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Fire safety engineering — Verification and validation protocol for building fire evacuation models

Ingénierie de la sécurité incendie — Protocole de vérification et de validation de modèles d'évacuation dans un bâtiment en cas d'incendie

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 04, *Fire safety engineering.*

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The objective of fire safety engineering is to assist in the achievement of an acceptable predicted level of fire safety. Part of this work involves the use of calculation methods and models to predict human behaviour in case of a fire. Evacuation analyses are performed to mitigate the adverse effects of a fire on people. The main principles that are necessary for establishing credibility of these evacuation models are verification and validation. This document addresses the procedures for verification and validation of evacuation models. The context of applications addressed in this document is building fires.

Evacuation models are applied to establish the time for an evacuating population to reach a place of safety. Evacuation models are also used to examine evacuation dynamics of different scenarios and to evaluate the effectiveness of procedural solutions.

Evacuation models present different levels of sophistication, ranging from simplified methods (such as capacity analysis or flow calculations) to complex computational agent-based models. Microscopic models represent evacuees in computer models as agents. Each evacuee is represented by an autonomous agent with certain properties, e.g. pre-evacuation time and walking speed. A crowd is built up of a group of agents acting together in a multi-agent-based evacuation model. Agents act according to behavioural rules defined in the model. These rules can represent agent-to-agent or agent-to-environment interactions. The macroscopic approach instead represents a crowd at an aggregate level, generally adopting analogies with other physical systems (e.g. hydraulic flows). In addition, in relation to their modelling assumptions in terms of space representation (coarse or fine network approach, continuous approach or hybrid), evacuation models are capable of representing geometries with a different level of accuracy.

Evacuation models operate at three main levels when they produce results, namely 1) Individual Level, 2) Aggregate Level and 3) Scenario level. The individual level deals with the simulation of the actions performed by each agent. The aggregate level concerns the interactions between agents or the interaction between agents and simulated objects which can influence the local conditions. The scenario level relates to the results that summarize the conditions at the end of the simulation, i.e. the final outcome of the model and the layout in which the evacuation takes place.

Potential users of evacuation models and those who are asked to accept the results need to be assured that these models provide sufficiently accurate predictions of human behaviour in fire. To provide this assurance, evacuation models being considered need to be verified for accuracy and validated for capability to reproduce the phenomena. A rigorous verification and validation process are a key element of quality assurance.

There is no fixed requirement of accuracy that is applicable to all possible applications of evacuation models. The accuracy level depends on the purposes for which an evacuation model is to be used. It is not necessary that all evacuation models demonstrate high accuracy in all their components as long as the error, uncertainty and limits of applicability of the models are known. The accuracy of the evacuation model predictions is also highly dependent on the competency of the user, e.g. model configuration, data input selection, results interpretation.

This document focuses on the predictive accuracy of evacuation models. However, other factors such as ease of use, relevance, completeness and status of development play an important role in the assessment of the use of the most appropriate model for a particular application. The assessment and suitability of evacuation models for the simulation of human behaviour in fire in several contexts of applications is supported by the use of a quality-assurance methodology to ensure that the requirements are being fulfilled. Tests and methods for measuring attributes of the relevant model characteristics are outlined in this document.

This document is complementary to ISO 16730-1, in which the procedures and requirements for verification and validation of calculation methods in fire safety engineering are addressed at a general level. This document should also be used in parallel with the relevant ISO documents in which design scenarios are discussed (ISO 16733-1 and ISO/TS 29761).

This document is intended to have the following users:

a) Conceptual model developers (individuals or organizations that perform development activities, including requirements analysis, design and testing of components): These users can use this document to document the usefulness of a particular fire evacuation model for building applications. Part of the model development process includes the identification of precision and limitations of applicability, and independent testing.

NOTE Model developers generally have access to more model components than a user, given their work in the model development phase.

b) Software model developers (individuals or organizations that maintain computer models, supply computer models, and those who evaluate computer model quality as part of quality assurance and quality control): These users can use this document to document the software features and capabilities and to assure users that an appropriate testing protocol is followed to ensure quality of the application tools by documenting the verification and validation of the model pursuant to this document,

c) Model users (individuals or organizations that use evacuation models to perform a fire safety analysis): These users can use models verified and validated pursuant to this document to assure themselves that they are using an appropriate model for a particular application and that it provides adequate accuracy.

