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Nomenclature

Notation

N	number of occupants
P	probability
T	time step
t	time (s)

Subscripts

C	cumulative
D	death
EVAC	evacuate
I	instantaneous
i	time step number
REMAIN	remain

1. INTRODUCTION

As Canada and other countries move from prescriptive-based building codes to performance/objective-based codes, new design tools are needed to aid in demonstrating that compliance with these new codes has been achieved. One such tool is the computer model FiRECAM™, which has been developed over the past decade by the Fire Risk Management Program of the Institute for Research in Construction at the National Research Council of Canada (NRC). FiRECAM™ is a computer model for evaluating fire protection systems in residential and office buildings that can be used to compare the expected safety and cost of candidate fire protection options.

To evaluate fire protection systems in light industrial buildings, a new computer model is being developed. This model, whose current focus is aircraft hangars and warehouses, is based on a framework that allows designers to establish objectives, select fire scenarios that may occur in the building and evaluate the impact of each of the selected scenarios on life safety, property protection and business interruption. The new computer model is called FIERAsystem [1], which stands for **Fi**re **E**valuation and **R**isk **A**ssessment system.

FIERAsystem uses time-dependent deterministic and probabilistic models to evaluate the impact of selected fire scenarios on life, property and business interruption. The main FIERAsystem sub-models calculate fire development, smoke movement through a building, time of failure of building elements and occupant response and evacuation. In addition, there are sub-models dealing with the effectiveness of fire suppression systems and the response of fire departments.

This report describes the theoretical framework of the Expected Number of Deaths Model (ENDM). The ENDM estimates the number of occupants in a building expected to die as a result of a fire. The calculations are carried out for each compartment in the building. This model uses results output by both the Life Hazard Model [2] and the Occupant Evacuation Model [3].

2. MODEL DESCRIPTION

The ENDM estimates the number of occupants in a building expected to die as a result of a fire. This model uses results output by both the Life Hazard Model (time-dependent probability of death for occupants of each compartment due to the effects of being exposed to high heat fluxes and hot and/or toxic gases) and the Occupant Evacuation Model (residual population in each compartment). The calculations are carried out for each compartment in the building. The main features of the model are described below.

2.1 Model Input

The ENDM requires the following input: either fed directly by the user (stand-alone mode) or from other FIERAsystem submodels in the hazard or risk analysis (integrated mode).

2.1.1 Evacuation probabilities

An input to the model is the probability that the initial occupants of each compartment will have successfully evacuated the building. The Occupant Evacuation Model determines this information for each compartment in the form of the cumulative probability curve up to and including a certain time step.

2.1.2 Life Hazard Probabilities

Another input to the model is the probability that, initially, occupants in each compartment will die due to exposure to the fire hazards. The Life Hazard Model determines this information for each compartment in the form of the cumulative probability curve of death up to and including a certain time step.

2.1.3 Exit Routes

An exit route is defined in this model to be a direct means of exiting the building. For the ENDM to operate, it is necessary to specify which compartments in the building contain an exit route. A compartment will contain an exit route if the occupants of that compartment can exit the building without having to go through other compartments to do so.

2.2 Model Output

The output from the ENDM is the number of initial occupants that can be expected to die or to safely evacuate during a fire. These numbers are output for each compartment in the building.

3. METHODOLOGY OF THE ENDM

The basic purpose of DNTM is to determine the interaction between the probability that occupants will evacuate the building and the probability that they will die from the fire hazards. Each of these quantities was originally determined independently of the other. The details of the calculations performed by the model (Figure 1) are discussed in the following sections.

