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Verification Testing of Evacuationz, a Coarse Network Evacuation Model

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Abstract:

Several evacuation models exist in the market. It is an issue for both the user and developer to evaluate the ease of use and the quality of the model results. Verification is the process of determining that the results of a calculation method match with the developer's conceptual modelling representation expectations, i.e., the modelling implementation is accurate. Different testing procedures are available for the verification of evacuation models/simulators. Recently, International Organization for Standardization (ISO) released ISO:20414, a standard procedure including a detailed list of verification tests. It includes testing of 4 components – Basic components, Behavioural components, Fire-people interaction Components, and Building-specific Components.

This thesis focuses on applying the verification tests included in ISO:20414 to the fire evacuation model Evacuationz. This software is a coarse network model using pseudo-random sampling from distributions and it can be used in the context of fire risk assessment. The scope of this work is dual, namely 1) to perform a systematic verification of the Evacuationz model using ISO:20414, 2) to evaluate the applicability of ISO:20414 to coarse network models, being this the first time, this testing procedure document is applied for such type of models.

In this thesis, a total of 21 verification tests of ISO standard are considered. Nevertheless, 16 verification tests were successfully conducted and achieved desirable results. The majority of the tests were performed explicitly, but movement around a corner was performed implicitly because corners cannot be represented directly in coarse network models. Since the version under consideration of the software does not support horizontal counterflows, one test did not yield the expected result. Also, four tests could not be conducted because of the software limitations, i.e., features such as disabling exits, showing occupant incapacitation using FED, or the inclusion of modern building evacuation features such as Lifts and Escalators were not present in the version of the software in use.

Overall, it can be concluded that the ISO:20414 procedure concerning verification testing is considered applicable to coarse network models.

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1. Introduction

Evacuation modelling is a tool used in performance-based design to analyze the evacuation time of people in case of fire, earthquake, or any other emergency. Fire evacuation modelling is a branch of science concerned with simulating human behaviour in the event of a fire. Before introducing evacuation simulations, evacuation time was computed using manual calculations following the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering (Gottuk et al., 2016). As modern architecture is including more complex buildings, it is becoming difficult to assess evacuation time through manual calculations so alternate solution in form of evacuation models were introduced. Evacuation models were developed to obtain a more realistic and simply to be able to quantify performance of evacuation time. Nowadays, the evacuation modelling market includes over 70 evacuation models (Lovreglio et al., 2020). Given the presence of a large number of software in the market, a systematic comparison of their predictive capabilities is needed. These models may adopt different approaches for the representation of the movement of people and the visual display of results. These representations can be categorized into microscopic and macroscopic models. Microscopic models depict the occupants evacuating as agents in the model, where each agent has certain properties, such as walking speed, pre-evacuation time and behaviour defined in the model. In contrast, macroscopic models represent a crowd, using similarities from other physical systems (such as hydraulic flows) (ISO, 2020). Verification of the models is very important as it ensures that the software is correctly implemented.

The introduction of the performance-based design has resulted in a paradigm shift in the fire safety design of buildings, necessitating the development of evacuation modelling tools. Evacuation modelling is becoming an essential tool with the increasing use of performance-based design(Cuesta et al., 2016). The performance-based design method is based on the idea that any fire safety design can be employed in a building if it provides an appropriate level of safety (Hurley & Rosenbaum, 2015). There is another way to perform safety analysis in the fire engineering field which is prescriptive-based design. Prescriptive-based design is a design of the building based on a pre-defined set of rules defined in the codes and standards. This design has many drawbacks, one of them is that it is difficult to embody architectural innovation in the buildings. It can also lead to unnecessary safety measures and the design can become obsolete as the fire industry evolves (Strömgren, 2018) .

In contrast, the Performance-based design enables a comparative analysis between the Required Safe Egress Time (RSET) and Available Safe Egress Time (ASET). The concepts of ASET and RSET are essential for evaluating occupants' safety. The ASET is the time between the start of the fire and before untenable conditions develop. RSET refers to the time required by the people in the building to reach a safe place.

In ASET, using manual calculations and fire simulation design fire is created to calculate untenable condition such as heat, soot, toxicity and spread of fire in the building. RSET is estimated using manual calculations (Gottuk et al., 2016) (V.M. Predtechenskii et al., 1969) and evacuation models. The difference between ASET and RSET is the Margin of Safety (MOS). RSET must be lower than ASET to ensure fire safety of occupants in the building.

Evacuation models can calculate the time required by people to reach a safe place and predict emergent behaviour (e.g., congestion levels, exit blockage, toxicity, route choice of the occupants, etc.). As the human factor is involved, evacuation models generally make use of pseudo-random sampling from distributions to consider behavioural uncertainty (Ronchi et al., 2014). Verification and Validation (V&V)

of the evacuation modelling software are essential tasks to ensure the accuracy of their results. They have been ranked as the main factor affecting model selections during a recent survey (Lovreglio et al., 2020).

To date, evacuation models are classified in their space representation according to 4 types of approaches, namely 1) Coarse network models, 2) Fine network models, 3) Continuous models, and 4) Hybrid models (Ronchi & Nilsson, 2016). In this thesis, for the first time, verification testing on a coarse network model has been performed using the International Organization for Standardization (ISO) document on verification and validation (ISO 20414). Earlier, verification testing has been applied on continuous models such as FDS+Evac (Wu, 2019) (Korhonen & Hostikka, 2010) , Pathfinder (Thunderhead Engineering, 2021) and many others. The advantage of the coarse network approach over the other network model is that it reduces the computation time so that repeated simulations can be completed in a short time frame (Ronchi, Kuligowski, et al., 2013). So, for this thesis, a software named Evacuationz has been studied and the ISO verification procedure is applied to it. Evacuationz is a coarse network model that uses node configurations to build space and allow for the evacuation of occupants. The advantage of using Evacuationz is that many simulations can be performed in a very short simulation time and there is no limit to the people being simulated in the model.

2. Aim and objectives

The main aim of the thesis is to check the application of the verification test procedure presented in ISO 20414 (ISO, 2020) on a coarse network model. The evacuation model selected for this objective is Evacuationz software. It is a coarse network model representation having many advantages mentioned in the introduction. The thesis initially presents an overview of the past verification methods that exist and the comparison with the current standard which is the ISO standard on verification and validation. This document will help in verifying the applicability of the ISO document to test coarse network models.

This thesis aims to answer the following research questions:

1. Does the Evacuationz software as a coarse network model meet the requirements of the verification test procedure presented in the ISO 20414 standard?
2. Is the ISO 20414 standard suitable for testing coarse network models, or is there a need for a different testing procedure?

Hence, to answer the above research questions, the following work was performed:

- Twenty-one verification tests were conducted using Evacuationz software using the ISO: 20414 procedures.
- The suitability of using the verification testing procedure of ISO 20414 for this specific model type (coarse network models) was assessed.

3. Limitations

There have been few limitations to the work and results in this thesis. Firstly, the software results are affected by user choices, so the experience and expertise of the user have potentially an effect on the results. Therefore, users have to be careful with the choice of input data they are using for all the tests performed. This is because many different approaches can be used to represent a given test or scenario. This is limitation of coarse models. In some cases, tests were performed implicitly (definition of explicitly and implicitly mentioned in section 8) but they could have been done explicitly by a user with more expertise/experience.

Secondly, the network approach potentially affects the representation of the building space. Also, given the coarse network approach, it is only possible to represent explicitly simpler geometries such as (e.g., rectangles or squares). Different shapes of areas such as curved spaces or L-shape should be represented implicitly.

Third, uncertainty analysis was not performed due to time constraints, which is also a major limitation of the thesis. Only behavioural uncertainty was taken into account.

4. Method

The first step of this thesis was a review of the verification testing for evacuation models. This includes the International Maritime Organization (IMO) test procedure (IMO, 2016), Richtlinie für Mikroskopische Entfluchtungsanalysen (RiMEA) test procedure (RiMEA, 2016), the National Institute of Standard and Technology (NIST) test procedure (Ronchi, Kuligowski, et al., 2013), and the ISO 20414 testing procedure (ISO, 2020). These were investigated to gain a better understanding of the current status of verification testing for evacuation models. Scientific papers on the topic were also used to gain a better understanding on the evacuation modelling subject. These were retrieved from scientific databases such as Lund university library (LUB) and ScienceDirect, and search engines such as Google Scholar. This was complemented by material provided by the thesis supervisors.

Verification tests were conducted to generate relevant results. Modelling also depends on the capabilities of the model tester since a single scenario could be conducted by adopting different input configurations. Model users may need to modify the default assumptions of the software to represent different scenarios. In the context of verification testing, the model user must ensure that the results are in line with the conceptual modelling representation and that the results of the software are reasonable (i.e., in line with the modelling assumptions adopted).

ISO 20414: 2020 was chosen for performing the verification procedure as it is the latest verification and validation standard available. Likewise, the scope of the thesis is linked to the application of the ISO standard, therefore it is the most appropriate test procedures to use for this research. All 21 verification tests included in the ISO 20414 document were reviewed to understand the purpose behind each test and its relevance to the application of the evacuation model under consideration.

Thereafter, Evacuationz software was learnt using the verification guide from the Evacuationz website and the Evacuationz exercise guide provided by the developer. These documents provided all the information and feature of the software needed to perform the test. Also, the website of the software developer (https://Evacuationz.wordpress.com/) was accessible to get more information.

Figure 1 represents the flowchart showing the steps involved to execute the test in the evacuation model. After conducting a comprehensive study of the software, each test was implemented in the software by building the geometry and performing the input file configuration. Following this step, the initial input configuration was discussed with the thesis supervisors to identify possible issues. This was to make sure that the tests performed were correctly implemented in the model. If the student was not able to perform the test explicitly, then this was discussed with the supervisor to examine the manners in which such scenarios can be represented. After this step, if the test was not still performed, then it was mentioned in the discussion section with the reason why it was not possible to perform it.

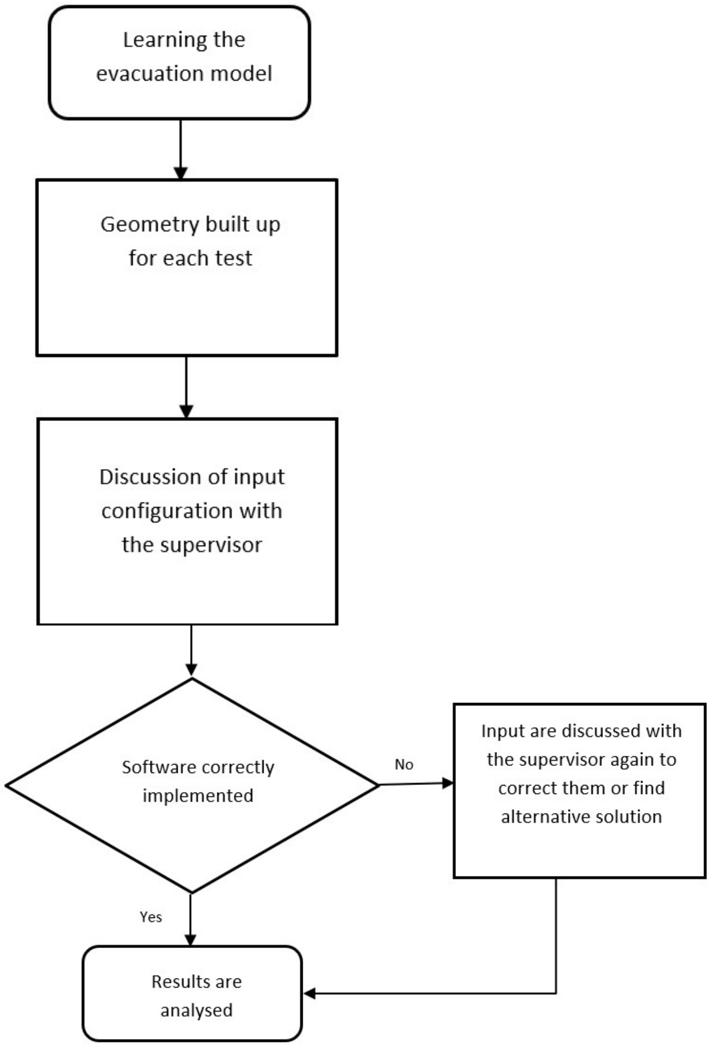

Figure 1 A flow chart depicting the steps taken for verification tests using Evacuationz.

Subsequently, the compiled results from each test were compared with the expected results mentioned in the ISO 20414 standard. This may require manual calculations to be performed to check the difference between the model and expected results. The results were illustrated in the form of graphs and in tables to make the conclusions from the result easier to be understood. The Evacuationz guide was used to check that the features are present or absent for performing each test. The analysis of the tests was then noted and then reported in the discussion section.

5. The Evacuationz model

Evacuationz software is a coarse network model that works on the nodes/arc configuration principle to reproduce simple and complex structures. It has unlimited nodes that are used to define building spaces. The "Evacuationz" software documentation states, "*It is a risk-based model of the Monte Carlo approach in producing probability distributions of evacuation times collected from repeated simulations of a specified scenario*"(Spearpoint, 2016). This means that the model uses a probabilistic approach to facilitate risk assessment in the fire safety engineering context. The model makes use of a network modelling approach and represents movement adopting key relationships between speed/density and flow/density (Steven M.V. Gwynne and Eric R. Rosenbaum, 2016).

The current version used for the thesis is Version 2.0. Evacuationz does not incorporate a Graphical User Interface (GUI). However, an external GUI can be used to generate the network for Evacuationz using yED software. The yED is a diagramming software useful to construct flow charts, network diagrams and graphs. Hence, it can also be used to draw nodes and networks for the Evacuationz software.

5.1 Evacuationz Input Files

Evacuationz software requires 6 input files. The input files are knowns as *Map, Agent-Type*, *Populate*, *Scenario*, *Simulation*, and *Exit-behaviour*. Each file is used to represent certain characteristics of the simulation, such as room dimensions, occupant characteristics and simulation mechanism. These are used to get the results of the scenarios. The language format of the file is XML (Extensible Mark-up Language) format (Tsai, 2007). In case there are errors in the input files, the model can help identifying them using a log file. The simulation results are in the format of Comma-separated value (csv) identifying the movement of each occupant/ agent in the software. Output files are explained later in this section.

(a) MAP file

The *Map file* is the essential input file for the model. It defines the physical features such as building space, and it is used to represent the network representing connections between the rooms, floors, etc. Depending on the model configuration in use, each node can be employed to represent a room, corridor, staircase, floor, part of a room, exit, etc. Each node must be linked to a specific name, reference number, and dimension. Nodes can have as many occupants as the maximum occupant density permits. To connect 2 nodes, paths are required. Connections are the paths connecting one or more nodes. Each connection should have a defined path (node reference) with a specific distance (distance between the nodes) and connection types such as door width, staircase width, stairs tread, stair riser, etc. Many connections can be made from a single node connecting to multiple nodes or another node (Tsai, 2007).

Nodes and connections are defined by their length and width dimensions. Connections utilize the effective width principle to regulate the influence of door constrictions and stair designs on people's flow (Pauls et al., 2007). A network must contain one or more 'safe' nodes that represent people's final destinations (Spearpoint, 2013). Each map file must have a defined exit (exit node) for the agent to follow the Exit Behaviour; otherwise, the file will not run.

Figure 2 represents an example of the network system. It illustrates the 2 rooms (nodes) connected through path 1 and following another path connecting the room 2 to the exit (also known as the safe node).

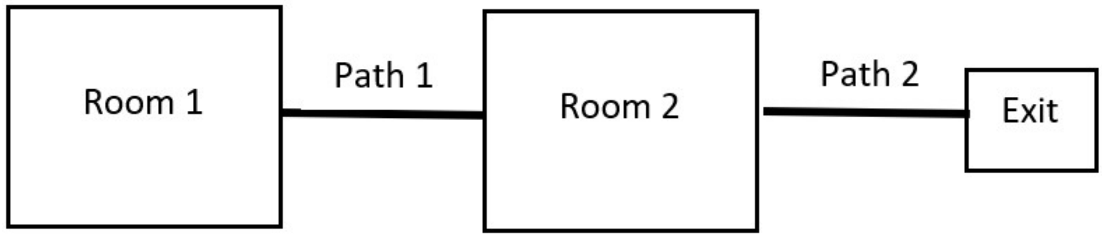

Figure 2 Geometry representation of network system

The example of the *Map input file* is shown in the text below. In this text, a node is represented with a dimension of 40 meters (m) long and 2 m wide corridor connected to the exit node. The connection between the corridor node and exit node is named as "Route" with width of 2 m is as shown below.

```
<EvacuatioNZ_Map version='2.00'>
  <Node>
    <Name>Corridor</Name>  <!-- Name of the node -->
    <Ref>1</Ref>   <!-- Node Reference number -->
    <Length>40.0</Length>  <!-- Length of the node -->
    <Width>2.0</Width>  <!-- Width of the node -->
  </Node>
  <Node type='enz_safe'>
    <Name>Exit</Name>   <!--Name of the safe node -->
    <Ref>99</Ref>  <!-- Node reference number of the safe node -->
  </Node>
  <Connection>
        <Name>Route</Name>  <!-- Name of the connection -->
        <NodeRef>1</NodeRef>  <!-- Reference number of connection node -->
    <NodeRef>99</NodeRef>  <!-- Reference number of connection node -->
          <Length>0.0</Length>  <!-- Length between the nodes -->
          <Width>2.0</Width>  <!-- Width between the nodes -->
  </Connection>
</EvacuatioNZ_Map>
```

(b) POPULATE file

The *Populate file* defines many model features such as the number of occupants, type of distribution and type of occupants. The populate file is linked to the *Agent-Type file*; the type of agent is defined in the *Agent-type files* and used as bases for the agent characteristics in this file.

