Verification Testing of MassMotion 11.8 for ISO 20414

Version 1
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Contents

List of Tables

List of Figures

1 Introduction

1.1 Context

MassMotion is a pedestrian dynamics and evacuation simulation software tool developed by Oasys (Ove Arup SYStems).

This report documents the verification testing of MassMotion for evacuation modelling. It has been developed by the Oasys MassMotion product team in association with Arup Fire engineers. It is intended to provide the reader with sufficient information to demonstrate that MassMotion is able to represent the key aspects of human behaviour during an evacuation event (to a level of accuracy which facilitates reasonable estimates of key predictive outputs typical of such models).

Verification is a continual process, particularly as understanding of human behaviour in fire increases (and, thus, evacuation data / models are enhanced). Verification is defined as whether a given conceptual model of a given system has been implemented correctly within calculation / algorithm. Validation is defined as whether the implemented conceptual model within a calculation / algorithm sufficiently represents the key aspects of reality / the system it is intended to represent. Verification should be considered relative to a given application which a computer simulation / modelling tool is being used. The verification process should comprise of successfully testing all parts and agent behaviours which are required to be represented for a given application.

To reference this document please use Verification Testing of MassMotion 11.8 Evacuation Modelling for ISO 20414:2020, Oasys, 2024.

1.2 Test Summary

The verification testing has been conducted to demonstrate that the theory is correctly implemented within MassMotion (and that the model results are in accordance with the inputs and the theory specification). The following document refers to tests performed in accordance with ISO 20414:2020 Fire safety engineering: Verification and validation protocol for building fire evacuation models. The full range of verification tests undertaken is presented in Table 1.

All the verification tests investigated passed the stated acceptance criteria. Results from the verification tests indicate that MassMotion is able to predict the expected results for those cases tested.

1.3 Automated Testing

In order to improve the efficiency, speed and consistency of testing, an automated test suite was produced. The following technologies are used:

- GitHub Actions Runner 2.303.0 - automated building and testing;
- Catch 2.2.2 - C++ unit testing framework; and
- pdfTex 1.40.19 - pdf report generation.

This report was computer generated following a successful run of automated testing.

ID	Title	Status
1	Pre-Evacuation time assignment	Pass
2	Walking speeds in a corridor	Pass
3	Walking speeds on stairs	Pass
4	Movement around a corner	Pass
5	Assigned occupant demographics	Pass
6	Counter-flows	Pass
7	People with movement disabilities	Pass
8	Exit route allocation	Pass
9	Dynamic availability of exists	Pass
10	Congestion in front of a flight of stairs	Pass
11	Maximum exit/door flow rates	Pass
12	Stair flow rates	Pass
13	Relationship between walking speed, unidirectional flow and density	Pass
14	Group behaviour	N/A
15	Social influence on exit choice	N/A
16	Affiliation to familiar exits	Pass
17	Route choice	Pass
18	Reduced visibility vs walking speed	N/A
19	Occupant incapacitation	N/A
20	Lift usage	Pass
21	Escalator usage	Pass

Table 1: Summary of MassMotion Verification Tests

2 MassMotion

2.1 Introduction

MassMotion is developed by Oasys Software Limited, a wholly owned subsidiary of Arup Group Limited. It is ISO9001-TickIT certified [9], indicating that it's development satisfies the international quality management system standards for software.

MassMotion is a pedestrian movement and evacuation simulation program. It features 3-dimensional environments, automatic agent way-finding and discrete event logic to model different types of scenarios. In the context of this document, it is intended to aid designers to make informed decisions about the evacuation planning and operation of complex facilities.

2.2 History

Table 2 documents the MassMotion version history.

Version	Build	Release Date
11.5	11.5.8.0	Feb-2023
11.0	11.0.9.1	Oct-2021
10.6	10.6.14.0	Sep-2020
10.5	10.5.8.0	Feb-2020
10.0	10.0.13.0	Jul-2019
9.5	9.5.0.15	Feb-2018
9.0	9.0.13.0	Mar-2017
8.5	8.5.2.0	Apr-2016
8.0	8.0.8.0	Jun-2015
7.0	7.0.5.0	Feb-2015
6.1	6.1.1.8	Oct-2014
5.5	5.5.0.2	May-2013
5.0	5.0.6.4	Sep-2013
4.5	–	Nov-2011
4.0	–	Apr-2011

Table 2: MassMotion Version History

This report is based on the latest version of MassMotion.

2.3 Geometrical Components

Within MassMotion, the physical environment is represented by a series of geometrical components. Table 3 lists the geometrical component types available.

Components	Description
Floors	Horizontal regions of the physical environment on which agents can walk. Agent movement is constrained by the boundaries of the floors.
Links	A physical horizontal connection where agents transition from one geometric component to another. A link can represent a doorway in the physical environment.
Stairs, Ramps and Escalators	A physical vertical connection where agents transition from a geometric component at one level to a geometric component at another level.
Portals (Entry and Exit)	Agents enter or exit a simulation through a portal (or an associated floor). Entry portals introduce agents to the model. Exit portals define the end goal of the agents.
Barriers and Obstacles	Barriers and obstacles restrict the movement of agents within the physical environment.
Server Processing	Define a one-way circulation element that may be precisely controlled. (Often utilised for passenger processing or security areas.)

Table 3: MassMotion Geometrical Component Types

2.4 Agents

Within MassMotion, agents are created at the start of a simulation through the use of entry portals. Agents do not occupy any space in a geometry prior to the start of a simulation. All agents are created over a given time period (minimum of 1second). Entry portals have the capability to create agents directly on the portal or randomly on the associated floor connected to the portal.

2.5 Agent Attributes

Agent attributes (see Table 5) are the parameters which define how the agent

- interacts with the geometry components,
- interacts with other agents, and
- makes decisions.

Agent attributes are mandatory: these are provided with default values or are assigned randomly from a uniform probability distribution (the limits of which are defined by minimum and maximum values).

2.6 Agent Route Selection

Agents are placed in the physical environment (defined by geometrical components) and are assigned goals (e.g. the need to evacuate via an exit portal). The behavioural profile of an agent compels it to make a series of choices and, subsequently, execute actions that will lead them to their goal.

Each agent:

- is provided with an origin and destination matrix at the outset of the simulation (i.e. the agent itinerary);
- makes a series of choices to arrive at their destination based on their itinerary and behaviour profile.