3.1 Evacuation probabilities

In each time step, the probability that occupants in each compartment will evacuate is first considered,

$$N_{EVAC}(T_i) = N_{REMAIN}(T_i) * P_{EVAC}(T_i) \tag{1}$$

Where:

$N_{EVAC}(T_i)$ = Number of occupants that will evacuate during time step starts at T_i
$N_{REMAIN}(T_i)$ = Number of occupants remaining at the current time step
$P_{EVAC}(T_i)$ = Probability that occupants will evacuate during the current time step

The occupants remaining in the compartment at the beginning of the time step are given a chance to exit the building based on the instantaneous probability of evacuation for that time step. If the compartment does not have an exit route, then it is assumed that the occupants must go through another compartment that has an exit to reach safety. If the path to the exit route is untenable, this will reduce the likelihood that the occupants can evacuate the building. This is taken into account by reducing the likelihood that occupants can safely evacuate as follows:

$$N_{EVAC}(T_i) = N_{EVAC}(T_i) \quad * \quad \left[1 - P_{DEATH\ IN\ EXIT\ ROUTE}(T_i)\right] \tag{2}$$

Where $P_{DEATH\ IN\ EXIT\ ROUTE}(T_i)$ is the probability that occupants will be killed while attempting to evacuate. This probability is determined in the Life Hazard Model. This reduction is only applied to those compartments that don't have an exit route. After the above calculations, the number of occupants remaining in the compartment, which can then be exposed to the life hazards, is recalculated as:

$$N'_{REMAIN}(T_i) = N_{REMAIN}(T_i) - N_{EVAC}(T_i) \tag{3}$$

Where $N'_{REMAIN}(T_i)$ is the number of occupants remaining in the compartment after some of them have managed to evacuate.

After performing the calculations of evacuation, the probability of death is applied to the remaining occupants in the compartment to calculate the number of occupants that will die during the current time step as follows:

$$N_{DEAD}(T_i) = N'_{REMAIN}(T_i) * P_{DEATH}(T_i) \quad (4)$$

Where:

$N_{DEAD}(T_i)$ = Number of occupants that will die during the current time step
$P_{DEATH}(T_i)$ = Probability that occupants will die during the current time step

The probability of death was originally determined in the Life Hazard Model assuming that the remaining occupants stay in their original compartment for the duration of the fire. Therefore, that assumption is also inherent in this model. This assumption is conservative, as it implies a worst-case scenario.

3.2 Calculation of Instantaneous Probability Curves

The calculations described above utilize the instantaneous probabilities. Those are the probabilities of an event occurring over the current time step based on the population at the beginning of that time step. The instantaneous probability curves are therefore dependent on the choice of time step size.

Both the Life Hazard Model and the Occupant Evacuation Model produce instantaneous as well as cumulative probability curves. However, the instantaneous probability curves are based on the user specified time step size for those models, which may not be the same as the step size chosen for the ENDM. The instantaneous probability curves are therefore recalculated, based on the cumulative probability curve (which does not depend on the time step size) as follows.

A cumulative probability curve, $P_C(t)$ can be constructed from the instantaneous probability curve, $P_I(t)$ as follows:

$$P_C(T_i) = P_C(T_{i-1}) + P_I(T_{i-1}) * (1 - P_C(T_{i-1})) \quad (5)$$

Equation 5 states that the cumulative probability of an event occurring at time T_i is equal to the cumulative probability that the event occurred at a previous time (T_{i-1}), $P_C(T_{i-1})$, plus the instantaneous probability, $P_I(T_{i-1})$, times the population at the beginning of the time step ($T_i - T_{i-1}$). The instantaneous probability curve, used in the ENDM, can be calculated based on a given cumulative probability curve by rearranging Equation 5 to give:

$$P_I(T_{i-1}) = \frac{P_C(T_i) - P_C(T_{i-1})}{\left(1 - P_C(T_{i-1})\right)} \quad (6)$$

Equation 6 calculates the instantaneous probability curve based on the users specified period of time over which the model performs the calculations and the time step size. Numerical problems may arise when using Equation 6 in cases where the cumulative probability approaches 1, in which case the denominator approaches a number very close to zero. To avoid such difficulties, the cumulative probability $P_C(T_i)$ is assumed to be 1 upon exceeding a certain predefined limit (0.9999). This means that all of the occupants have either died or evacuated, depending on which curve is being calculated. Consequently, the instantaneous probability for that time step ($P_I(T_{i-1})$) becomes 1. The value of P_I at times past T_{i-1} is not defined and will make no difference in the remaining calculations, so it is assumed to remain at 1.