Nodes can be populated in this file either by a fixed number or in the form of distribution. Five types of distribution can be used to define the properties of the occupants: Normal distribution, Uniform distribution, Lognormal distribution, Triangular distribution, and Weibull distribution. The upper and lower distribution limit must be indicated as distributions are truncated. More features such as different types of occupancies (linked to different agent properties) can be shown when defining the population in the nodes as long as the probability of all agents adds up to 100 per cent (Spearpoint, 2013).

The text below is an example of the *Populate input file*. It shows a single agent in a node known as a corridor. An adult agent is the type of agent (default type) with probability a of 100 %.

```
<EvacuatioNZ_Populate version='2.00'>
<PopulationDefinition log="enz_true">     <!--Basic agent type -->
<Agents>1</Agents>     <!-- Number of agents -->
<NodeRef>Corridor</NodeRef>    <!-- Location of agents -->
       <AgentType>
         <Name>adult</Name>     <!-- Name of agents specified-->
          <Probability>100</Probability>  <!--  sub of all the agents types used in scenario to be 100% -->
           </AgentType>
</PopulationDefinition>
</EvacuatioNZ_Populate>
```

(c) SIMULATION file

The *Simulation file* is used to define the modelling system to develop. Variables that can be changed are Maximum Simulation time, Timestep, Maximum Node Density, Start distance, Speed, and Pre-evacuation time.

Time step It can be used for doing sensitivity analysis. 1 second (s) is used as default as the time step. Each time step, a person's movement speed is recalculated, resulting in a simulation where the time to traverse a constriction varies (Spearpoint, 2013).

Time Max is the maximum simulation time, irrespective of whether the occupant has evacuated to the safe node. The default value for max simulation time is 1800 s.

Maximum Node Density – It is the maximum number of occupants that are allowed to enter a node.

The text below is an example of a simulation input file. The simulation's maximum time is set to 3600 s (1 hour), the time step is set to 1 s, and the time frequency is set to 10 minutes. These are the software's default values, but they can be changed by the user.

```
<EvacuatioNZ_Simulation version='2.00'>
              <TimeMax units='hr'>1</TimeMax>   <!-- Max. simulation time for each iteration -->
              <TimeStep units='s'>1.0</TimeStep>    <!-- Iteration time step -->
              <TimeFrequency units='min'>10</TimeFrequency>    <!--  Time Frequency->
</EvacuatioNZ_Simulation>
```

(d) SCENARIO file

The *Scenario file* specifies the model's input and output files. In the scenario file, the model tester can specify the number of simulation runs. The user can indicate the required input and output files using the scenario file. *Simulation, Agent Type*, *Exit Behaviour, Populate*, and *Map* are the general five input files.

Depending on the scenario, an agent log file may be introduced when it is required to identify the agent's name and the agent's characteristics. The outcome is in the form of evacuation time file , pre-evacuation time file, node outputs file, result file and is shown in the output files.

The text below shows an example of a scenario file in which the path to the file location, also known as the file path, must be specified for all input and output files. The number of simulation runs can also be specified. All the other five input files, *Simulation, Agent Type, Exit Behaviour, Populate, and Map*, must be assigned to a specific file path in order for the simulation to run. If no input files are specified, the software will use the default files. In addition, the path files for the output file must be located in the same place as the input files.

```
<EvacuatioNZ_Scenario>
  <Simulations>10</Simulations>   <!--Number of simulations assigned -->
  <Files>
  <!-- Input files -->
  <Simulation>%InputFolder%\IMO Test_2\simulation.xml</Simulation>  <!--File path of the simulation input file-->
  <AgentType>%InputFolder%\IMO Test_2\agent-type.xml</AgentType>  <!--File path of the AgentType input file-->
  <ExitBehaviour>%InputFolder%\IMO Test_2\exit-behaviour.xml</ExitBehaviour>  <!--File path of the Exit Behaviour Input  file-->
  <Populate>%InputFolder%\IMO Test_2\populate.xml</Populate>  <!--File path of the Populate Input file-->
  <Map>%InputFolder%\IMO Test_2\map.xml</Map>  <!--File path of the Map input  file-->
  <!-- Output files -->
  <Evacuation>%InputFolder%\IMO Test_2\~evac.csv</Evacuation>   <!--File path of the Evacuation output  file-->
  <Nodes minmax='enz_false'>%InputFolder%\IMO Test_2\~nodes.csv</Nodes>  <!--File path of the Node output file-->
  <Agents safe_time='enz_false'>%InputFolder%\IMO Test_2\~agents.csv</Agents>  <!--File path of the Agent path output  file-->
  <Results>%InputFolder%\IMO Test_2\~results.html</Results>  <!--File path of the Results output  file-->
  <Base>%InputFolder%\IMO Test_2\~base.xml</Base>  <!--File path of the base output  file-->
  <PreEvacuation type='enz_full'>%InputFolder%\IMO Test_2\~prev.csv</PreEvacuation>  <!--File path of the pre-evacuation time  output  file-->
  </Files>
</EvacuatioNZ_Scenario>
```

(e) Agent-Type File

The *Agent Type file* requires the user to define the individual occupant's behavioural and movement characteristics for the simulation. Each group of agent types can have different characteristics including walking speed, pre-evacuation time, start distance (location of the agent in the node), group behaviour, etc. Based on the characteristics of each occupant in the *Agent-Type file*, the *Populate file* uses the same occupants to populate each node.

An example of an *Agent-Type file* is shown below. The agent is named adult, and it has an assigned walking speed of 1 m/s, a pre-evacuation time of 0 s, and a fixed travel distance in the node of 40 m. The exit behaviour of the agent is specified in the *Exit Behaviour file*.

```
<EvacuatioNZ_AgentType version='2.00'>
    <!-- Basic agent type -->
     <AgentTypeDefinition>
       <Name>adult</Name>  <!-- Assigned name of the agent type -->
       <Speed units='m/s'>1.00</Speed> <!-- Assigned speed of the agent -->
       <PreEvacuation>0</PreEvacuation>  <!-- Assigned pre-evacuation time -->
       <StartDistance type='enz_fixed' units='m'>40.0</StartDistance>  <!--Assigned the start distance of the agent in the nodes -->
       <ExitBehaviour>enz_exit_behaviour</ExitBehaviour> <!--The assigned exit behaviour type of the agent in exit behaviour input file-->
     </AgentTypeDefinition>
</EvacuatioNZ AgentType>
```

(f) EXIT BEHAVIOUR file

The *Exit Behaviour File* specifies the exit behaviour for each type of occupant. Similar to the *Populate file*, different kinds of exit behaviour can be used in the same node as long as the sum of the probability of all exit behaviour is up to 100 percent. Exit Behaviour can be implemented using different exit behaviour types such as Preferred Route, Exit Sign Route, Shortest Path to Next Node, Minimum Nodes to Safe Route, Random route and Minimum total path travel to the specified safe node(Spearpoint, 2013).

- Shortest total travel path – This is the default function, in which the agent takes the shortest total travel path to an exit/safe node. The input line for using this behaviour type is **'enz_min_distance_to_safe'**.
- Preferred Route - This function is used when the user wants to set up specific routes for evacuating the agents. The input line for using this behaviour type is **'enz_preferred**'.
- Exit Sign Route - This function can be included to direct the occupants towards exit signs. The input line for using this behaviour type is **'enz_exit_sign'**.
- Shortest Path to Next Node - Using this function, the agent selects the shortest path to reach the adjacent node. The input line for using this behaviour type is **'enz_shortest_path_to_next_node'.**
- Minimum Nodes to Safe Route - This function is used to allow the agent to travel the least number of nodes to reach the exit/safe. The input line for using this behaviour type is **'enz_min_nodes_to_safe'.**

- Random route - As the name suggests, this function represents that the software gives an alternative choice to the agent to randomly choose a safe node or select a path. The input line for using this behaviour type is **‘enz_random’.**
- Minimum total path travel to specified safe node - In this function, the user can specify the safe node which the agent has to reach and with minimum distance. The input line for using this behaviour type is **‘enz_min_distance_to_specifed’**.

The text below is an example of an *Exit Behaviour input file*. As previously stated, the software contains various types of behaviour. First, a name is assigned to the exit behaviour, followed by an exit behaviour type and its associated probability; in this example, there is only one exit behaviour, so the probability is 100%.

```
<EvacuatioNZ_ExitBehaviour version='2.00'>
   <ExitBehaviourDefinition>
       <Name>Min</Name>  <!-- Name of the exit behaviour -->
       <ExitBehaviourType type='enz_min_distance_to_safe'>
       <!-- Assigned exit behaviour for the    scenario -->
            <Probability>100</Probability>
            <!-- Sum of the exit behaviour type used in the scenario to be 100% -->
       </ExitBehaviourType>
   </ExitBehaviourDefinition>
</EvacuatioNZ_ExitBehaviour>
```

5.2 Evacuationz Output files

Output files are generated by Evacuationz in Comma Separated Values (CSV) format along with a Log file in .html format. The name of the output files are known as Nodes, log, connection, and pre-evacuation time.

Node output file – The node output file is a csv file specifying the number of agents travelling between the nodes each second.

Agent file - It is a csv file presenting the results movement of each agent. It displays the agent's position in which node they are each second.

Log file – It is an html document providing a summary of all the input files, output files and default values taken in the software such as specific flow rate, maximum node density door flow model, time step and maximum time for the scenario.

Pre-evacuation time file - Pre-evacuation time file is a csv file. It can be specified using a fixed value or as a distribution. The values can be specified in the *AgentType input file*. This show the agents pre-evacuation time (s), age(yrs.) , gender , BMI (kg/m^2) , Maximum speed(m/s) and start distance (m).

Result file – The result file is a HTML document. It provides the summary of the simulation results which consist of total evacuation time, area of nodes, connections, and population density in the nodes.

6. Verification of Evacuation Models

The use of evacuation modelling is increasing as the use of performance-based design approaches grows. As a result, many new evacuation models are being developed. As the number of these models grow, verification is a must for modelling in order to ensure that outcomes are correct and realistic. Model verification is important since it ensures that the underlying modelling principles in the software is implemented appropriately. The definition of verification as per ISO document is “the 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” (ISO, 2020).

6.1 Existing Testing Methods

IMO test procedure (IMO, 2007) (IMO, 2016), RiMEA testing procedure (RiMEA, 2016), the Technical Note 1822 (Ronchi et al., 2013) and International Organization for Standardization (ISO, 2020) are crowd and evacuation model testing procedures used all around the world by model testers. All the test procedures were developed to standardize the testing of the features of the evacuation model and how effectively show the correct implementation of the developer’s conceptual description of behaviour and movement of people.

IMO test procedure

The International Maritime Organization (IMO) published 2007 a first testing procedure(IMO, 2007) later updated in 2016 (IMO, 2016) concerning the use of evacuation models for conducting evacuation analysis on existing passenger ships, roll-on/roll-off ships, and ships carrying more than 36 passengers. This document was the first verification testing procedure for evacuation models ever designed. As per this test procedure, there are a set of tests that are to be performed for evacuation models, including 1) component testing, 2) functional verification, 3) qualitative verification, and 4) quantitative verification.

1) Component testing is used to ensure that various features of the component are working. It is assumed that the software needs to run a set of basic test scenarios to ensure that the key subcomponents of the model work as intended. The test included in the IMO standard are maintaining set walking speed in corridor and staircase, exit flow rate, response duration, rounding corners and assignment of population demographics parameters (IMO, 2016).

2) Functional verification involves the testing of the various ranges of features of the software. That is required to perform the specific simulation. The full range of model capabilities, as well as any underlying assumptions, must be laid out in an understandable manner, and the proper use of these capabilities must be explained by the model developers in order to meet functional verification (IMO, 2016).

3) Qualitative verification is used to show the model’s behavioural capabilities can produce the predicted human behaviour using the model. The test includes Counterflow – two rooms connected via a corridor, exit flow: crowd dissipation from a large public room, Exit route allocation, Staircase, Flow density relation (IMO, 2016).

4) Quantitative verification is the process of comparing model predictions with valid data obtained from evacuation demonstrations. It is currently not possible to thoroughly quantitatively verify egress models because there is not enough trustworthy experimental data available (IMO, 2016).

IMO test procedure was created to perform verification of evacuation models for maritime applications. The overall aim of the testing procedure was to ensure that the fundamental parts adopted by evacuation models/simulators worked as intended. The test procedure focuses mostly on basic features and requires the verification of key components of evacuation simulators. The IMO test system includes the essential prerequisite for the verification of a model.

IMO test procedure was designed for maritime evacuation applications only. Therefore, it is not directly applicable to buildings.

RiMEA test procedure

The RiMEA (Richtlinie für Mikroskopische Entfluchtungsanalysen) test procedure (RiMEA, 2016) emerged as an improvement on the IMO test procedure with a specific focus on buildings. This testing procedure focused indeed on the use of crowd models (i.e., not only evacuation models) for buildings. This is different than the IMO procedure, which only focused on the ship evacuation. Both testing procedures present similarities in terms of the required verification testing. Components of human behaviour are considered, but since the scope is not fire safety engineering, the fire interaction with humans is not considered explicitly. One limitation of this testing procedure for fire safety applications is that modern evacuation features of the building, such as escalators, lifts, etc., are not taken into consideration (Ronchi et al., 2013). The RiMEA testing procedure contains a comprehensive list of verification tests for analyzing individual building components and features. However, validation testing was still not considered explicitly in this testing procedure.

NIST test procedure

NIST (National Institute of Standards and Technology) developed Verification and Validation (V&V) test guidelines in 2013 to improve existing test procedures, such as IMO and RIMEA test procedures. The test document outlining this procedure is named "The Process of Verification and Validation of Building Fire Evacuation Models" (Ronchi et al., 2013).

Earlier existing procedures considered categories based on human behaviour, and features of modern buildings (Kuligowski et al. 2005). However, this test procedure includes 17 verification tests and categorises based on five core evacuation model components: flow condition, exit usage, movement and navigation, pre-evacuation time and route availability (Gwynne et al., 2012).

It creates a more detailed classification of crucial components that testers should look at in models used to create simulation assessments. As method for model output verification, both quantitative and qualitative evaluations are provided.

Figure 3 refers to the timeline of the publication of evacuation model testing procedures.

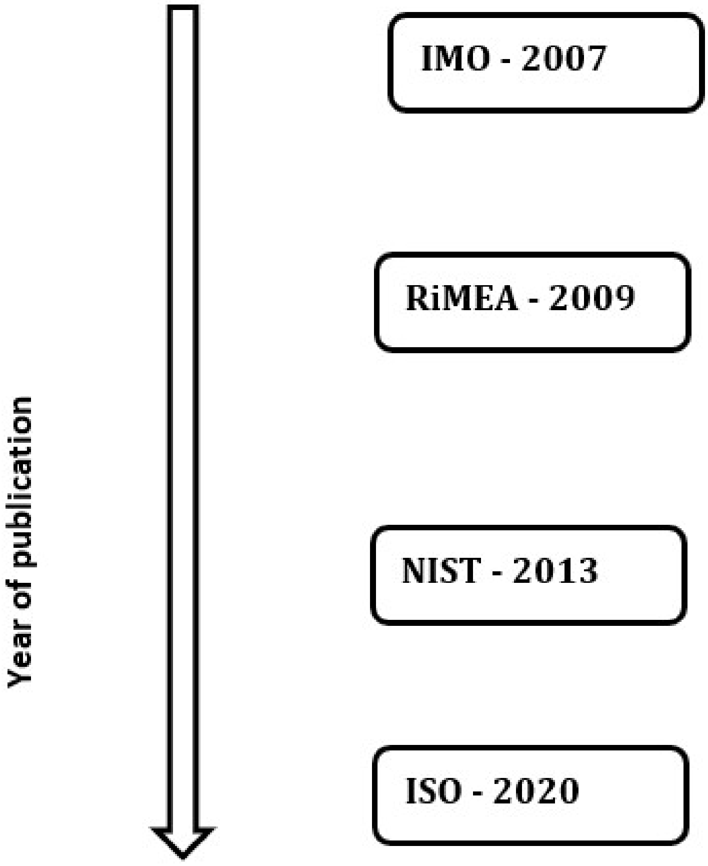

Figure 3 Order of year of publication of test procedures of the evacuation model as such as ; 1) IMO (International Maritime Organisation), 2) RiMEA (Richtlinie für Mikroskopische Entfluchtungsanalysen), 3) NIST (National Institute of Standards and Technology), 4) ISO International Organization for Standardization)

7. The ISO V&V Standard

In this section, the ISO:20414 (ISO, 2020) testing procedure is presented as it has been used in the present thesis. The ISO:20414 procedure has also been compared with the other existing testing procedures.