The route selection of an evacuating agent can be specified in two ways:

- Least Cost – Agents travel via the 'easiest' route. Agents are aware of all / some exit portals (at the start of the simulation and as exit portals become available / unavailable). The effort, or 'Cost', associated with each route (to an exit portal of which they are aware) is calculated for the agent at each time step. The agent will take the 'Least Cost' path to an exit portal.
- Specified Destination – An exit portal is specified for each agent. The agent will take the 'Least Cost' route to the specific exit portal.

Agents have the ability to recognise congestion. By default, agents are only aware of congestion in their local proximity and on the current floor object they are located on. They will consider alternative routes, based on their familiarity with the environment, adapting to current conditions.

MassMotion performs a dynamic calculation, at each time step for the duration of the simulation, throughout the model. Agents are able to adapt to their surroundings based on evolving situations (the dynamic availability / unavailability of exit portals for example) rather than being restricted by pre-defined agent parameters.

2.7 Agent Movement

Agents move through the physical environment. The speed at which an agent moves is a function of:

- the individual characteristics (e.g. preferred speed, radius, and route selection weighting) of the agent;
- the physical surroundings (e.g. spatial environment and the geometrical component on which the agent is located);
- the proximity of other agents.

The movement of agents through the model is a reflexive process implemented via a 'Social Forces' algorithm. At each time step, 'forces' act upon the agents causing them to move accordingly. The 'Social Forces' algorithm has been calibrated in accordance with Fruin's Level of Service model developed for pedestrian planning.

2.8 Comparison with Other Software Specifications

The National Institute of Standards and Technology, Technical Note 1680 [10], provides a standardised list of features for some of the most prominent evacuation models on the market. Table 4 reproduces part of this review for MassMotion, Simulex [11], STEPS [12], Legion [13] and buildingEXODUS [14].

	MassMotion	Simulex	STEPS	Legion	building EXODUS
Modelling Methodology	Behavioural	Partial Behavioural	Behavioural	Behavioural	Behavioural
Purpose	Any Building Type	Any Building Type	Any Building Type	Any Building Type	Any Building Type
Grid / Structure	Continuous	Continuous	Fine Node	Continuous	Fine Network
Perspective of Model / Occupant	Individual and Individual / Global	Individual	Individual	Individual	Individual
Behaviour	Artificial Intelligence / Probabilistic	Implicit	Conditional / Probabilistic	Artificial Intelligence / Probabilistic	Implicit
Movement	Conditional (Fruin Speed-Density)	Inter-person Distance (Fruin Speed Density)	Inter-person Distance / Emptiness of Next Grid Cell	Inter-person Distance / Conditional	Potential, Emptiness of Next Grid Cell
Route Choice	Conditional	Shortest / Altered Distance Map	Conditional	Conditional	Various
Validation	Codes / Drills / Literature / Other Models	Drills / Literature / Third Party	Drills / Validation Against Past Experiment Literature	Codes / Drills / Validation Against Past Experiment Literature / Third Party Validation	Drills / Literature / Other Models / Third Party

Table 4: Features of Evacuation Models

3 Theoretical Model Specification

3.1 Context

The data and underlying theories which MassMotion employs are those based on general human behaviour observed during circulation, i.e. they are not specific to / for evacuation. During an evacuation, it is commonly observed that both normalcy bias and optimism bias occur, i.e. people often think that they are not in danger and that nothing bad will happen to them [15]. As such, human behaviour during an evacuation and normal circulation are (generally) comparable. If the level of risk perceived by an individual increases, e.g. as a result of seeing fire / smoke within close proximity, then the individual is likely to adapt their behaviour according to the level of risk perceived.

With the exception of those within close proximity of fire / smoke, or for events where considerable fire / smoke spread occurs, the majority of people during an evacuation would not be directly exposed to, or be aware of, fire / smoke. The level of risk perceived by the majority of people during an actual evacuation is, therefore, likely to be low (without additional information being provided to indicate otherwise).

In addition, an evacuation modelling analysis would typically preclude the exposure of people / agents to fire / smoke as part of the acceptance criteria (with the understanding that those people / agents initially within close proximity to fire / smoke would move to an exit or protected area promptly).

The level of risk perceived by the majority of people / agents within a typical evacuation model is, therefore, likely to be low. Consequently, the underlying data and theories employed within MassMotion, though based on general human behaviour observed during circulation, are deemed appropriate for modelling human behaviour during an evacuation.

For specific engineering applications where it is likely that evacuees will experience a heightened level of perceived risk, the modeller should determine:

- the extent to which the underlying theories and data remain valid;
- whether alteration of the default configurable parameters (e.g. decreasing pre-evacuation times, increasing travel speeds) might yield more probable predictions.

MassMotion does not model external stimuli such as fire and smoke. To consider the stimuli upon the agents behaviour a user is required to configure the agents attributes to represent the stimuli's impact e.g. reducing the pre-movement times to reflect increase sense of urgency due to seeing fire/smoke.

3.2 Agent Motion

In MassMotion, agent motion is separated into an agent decision making process and an agent movement process:

- Agents are given a goal as defined by an event. The contemplative agent decision making process analyses distance, congestion, and terrains between the origins and destinations to develop route costs to the agent goals. This is used to select the most appropriate route for an agent inside the dynamically changing environment.

- The reflexive agent movement process (see Figure 1) governs an agents basic movements and responses to the environment, i.e. agents navigate through the environment avoiding obstructions and other agents.

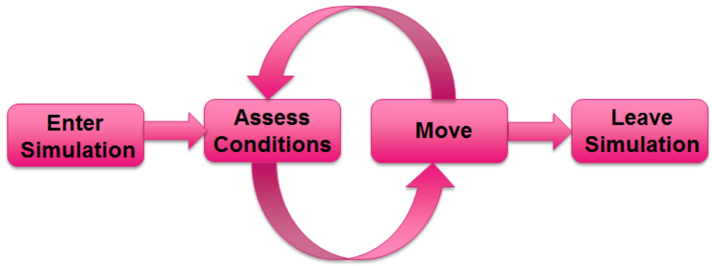

Figure 1: MassMotion Reflexive Movement Process

The following sub-sections outline the key functional components of MassMotion for evacuation modelling. A more detailed description of each component can be found in the MassMotion User Manual [1].

3.3 Agent Events

Once the MassMotion physical environment is defined (using the geometrical components), agent events are created to initiate, control or influence agent flow during a simulation.