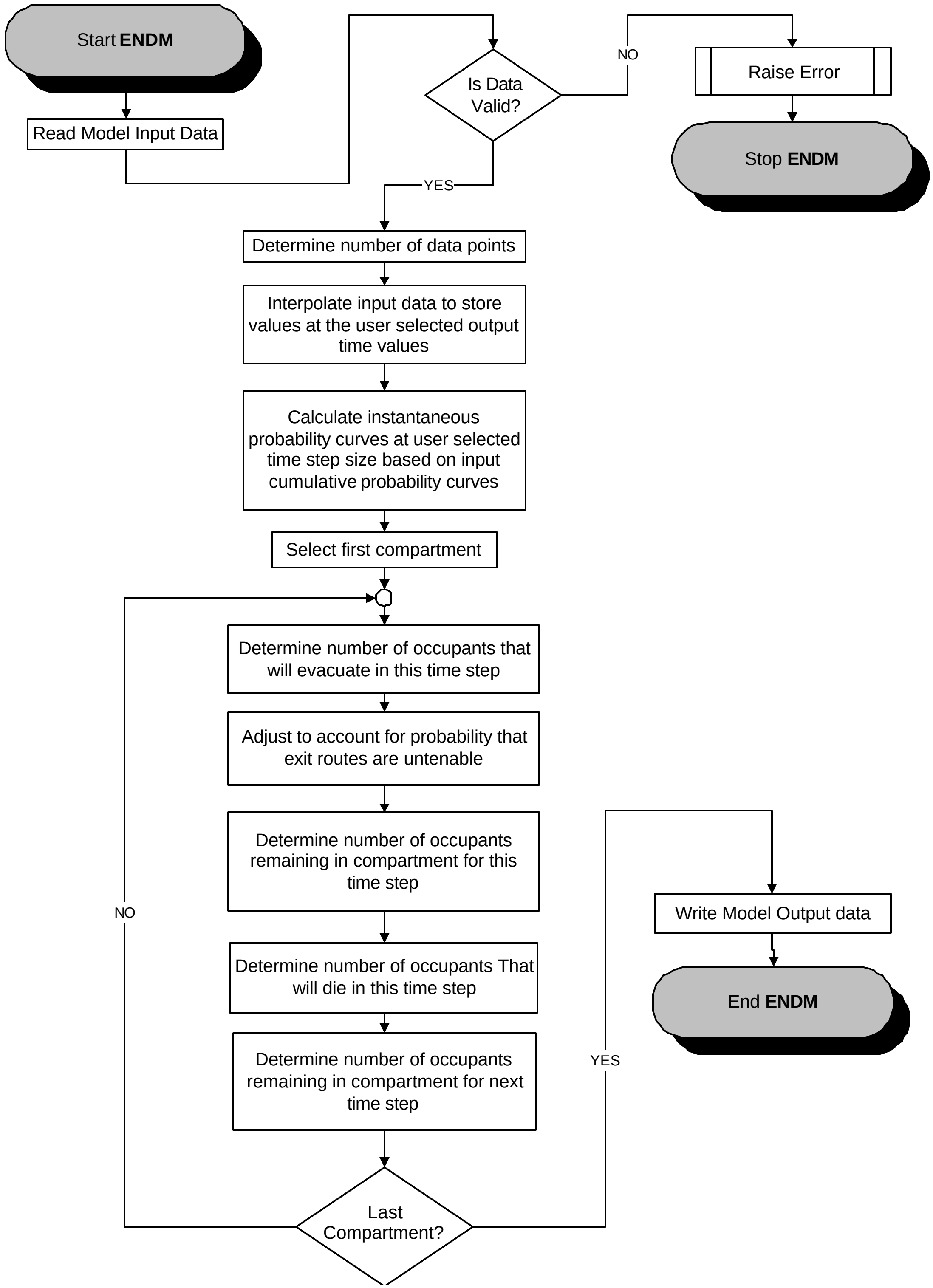

Figure 1 DNTM flowchart

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