Verification Testing included in the ISO:20414 Standard:

Four components are included in the ISO verification testing procedure:

- Basic components
- Behavioural components
- Fire-people interaction components
- Building-specific components

Sub-tests are used to evaluate the model by analyzing the results obtained with them. Change in the time steps, door width change, change in the width of the corridors and many more might be considered as the criteria for the sub-tests.

Basic components

The basic components focus on checking simple scenarios. Each component is briefly described and a related test that can be used for its testing is presented. It should be noted that some of the recommended tests for elementary components are based on geometric layouts (ISO, 2020). Thirteen tests are included in ISO:20414 for basic component testing:

Test 1 - Pre-evacuation time assignment

Test 2 - Walking speed in a corridor

Test 3 - Walking speed on stairs

Test 4 - Movement around a corner

Test 5 - Assigned demographics

Test 6 - Horizontal counter-flows

Test 7 - People with movement disabilities

Test 8 - Exit route allocation

Test 9 - Dynamic availability of exit

Test 10 - Congestion in front of a flight of stairs

Test 11 - Maximum exit/door flow rates

Test 12 - Stair flow rates

Test 13 - Relationship between walking speed, unidirectional flow, and density

Behavioural Components

This set of components tests are the representation of human behaviour in the model based on current understanding in the human behaviour in fire field. Theories of human behaviour, such as affiliation (Sime, 1985) and social influence (Deutsch et al, 1955) are being tested to check to which extent evacuation models are able to represent them. Four tests of this kind are included within ISO:20414:

Test 14 - Group Behaviour

Test 15 - Social influence on exit choice

Test 16 - Affiliation to familiar exits

Test 17 - Route choice

Fire-People Interaction Components

Fire-People Interaction Components shows the interaction of the agents with the effect of the fire. The components show the impact of smoke (such as Fractional Effective Dose and toxicity) on agents in the evacuation model and movement of agents in the smoke (Purser, 2003). Two tests are included in the ISO:20414 for Fire -People interaction component:

Test 18 - Reduced visibility vs. walking speed

Test 19 - Occupant incapacitation

Building-Specific Components

Building-Specific Components includes the components of buildings that are increasingly used nowadays (including during evacuation) such as lifts and escalators (Kinsey, 2011):

Test 20 - Lift usage

Test 21 - Escalator usage

Overview of four V&V test procedures

Table 1 summarizes all verification tests performed by the IMO test procedure, the RiMEA test procedure, the NIST test procedure, and the ISO test procedure. The new ISO test procedure tests were used as a standard in the comparison. All tests were classified into four categories: Basic components, Behavioural components, Fire-people interaction Components, Building-specific Components which is a novel categorization system based on the ISO document. Additionally, tests can be classified in various ways, including by levels (individual/aggregate and scenario), covered in the component.

Table 1 Comparison of verification test procedures as presented by (Wu, 2019)

Components	Verification Tests according to ISO standard	IMO	RiMEA	NIST
Basic	Test 1 : Pre-Evacuation time assignment	Test 5	Test 5	Test 1.1
	Test 2 : Walking speed in a corridor	Test 1	Test 1	Test 2.1
	Test 3 : Walking speed on stairs	Test 2 & 3	Test 2 & 3	Test 2.2
	Test 4 : Movement around a corner	Test 6	Test 6	Test 2.3
	Test 5 : Assigned demographics	Test 7	Test 7 & 8	Test 2.4
	Test 6 : Horizontal counter - flows	Test 8	No	Test 2.8
	Test 7 : Overtaking people with movement disabilities	No	No	Test 2.10
	Test 8 : Exit route allocation	Test 10	Test 10	Test 3.1
	Test 9 : Dynamic availability of exit	No	No	Test 4.1
	Test 10 : Congestion in front of a flight of stairs	Test 11	Test 13	Test 5.1
	Test 11 : Maximum flow rates at an opening /exit	Test 4	Test 12	Test 5.2
	Test 12 : Stair flow rates	No	No	No
	Test 13 : Relationship between flow rate , density and walking speed in a corridor	No	Test 4	No
Behavioural	Test 14 : Group Behaviour	No	No	Test 2.9
	Test 15 : Social influence on exit choice	No	No	Test 3.2
	Test 16 : Affiliation to familiar exits	No	No	Test 3.3
	Test 17 : Route choice based on geometric layout	No	Test 14	No
Fire-people interaction	Test 18 : Reduced visibility vs walking speed	No	No	Test 2.5
	Test 19 : Occupant incapacitation by fire/ smoke	No	No	Test 2.6
Building-specific	Test 20 : Lift usage	No	No	Test 2.7
	Test 21 : Escalator usage	No	No	No

8. Simulation test and results

The results of each test run by the evacuation modelling software are reported using the ISO test template (Annex B) (ISO, 2020).

Test 1 - Pre-evacuation time assignment

The ability of the evacuation model to reflect the pre-evacuation time assignment of a population in accordance with the provided values must be quantified by model testers. Analyses of various pre-evacuation time distributions are conducted.

1. Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

The Evacuationz model can generate uniform distributions, normal distributions, log-normal distributions, triangular distributions, Weibull distributions, fixed distributions, discrete distributions (including truncated distributions. Only uniform and normal distributions were taken into consideration. This mirrored the same distributions studied in a previous thesis testing the continuous model FDS+ EVAC (Wu, 2019).

Scenario 1- Uniform distribution is the first case, the agent input file specifies pre-evacuation times as "**enz_uniform"** with minimum of 5 s and maximum of 20 s. These values were used as they are the same as in the example presented in the Evacuationz verification guide (Spearpoint, 2016).

Scenario 2- Normal distribution is the second case, the agent input file specifies pre-evacuation times as "**enz_normal**" with mean as 50 s and standard deviation as 30 s. These values were used as they are the same as in the example presented in the Evacuationz verification guide (Spearpoint, 2016).

2.Geometry

Figure 4 represents the geometry of the test 1.

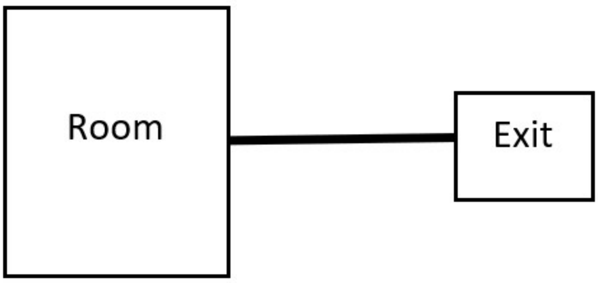

Figure 4 Geometrical representation of Test 1

3. Scenario configuration

Initially 10 simulation runs were performed but after analysis it was observed that 100 datapoints did not allow for a comprehensive statistical analysis of results, so this number was increased to 50 simulation runs resulting in 500 datapoints. Still these datapoints did not allow for a comprehensive statistical analysis. As there was a limitation of increasing the number of agents in the assigned room following the geometry in the ISO document test 1, it was concluded that the room size could be increased to 1000 m x 1000 m with 1000 occupants in the room resulting into 1000 datapoints. Hence, 1000 occupants are put randomly in the room (1000m x 1000m) for each case of distribution.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

5. Has the model tester performed a blind or open calculation?

[ ] Blind[1]

[**x**] Open[2]

6. Did you run multiple simulations of the same scenario to produce the results?

1 simulation run was conducted for each uniform and normal distribution for pre-evacuation time. Instead of running more simulations, more occupants were added to represent denote for the pre-evacuation distribution in single simulation run. As already mentioned in scenario configuration.

7. Did you repeat the test to study the different configurations of this test?

No

8. Results

Scenario 1: Uniform distribution

The results of the pre-evacuation time uniform distribution test are shown in Figure 5. Pre-evacuation time is depicted on the Y-axis, while the agent number is represented on the X-axis. A visual examination for a uniform distribution reveals a linear trend that was discovered through the simulation of the case. As a result, the pre-evacuation time data ranges from 5 to 20 seconds. Each value falls within the range of the highest and least values.

To verify the test results, the Kolmogorov-Smirnov test (KS test) was utilised. To demonstrate a difference in the distributions, the p value produced from the KS test must be less than the threshold value (Fisher, 1990). The critical value of 0.05 was exceeded by the computed p value for the uniform distribution, which

[1] Basic information about the scenario that is to be represented to the user. This includes giving the user details on the geometry of the structure such as floor plans. The additional details are up to the user to decide to perform on the model (Kuligowski & Peacock, 2005).

[2] The user is provided with all the scenario's details. This also includes benchmark runs and input and evacuation data that were obtained by blind calculation (Kuligowski & Peacock, 2005).

was 0.9. (p value). As a result, the graph depicts that for the specified minimum of 5 s and maximum of 20 s, the pre-evacuation time does not take a shape other than a uniform distribution.

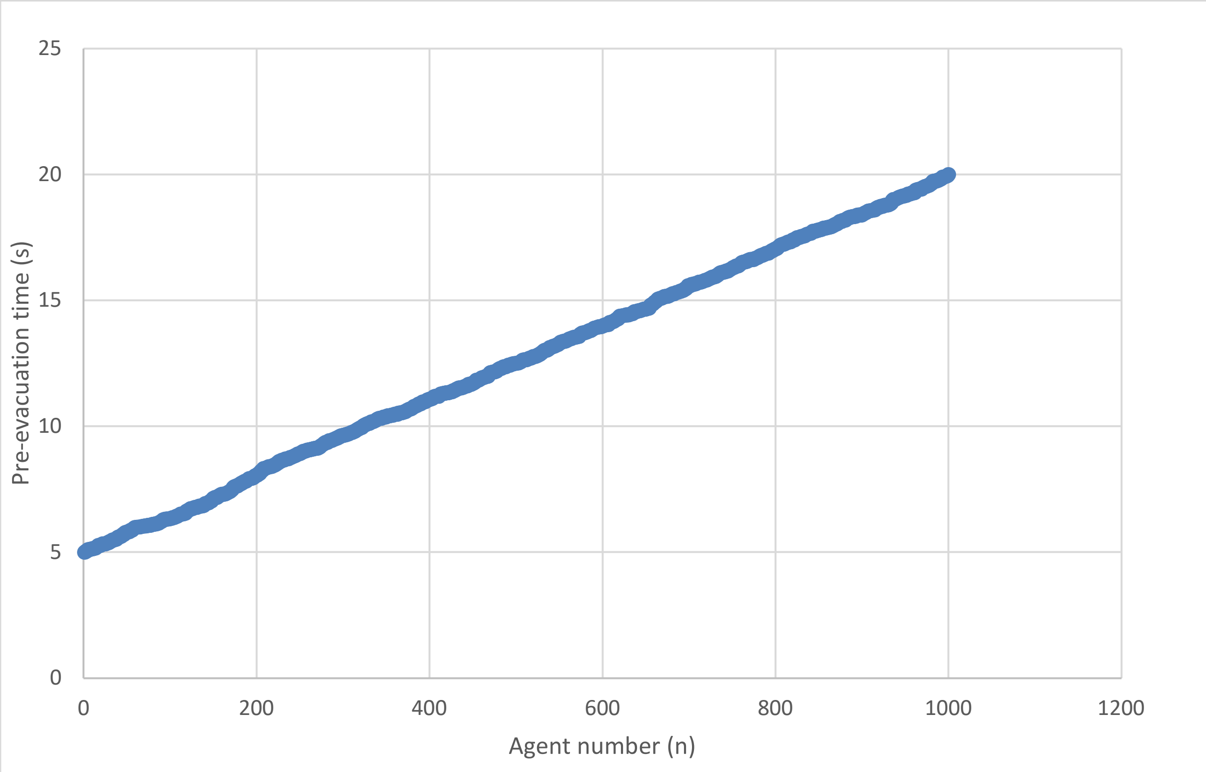

Figure 5 Graphical representation using uniform distribution of pre-evacuation time

Scenario 2: Normal distribution

A histogram is the outcomes of the normal distribution of pre-evacuation time is shown in Figure 6. The probability is shown on the Y axis, while the pre-evacuation period is shown on the X axis. It was found that the graphical representation in Figure 6 does not show a complete normal distribution, even after increasing the datasets from 100 to 1000. Evacuationz software truncates the values lower than 0, due to this it is not possible to show a symmetric normal distribution.

To verify the test results, the Kolmogorov-Smirnov test (KS test) was performed. To demonstrate a statistical difference, the p value from the KS test must be lower than the threshold value (Fisher, 1990). The critical value for the normal distribution was 0.05, hence the p value was smaller than that at 0.02 (p value). With this value, the data's normal distribution cannot be confirmed. Hence, the datapoints for pre-evacuation time is not completely in form of normal distribution due to truncation performed by the software. A more suitable test would have considered a distribution which is not automatically truncated at 0.

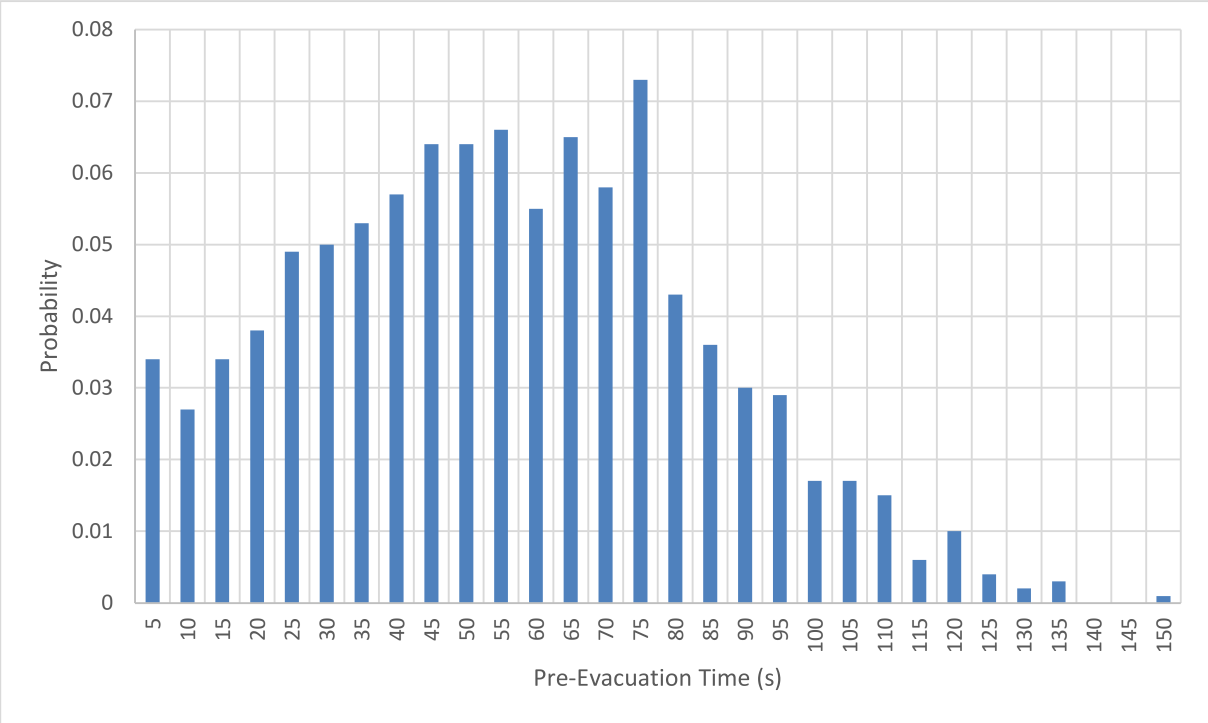

Figure 6 Histogram representation using normal distribution of pre-evacuation time

Test 2 - Walking speed in a corridor

The ability of evacuation model to maintain the assigned walking speed to cover horizontal distance of 40 m shall be verified. The occupant should be able to cover distance in 40 s.

1. Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

This model allows to assign walking speed of 1 m/s to an agent. For the movement of the agent in the corridor it is essential to specify it to an exit.

2. Geometry

The corridor was illustrated as in the Figure 7 below.