Agent event properties include:

- **Origin** – The entry portal through which the agent enters the physical environment of the model.
- **Start Time** – The simulation time at which the evacuation is initiated.
- **Pre-movement Time** – The duration for which the agent is held at its initial location.
- **Destination** – The target or goal for an agent: either

  a specific exit portal in the physical environment, or

  the 'Least Cost' exit portal as determined (by MassMotion) dynamically.
- **Simulation Duration** – Duration of the simulation of the evacuation event.

Events can be specified to all agents, proportions of agents or individual agents, to better represent the evacuation scenario of interest. (Events may also be defined to represent the opening / closing of entry and exit portals.)

3.4 Agent Attributes

Within MassMotion, agents are assigned physical and behavioural attributes. The default physical, movement, and route choice attributes assigned to agents are outlined in Table 5. (Where a minimum and maximum value are stated, the attribute is assigned randomly from a uniform probability distribution between the defined values for each simulation.)

	Parameter	Default Data	Basis of Default Values
Movement	Body Radius(m)	0.25	Fruin [5][6] discusses a body ellipse of dimension 0.6m by 0.4m with an area of $0.2m^2$. A 0.25m radius circle yields an area that is nearly identical while being far more efficient in computing agent movements and interactions.
	Preferred Horizontal Terrain Walking Speed Distribution(m/s)	Minimum = 0.65 Maximum = 2.05 (Mean = 1.35 Standard Deviation = 0.25)	The default preferred horizontal terrain walking speed distribution range (0.65m/s to 2.05m/s – uniformly distributed) is based on Fruin's [5][6] observations of commuter speed profile for a range of ages and genders.
	Stair (Up – Stair Angle X) Impact on Agent Speed (% of Preferred Horizontal Terrain Walking Speed)	$(0^\circ < X < 27^\circ)$: 42.5 $(27^\circ \leq X \leq 32^\circ)$: 42.5 – 37.8 $(X > 32^\circ)$: 37.8	The default preferred stair walking speed distribution ranges is based on Fruin's [5][6] observations of commuter speed profile for a range of ages and genders. (Note: Linear interpolation is applied to the % of the preferred horizontal terrain walking speed for $27^\circ \leq X \leq 32^\circ$.)
	Stair (Down – Stair Angle X) Impact on Agent Speed (% of Preferred Horizontal Terrain Walking Speed)	$(0^\circ < X < 27^\circ)$: 57.4 $(27^\circ \leq X \leq 32^\circ)$: 57.4 – 49.8 $(X > 32^\circ)$: 49.8	
	Ramp (Up – Ramp Angle X) Impact on Agent Speed (% of Preferred Horizontal Terrain Walking Speed)	$(0^\circ < X < 5^\circ)$: 100 $(5^\circ \leq X \leq 10^\circ)$:88.5 $(10^\circ \leq X \leq 20^\circ)$:88.5-75.0 $(20^\circ < X)$:75.0	The default preferred ramp walking speed distribution ranges is based on a study referenced by Fruin [5][6] of controlled experiments of soldiers on a treadmill walking at varying inclines.
	Ramp (Down – Any Angle) Impact on Agent Speed (% of Preferred Horizontal Terrain Walking Speed)	100.0	
	Maximum Acceleration(m/s^2)	3.0	The default maximum acceleration, turning rate and shuffle factor is based on qualitative model observations and sensitivity analysis by Oasys.
	Maximum Turn Rate (degrees/s)	45.0	
	Shuffle Factor (% of Preferred Horizontal Terrain Walking Speed Below Which Agents can Shuffle in Any Direction)	0.1	

	Parameter	Default Data	Basis of Default Values
	Direction Bias	Direction: Keep Right Strength: Strong	The default direction bias is calibrated to yield crowd characteristics (in terms of flow and motion) that are consistent with Fruin's Levels of Service A to F [5][6]. The 'Keep Right' value was selected based on an observed preference (in a number of countries) to favour moving to the right when resolving movement conflict.
Route Choice	Horizontal Distance Cost (factor)	Minimum = 0.75 Maximum = 1.25	The underlying network route costs, that the agents respond to, are based on the costs for journey segments in the Transport for London, Business Case Development Manual [16]. The default variability ranges are intended to produce stochastic variation within a population where route options have very similar costs, without significantly altering the mean distribution of route choices.
	Vertical Distance Cost (factor)	Minimum = 0.75 Maximum = 1.25	
	Queue Cost (factor)	Minimum = 0.75 Maximum = 1.25	
	Processing Cost (factor)	Minimum = 0.75 Maximum = 1.25	

Table 5: Default Agent Attributes

The default agent attributes, indicated in Table 5, need not be assigned to an agent as user defined values may be specified. This allows the modeller to have additional control of the agent attributes within the evacuation model. In all cases, it is recommended that the modeller assess:

- the validity of the default agent attributes with respect to the evacuation scenario of interest;
- whether alternative values, drawn from appropriate published literature presenting reliable agent attribute data, are more appropriate.

All input data should be documented and justified within the documentation describing the scenario, data and simulation predictions for a given engineering application where an evacuation model is built.

In addition to these user configurable parameters, there are also a number of 'hard-coded' parameters which influence low level agent behaviour, e.g. parameters associated with the Social Forces model. Testing such parameters is beyond the scope of this document.

3.5 Agent Route Selection

MassMotion manages the complexity of the physical environment by automatically creating a network from the geometric components (Figure 2).

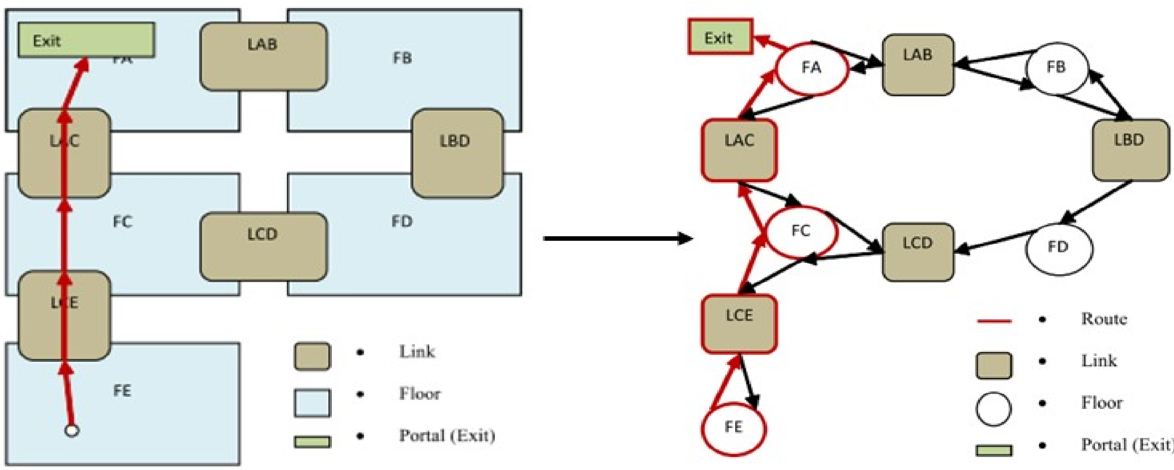

Figure 2: MassMotion Translation of a Floor / Link System into a Network

MassMotion manages these network assignments individually without the need for the modeller to manually create or maintain them.