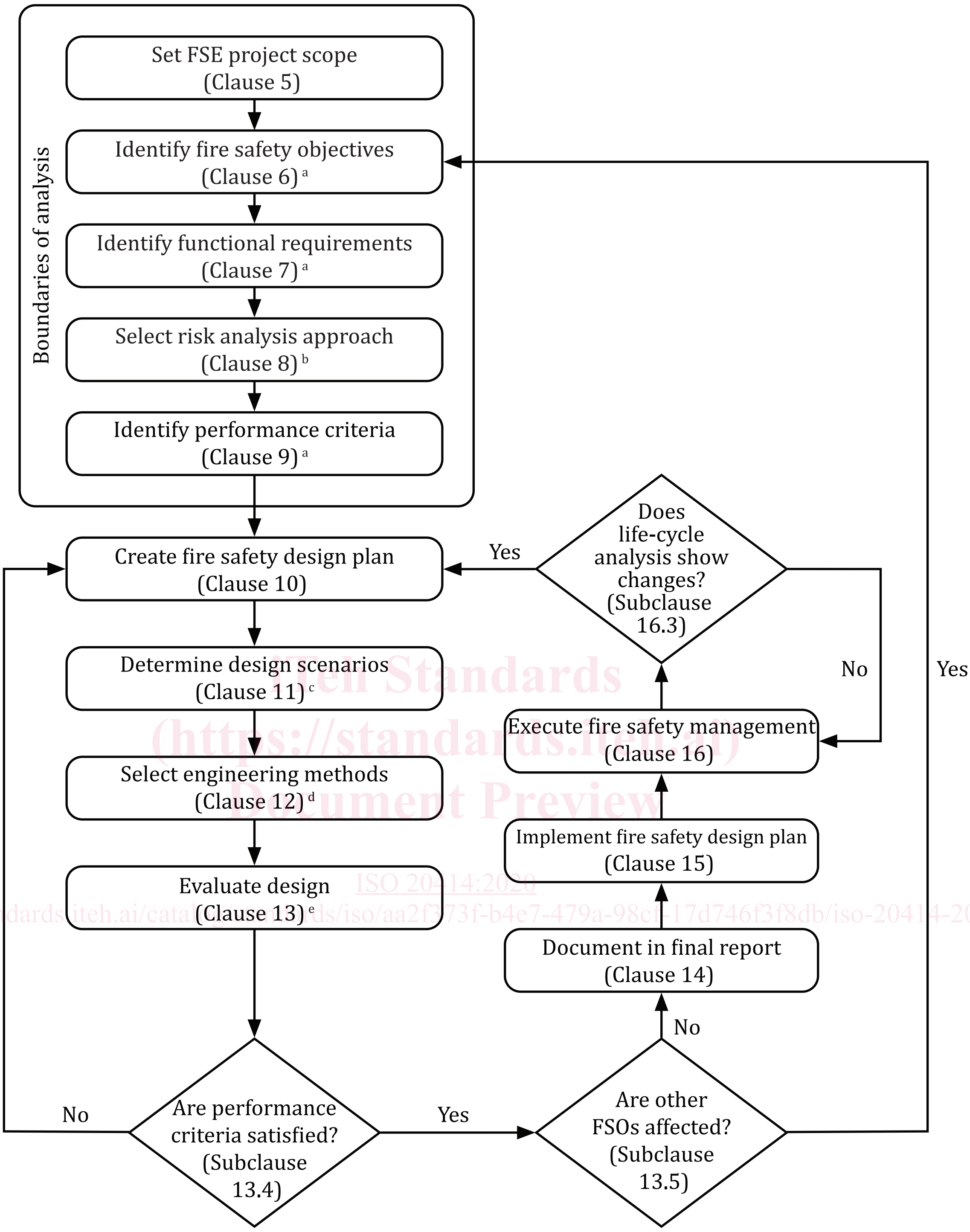
d) Developers of performance codes and standards: These users can use this document to specify the verification and validation procedure for evacuation models used in fire safety designs for a given set of applications.

e) Approving bodies/officials (individuals or organizations that review or approve the use of evacuation models): Theses users can use this document as a basis to ensure that the results submitted show clearly that the evacuation model is used within its applicability limits and has an acceptable level of accuracy.

f) Educators: These users can use this document to demonstrate the application and acceptability of evacuation models being taught.

