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Fire safety engineering — Assessment, verification and validation of calculation methods —

Part 5:
Example of an Egress model

Ingénierie de la sécurité incendie — Évaluation, vérification et validation des méthodes de calcul —

Partie 5: Exemple d'un modèle d'évacuation

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Foreword

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The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

ISO 16730 consists of the following parts, under the general title *Fire safety engineering — Assessment, verification and validation of calculation methods*:

— *Part 3: Example of a CFD model (Technical Report)*

— *Part 5: Example of an Egress model*

The following parts are under preparation:

— *Part 2: Example of a fire zone model (Technical Report)*

— *Part 4: Example of a structural model (Technical Report)*

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For the particular case of the example application of ISO 16730-1 described in this part of ISO 16730, ISO takes no responsibility for the correctness of the code used or the validity of the verification or the validation statements for this example. By publishing the example, ISO does not endorse the use of the software or the model assumptions described therein, and state that there are other calculation methods available.

Fire safety engineering — Assessment, verification and validation of calculation methods —

Part 5: Example of an Egress model

1 Scope

ISO 16730-1 describes what the contents of a technical documentation and of a user's manual should be for an assessment, if the application of a calculation method as engineering tool to predict real-world scenarios leads to validate results. The purpose of this part of ISO 16730 is to show how ISO 16730-1 is applied to a calculation method, for a specific example. It demonstrates how technical and users' aspects of the method are properly described in order to enable the assessment of the method in view of verification and validation.

The example in this part of ISO 16730 describes the application of procedures given in ISO 16730-1 for an evacuation model (EXIT89).

The main objective of the specific model treated in this part of ISO 16730 is the simulation of the evacuation of a high-rise building with a large occupant population.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16730-1, *Fire safety engineering — Assessment, verification and validation of calculation methods — Part 1: General*

3 General information on the evacuation model considered

The name given to the evacuation model considered in this document is "EXIT89". EXIT89 is a computer model developed to simulate the evacuation of a high-rise building with a large occupant population. Some of the features of the model include

— the presence of disabled occupants throughout a structure,

— random delay times among occupants to simulate the spread of start times that will occur in large groups of people,

— the choice of using shortest paths or directed routes for evacuation so that the user can demonstrate the impact of a trained staff streamlining evacuation vs. the crowded use of familiar paths by an untrained, unassisted population,

— counterflows, either to simulate the impact of the operations of the fire service or to handle merging flows or the presence of obstructions in the travel path,

— a choice of options affecting travel speed, and

— occupant travel up or down stairs.

4 Methodology used in this part of ISO 16730

For the calculation method considered, checks based on ISO 16730-1 and as outlined in this part of ISO 16730 are applied. This part of ISO 16730 lists in Annexes A and B the important issues to be checked in a left-hand column of a two-column table. The issues addressed are then described in detail and it is shown how these were dealt with during the development of the calculation method in the right hand column of the Annexes A and B cited above, where Annex A covers the description of the calculation method and Annex B covers the complete description of the assessment (verification and validation) of the particular calculation method. Annex C describes a worked example, and Annex D adds a user's manual.

Annex A
(informative)

Description of the calculation method

A.1 Purpose

Definition of problem solved or function performed	— it handles large, complex buildings; — it tracks large occupant populations over time; — combined with a smoke model, it can predict effects of fire spread on evacuation. The evacuation model was designed — to be able to handle a large occupant population, — to be able to recalculate exit paths after rooms or nodes become blocked by smoke, — to track individuals as they move through the building by recording each occupant's location at set time intervals during the fire, and — to vary travel speeds as a function of the changing crowdedness of spaces during the evacuation, i.e. queuing effects. Other features allow the modelling of travel both up and down stairs, as well as the effect of counterflows.
(Qualitative) description of results of the calculation method	— Output includes — total evacuation time, — floor clearing times, — stairwell clearing times, — exit usage, and — details on location of each individual over time.
Justification statements and feasibility studies	At the time the evacuation model was first written, evacuation models tended to treat building occupants like fluid in a pipeline, with no behaviours such as delays in responding to alarms, etc. These hydraulic-style models were useful in calculating optimal evacuation times but would consistently calculate times that were short and unrealistic. The only model that treated occupants as individuals (EXITT) was based on a family group in a home setting. There was a need to develop an evacuation model that would fit into the framework of HAZARD I, but allow its application to be extended beyond dwellings, to more complex structures like high-rise buildings. The evacuation model developed here is capable of tracking a large population of individuals as they followed exit routes through large and complex structures. The evacuation model uses a shortest route algorithm to move individuals, calculates travel speeds based on densities at building nodes (or spaces), and used the decision and tenability rules of EXITT concerning reaction to smoke. Over time, new features shown to affect evacuation time, such as counterflows, were added to the model. Delay times for individuals or occupant groups can be selected from uniform or log normal distributions.