The agent route selection process is based on the network.

An individual agent selects the route between the origin and destination points. The route selection within the network is based on the perceived costs of all the available routes that bring the agent to its ultimate goal without back-tracking.

Cost perception is the process by which an agent analyses the distance, congestion, and terrain type in order to assign costs to all the routes available to the agent. The most cost effective route is chosen. The total route cost (measured in time (seconds))

$$Cost = \left(W_D \times \left(\frac{D_G}{V}\right)\right) + (W_q \times Q) + (W_L \times L)$$

where:

$Cost$ = perceived total travel time along the route (s);

W_D = 'distance' weight (agent property) (-);

D_G = total distance from the agent position to the ultimate goal (m);

V = desired velocity of the agent (agent property) (m/s);

W_q = 'queue' weight (agent property) (-);

Q = expected time in queue before reaching link entrance (s);

W_L = 'geometric component traversal' weight (agent property) (-);

L = geometric component type cost (s).

The cost calculation is randomised (assigned different modifiers) slightly such that a statistically large population sample size with different behaviours is represented.

Flexibility within the MassMotion solution algorithm allows agents to modify their route selection dynamically (i.e. during the simulation) according to the local conditions.

3.6 Agent Movement

The MassMotion agent movement process includes spatial analysis, where each individual agent is aware of all walk-able surfaces of the physical environment (considering obstructions and other agents within their immediate vicinity). An agent is aware of all the complete paths between its location and its goal.

The preferred travel speed of an individual agent is a function of the terrain (or geometric component). The actual travel speed of the agent is also a function of the density of all the agents in the immediate vicinity of the agent, and is modified by MassMotion accordingly. (This represents the human preference to maintain a given spacing between persons according to the average speed at which they are moving).

The terrain, agent density and agent speed relationship is configured according to the work of Fruin [5][6] (Figure 3).

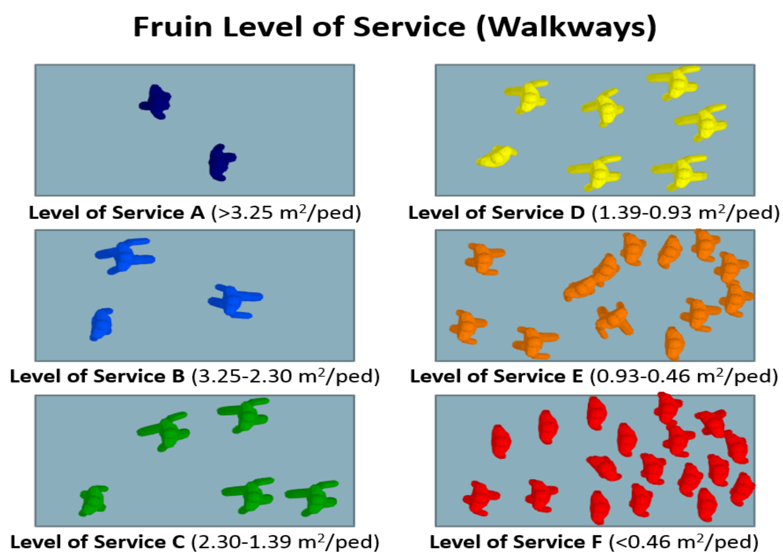

Figure 3: Illustration of Fruin 'Levels of Service (Walkways)'

The Fruin 'Levels of Service' are based on data (travel speeds) collected for different terrains in the New York Subway in the 1970s.

Fruin's work is widely cited in a number of evacuation modelling texts (e.g. IMO 1238 [7], SFPE Handbook [9] PD 7974-6 [10]), and used within in a number of evacuation models as default parameters (e.g. buildingEXODUS [8], Pathfinder [11]).

3.7 Social Forces

Within MassMotion, agents are capable of adjusting to dynamically changing conditions within the physical environment (e.g. avoiding obstructions and other agents) utilising a modified Social

Forces model [2][3][4].

The Social Forces model assumes that the motion of an agent can be predicted from the 'social forces' to which the agent is subject. These 'social forces' are a measure of the motivations of the agent to perform certain actions (movements) and comprise of:

- a term describing the acceleration / deceleration towards the desired velocity of motion;
- a term(s) describing the agents desire to maintain a preferred distance from the boundaries of geometric components and from other agents – 'repulsive forces';
- a term(s) describing the agents desire to achieve its goals – 'attractive forces'.

The resulting equations of motion are nonlinearly coupled Langevin equations [2][3].

A schematic representation of the process leading to behavioural change (i.e. modification of agent route choice and / or agent movement) is illustrated in Figure 4 [2][3].