Figure 7 Geometrical representation of Test 2 form of nodes

3. Scenario configuration

The node system was used to represent an exit in a 40 m x 2 m corridor. With a starting distance of 40 m, 1 occupant is placed. The occupant's walking speed was set to 1m/s, with a pre-evacuation time of 0 s.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node. The model could assign walking speed to the agent.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

1 simulation run was performed for each scenario as there will be no changes in the evacuation time as the input values are fixed.

7. Did you repeat the test to study the different configurations of this test?

3 scenarios were performed to check the effect of time step on the evacuation time horizontal corridor.

Scenario 1 - In the standard case, the time step is 1 s.

Scenario 2 - In the scenario 2, time step is decreased to 0.75 s.

Scenario 3 - In the scenario 3, time step decreased to 0.5 s.

8. Results

In the standard case, evacuation time was 41 s due to the agent's transition time as it moved between the corridor node and the exit node. The model's predicted result was 40 s (assuming that no acceleration is considered). Table 2 shows that changing the time step can result in a slight change in the evacuation time.

Table 2 Simulated results for all the scenarios

Scenarios	Time Step		
	Value (m/s)	Evacuation (s)	Difference (%)
1	1	41	-
2	0.75	41.25	0.6
3	0.5	40.50	-1.2

Test 3 – Walking Speed on the stairs

The evacuation model shall verify the movement of occupants upward and downward.

Occupants should be able to cover stairs in 10 s.

1.Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

The model allows to create stairs by using the connection type as '**enz_stairs**' in the map input file.

2. Geometry

The stair was illustrated in the Figure 8.

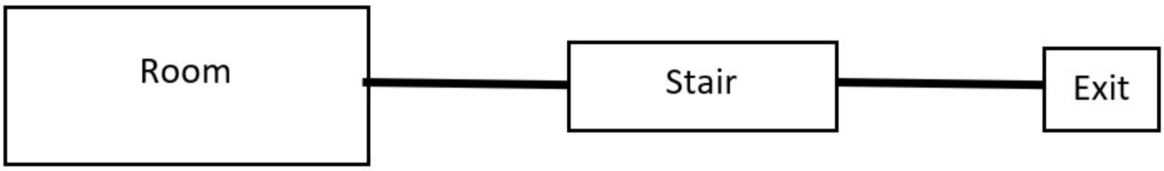

Figure 8 Geometrical representation of Test 3 in form of the node system

3. Scenario configuration

Room 1 was created with a length of 200 m and a width of 5 m represented by <node>. A walking speed of 1 m/s and a pre-evacuation time of 0 s were assigned to single agent. The model requires an unimpeded walking speed to be assigned and then modifies speed based on the SFPE equations (assuming movement downward). Another node was designated as the stairs, with specifications of 10 m length and 2 m width. The tread was 280 mm, the riser was 180 mm, and the width was 2m. Stairs are assumed to be downward movement.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node**.** This model allows to create stairs using input line **'enz_stairs'** in map input file with the assigned walking speed.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

1 simulation run was performed as the input variables of the test that are constant and there will be no change in the evacuation time even after increasing the number of simulation runs.

7. Did you repeat the test to study the different configurations of this test?

Not required

8. Results

The total length of the stairs was 10 m, and the walking speed is 1 m/s so the expected evacuation time so the occupant shall be 10 s according to ISO standard.

The SFPE Handbook, Table 3-13.4, gives a walking speed of 0.95 m/s for the given step dimensions, so the time to travel 10 m is 10 / 0.95 = 10.5 s. Hence, using the equation to calculate stair travel speed.

Speed - $S = kt(1 - 0.266\, D_o)$

Where $kt = 51.8\,.\sqrt[2]{(\frac{T}{R})}$

$kt = 51.8\,.\sqrt[2]{(\frac{280}{180})}$ = 64.6

When D_o was small thus Do was taken as 0.54 agents/m^2

$S = 64.6\ (1 - 0.266.x\ 0.54)$

= 55.3 m/min

= 0.92 m/s

Thus, the travel time is 10/0.92 = 10.9 s, whereas the result as per model was 12 s. The movement is assumed to be in the downward direction. The percentage difference between the expected value mentioned in the ISO standard and value received by the test is 18.8% (more discussed in section 9).

Test 4- Movement around a corner

The model shall verify that the occupant movement is within scenario boundaries.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[**x**] Partially

[ ] No, this feature/behaviour cannot be represented

In coarse network models, the representation of the corners cannot be done directly. Nevertheless, as shown in Figure 9, it can be illustrated indirectly.

2. Geometry

This test was illustrated as in the Figure 9.

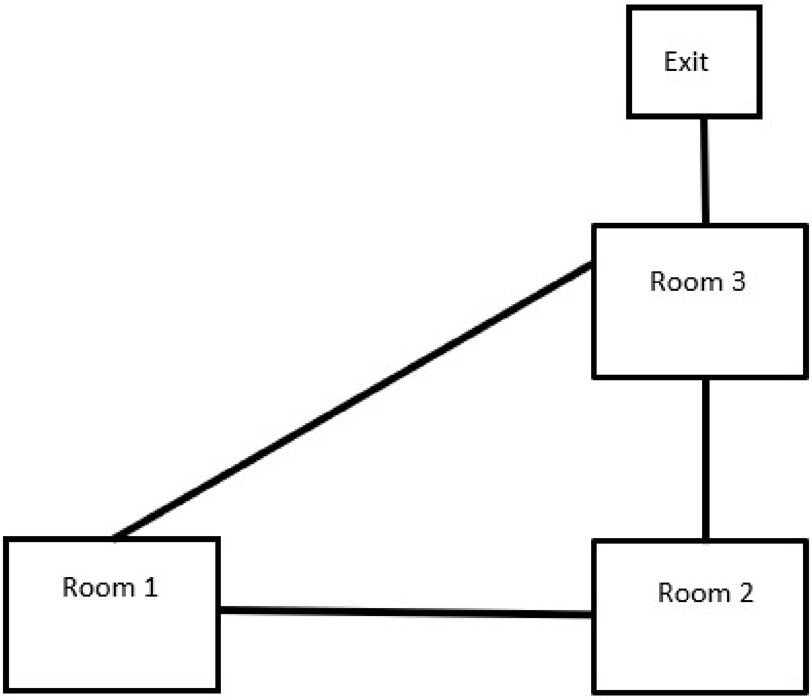

Figure 9 Geometrical representation of Test 4 in form of node system

3. Scenario configuration

In this scenario to represent a corner, four nodes were created: three rooms and one exit. Rooms 1 and 3 have a length of 10 m and a width of 2 m, while room 2 has a length of 2 m and a width of 2 m. The room had a total of ten people in it. The pre-evacuation time was set to 0 s.

4. How have the behaviours been represented?

[ ] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[**x**] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

5. Has the model tester performed a blind or open calculation?

[**x**] Blind

[ ] Open

6. Did you run multiple simulations of the same scenario to produce the results?

1 simulation run was performed as the input variables of the test were configured in a deterministic way.

7. Did you repeat the test to study the different configurations of this test?

No

8. Results

It is noted that occupants are moving between the nodes. As this model is a coarse network model, due to which occupants can only move in nodes and occupants will not penetrate the boundaries. As a result, the major goal of the test, which was to see if the occupants could not penetrate the borders, was met.

Test 5 – Assigned demographics

The ability of the model to illustrate the consistency between the walking speed distribution**.** Different distributions for walking speed are performed and analysed.

1. Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

As discussed earlier also in test 1 Evacuationz model can generate uniform distributions, normal distributions, log-normal distributions, triangular distributions, Weibull distributions, (including truncated distributions). However only uniform and normal distributions were taken into consideration. This is in line with the previous thesis applying ISO 20414 to the continuous model FDS+ EVAC . Those are among the most used distributions.

Scenario 1- Uniform distribution is the first case, the agent input file specifies walking distribution as "**enz_uniform"** with minimum of 0.25 m/s. and maximum of 1.5 m/s.

Scenario 2- Normal distribution is the second case, the agent input file specifies walking speed as "**enz_normal**" with mean as 1 m/s and standard deviation as 0.25 m/s.

2. Geometry

This test was illustrated as in the Figure 10.

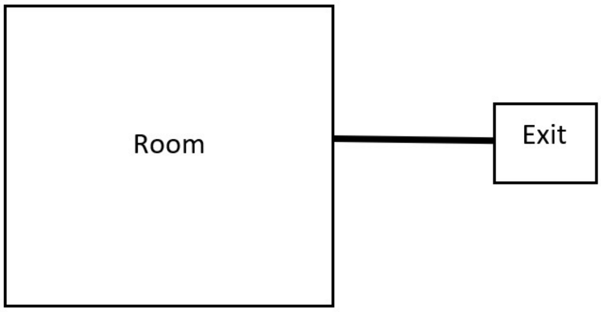

Figure 10 Geometrical representation of Test 5 in form of node system

3. Scenario configuration

In this case, the room and exit were created as two nodes. The room has a length of 100 m and a width of 100 m. The room had a total of 100 people in it. The pre-evacuation time was set to 0 s.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node. The normal and uniform distribution was considered for this test. In the agent input file, the function **'enz_distribution'** was used to represent the distribution of walking speed.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

Yes, 10 simulation runs represent 1000 datapoints because each simulation run contains 100 agents. The same as in test 1, uniform and normal distributions were used to assess the walking speed distributions in this test.

7. Did you repeat the test to study the different configurations of this test?

No

7. Results

Scenario 1 - The Figure 11 illustrates the uniform distribution of walking speed. The Y-axis illustrates walking speed (m/s) and X-axis represents the agent number. For uniform distribution it is observed that a linear graph is obtained from the simulation of the scenario. Hence, data obtained from the simulation is evenly distributed for the walking time period 0.2 m/s to 1.5 m/s. All the values are within the maximum and minimum values.

Kolmogorov-Smirnov test (KS test) was used to verify the test results. The p value obtained from the KS test must be lower than the threshold value to indicate statistical differences (Fisher, 1990). The p value calculated for uniform distribution was 0.86 which is more than critical value of 0.05 (p value). Hence, the graph depicts that the walking speed distribution is not different than a uniform distribution.

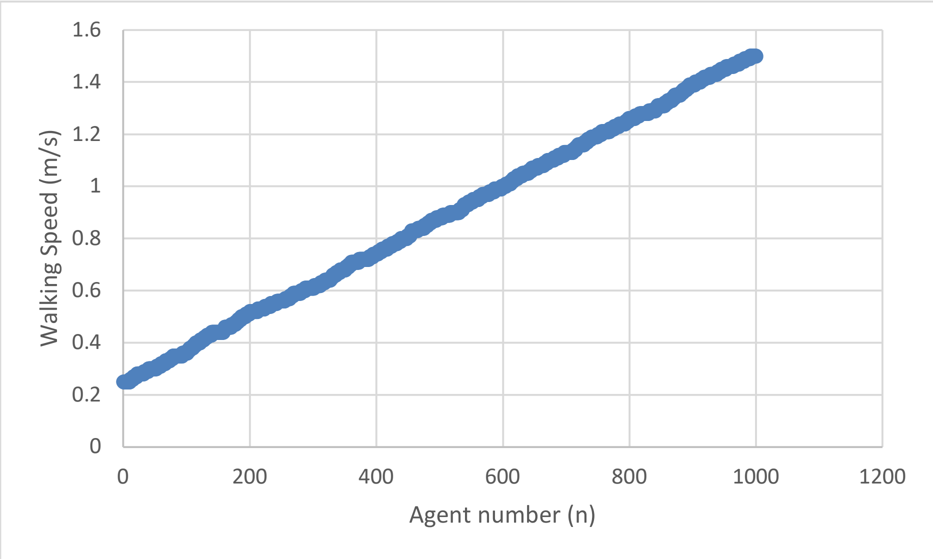

Figure 11 Graphical representation of walking speed distribution- Uniform distribution

Scenario 2- The Figure 12 represents the normal distribution of pre-evacuation time. The Y axis illustrates the probability and X axis represent the walking speed (m/s). For normal distribution a parabolic histogram graph is obtained from the simulation of the scenario which matches the pattern of a normal distribution. The distribution of walking speed is noted from the range of 0.27 m/s to 1.82 m/s.

Kolmogorov-Smirnov test (KS test) was used to verify the test results. The p value obtained from the KS test must be lower than the threshold value to show statistical differences (Fisher, 1990). The p value calculated for normal distribution was 0.12 which is more than critical value of 0.05 (p value). Hence the graph depicts the walking speed distribution is not different than a normal distribution (mean 1 m/s and standard deviation 0.25 m/s). As this distribution is not truncated (in contrast with the previous test 1), it confirms that distributions can be represented accurately by the model.

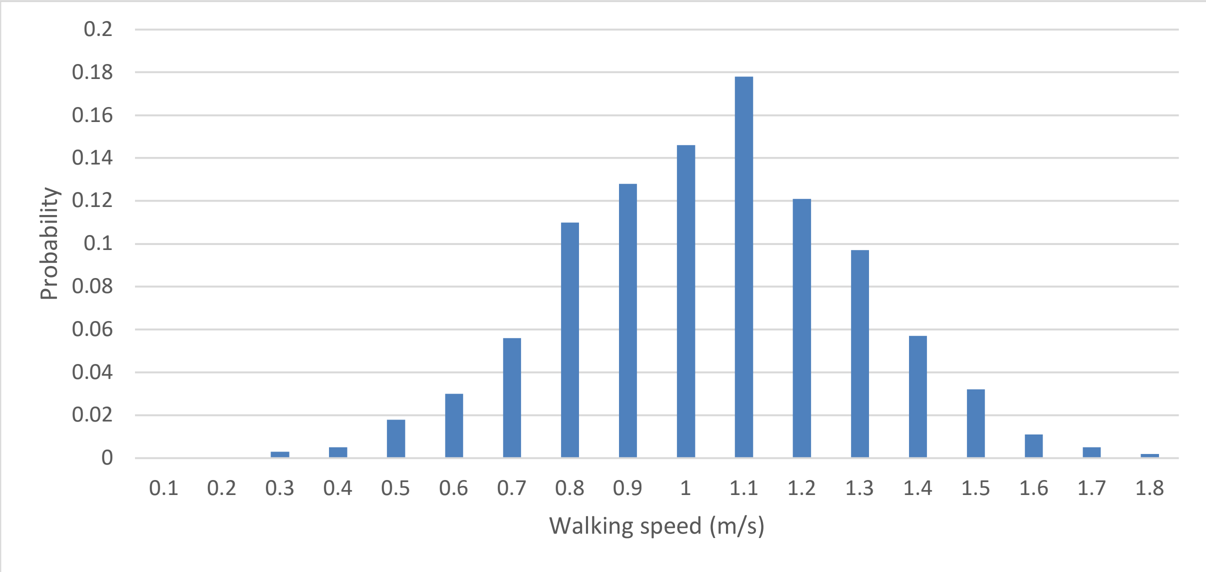

Figure 12 Histogram representation of walking speed distribution- Normal distribution

Test 6 – Horizontal counter-flows

Evacuation model to illustrate the horizontal counter-flows shall be verified. 10 Agents, 50 agents and 100 agents were set in counterflow, and the impact of these agents on evacuation time was investigated.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[**x**] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

Exit behaviour and agent input file were used to create different agent groups with different exit behaviour.

2. Geometry

This test was illustrated as in the Figure 13.

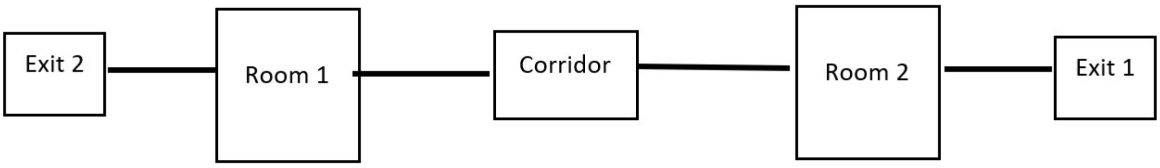

Figure 13 Geometrical representation of Test 6 in form of node system

3. Scenario configuration

Three nodes with specific dimension as rooms 1 and 3 have lengths of 10 m and widths of 10 m, while the corridor has a length of 10 m and a width of 2 m. 2 exit nodes are specific to direct the occupant flow to the exit. To demonstrate occupant walking speed characteristics, the speed distribution is assumed to be mean 1 m/s and standard deviation 0.25 m/s. The pre-evacuation time was set to 0 s.

4. How have the behaviours been represented?

[ ] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[**x**] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

For scenario 1, the **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node. For scenarios 2, 3, and 4, the exit behaviour type **'enz_min_distance_to_specified'** was used to direct both types of occupant groups to the specific exit nodes. To monitor the counter flow for the scenarios, occupants of room 1 were directed to exit 1, and occupants of room 2 were directed directly to exit 2.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

The number of people in room 1 remains constant at 100 in each scenario, while the population of room 2 is increased to monitor the counterflow.