A.2 Theory

Underlying conceptual model (governing phenomena)	Time to escape is based on distance to exits and walking speed. Walking speed is based on density, as well as occupant characteristics. Predtechenskii and Milinskii developed formulae based on observations of occupant movement in smoke-free environments, taking into consideration age (adult/child), dress (summer/midseason/winter), and encumberances (baggage/knapsack/package/child in arms). In their book, they printed a table showing the results of calculations for people moving on horizontal paths, and up or down stairs, at normal speed and at emergency speed. This table was incorporated into the model. Observations of actual evacuations have shown that delay times tend to follow a lognormal distribution. Sometimes, circumstances can result in all occupants in a space delaying evacuation for a similar period of time. Whether alone or in a group, each individual has his/her own starting time. Model users can specify their own distribution, setting the mean and standard deviation for a lognormal distribution, or min/max for a uniform distribution.
Theoretical basis of the phenomena and physical laws on which the calculation method is based	— network representation of building; — local perspective; — no explicit behavioural considerations (uses delay times); — walking speeds based on crowd densities; — option for shortest route calculations or directed paths; — smoke input from CFAST output can be used to block nodes during an evacuation. The evacuation model uses formulae for travel speed that are based on research conducted in smoke-free environments. There are no physical laws applied.

A.3 Implementation of theory

Governing formulae	Travel speed calculations Density of a stream of people, D, is: $D = Nf/wL$ (m²/m²) where N is the number of people in the stream; f is the area of horizontal projection of a person; w is the width of the stream; L is the length of the stream. Walking speed on a horizontal path, V, is: $V = 112D^4 - 380D^3 + 434D^2 - 217D + 57$ (m/min) For movement down stairs: $V\downarrow = Vm\downarrow$ (m/min) where $m\downarrow = 0{,}775 + 0{,}44e^{-0{,}39D\downarrow} \bullet \sin(5{,}61D\downarrow - 0{,}224)$ For movement up stairs: $V\uparrow = Vm\uparrow$ (m/min) where $m\uparrow = 0{,}785 + 0{,}09e^{3{,}45D\uparrow} \bullet \sin 15{,}7D\uparrow$ for $0 < D\uparrow < 0{,}6$; $m\uparrow = 0{,}785 - 0{,}10 \sin(7{,}85D\uparrow + 1{,}57)$ for $0{,}6 \le D\uparrow \le 0{,}92$. In emergencies, the fear that makes people try to flee danger raises the speed of movement at the same densities. $Ve = \mu e \bullet V$ where $\mu e = 1{,}49 - 0{,}36D$ for horizontal paths and through openings; $\mu e = 1{,}21$ for descending stairs; $\mu e = 1{,}26$ for ascending stairs. The maximum possible calculated walking speed under "emergency" conditions is 1,36 m/s and under "normal" conditions is 0,91 m/s. The minimum possible calculated walking speeds are 0,18 m/s and 0,15 m/s, respectively.
Mathematical techniques, procedures, and computational algorithms employed, with references to them	Delay times are set for each location by the user and then additional delay times can be randomly assigned to individuals. Delay times can be selected from a uniform or lognormal distribution defined by the user.

Identification of each assumption embedded in the logic; limitations on the input parameters that are caused by the range of applicability of the calculation method	The travel speed calculations by Predtechenskii and Milinskii assume a maximum density of 0,92. They describe this as "verified under actual conditions". The formulae for travel speed were based on observations in smoke-free environments. Because of the arrays that store information for nodes and stairwells, there is a limit of up to 10 stairwells in the building and 89 nodes on each floor (outside of the stairwells). Currently, the model can handle up to 26 000 occupants in 10 000 nodes over 1 400 time intervals. The time intervals are set at 5 s. Delay time implementation assumes that people don't stop moving once they've begun their evacuation. Counterflow implementation assumes that the two flows only shrink the available floor space (there is no other interference in movement). Shortest route algorithm does not allow occupants to vary paths once the routing has been set, until a blockage occurs somewhere on the floor. Travel on stairs assumes that people do not leave the stairs and don't slow down or rest. Choice of distributions for delay times is limited to uniform and lognormal distributions. Appropriate ranges of delay times can be found in the literature (for example, Reference [1]). Many of these delay times are reported from observations at drills, not actual fire emergencies.