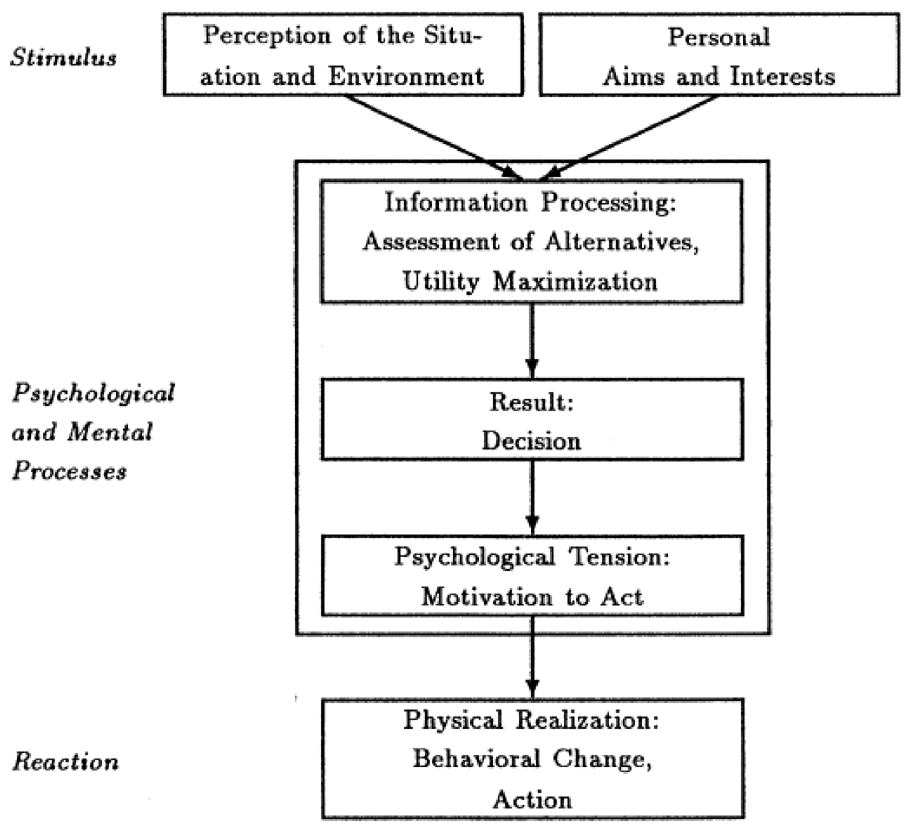

Figure 4: Schematic Representation of Processes Leading to Behavioural Changes

This proposes that a sensory stimulus (e.g. a change in the physical environment) causes a behavioural reaction (e.g. modification of the agent route selection and / or agent movement) that depends on the aims of the agent and is chosen from a set of alternatives with the objecting of utility maximisation (e.g. arriving at an exit portal in the shortest possible time).

Within MassMotion, the Social Forces algorithm generates a series of component forces (shown in Table 6) which are used to determine the movement of an agent (with varying influence according to the local environment).

Component Force	Colour	Description
Goal	Bright Green	Attractive force moving the agent towards its goal / target at the desired travel speed.
Neighbour	Bright Yellow	Repulsive force from each neighbouring agent (to maintain adequate separation between agents).
Drift	Purple	Repulsive force moving the agent in the direction of the preferred bias when faced with oncoming agents.
Collision Veer Force	Turquoise	Repulsive force to prevent anticipated collisions with a neighbouring agent.
Collision Yield Force	Orange	Repulsive force (and / or torque) causing the agent to slow down avoid a collision with a neighbouring agent.
Cohesion	White	Attractive force moving the agent towards the centroid of neighbouring agents with similar goals / targets.
Marshal / Orderly Queuing	Grey	Attractive force pushing the agent towards the middle of a goal / target when approaching.
Corner	Brown	Repulsive force enabling the agent to navigate a corner.
Panic	Pink	Strong force pulling the agent back to a walk-able surface (when the agent attempts to move outside the boundaries of the walk-able surface).
Obstacle(Constrained Net Force)	Blue	Resulting net force.
Obstacle(Constrained Velocity)	Black	Resulting velocity.

Table 6: Social Forces Model – Component Forces

Notes:

- ‘Obstacles’ do not generate a repulsive force: they are used to constrain other forces.
- When component forces are summed, the resulting net force is reduced such that it does not push the agent into a boundary.

Sources of Literature

MassMotion User Manual [1].

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PD 7974 The Application of Fire Safety Engineering Principles to Fire Safety Design of Buildings – Part 6: Human Factors: Life Safety Strategies – Occupant Evacuation Behaviour and Condition, British Standards Institute, 2004 [10].

Pathfinder Technical Reference, Thunderhead Engineering Consultants Inc., 2009 [11].

4 Test 1: Pre-evacuation time assignment

4.1 Objective

Assess consistency between user pre-evacuation time assignment and model representation.

4.2 Geometry

A room of size 8m by 5m with a 1m exit.

The MassMotion geometry, for each test case, consists of:

- two floors (8m x 5m) connected via a 1m wide link, and
- a portal on each floor representing where agents enter and exit simulation.

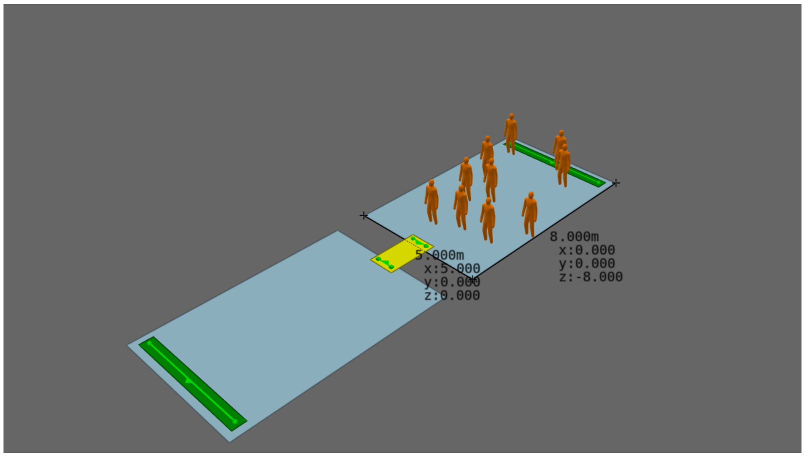


Figure 5: Test 1 Physical Environment

4.3 Scenario(s)

Ten occupants are randomly located in the room. Check the types of distributions used by the evacuation model to represent pre-evacuation times. Impose a pre-defined distribution (e.g.uniform, normal, log-normal, etc.) of pre-evacuation times in accordance with the input distributions provided within the evacuation model. Repeat the test for each distribution of pre-evacuation time embedded in the model.

4.4 Expected result

Verify that each occupant starts moving at the appropriate time and that the pre-evacuation of the population fall within the specified range.

4.5 Test method

The test method is a quantitative verification of the model assignment expressed in terms of pre-evacuation time. In relation to the type of distribution under consideration, the model tester should identify a suitable quantitative method to evaluate the differences among the simulated and assigned distributions.

4.6 User action

The entrance portal on the floor is set to distribute agents on the floor.

Table 7 shows distributions used to represent pre-evacuation times .

Distribution	Properties
Constant	Value = 10.00
Uniform	Min = 10.00 Max = 100.00
Triangular	Min = 10.00 Max = 100.00 Mode = 55.00
Normal	Min = 10.00 Max = 100.00 Mean = 55.00 Standard Deviation = 20.00
Log Normal	Shift = 10.00 Max = 100.00 Mu = 3.52 Sigma = 0.90

Table 7: Test 1 Pre-evacuation Time Distribution Summary

For each distribution type (constant, uniform, triangular, normal, and log normal), 50 simulations of 10 agents are run. An activity type based agent filter is used to determine the number of agents who are waiting according to their assigned pre-evacuation time at every step of the simulation.