General principles are described in ISO 23932-1, which provides a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and knowledge of the consequences of such behaviour on life safety, property and the environment. ISO 23932-1 provides the process (necessary steps) and essential elements to design a robust performance-based fire safety programme.

ISO 23932-1 is supported by a set of fire safety engineering International Standards on the methods and data required to undertake the steps in a fire safety engineering design as summarized in ISO 23932-1 and shown in Figure 1 (taken from ISO 23932-1). This set of International Standards is referred to as the Global fire safety engineering analysis and information system. This global approach and system of standards provides an awareness of the interrelationships between fire evaluations when using the set of fire safety engineering International Standards.



Key

a See also ISO/TR 16576 (Examples).

b See also ISO 16732-1, ISO 16733-1, ISO/TS 29761.

c See also ISO 16732-1, ISO 16733-1, ISO/TS 29761.

d See also ISO/TS 13447, ISO 16730-1, ISO/TR 16730-2 to 5 (Examples), ISO 16734, ISO 16735, ISO 16736, ISO 16737, ISO/TR 16738, ISO 24678-6.

e See also ISO/TR 16738, ISO 16733-1.

Figure 1 — Flow chart of the fire safety engineering process

Fire safety engineering — Verification and validation protocol for building fire evacuation models

1 Scope

This document describes a protocol for the verification and validation of building fire evacuation models. This document mostly addresses evacuation model components as they are in microscopic (agent-based) models. Nevertheless, it can be adopted (entirely or partially) for macroscopic models if the model is able to represent the components under consideration.

The area of application of the evacuation models discussed in this document includes performance-based design of buildings and the review of the effectiveness of evacuation planning and procedures. The evacuation process is represented with evacuation models in which people's movement and their interaction with the environment make use of human behaviour in fire theories and empirical observations[5]. The simulation of evacuation is represented using mathematical models and/or agent-to-agent and agent-to-environment rules.

The area of application of this document relates to buildings. This document is not intended to cover aspects of transportation systems in motion (e.g. trains, ships) since specific ad-hoc additional tests may be required for addressing the simulation of human behaviour during evacuation in these types of systems[6].

This document includes a list of components for verification and validation testing as well as a methodology for the analysis and assessment of accuracy associated with evacuation models. The procedure for the analysis of acceptance criteria is also included.

A comprehensive list of components for testing is presented in this document, since the scope of the testing has not been artificially restricted to a set of straightforward applications. Nevertheless, the application of evacuation models as a design tool can be affected by the numbers of variables affecting human behaviour under consideration. A high number of influences can hamper the acceptance of the results obtained given the level of complexity associated with the results. Simpler calculation methods, such as macroscopic models, capacity analyses or flow calculations, are affected to a lower extent by the need to aim at high fidelity modelling. In contrast, more sophisticated calculation methods (i.e. agent-based models) rely more on the ability to demonstrate that the simulation is able to represent different emergent behaviours. For this reason, the components for testing are divided into different categories, enabling the evacuation model tester to test an evacuation model both in relation to the degree of sophistication embedded in the model as well as the specific scope of the model application.

In Annex A, a reporting template is provided to provide guidance to users regarding a format for presenting test results and exemplary application of verification and validation tests are presented in Annex B.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943, *Fire safety — Vocabulary*

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

ISO/IEC 25000, *Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Guide to SQuaRE*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and ISO 16730-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
acceptance criteria
criteria that form the basis for assessing the acceptability of the safety of a design of a *building* (3.8)

Note 1 to entry: The criteria can be qualitative, quantitative or a combination of both.

[SOURCE: ISO 13943:2017, 3.3 — modified]

3.2
accuracy
degree of exactness actually possessed by an approximation, measurement, etc.