4 scenarios are created as follows:

Scenario 1 - 100 occupants present in room 1. This is standard scenario in which the evacuation time of 100 occupants is simply obtained for comparison against the scenarios with the occupants in counterflow. Hence the occupants in counterflow are 0.

Scenario 2 - 100 occupants present in the room 1 while 10 occupants present in the room 2 for counter-flow.

Scenario 3- 100 occupants present in the room 1 while 50 occupants present in the room 2 for counter-flow.

Scenario 4 - 100 occupants present in the room 1 while 100 occupants present in the room 2 for counter-flow.

8. Results

In the test using table 3 it was observed that the total evacuation time was increasing for first 3 scenarios but for scenario 4 the evacuation time decreased. It proves even with increase in number of agents the evacuation time increases in some cases and decreases in till case 1-3 but not for the case 4. Also, in Figure 13 there is not much variation in the graphical representation even after increasing the occupants in the counterflow. It does up to a point although there may be some unresolved inconsistency / bug.

So, it shows that the software currently does not represent the counterflow.

Table 3 Total Evacuation time for each scenario

Scenario	Total Evacuation Time (s)	Evacuation time (s) by agents in Counterflow
1	138	Not applicable
2	212	67
3	440	320
4	334	333

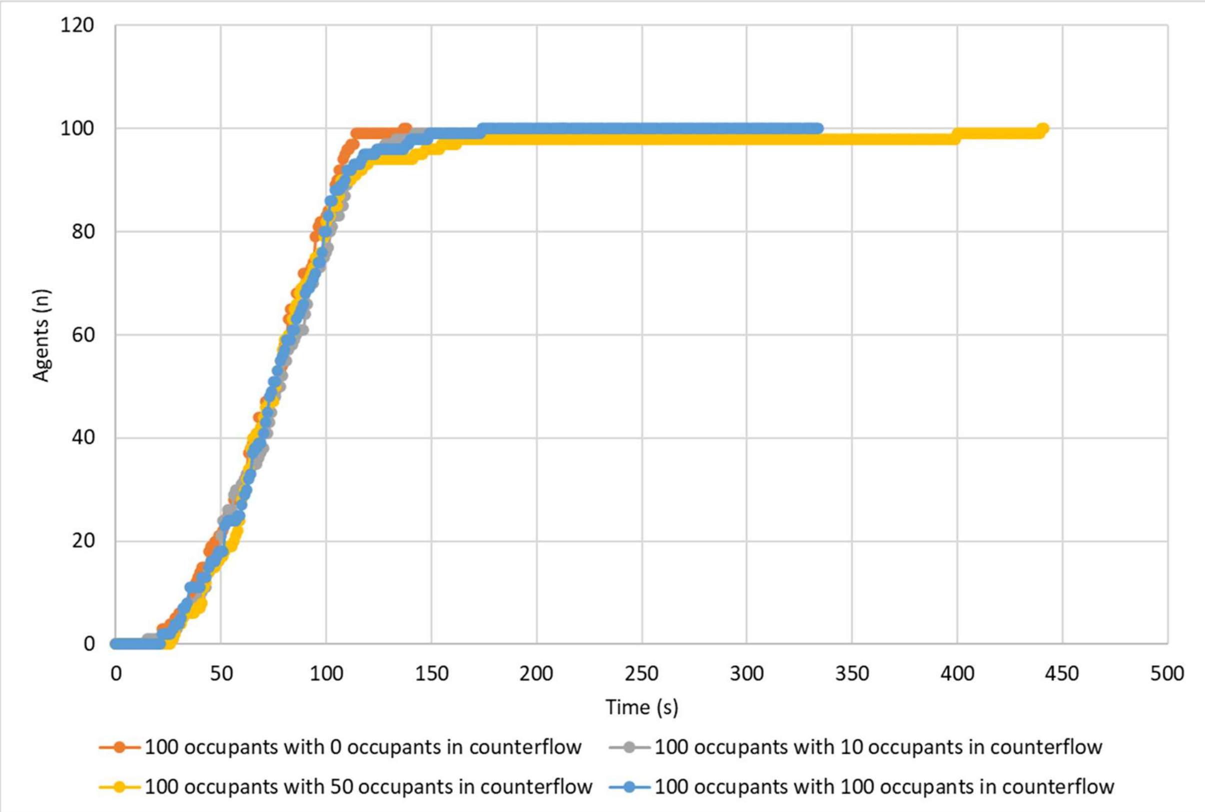

Figure 14 Graphical representation of the total *evacuation time for 100 occupants with counterflow of 0, 10, 50, 100 agents*

Test 7- People with movement disabilities

Evacuation model to verify the consequence of the disabled occupant on the other occupants.

1.Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[**x**] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

If you answered "No", the test report is completed here.

As ramp is not currently available in Evacuationz, a stair was chosen for the test. In the map input file, the stair was generated using the connection type **'enz_stairs'**. The occupant's walking speeds can be specified in the agent input file.

2. Geometry

This test was illustrated as in the Figure 15.

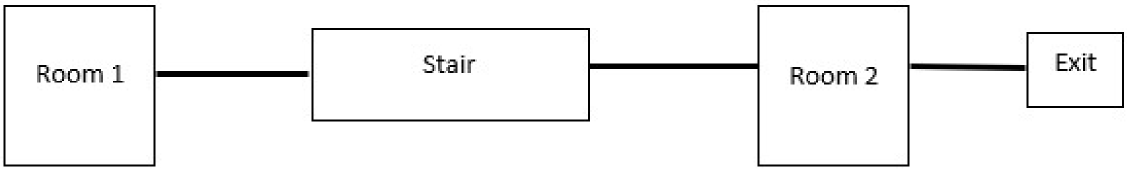

Figure 15 Geometrical representation of Test 7 in form of node system

3. Scenario configuration

There are four nodes created: room 1 (5 m x 4m), the stair (12 m x 1.5 m), room 2 (5 m x 4m), and an exit node. The tread on the stairs was 280 mm, the riser was 180 mm, and the width was 1.5 m.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

In the agent input file, two kind of agents were defined, and the walking speed indicated in the test was assigned to the agents. The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node. The walking speed of 1.25 m/s was attributed to 24 occupants, and the walking speed of 0.4 m/s was assigned to one impaired occupant. The pre-evacuation time was set to 0 s.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No, as the input variables did not change, only one simulation run was performed in the scenario.

7. Did you repeat the test to study the different configurations of this test?

3 scenarios were created to study influence the of disability of the one agent on the other agents.

Scenario 1: One agent (disabled) walks at a speed of 0.4 m/s, while the remaining 24 agents walk at a speed of 1.25 m/s.

Scenario 2: All 25 agents shared the same characteristics and were assigned a walking speed of 1.25 m/s.

Scenario 3: In this scenario, one disabled agent was assigned walking speed of 0.4 m/s.

8. Results

Table 4 shows the difference in evacuation times between all scenarios.

Table 4 Evacuation time of each scenario

Scenario	**1**	**2**	**3**
Evacuation Time (s)	78	66	89

The agent log file shows that in scenario 1, there was no congestion due to the disabled occupant, but the evacuation time was increased by 12 s. Each agent's movement was observed in agent log file and there was no congestion due to the disabled occupant noted; however, the evacuation time raise when the disabled agent arrived at the exit last, resulting in a 78 s evacuation time in scenario 1.

In scenario 3, where there was just one disabled occupant, the evacuation time was significantly longer than in scenario 1, which was 89 s.

Temporary blockage owing to a disabled occupant was not observed in this model, according to the findings.

<u>Test 8- Exit route allocation</u>

Model shall verify the ability to assign agents to the specified exits. Rooms 1,2,3,5,6,7,8,9,10,11 and 12 there was one occupant each, while room 4 had two occupants. Occupants of room 1,2,3,4,7,8,9 and 10 must exit from exit 1 whereas occupants of room 5,6,11 and 12 must exit from exit 2.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

Specific exits were assigned using the exit behaviour input file. Feature known as '**enz_min_distance_to_specified**' was used for this test.

2. Geometry

Figure 16 represents the geometrical representation of test 8.

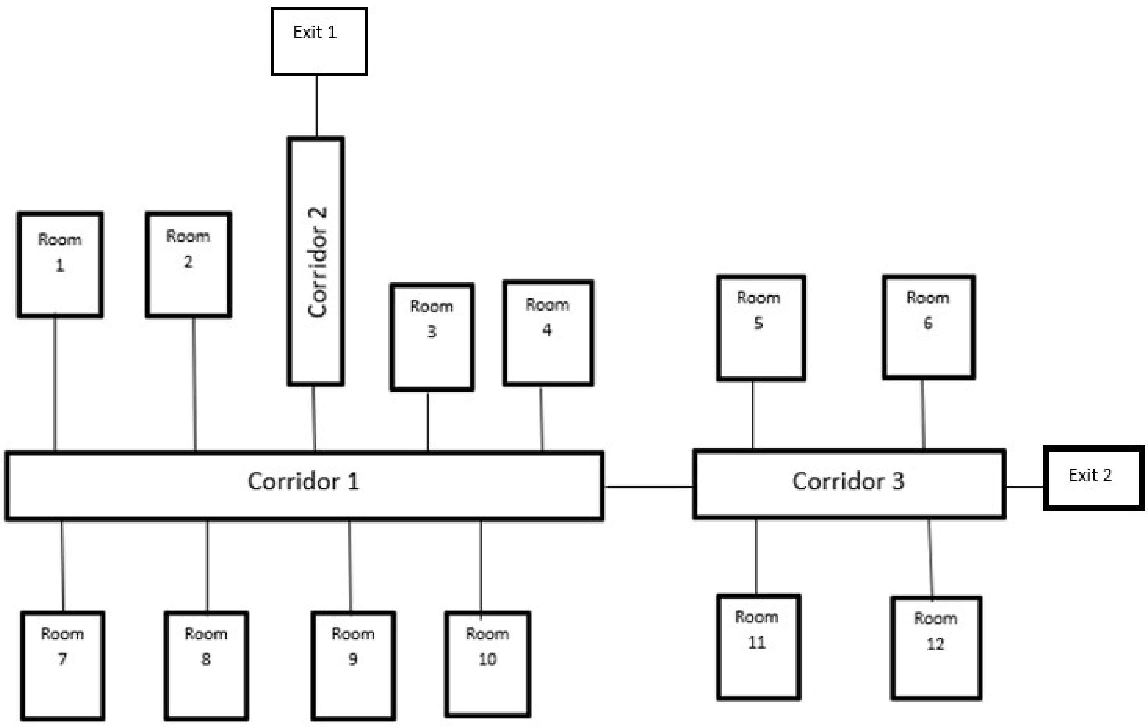

Figure 16 Geometrical representation of Test 8 in form of node system

3. Scenario configuration

To represent the situation, a total of 15 nodes are generated and connected as stated in the test. A total of two safe nodes have been added to symbolize the exit. In the test of geometry, there are 12 room nodes, 3 corridor nodes, and 2 exit nodes. Instead of a single corridor, corridor 1 and 3 corridor were created to simplify for the user to assign the exit 2 for occupants of room 5, room 6, room 11 and room 12. Pre-evacuation time for each occupant was set as 0 s.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of the people for this scenario, but it allows the representation of the variable(s) using other model features.

In this test, rooms 1,2,3,5,6,7,8,9,10,11 and 12 there was one occupant each, while room 4 had two occupants. To direct the occupant to assigned exit nodes, the exit behaviour type 'enz min distance to specified' was used. Occupants of rooms 1,2,3,4,7,8,9, and 10 were assigned exit routes via corridors 1 and 2; occupants of rooms 5,6,11, and 12 were assigned routes via corridor 3.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

1 simulation run was performed, as exits are assigned deterministically so for every additional simulation, the results will be same as there was no variation in input variable.

7. Did you repeat the test to study the different configurations of this test?

Not Required

8. Results

The main exit (exit via corridor 1 and 3) as exit 1 was given to the agents that were present in the rooms 1, 2, 3, 4, 7, 8, 9, and 10 and a secondary exit (exit route via corridor 3) as known as exit 2 was given to agents in rooms 5, 6, 11 and 12. The occupant's movement can be seen in the agent and log file. It was discovered that the occupants evacuated through the exits specified in the model.

Test 9 – Dynamic availability of exit

This test investigates how the model represent the change of the exit choice based on the availability of the exit during evacuation. The model needs to represent the blockage of an exit at a given point in time explicitly.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[**x**] No, this feature/behaviour cannot be represented

Test 10 – Congestion in front of a flight of stairs

The ability of the evacuation model to represent the congestion of occupants in front of the flight of the stairs shall be verified.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

2. Geometry

This test was illustrated as in the Figure 17 below.

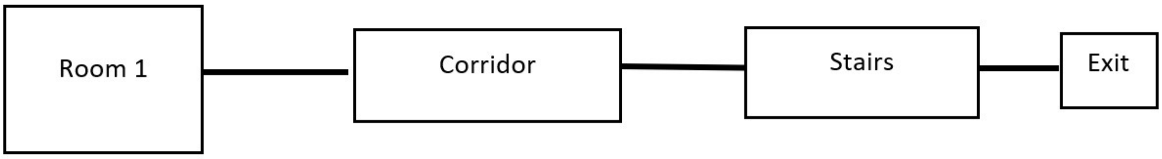

Figure 17 Geometrical representation of Test 10 in form of node system

3. Scenario configuration

In this scenario, Room 1 (8m x 5 m), corridor (13m x 2 m), stairs (10m x 2 m), and an exit node are the four nodes that were created. In room 1 there were total 150 people. The pre-evacuation time was set to 0 s and walking of the occupants was set as 1 m/s.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

No

8. Result

The ISO standard specified 150 occupants for this test; however, since the room was too small to accommodate 150 occupants in the model (as it has a cap in maximum allowed density), only 110 occupants were observed in the test results. It is because the nodes have default maximum occupant load of 2.75 agents/m^2 (Spearpoint, 2016).

The Figure 18 depicts the congestion in front of stairs from time 35 – 70 s. As the number of occupants are increasing at the flight of the staircase the evacuation time of the occupants is increasing. Hence, this model represents the congestion in flight of the stairs.

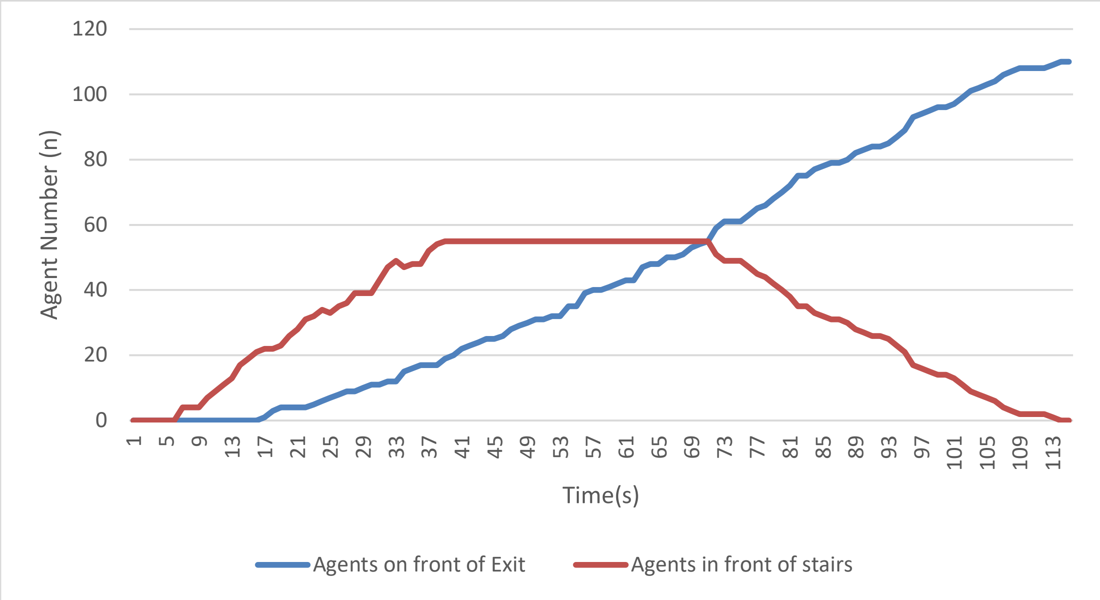

Figure 18 Congestion at the flight of the stair

<u>**Test 11 – Maximum flow rates at an opening/exit**</u>

This test represents flow rate analysis for the exits.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

Flow rate and specific flow can be obtained in the scenario input file by adding a line with the assigned file path as <connection>file path</connection>.