4.7 Test Result

The results are summarized in Table 8.

Distribution	Minimum	Maximum	Average (Mean)	Standard Deviation
Constant	10.20	10.20	10.20	0.00
Uniform	10.40	100.00	54.20	26.75
Triangular	14.00	97.20	54.61	19.02
Normal	12.40	97.60	54.83	17.50
LogNormal	12.40	96.60	43.98	21.45

Table 8: Test 1 Distribution Results Summary

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

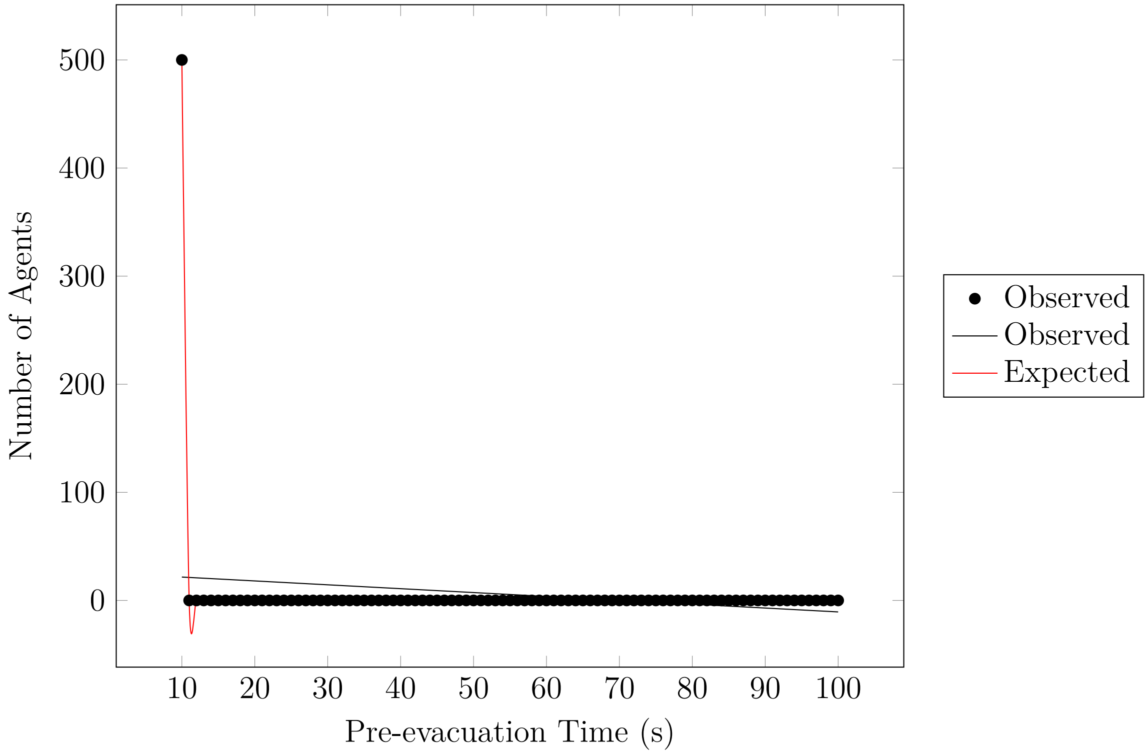


Figure 6: Test 1 Constant Distribution Histogram

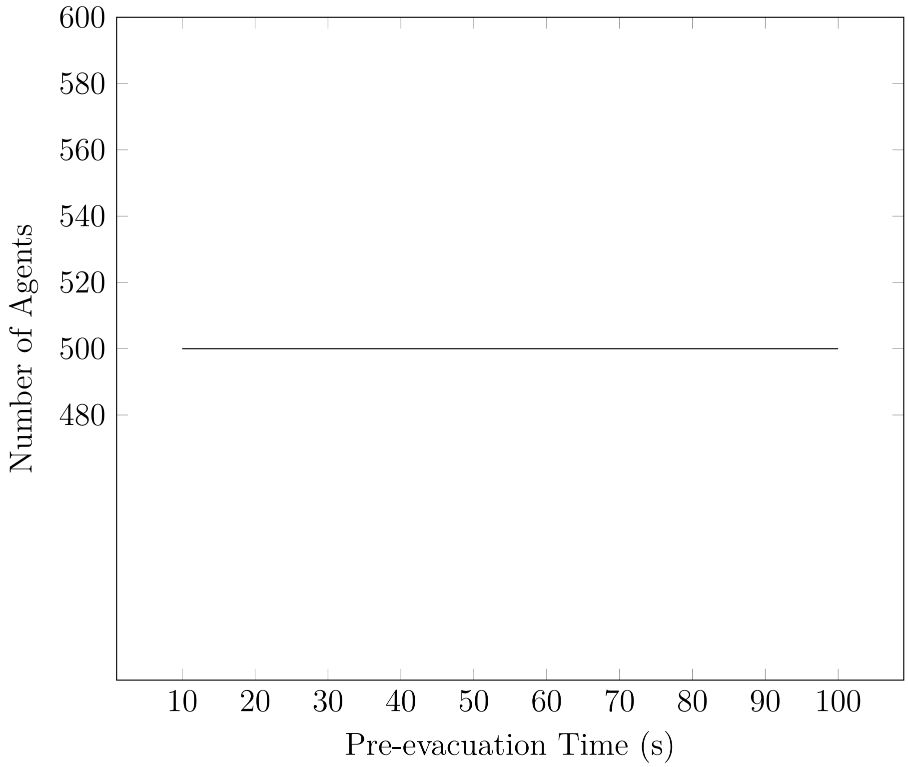


Figure 7: Test 1 Constant Distribution Cumulative Graph

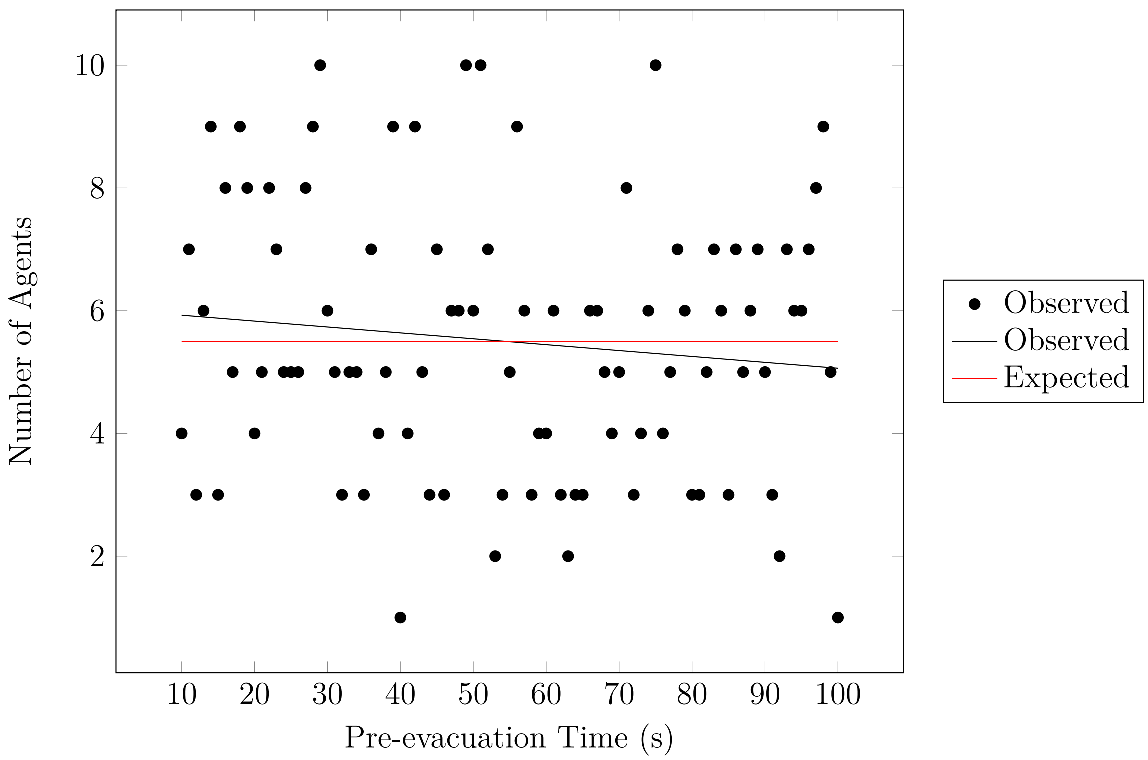


Figure 8: Test 1 Uniform Distribution Histogram

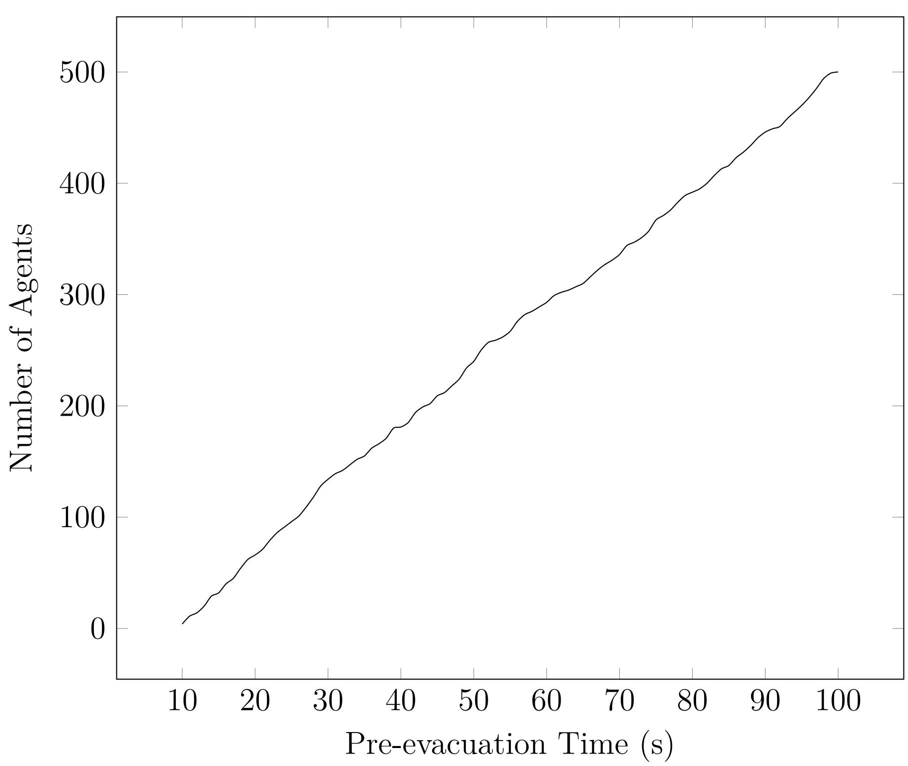