Discussion of precision of the results obtained by important algorithms, and, in the case of computer models, any dependence on particular computer capabilities	Travel distances are calculated by breaking the floor space in a building into defined nodes, and then defining paths from node to node. The size of nodes affects travel paths. Larger nodes result in fewer, longer, but less precise travel paths. Smaller nodes allow more precise paths, but there is a limit to the number of nodes that can be defined for each floor. Movement from node to node is calculated at pre-set time intervals. The size of the time step affects precision of movement. The default setting is 5 s. NOTE The model uses a random number generator in Visual Fortran v6.5. From the online documentation: "The RANDOM_NUMBER generator uses two separate congruential generators together to produce a period of approximately 10**18, and produces real pseudorandom results with a uniform distribution in (0,1). It accepts two integer seeds, the first of which is reduced to the range [1, 2147483562]. The second seed is reduced to the range [1, 2147483398]. This means that the generator effectively uses two 31-bit seeds."[21] For more information on the algorithm, see the following: — *Communications of the ACM vol 31 num 6 June 1988, titled: Efficient and Portable Combined Random Number Generators by Pierre L'ecuyer.* The model selects delay times from either a uniform or a lognormal distribution. The user determines the min/max for a uniform distribution or the mean and standard deviation for a lognormal distribution. There is little data available for observed distributions, so the user shall decide if the entered distribution is consistent with the observations reported in the literature.
Description of results of the sensitivity analyses	The largest body size option is 50 % greater than the smallest, but the calculated times might not vary that much. Larger body sizes result in a calculated density for a certain number of occupants that is larger than would be calculated with the same number of occupants with a small body size. The larger density results in slower travel speeds. But, if there are few people predicted to be in a given space, or if that space is large, the calculated density might not differ very much for different body sizes. As a result, then, the calculated travel times is fairly similar. NOTE 1 The travel times are valid only for smoke-free environments. NOTE 2 Luggage carried and goods left on the route can influence the predictive correctness of computed results in view of their applicability to real-world evacuations. A project to evaluate the predictive capabilities of computer egress models found that the evacuation model provided reasonably accurate predictions of total egress time for office and apartment buildings 6 to 15 stories in height, can underpredict the total evacuation time for abuilding if prior knowledge of the occupant load is not provided, and is sensitive to the number of occupants, the size option, and calculated travel speed.

A.4 Input

Required input	— network description; — body size (three choices; chosen size applies to all occupants); — emergency/normal speed; — path option; — smoke data, if any; — counterflows, if any; — delay (number affected and time distribution); — presence of disabled people. Counterflows can be modelled, but the user chooses the affected nodes and the times they are impacted. Shortest route algorithm adapted from Reference [16] can be a user choice.
Source of the data required	See annex for details.
For computer models: any auxiliary programs or external data files required	if smoke spread data is used as input
Provide information on the source, contents, and use of data libraries for computer models	None needed here

Annex B
(informative)

Complete description of the assessment (verification and validation) of the calculation method

(Quantitative) results of any efforts to evaluate the predictive capabilities of the calculation method in accordance with Chapter 5 of ISO 16730-1	Much of the testing done during model development to verify that the model performs the internal computations correctly was not documented. Errors that occur during that process were corrected. Where necessary and appropriate, comparisons between model predictions and available data were made. One such evaluation is described in this Annex. Four sample validation exercises
References to reviews, analytical tests, comparison tests, experimental validation, and code checking already performed. If, in case of computer models, the validation of the calculation method is based on beta testing, the documentation should include a profile of those involved in the testing (e.g. were they involved to any degree in the development of the calculation method or were they naive users; were they given any extra instruction that would not be available to the intended users of the final product, etc.)	Reference[2] Reference[3] (selected publications) Reference[4] Reference[5]
The extent to which the calculation method meets ISO 16730-1	The V&V process for this particular model meets the requirements of ISO 16730-1. Comment: ISO 16730-1 provides a good framework for laying out the features and characteristics of a model; however, — the process is easier to envision for a formula-based method and — model development in a field with scant data makes V/V process difficult. A.3 calls for a discussion of the precision of results obtained by important algorithms. In the case of this evacuation model, the source work (from Predtechenskii and Milinskii) doesn't discuss the precision of their analysis, and since the model would essentially be compared with observed evacuation times in real fires, little of which is precisely known, it is not possible to provide a discussion of precision for the model.