2. Geometry

This test was illustrated as in the Figure 19

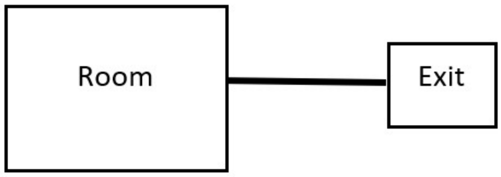

Figure 19 Geometrical representation of Test 11 in form of node system

3. Scenario configuration

2 nodes are created namely Room (8m x 5 m) and an exit node. The width of the door connection is 1 m and the effective width is not assumed but is calculated adopting a boundary layer width mechanism.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The walking speed of 100 occupants was set as 1 m/s and pre-evacuation time was set as 0 s.

Scenario 1 - In this scenario the agent start distance is set to be a minimum. Hence, in the agent input file the start distance feature used as '**enz_minimum'**. The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

Scenario 2 – In this scenario the agent start distance is random, so the location of the agent is random in the room. The feature used for this scenario is set as '**enz_random'.** The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

Two scenarios were considered to observe the flow rate at the exit and the impact of changing the agent's start distance on the flow rate at the exit.

In scenario 1, the minimum start distance was used for agents, whereas in scenario 2, the start distance of agents was assigned as random in the room.

8. Results

Scenario 1- In this scenario the agents were assigned for minimum start distance. A time interval of 30 s was used to calculate flow rates and effective width of 0.7 m was considered.

Scenario 1 shown in the Figure 20 illustrates that the specific flow rate with respect to evacuation time. It represents that the flow rate values are close to the threshold values of 1.33 p/m/s. The maximum rate was 1.42 p/m/s. This difference can be due to the approximation in time intervals used for the flow rate calculations.

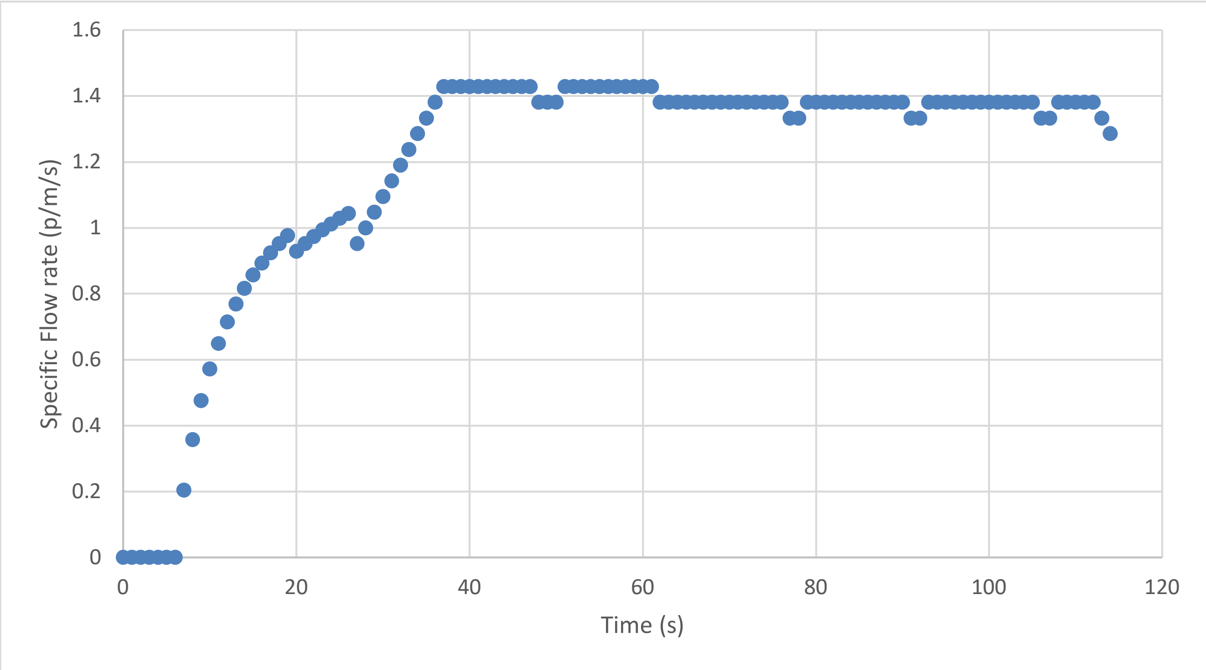

Figure 20 Flow rate vs time for agents having minimum start distance

Scenario 2- In this scenario the agents were assigned for random start distance. A time interval of 30 s was used to calculate flow rates and effective width of 0.7 m was considered. Scenario 2 is shown in Figure 21 illustrates that the specific flow rate for random start distance with respect to evacuation time. It represents that the flow rate values are higher than the threshold values of 1.33 p/m/s. The maximum rate was 1.52 p/m/s. This difference can be due to the approximation in time intervals used for the flow rate calculations.

The difference in the maximum flow rate for minimum start distance and random start distance is 6.8%. Hence, placing the agent randomly in the room has resulted in an increase in the maximum flow rate.

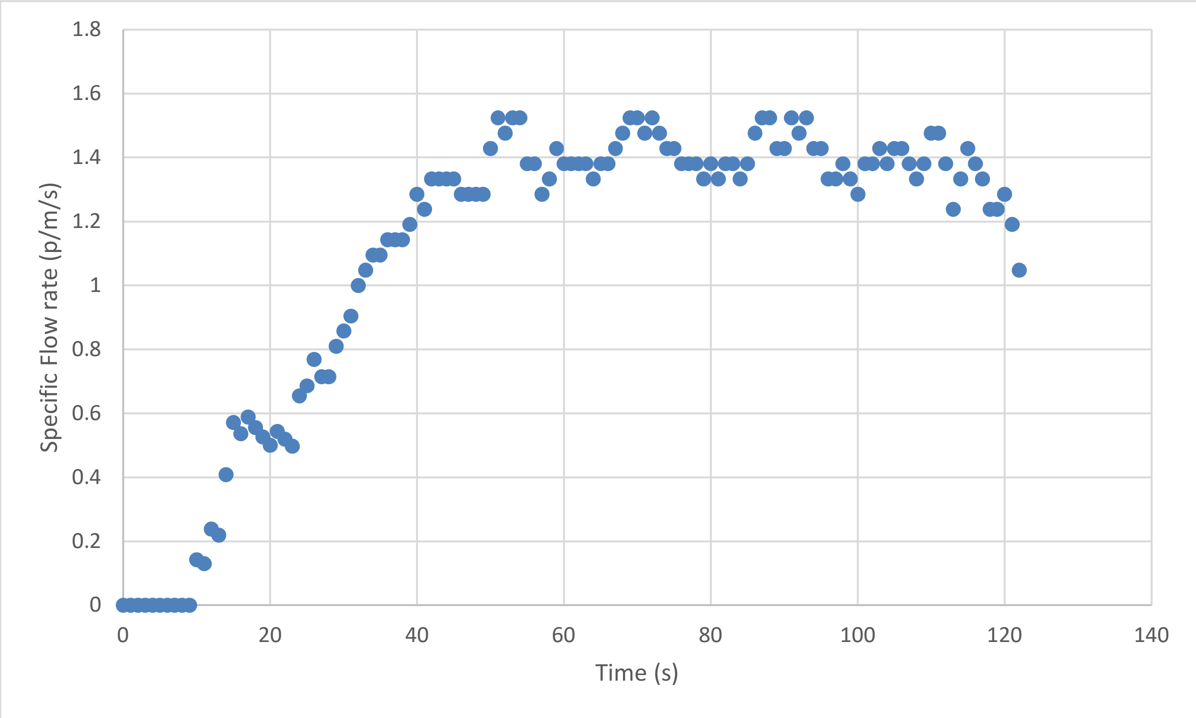

Figure 21 Flow rate vs time of Scenario 2

Test 12 - Stair flow rates

Model shall represent the ability of the model to verify the change of flow rate with respect to the change of the stair width.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[x] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

In this test, the agent start distance was set to be a minimum. Hence, in the agent input file the start distance feature was used as **'enz_minimum'**.

2. Geometry

This test was illustrated as in the Figure 22.

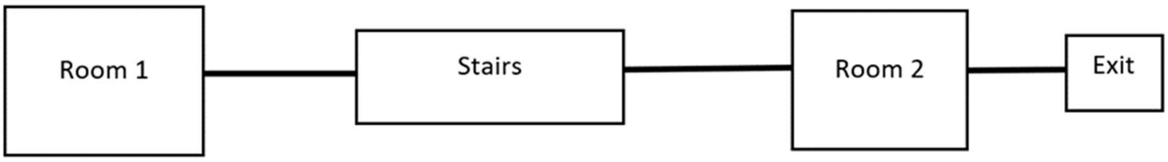

Figure 22 Geometrical representation of Test 12 in form of node system

3. Scenario configuration

4 nodes are created, namely a Room 1 (10 x 10 m), stair, Room 2 (10 x 10 m) and an exit node. Stairs were assigned with tread as 280 mm, Riser 180 mm and width 2m.

Only one case of downward movement is assumed in the scenario.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node. The walking speed of 100 occupants was set as 1 m/s and pre-evacuation time was set as 0s.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

Yes, the width of stairs was changed to observe the difference in flow rate due to the change in width of stairs. 5 staircase widths of 1m, 1.2m, 1.4m, 1.6m, 1.8m are considered.

8. Results

A time interval of 5 s was used for calculating flow rates. The effective width of the doors of the staircase was changed for each case where the width of stair was increasing.

For calculating the flow rate in the staircase, occupants that enter first in the next room were considered. The width of the staircase and door width of the room 2 were the same.

Table 5 illustrates the flow rate calculated for movement of the occupants in the stairs. It is noted that the average flow rate is increasing with increase in the width of the staircase.

Table 5 Average flow rate vs width of stairs

Width of Stairs	m	1	1.2	1.4	1.6	1.8
Effective width of door of staircase	m	0.7	0.9	1.1	1.3	1.5
Average Flow rate	P/m/s	0.506	0.841	1.015	1.162	1.20

Test 13 - Relationship between flow rate, density, and walking speeds in a corridor

This test represents the ability of the model to represent the uni-direction flow. It is the relationships between the walking speed and densities.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[**x**] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

Agent input file and exit behaviour input file was modified to check the uni- directional flow.

2. Geometry

This test was illustrated as in the Figure 23.

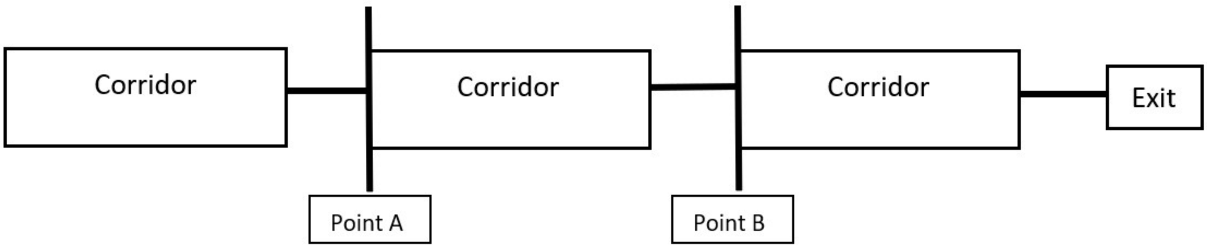

Figure 23 Geometrical representation of Test 13 in form of node system

3. Scenario configuration

4 nodes are considered in which 3 corridor (20m x 2m) and exit node were created. Population density in the *agent input file* was increased in each scenario by 1p/m^2 for the all the 3 nodes. In this test, the last agent's start distance is at point A and the end distance is at point B.

4. How have the behaviours been represented?

[ ] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[**x**] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node. One occupant was set at line A and other occupants were distributed in all 3 nodes using *exit behaviour* and *agent input file*.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

5 scenarios are created with population density as 0.5 p/m^2, 1 p/m^2, 2 p/m^2, 3 p/m^2 and 4 p/m^2 respectively.

4 scenarios are created as follows:

Scenario 1 – Population density in this scenario is set as 0.5 p/m^2.

Scenario 2 – Population density in this scenario is set as 1 p/m^2.

Scenario 3 – Population density in this scenario is set as 2 p/m^2.

Scenario 4 – Population density in this scenario is set as 3 p/m^2.

Scenario 5 – Population density in this scenario is set as 4 p/m^2.

Hence population density was increased by 1 person/m^2.

8. Results

It was observed in scenarios 4 and 5 that population density is more than the maximum admitted density of 2.75 agents/m^2 (Spearpoint, 2016) due to this data from these scenarios were not used to obtain results for this test.

The travel time of the last agent from point A to point B is shown in the table below. It can be observed that with increase in the occupant density there is increase in the travel time for the occupant also.

Table 6 Results of the last agent from point A to point B

Scenario	**1**	**2**	**3**	**4**	**5**
Travel time (s)	10	17	64	-	-
Speed (m/s)	0.9	1.03	0.88	-	-

The maximum flow rate and flow rate as calculated in table 7.

Table 7 Results of maximum flow rate and flow rate for each scenario

Scenario	1	2	3	4	5
Maximum flow rate (p/m/s)	0.7	0.82	1.29	-	-
Flow rate (p/m/s)	0.53	0.63	1.21	-	-

Figure 24 represents the graphical representation of relationship for walking speed, density and flow rate for case 1-3. The trend in the graph represents that the walking speed decreases with increase of population density.

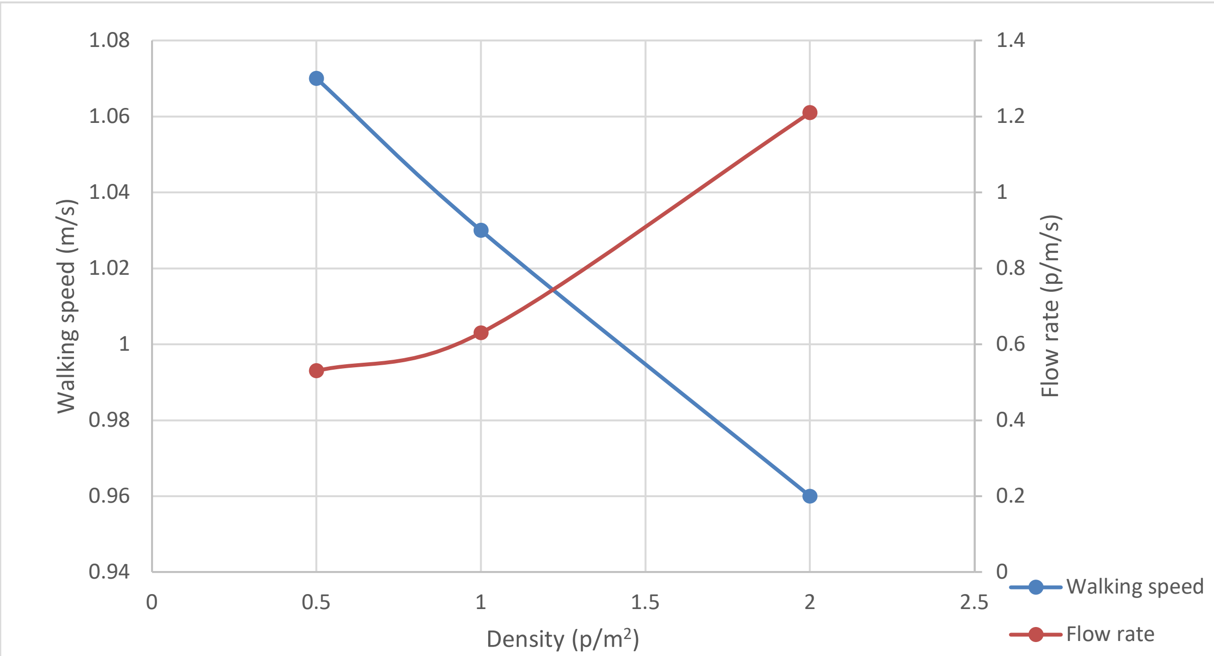

Figure 24 Representation of walking speed, density and flow rate

Test 14 – Group Behaviour

Evacuation models to represent group behaviour shall be verified. The difference of the evacuation time between the first and last occupant of the group 1 should be less than 10 s.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

To represent the feature of group behaviour the input log file uses ‘**enz_group**’ for the specified group and different start distances to the agents.

2. Geometry

This test was illustrated as in the Figure 25.

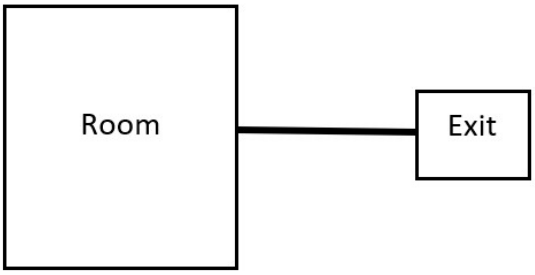

Figure 25 Geometrical representation of Test 14 in form of node system

3. Scenario configuration

- **Case 1**- 4 Agents were assigned a walking speed of 1.25 m/s while 1 agent with a walking speed of 0.5 m/s in Group 1. All agents were assigned as a group together using feature named known as ‘**enz_group’** in the populate file. Agents in Group 2 were at a constant unimpeded walking speed of 0.2 m/s.
- **Case 2**- As descripted in the test scenario in group 1, one agent has speed of 0.5 m/s and other 4 agents have speed of 1.25 m/s. Its normal scenario without any group behaviour influence.

