a	0.0	1.0	0.0	0.0	0.0	122.5
2c	30	2.5	28.3	14.1	0.0	0.0	0.0	0.0	1.0	0.0	29.5
2d	60	2.5	28.3	n/a	0.0	0.0	0.0	1.0	0.0	0.0	62
3a	60	2.5	282.6	57	0.0	30.0	0.1	0.1	1.0	0.4	30.0
3b	300	2.5	282.6	n/a	0.0	0.0	1.0	1.0	0.0	0.4	300.0
4a	60	2.5	282.6	57	0.0	30.0	0.1	0.0	1.0	0.0	88.5
4b	600	2.5	282.6	n/a	n/a	0.0	1.0	0.0	0.0	0.0	602.0
4c	300	2.5	141.3	n/a	0.0	0.0	0.0	1.0	0.0	0.0	301.5

All of the scenarios other than Scenario 3a yield results in which the computed t_E has a value close to that specified in C/VM2, meaning that the model is consistent and in agreement with the verification method values. In the case of Scenario 3a, the model predicts a t_E of 30 s (instead of the specified value of 60 s). However, the result obtained with the proposed model seems a good match given that it should be less that t_E from Scenario 4a (i.e., 60 s) due to the familiarity with the building.

The above can be exemplified as follows: The agent is sleeping and waked up because of the alarm, sees smoke (since it was visible 30 s before the alarm sounds) and immediately reach the evacuating state (since is familiar with the building). For the case when the agent is unfamiliar with the building (i.e., scenario 4a), it takes 30 s more to the agent to reach the evacuating state.

Graphical results of the behaviour of the level of perceived risk in respect with time for each C/VM2 scenario are show in Figure 2. Is important to note that inflection points in the curves are consequence of the time when the agent i reaches the investigating state as result of an alarm alert or a smoke cue.

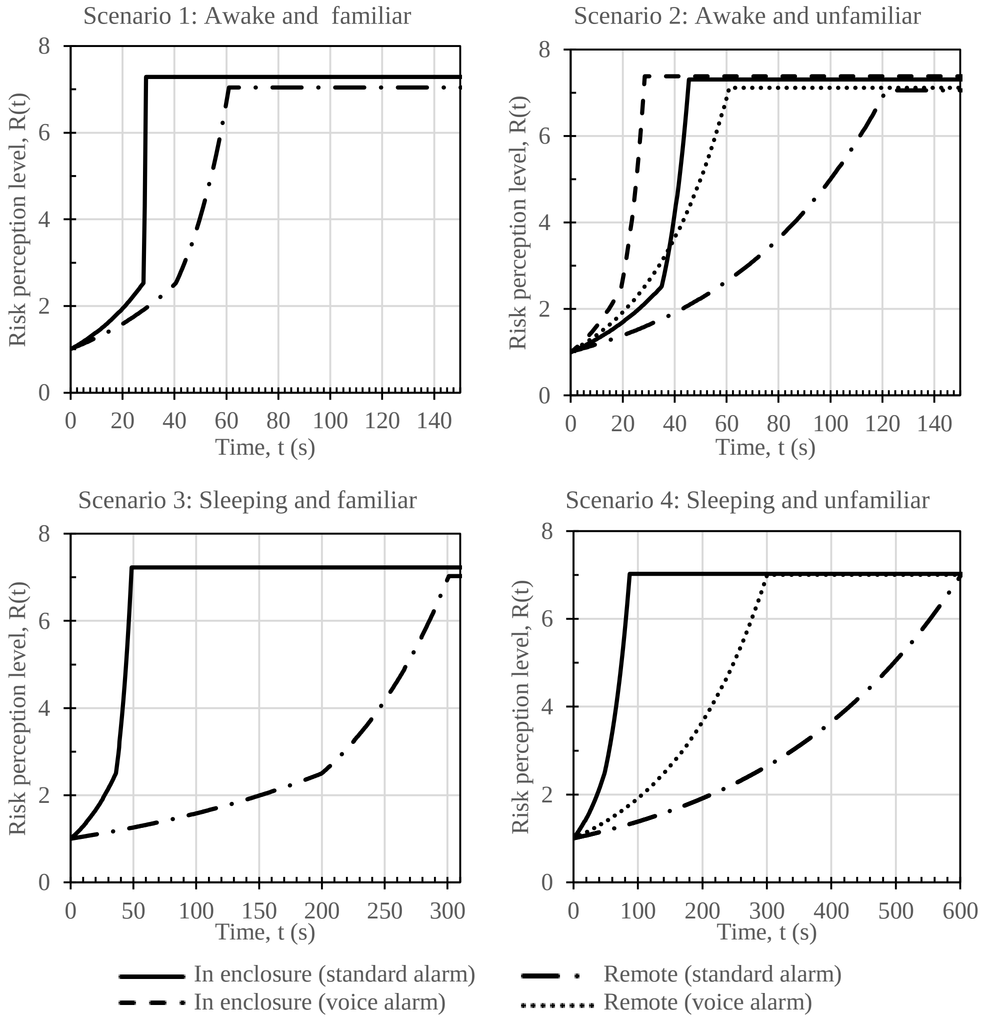

Figure 2. Change of risk perception for each building use category

5. CONCLUSION

New capabilities were incorporated into the EvacuatioNZ model to add a risk perception level to the existing agents based on the interpretation of the EDM equations. The EDM is typically constrained by user defined inputs, however in this project a set of parameters for 11 of the C/VM2 pre-travel scenarios were defined.

New Zealand verification methods define pre-travel times based on best practice or from experimental studies, often limited to a specific scenario. These are not based on the actual behaviour of different types of occupants that can be found within a building. A consistent set of parameters for different human behaviour is key for the prediction of more realistic evacuation times, which will allow fire engineers to calculate the egress time considering actual characteristics of the occupants and the building.

Developing a consistent set of parameters is a base line to follow for future research. C/VM2 building use where the occupants are under care of a trained staff could be modelled with the EDM cue for social influence. This was not considered part of the scope of this project, but the possibility of adapting and extending the database for this parameter is open for future work.

It is recommended to develop a case study to define other parameters for the EDM not accounted for in C/VM2 such as the occupant level of training, gender, age, physical capabilities, etc. The study should include the influence of the individual characteristics, the relation the test subjects have with the building, and the cues received by the subject.

The incorporation of these model capabilities into the EvacuatioNZ egress simulation program is a first step to developing a focused approach to calculate pre-evacuation times that correspond to a specific scenario. Implementing these methodologies could help mitigate the cost of fire protection features and maximize the benefit of innovative egress systems in future building construction.

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