Note 1 to entry: Accuracy includes *error* (3.19) and uncertainty.

3.3
agent
simulated *occupants* in an *agent-based model* (3.4)

3.4
agent-based model
computational model for simulating the actions and interactions of autonomous *agents* (3.3) using a set of rules

3.5
arrival time
time interval between the time of a warning of fire being transmitted to each occupant and the time at which each individual occupant of a specified part of a *building* (3.8) or all of the building is able to enter a place of safety

3.6
assessment
process of determining the degree to which an *evacuation model* (3.20) is an accurate representation of the real world from the perspective of the intended uses of the model and the degree to which the model implementation accurately represents the developer's conceptual description of the model and the solution to the modelling approach

Note 1 to entry: Key processes in the assessment of suitability of a calculation method are *verification* (3.37) and *validation* (3.36).

3.7
behavioural uncertainty
uncertainty in evacuation scenarios associated with the impact of *human behaviour in fire* (3.24) during evacuation

3.8
building
structure or edifice intended for different uses

Note 1 to entry: Examples of uses include residential, offices, hotels, shopping malls, industrial premises, hospitals, arenas, theatres, exhibition halls, train stations, etc.

3.9
calibration
process of adjusting modelling parameters in a computational model for the purpose of improving agreement with experimental data

[SOURCE: ISO 13943:2017, 3.42 — modified]

3.10
component testing
process of checking that the components of a model work as intended

3.11
computer model
operational computer programme that implements a conceptual model

3.12
crowd
occupants or *agents* (3.3) whose behaviour, in conjunction with the *environment* (3.18), influences those around them

3.13
default value
standard setting or state to be taken by the programme if no alternate setting or state is initiated by the system or the user

3.14
default setting
an initial condition or algorithm provided by a developer as part of the model software

3.15
density
the number of occupants divided by the available area pertinent to the space where the occupants are located

3.16
deterministic model
model that uses science-based mathematical expressions or rules to produce the same result each time the method is used with the same set of input data values

[SOURCE: ISO 13943:2017, 3.80 — modified]

3.17
emergent behaviour
behaviour which occurs due to the interactions among smaller or simpler entities which do not exhibit such properties themselves, e.g. *agents* (3.3)

3.18
environment
conditions and surroundings that can influence the behaviour of an item or persons when exposed to fire

[SOURCE: ISO 13943:2017, 3.95 — modified]

3.19
error
recognizable deficiency in any phase or activity of calculation that is not due to lack of knowledge

[SOURCE: ISO 13943:2017, 3.98 — modified]

3.20
evacuation model
computer model (3.11) for the representation of *evacuation behaviour* (3.21)

3.21
evacuation behaviour
behaviour of the occupants (in the real world) or *agents* (3.3) (in a model) meant to directly or indirectly influence them to reach a place of safety

[SOURCE: ISO 13943:2017, 3.100 — modified]

3.22
evacuation time
time interval between the time of a warning of fire being transmitted to the occupants and the time at which the *occupant* population of a specified part of a *building* (3.8) or all of the building are able to enter a place of safety

[SOURCE: ISO 13943:2017, 3.101 — modified]

3.23
fire safety engineering
application of engineering methods based on scientific principles to the development or *assessment* (3.6) of designs in *buildings* (3.8) through the analysis of specific fire scenarios or through the quantification of risk for a group of fire scenarios

3.24
human behaviour in fire
actions performed in the event of a fire as a result of a behavioural or decision-making process (i.e. recognition of fire, way-finding, pre-evacuation, etc.)

3.25
macroscopic model
computer model (3.11) in which *occupant* movement is represented only at an aggregate level, based on computer-assisted algorithms

3.26
microscopic model
computer model (3.11) in which *agents* (3.3) perform autonomous movement based on individual parameters, capabilities and behavioural attitudes based on computer-assisted algorithms

3.27
model component
part which constitutes a model (i.e. a sub-model, algorithm or behavioural rule)

3.28
modelling
process of construction or modification of a model movement behaviour which enables occupants of a *building* (3.8) to reach a place of safety or safe refuge once they have begun to evacuate

3.29
occupant
person whose main physical characteristics are *walking speeds* (3.38) and body size

Note 1 to entry: *Evacuation models* (3.20) generally account for gender implicitly, i.e. as a consequence of the assumed body size and walking speeds. For this reason, gender is not explicitly mentioned in this document when referring to occupants.