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

No

Results

Case 1- 1 agent from group 1 reaches exit at 23 s while the last agent from group 1 reaches in 28 s. Hence the time difference was less than 10 s. The agents in the group 1 were moving at the slowest speed of the agent of the group.

Case 2 – In this case the agents of group 1 there was a high difference of 24 s between the first and last agent to reach the exit.

Hence, group behaviour was observed in the scenario 1 where the '**enz_group'** feature was implemented the difference between the evacuation time reaching the first agent and the last agent was less 10 s of group 1. It shows the expected result as mentioned in the ISO document.

<u>Test 15 – Social influence on exit choice</u>

The test depicts the concept of social influence for one agent by another agent.

1. Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[**x**] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

In exit behaviour input file, the behaviour was inserted to check the social influence of the agents.

2. Geometry

This test was illustrated as in the Figure 26.

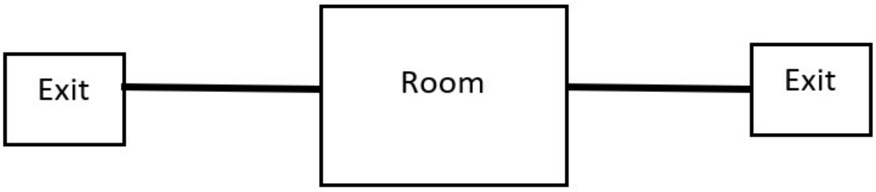

Figure 26 Geometrical representation of Test 15 in form of node system

3. Scenario configuration

2 scenarios are considered for this test.

Scenario 1: Single occupant with a pre-evacuation time of 0 s and walking speed of 1 m/s. Exit behaviour of the agent is assigned as enz_random in the exit behaviour input file.

Scenario 2: 2 occupants are considered with the same characteristics as mentioned in scenario 1. The first agent is placed 1 m away from the wall and the second agent is placed 2 m away from the wall.

4. How have the behaviours been represented?

[ ] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[**x**] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

Scenario 1: In the *exit behaviour input file*, the single occupant is assigned with '**enz_random**'.

Scenario 2: In the agent input file, second agent is assigned with special attribute as '**Attribute type="enz_leader" '**.In the *exit behaviour input file*, first occupant is assigned with '**enz_follow_any_leader'** and second occupant is assigned with '**enz_min_distance_to_specified**'.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

Yes, 100 simulations were run to see the agent exit choice for both scenario each.

7. Did you repeat the test to study the different configurations of this test?

No

8. Result

Exit usage of the agent 1 for both scenarios:

Scenario 1: Average usage of exit 1 - 49 %

Average usage of exit 2 - 51 %

Scenario 2: Average usage of exit 1 - 0 %

Average usage of exit 2 - 100 %

In every simulation run of scenario 2, agent 1 was following agent 2 hence using exit 2.

<u>**Test 16 - Affiliation to familiar exits**</u>

Evacuation model shall be verified to behaviour of the agent based on the concept of affiliation (Sime, 1985).

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[**x**] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

2. Geometry

This test was illustrated as in the Figure 27.

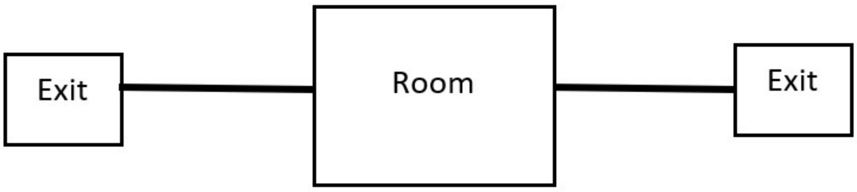

Figure 27 Geometrical representation of Test 16 in form of node system

3. Scenario configuration

Room node of dimension 15 m x 10 m is considered with 2 exit nodes.

2 scenarios are considered for this test:

Scenario 1: Single occupant with a pre-evacuation time of 0 s and walking speed of 1 m/s.

Scenario 2: Single occupant is considered with the same characteristics as mentioned in scenario 1. The agent is placed in the center of the room.

4. How have the behaviours been represented?

[ ] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[**x**] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

Scenario 1: In the *exit behaviour input file*, the single occupant is assigned with '**enz_random**'. This input line indicates that the software provides the occupant with the option of randomly selecting a safe node.

Scenario 2: In the *exit behaviour input file*, the single occupant is assigned with '**enz_preferred**' for exit 2. This input line represents the specify an exit to the occupant.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

Yes, 100 simulations were run to see the agent exit choice for both scenario each.

7. Did you repeat the test to study the different configurations of this test?

No

8. Results

Results obtained for 100 simulations run:

Exit usage of the agent 1 for both scenarios:

Scenario 1: Average usage of exit 1 - 51 %

Average usage of exit 2 - 49 %

Scenario 2: Average usage of exit 1 - 44 %

Average usage of exit 2 - 56 %

Hence it was noted that the exit usage of exit 2 increase from 49 % to 56 %.

Test 17 — Route choice based on geometric layout

This test verifies the where the occupant will choose a longer route or short route in same horizontal level or different floor level.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[**x**] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

2. Geometry

This test was illustrated as in the Figure 28.

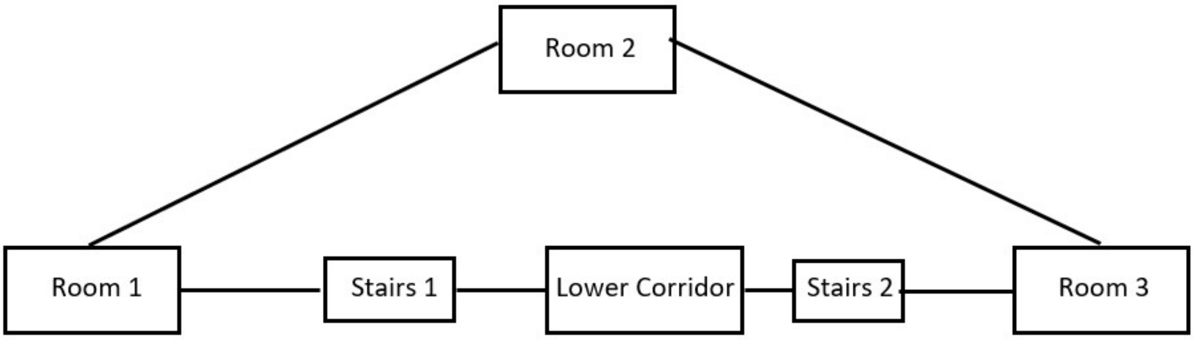

Figure 28 Geometrical representation of Test 17 in form of node system

3. Scenario configuration

3 nodes represented as the corridor on the upper floor, 2 nodes represented as stairs, 1 nodes as lower floor corridor and safe node as the exit node.

4. How have the behaviours been represented?

[ ] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[**x**] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

One occupant was represented in this scenario. The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

5. Has the model tester performed a blind or open calculation?

[ ] Blind

[**x**] Open

6. Did you run multiple simulations of the same scenario to produce the results?

50 simulation runs were performed to observe the result.

7. Did you repeat the test to study the different configurations of this test?

No

8. Results

It was noted that single occupant was always choosing the shorter route to exit which was corridor 1 to staircase 1 and then lower floor corridor in all the 50 simulation runs.

<u>Test 18 — Reduced visibility vs walking speed</u>

This test depicts the impact of the smoke on the walking speed of agent in the room.

1.Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[**x**] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[ ] No, this feature/behaviour cannot be represented

The map file was modified to represent the impact of the smoke on the agents walking speed as follows :

<Smoke>

<Time>0,60</Time> *< !--specifies time after which node get filled with smoke, for example here smoke starts after 60 s -->*

<Density model='enz_jin' type='enz_extinction' kind='enz_irritant'>0.5,0.0</Density> *< !-- specifics the smoke coefficient-- >*

</Smoke>

The software uses Jin's curve for the smoke as per software guide. Walking speed of the agent depends on the extinction coefficient and time representation of the smoke used for the input values.

2. Geometry

This test was illustrated as in the Figure 29.

Figure 29 Geometrical representation of Test 18 in form of node system

3. Scenario configuration

A corridor of dimension 100 m by 2 m was considered with a 1m wide exit. An occupant with unimpeded walking speed of 1.25 m/s. In this test irritant smoke started to be present after 60 s.

Following scenarios are considered as sub models:

Table 8 Scenario with extinction coefficient and walking speed

Scenario	Extinction Coefficient $(1/m)$	Walking Speed (m/s)
Main Scenario	1	1.25
1	3	1
2	0.5	1
3	3	0.75
4	0.5	0.75

4. How have the behaviours been represented?

[**x**] Explicitly: the model has a dedicated option to configure the relevant population characteristics and response for this scenario

[ ] Implicitly: the model does not include a dedicated option to configure all characteristics of people for this scenario, but it allows the representation of the variable(s) using other model features.

The **'enz_min_distance_to_safe'** exit behaviour type is used in this test to assign agents to the shortest total travel path to the safe node.

5. Has the model tester performed a blind or open calculation?

[**x**] Blind

[ ] Open

6. Did you run multiple simulations of the same scenario to produce the results?

No

7. Did you repeat the test to study the different configurations of this test?

Yes, as previously stated, there are 5 scenarios considered to observe the agent's evacuation time.

8. Results

As the extinction coefficient increases, the walking speed decrease hence evacuation time increases. Evacuation time without smoke was noted as 82 s. From the table, extinction coefficient increases evacuation time increase and walking speed decreases. The evacuation value is the same for irritant smoke with an extinction coefficient greater than 1 /m.

Table 9 Evacuation results of each scenario

Scenario	Extinction Coefficient (1/m)	Walking Speed (m/s)	Evacuation time (s)
Main Scenario	1	1.25	322
1	10	1	441
2	7.5	1	441
3	3	1	441
4	0.5	1	377
5	10	0.75	508
6	7.5	0.75	508
7	3	0.75	508
8	0.5	0.75	444
9	10	0.5	640
10	7.5	0.5	640
11	3	0.5	640
12	0.5	0.5	577
13	10	0.25	-
14	7.5	0.25	1039
15	3	0.25	1039
16	0.5	0.25	975

Hand calculation was used to compare with results obtained from the model. The Jin's curve and equation $V^s_i = v^0_i \times c(K_s)$ (Ronchi, Gwynne, et al., 2013) were used for the hand calculation.

Table 10 Evacuation time analysis with hand calculation

Scenario	Extinction Coefficient (1/m)	Assigned Walking Speed (m/s)	Evacuation Time (s)	Reduced Walking speed (m/s)	Hand calculation (m/s)	Difference (%)
Main Scenario	1	1.25	141	1.06	1.15	8.00
1	3	1	210	0.71	0.723	1.80
2	0.5	1	194	0.77	0.78	1.20
3	3	0.75	260	0.57	0.564	1.05
4	0.5	0.75	244	0.61	0.62	1.62
5	3	0.5	360	0.41	0.415	1.20
6	0.5	0.5	344	0.43	0.435	1.15

Test 19 — Occupant incapacitation by Fire/Smoke

Occupant incapacitation due to fire/smoke to be verified in the model. Incapacitation due to smoke to be presented using Fractional Effective Dose (FED).

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[**x**] No, this feature/behaviour cannot be represented

Test 20 — Lift usage

To verify the model's representation of elevators for occupant evacuation.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[**x**] No, this feature/behaviour cannot be represented

Test 21 — Escalator usage

To verify model's representation of escalators for evacuation of occupants.

Does the model include a sub-model capable of representing the feature/behaviour included in the test?

[ ] Yes, feature/behaviour explicitly represented

[ ] Yes, feature/behaviour implicitly represented

[ ] Partially

[**x**] No, this feature/behaviour cannot be represented

9. Discussion

Evacuation modelling is important for the performance-based design to calculate the RSET. There are many evacuation models in the market such as Pathfinder (Thunderhead Engineering, 2021), Massmotion (Massmotion, 2019) , Simulex (Simulex, 2015), FDS+Evac (Korhonen & Hostikka, 2010), buildingExodus (Galea et al., 2017), SimWalk (Simwalk, 2017), etc. The different network models such as coarse, fine, continuous and hybrid network model will be tested differently given their capabilities. Given the presence of a large number of software in the market, the verification of these models is important. As, the user will be unable to determine whether the software's results are accurate or not unless the software has been previously verified. Commonly, the verification is performed by using various standard test procedures such as IMO (IMO, 2016), RiMEA (RiMEA, 2016), NIST (Ronchi, Kuligowski, et al., 2013) and ISO (ISO, 2020). The ways in which these test methods were used differed. For example, the IMO test is used in marine applications, whereas the RiMEA test procedure was developed for buildings while taking human behaviour into account. NIST developed a test procedure for future improvement that focuses on the occupant evacuation in a fire situation. In this study, a procedure based on ISO:201414 was adopted for verification.

The main goal of this thesis was to run a verification test procedure for a coarse network model. Evacuationz software (Spearpoint, 2013), which is a coarse network model, was chosen for this purpose. The advantage of using this software includes a shorter simulation time when compared to fine network models, continuous models, and hybrid models. Moreover, the software input is completely user-defined, and the results are dependent on the user's competency to set up the inputs accurately.

This thesis aims to answer the following research questions:

1) Is the ISO 20414 standard suitable for testing coarse network models (such as Evacuationz), or is there a need for a different testing procedure?
2) Does the Evacuationz software as a coarse network model meet the requirements of the verification test procedure presented in the ISO 20414 standard?

Out of the 21 verification tests, 17 were carried out. The remaining four tests have not been discussed in the thesis (as they were not conducted). The verification tests yielded following results:

In **Test 1**, the normal and uniform distributions of pre-evacuation time were used to verify the distribution. This model can use also other distributions such as Log-normal, Triangular, Weibull, (including truncated distributions). Due, to time constraints, only normal and uniform distributions were tested. A similar approach can be adopted to verify other distributions as well. To get more datapoints, the room size (considering a change compared to the original ISO test) was increased to 1000 m x 1000 m with 1000 occupants, which now resulted in 1000 data points.

From scenario 1 representing the uniform distribution, it was concluded that the model represents the uniform distribution accurately. In scenario 2, result was truncated (the data was self-truncated by the software); thus the complete normal distribution did not appear. Distribution was also tested in Test 5 but yielded the expected results.

Test 2 was used to verify that the assigned walking speed in the horizontal plane is maintained over the entire distance. The results were consistent across all runs. The evacuation time for the agent traveling in a 40 m corridor using the model was 41 s. However, the ISO standard, anticipated the time of 40 s, as it does not assume acceleration. The 1 s difference was caused due to the agent's transition time as it was moving between the corridor node and the exit node. Defining an exit or safe node in the model is critical; otherwise, the model will fail to run. Also, the simulation's time step was changed to observe changes in evacuation time. According to Table 2, the evacuation time can be affected using change in the time step in the simulation input file. It was seen that the evacuation time decreased as the time step decreased. Therefore, the evacuation model can demonstrate the consistency of assigned walking speed in a horizontal plane, but it is slightly sensible to time-step changes.

Test 3 was used to verify the walking speed on stairs using the evacuation model. Since the input variables were the same as in test 2, only one simulation run was required. Apart from that only straight stair was considered for testing because unconventional stairs such as spiral stairs and curved stairs were not currently represented explicitly in this model. Additional parameters such as stair thread and width were defined by the author. The evacuation time for the agent climbing 10 m of stairs using the model was 12 s, which was 2 s more than expected results mentioned in the ISO standard. The extra time is seen due to the transition of the occupants between the nodes (Spearpoint, 2016). The model requires an unimpeded walking speed to be assigned and then modifies speed based on the SFPE equations (Steven M.V. Gwynne and Eric R. Rosenbaum, 2016). Furthermore, in this model, it makes no difference whether the staircase is ascending or descending because the outcome is always the same (the model is currently developed mostly for descending evacuation). As a result, the stair movement was interpreted as downwards. Hence, the model can be considered to have correctly implemented the assigned walking speed.

Test 4 was used to track occupant motion in a corner. It was employed to make sure that agents could navigate corners without penetrating the walls. As in coarse network models corner cannot be represented explicitly, the alternative way of modelling corners with a network was performed as shown in Figure 9. This test showed that the occupants can only travel within the nodes and cannot penetrate the boundaries in any condition.

Test 5 was conducted to show the walking speed distribution which was used to see the occupant demographics. Similar to test 1, only uniform and normal distribution was used in this test. 10 simulation runs were performed to obtain 1000 datapoints as in each simulation 100 agents were present. From scenario 1 representing the uniform distribution it was concluded that model represents the distribution accurately. The test was also done for scenario 2, which represents the normal distribution as shown in Figure 12, indicating that the data was correctly distributed.

In Test 6, a horizontal counter flow test was performed with this network model. Horizontal counterflow occurs when a single or group of agents move towards exit while some occupant moves in the opposite direction. It is used to demonstrate the effect of occupants fleeing and passing by firefighters or other emergency responders moving towards the emergency such as fire and smoke. It was important to specify the exits for both the occupant groups (occupants of room 1 and room 3). The result showed that, as the number of agents were increasing in the counterflow the evacuation time was not increasing simultaneously in each scenario. Therefore, expected results of ISO standard were not matching the results from the experiment. Hence it was concluded that the counterflow cannot be performed with the current version of the software.

Test 7 was used to verify the impact of a disabled occupant on the other occupants. Three scenarios were performed to check the disabled occupant effect on the other occupants. The evacuation time was noted for all scenarios and the results showed that it took more time to evacuate with disabled occupants. By observing the agent log file, it was concluded that due to slow movement of disabled occupants the evacuation time was increasing but there was no effect due to the agent on the other occupants. Another scenario was conducted to verify the evacuation time, if only one disabled agent was present in the room. It took more evacuation time as compared to other scenarios. Hence, according to the test conducted the result showed that in this test it does not show temporary blockage due to disabled occupants. The model though produced the expected results as stated in the ISO standard, namely that scenario 1 must have a slower evacuation time than scenario 2.

Test 8 was used to verify the ability of the model to assign occupants to the assigned exits. Each room was represented as node and corridor and was split in 2 nodes to make it easier for author to perform this test. As the variable inputs did not change, therefore a single simulation run was performed. The occupants travelled to their assigned exits; the results of this model were satisfactory. The agent log file was used to analyze and monitor the movement of each agent. It demonstrated that the software could direct the occupant to specific exits. As a result, route selection allocation within the evacuation model works as intended.

Test 10 was performed to verify the congestion at the front of the flight of the stairs. Just like test 3 stairs was interpreted as downward movement. The ISO standard called for 150 occupants for this test; however, due to the room's inability to accommodate 150 occupants, only 110 were observed in the test results. This is due to the node's default maximum occupant load of 2.75 agents/m^2. In this model congestion in stair was noted, but due to lack of visual results it cannot be confirmed that congestion is at the flight of the staircase. However, using the graphical representation as shown in Figure 18 made using the output got from node output file. It was observed that the number of agents on the stair did not increase over a certain period. So, it can be noted that between 35 s to 70 s there was a stagnation line. Hence, it can be concluded that the software produces congestion in the staircase.

In **Test 11**, the maximum flow rate at the exit was determined. Two scenarios were considered based on the software ability. In scenario 1, the start distance for each agent was used as the minimum distance to exit, whereas in scenario 2, agents were assigned randomly in the room. The maximum flow rate in scenario 1 was found to be close to the software's default maximum flow rate of 1.33 p/m/s. The model works as intended for the scenario with the shortest start distance, but the scenario with the longest start distance has a maximum flow rate greater than 1.33 p/m/s, a difference of 6%. The approximation in terms of time intervals used in calculating the flow are likely to have impacted those results.

Test 12 represents the flow rate in the stairs. In this test the downward movement in stairs was considered. To represent it five scenarios were conducted (representing increase of stairs width 1 m, 1.2 m, 1.4 m, 1.6 m and 1.8 m respectively). The average flow rate of occupants in the stairs increases with the width of the exit, indicating that the impact of stair width was observed. As a result, the expected ISO standard result was noted.

Test 13 checked if the model can represent uni-directional flows. It was used to verify the relationship between flow rate, walking speed and densities. Five scenarios are created, each with a population density of 0.5 p/m^2, 1 p/m^2, 2 p/m^2, 3 p/m^2, and 4 p/m^2. The test was divided into steps. In step 1, the last agent situated at point A was identified in accordance with ISO standards, and the walking speed for each scenario was recorded. Figure 23, depicts the last agent moving from point A to point B. As the occupants in scenarios 4 and 5 exceeded the model's maximum density of 2.75 m^2, the results of occupants in these scenarios were not observed. As shown in Table 6, it was concluded that the agent's evacuation time increased as the density of occupants in the nodes increased. Step 2 involved determining the occupant flow rate in relation to walking speed and density. As per Table 7, the flow rate was observed to increase with increasing population density, whereas walking speed decreased with increasing population density. The graphical representation of this test did not completely show the parabolic line graph as mentioned in SFPE handbook (Steven M.V. Gwynne and Eric R. Rosenbaum, 2016) as the maximum density is not reached due to the maximum allowed density in the model.

Test 14 was performed to verify the group behaviour in the model. This was conducted using the group behaviour function where the occupants were travelling with the speed of the slowest agent in the group. Results showed that the model can represent group cohesion using the group behaviour feature mentioned in the test.

Test 15 was used to evaluate the representation of social influence of one agent on another one. It was considered in two ways. As expected, throughout the simulation, agent 1 followed the other agent towards exit 2. As a result, this network model represents social influence behaviour as expected.

Test 16 was used to verify the representation of the theory of affiliation. Affiliation to familiar exit was noted as there was increase of usage of the preferred exit. Hence, it can be proved from the results that the affiliation can be performed using this model.

In **Test 17**, occupants were given the option of choosing between a horizontal component and a vertical component to exit, given that the occupant must always choose the shorter distance to evacuate. As the model cannot create corner geometry this test was performed implicitly, as shown in Figure 28. Following the test, it was shown that the occupants always choose the shortest distance, even if one of the vertical components is shorter than the other. As a result, the expected ISO standard result for this test was obtained.

Test 18 shows the walking speed reduction due to the introduction of smoke to the occupant. It was seen that as the extinction coefficient increases then the evacuation time also increases and the speed decreases. In this model evacuation time is highly influenced by the smoke duration in the room. So, the test results are influenced with the duration of the smoke in room mentioned by the user. There was not much of a difference between the results of the test and manual calculation. Also, it is concluded from the calculation and test results that for the extinction coefficients 1 and 0.5 there is not much wide difference between the manual calculated and test results. Further research is needed to observe the movement of the occupant in the smoke.

Table 11 shows whether tests are capable to be represented explicitly or implicitly, and whether the calculation is open or blind.

Table 11 Representation of the behaviour and calculation used

Test	Explicitly/Implicitly	Open /Blind Calculation
Test 1	Explicitly	Open
Test 2	Explicitly	Open
Test 3	Explicitly	Open
Test 4	Implicitly	Blind
Test 5	Explicitly	Open
Test 6	Implicitly	Open
Test 7	Implicitly	Open
Test 8	Explicitly	Open
Test 10	Explicitly	Open
Test 11	Explicitly	Open
Test 12	Implicitly	Open
Test 13	Implicitly	Open
Test 14	Explicitly	Open
Test 15	Implicitly	Open
Test 16	Implicitly	Open
Test 17	Implicitly	Open
Test 18	Explicitly	Blind

As a result, it should be noted that since most of the inputs in this software are user-defined, it is critical that the user understands human behaviour as well as evacuation calculations. Understanding the input features is required in order to represent desired evacuation behavior/scenarios. In *the agent and exit behaviour input files*, various features for each agent had to be set.

The author was not able to perform the following tests:

Test 9 represents the model's ability to prevent dynamically the usage an exit. It is assumed to depict a scenario in which the exit is blocked due to fire and smoke at a given point in time, forcing the occupants to choose another exit to escape from the room. The current version of the software does not have the capability of disabling an exit.

Test 19 indicates that the occupants are incapacitated due to an untenable condition, such as the effect of smoke or fire. Fractional Effective Dose (FED) calculations are used to validate the results. Unfortunately, this software lacks the capability to display hazardous conditions such as exposure to physical hazards or toxic substances, thermal radiation, and so on, which the author was unable to perform. If there is smoke present, the software can only show that the occupants will be trapped in the premises.

Tests 20 and **Test 21** represent the ability to validate certain evacuation components in the evacuation model used in modern buildings, such as an escalator and a lift. Unfortunately, the test cannot be carried out explicitly with the current version of the software because it lacks those features.

Based on the testing procedure conducted, it can be concluded that the ISO20414 has been proven to be a useful tool also to test coarse network models. According to the test procedure performed, the verification tests specified in the standard are appropriate for coarse network models. From the above explanation, it can be noted that the basic components such as (test 1-13), Behavioral components (test 14-17), Fire-people interaction components (test 18-19) and building- specific components (test 20-21) were performed to see the ability of the model. The basic components are simple to perform, and the desired results were obtained. The test results for behavioural components were also satisfactory. The occupant's walking speed decreased as the smoke coefficient increased, so the fire-people interaction component can be performed using this model, but the occupant's incapacitation was not verified, so it must be included in future software upgrades. Unfortunately, due to model limitations, tests of building-specific components were not performed; however, this can be improved in a future version of the software. The developer can include software features and fix test-related issues in the model where the test failed or was not run using the model. In a few tests, identifying accurate positions of the node's occupants was difficult due to a lack of visual results in the model. Only occupant movement from one node to another or from one node to a safe node can be tracked. According to the ISO standard, expected results were broadly similar to model test results. As a result, it was discovered that an ISO standard verification test can be performed on a coarse network model.

There are a few key points that will be important in the future testing of the model. Due to time constraints, validation testing was not carried out. However, future research should be conducted on the coarse network model using validation testing (e.g., using the tests suggested in ISO 20414) to ensure its applicability to real-world scenarios. Furthermore, while the graphical representation using yED software was not used in this study, it may be useful in future studies. According, to the software's current status, when there are errors in the input files, the simulation is not working. To fix this issue, errors must be more explicitly accessible in the log file itself so that they can be identified quickly. For the test representing the stairs, future stairs feature should consider upward movement explicitly and possibly specific stair configurations (such as spiral stairs). Feature, such as horizontal counterflow should be added to the software to improve its applicability for scenarios including the rescue service in evacuation. Parameters such as FED or toxicity should be included for checking occupant incapacitation. To address modern evacuation issues, modern building components such as a ramps, elevators, and escalators must be incorporated explicitly. Those features can be utilized for instance to analyze high-rise building evacuations. The model should also address the current cap on maximum allowed densities in order to allow for the representation of highly congested scenarios.

Future improvements of the ISO test procedure should consider explicitly the case of models which have a cap in maximum allowed densities, i.e., how a tester should consider scenarios with models that cannot represent explicitly high-density scenarios. The description of tests 4 and 17 could be improved to be made clear (the figures can be misleading due to the numbering in connection to the room number provided).

10. Conclusion

Performance based design has increased the usage of evacuation models. For this reason, their correct implementation is important to ensure model reliability. Verification testing is required to increase trust in the use of evacuation modelling tools. There are several verification test procedures available in the literature and the ISO 20414 standard is presently the most updated version. The goal of this thesis was to use the ISO 20414 verification testing procedure to perform verification tests on a coarse network model called Evacuationz.

A total of 17 tests were successfully conducted out of 21 verification tests. Out of those tests, 16 tests had given the expected test result. The Evacuationz software was not able to perform a test on dynamic exit availability, incapacitation of occupants and showing modern evacuation features such as lift and escalator. Those features should be considered in future developments of the model.

It can be concluded that the ISO 20414:2020 standard can be adopted for coarse network model such as Evacuationz for software verification. The use of coarse network models relies significantly on user expertise. Therefore, it is important that model testers must be well-versed with all aspects of the model in order to obtain accurate results.

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12. Bibliography

Cuesta, A., Abreu, O., & Alvear, D. (2016). Evacuation modelling trends. In *Evacuation Modelling Trends*. https://doi.org/10.1007/978-3-319-20708-7

Deutsch, M., & Gerard, H. B. (1955). A study of normative and informational social influence upon individual judgement. Journal of Abnormal and. *Social Psychology*, *51*, 629–636.

Fisher, R. A. (1990). Introduction to " The Arrangement of Field Experiments " Introduction to " The Arrangement of Field Experiments ". *Methods*, *253*, 83–94.

Galea, E. R., Lawrence, P. J., Gwynne, S., Filippidis, L., Blackshields, D., & Cooney, D. (2017). *buildingExodus User Guide*. 528.

Gottuk, D., Hall, J. R., Harada, K., Kuligowski, E., Puchovsky, M., Torero, J., Jr, J. M. W., & Wieczorek, C. (2016). *2016_Book_SFPEHandbookOfFireProtectionEngineering*.

Hurley, M. J., & Rosenbaum, E. R. (2015). Performance-based fire safety design. In *Performance-Based Fire Safety Design*. https://doi.org/10.1201/b18375

IMO. (2007). Guidelines for evacuation analysis for new and existing passenger ships, *E MSC.1/Circ.1226*. 1–31.

IMO. (2016). Revised guidelines on evacuation analysis for new and existing passanger ships. *International Maritime Organization*, *MSC.1/Circ*(May 2016).

ISO. (2020). *BS ISO 20414 : 2020 BSI Standards Publication Fire safety engineering — Verification and validation protocol for building fire evacuation models*.

Kinsey, M. J. (2011). Vertical transport evacuation modelling. *University of Greenwich*, *September*. http://gala.gre.ac.uk/7786/

Korhonen, T., & Hostikka, S. (2010). *Fire Dynamics Simulator with Evacuation: FDS+Evac, Technical Reference and User's Guide (FDS 5.5.0, Evac 2.2.1)*.

Kuligowski, E. D., & Peacock, R. D. (2005). A Review of Building Evacuation Models. *National Institute of Standards and Technology*, 156.

Lovreglio, R., Ronchi, E., & Kinsey, M. J. (2020). An Online Survey of Pedestrian Evacuation Model Usage and Users. *Fire Technology*, *56*(3), 1133–1153. https://doi.org/10.1007/s10694-019-00923-8

Massmotion. (2019). *MassMotion*.

Pauls, J. L., Fruin, J. J., & Zupan, J. M. (2007). Minimum Stair Width for Evacuation, Overtaking Movement and Counterflow — Technical Bases and Suggestions for the Past, Present and Future. *Pedestrian and Evacuation Dynamics 2005*, 57–69. https://doi.org/10.1007/978-3-540-47064-9_5

Purser, D. (2003). Behaviour and travel interactions in emergency situations and data for engineering design. *2nd International Conference on Pedestrian and Evacuation Dynamics*, *August 2003*, 355–370.

RiMEA. (2016). *Guideline for Microscopic Evacuation Analysis*. *March*.

Ronchi, E., Gwynne, S. M. V., Purser, D. A., & Colonna, P. (2013). Representation of the Impact of Smoke on Agent Walking Speeds in Evacuation Models. *Fire Technology*, *49*(2), 411–431. https://doi.org/10.1007/s10694-012-0280-y

Ronchi, E., Kuligowski, E. D., Reneke, P. A., & Nilsson, D. (2013). *NIST Technical Note 1822 the process of verification and validation of building fire evacuation models*. 1–85.

Ronchi, E., Reneke, P. A., & Peacock, R. D. (2014). A Method for the Analysis of Behavioural Uncertainty in Evacuation Modelling. *Fire Technology*, *50*(6), 1545–1571. https://doi.org/10.1007/s10694-013-0352-7

Sime, 1985. (n.d.). *Movement towards the familiar person and place affiliation in a fire entrapment setting*.

Simulex. (2015). *Simulex User Guide*. 1–43.

Simwalk. (2017). *SimWalk User Guide*. https://www.simwalk.com/modules/simwalk_roadtraffic.html

Spearpoint, M. J. (2013). *EvacuatioNZ verification version 2.8*.

Spearpoint, M. J. (2016). *EvacuatioNZ verification version 2.11*.

Steven M.V. Gwynne and Eric R. Rosenbaum. (2016). Employing the Hydraulic Model in Assessing Emergency Movement. In *SFPE Handbook of Fire Protection Engineering* (5th ed., pp. 2115–2152). Springer.

Strömgren, M. (2018). *Performance-Based Design & Prescriptive Methods: It's Time to Work Hand in Hand*. Fire Safe Europe. https://firesafeeurope.eu/performance-based-design-prescriptive-methods/

Thunderhead Engineering. (2021). *Pathfinder Verification and validation guide*.

Tsai, W.-L. (2007). *Validation of EvacuatioNZ Model for High-Rise Building Analysis*.

V.M. Predtechenskii and A.I. Milinskii. (1969). *Planning for Foot Traffic Flow in Buildings*.

Wu, Y. (2019). *Testing the International Standards Organization Verification and Validation protocol for evacuation simulations-An application to the FDS+ Evac model*.