3.30
performance-based design
design that is engineered to achieve specified objectives and *acceptance criteria* (3.1)

[SOURCE: ISO 13943:2017, 3.295 — modified]

3.31
pre-evacuation time
time period after an alarm or fire cue is transmitted and before occupants first move (or travel) towards an exit

3.32
probabilistic model
model that treats phenomena as a series of sequential events or states, with mathematical equations or rules to govern the transition from one event to another

Note 1 to entry: For example, from ignition to established burning, and probabilities assigned to each transfer point.

[SOURCE: ISO 13943:2017, 3.314 — modified]

3.33
route availability
escape routes available to the occupants

3.34
simulation
exercise or use of a calculation method to represent components of a system, their interaction and their progression over time

3.35
simulation model
computer model (3.11) that treats the dynamic relationships that are assumed to exist in the real situation as a series of elementary operations on the appropriate variables

3.36
validation
process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method

[SOURCE: ISO 13943:2017, 3.416 — modified]

3.37
verification
process of determining that a calculation method implementation accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method

Note 1 to entry: The fundamental strategy of verification of computational models is the identification and quantification of *error* (3.19) in the modelling approach and its implementation.

[SOURCE: ISO 13943:2017, 3.419 — modified]

3.38
walking speed
maximum uncongested speed at which individual evacuees move towards a place of safety

4 Documentation

4.1 General

The technical documentation relating to testing should be sufficiently detailed so that all calculation results can be reproduced within the stated accuracy by an appropriately qualified independent individual or group. Sufficient documentation of calculation methods, including computer software, is essential for assessing the adequacy of the scientific and technical basis of the calculation methods, and the accuracy of computational procedures. Also, adequate documentation can assist in preventing the unintentional misuse of calculation methods. Reports on any verification and validation of a specific calculation method should become part of the documentation. The validity of a calculation method includes comparing results to data from real fire incidents, or from statistical surveys, tests and experiments, and shall be stated by applying quality assurance methodology. These give a measure or a set of measures that shall be compared to previously defined criteria to demonstrate whether agreed quality requirements are met.

Documentation shall include:

— technical documentation that explains the scientific basis of the calculation method, see 4.2; and

— a user's manual, in the case of a computer programme, see 4.3.

The following clauses describe necessary requirements for technical documentation and a user's manual. The list is not intended to exclude other forms of information that can assist the user in assessing the applicability and usability of the calculation method.

4.2 Technical documentation

Technical documentation is needed to assess the scientific basis of the calculation method. The provision of technical documentation of a calculation method is a task to be performed by model developers. Technical documentation must thoroughly describe the calculation method and its basis, demonstrate its ability to perform adequately, and provide users with the information they need to apply the calculation method correctly. In case of calculations that make use of algebraic formulae derived from experimental results by regression or when analytical solutions are applied, the user shall rely on relevant documentation from standards or similar material, like scientific literature. When standards are developed that contain calculation methods to be used for fire safety engineering, the source(s) for the calculation methods to be used together with technical documentation as described below shall be given, where applicable.

a) The description of the calculation method shall include complete details on:

1) Purpose:

— define the problem solved or function performed;

— describe the results of the calculation method;

— include any feasibility studies and justification statements.

2) Theory:

— describe the underlying conceptual model (governing phenomena), if applicable;

— describe the theoretical basis of the phenomena and physical laws on which the calculation method is based, if applicable.

3) Implementation of Theory, if applicable:

— present the governing equations;

— describe the mathematical techniques, procedures, and computational algorithms employed and provide references to them;

— identify all the assumptions embedded in the logic; take into account limitations on the input parameters that are caused by the range of applicability of the calculation method;

— discuss the precision (error) of the results obtained by important algorithms, and, in the case of computer models, any dependence on particular computer capabilities;

— describe results of the sensitivity analyses.

4) Input:

— describe the input required;