Figure 9: Test 1 Uniform Distribution Cumulative Graph

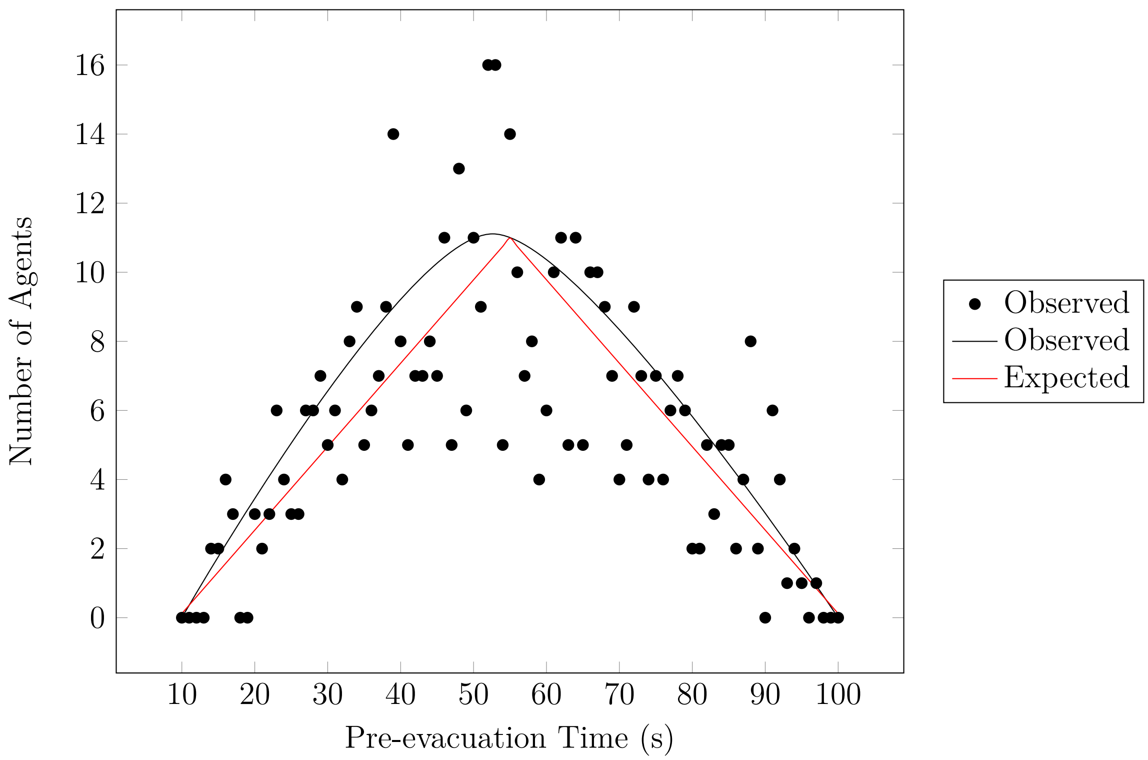


Figure 10: Test 1 Triangular Distribution Histogram

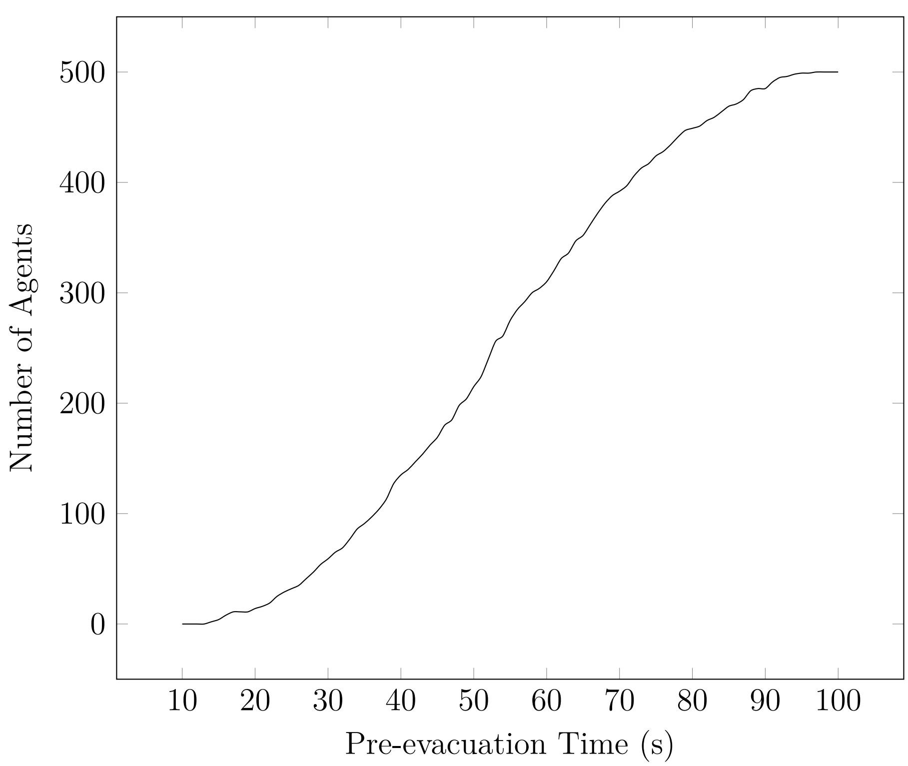


Figure 11: Test 1 Triangular Distribution Cumulative Graph

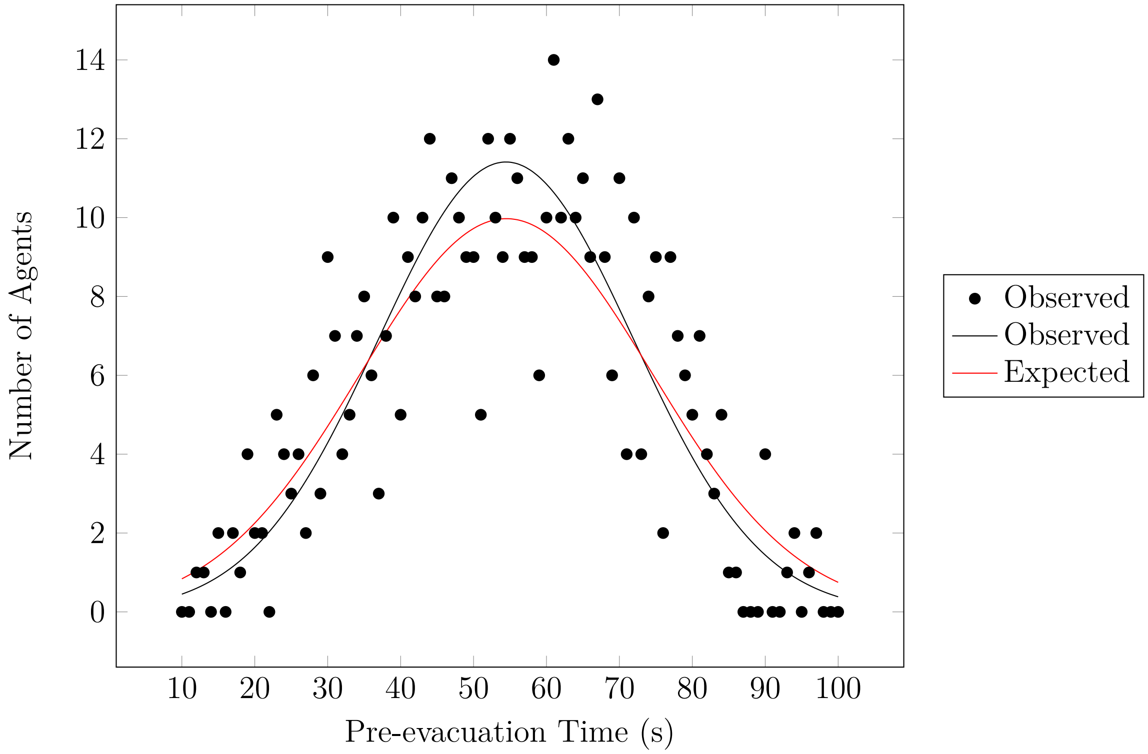


Figure 12: Test 1 Normal Distribution Histogram

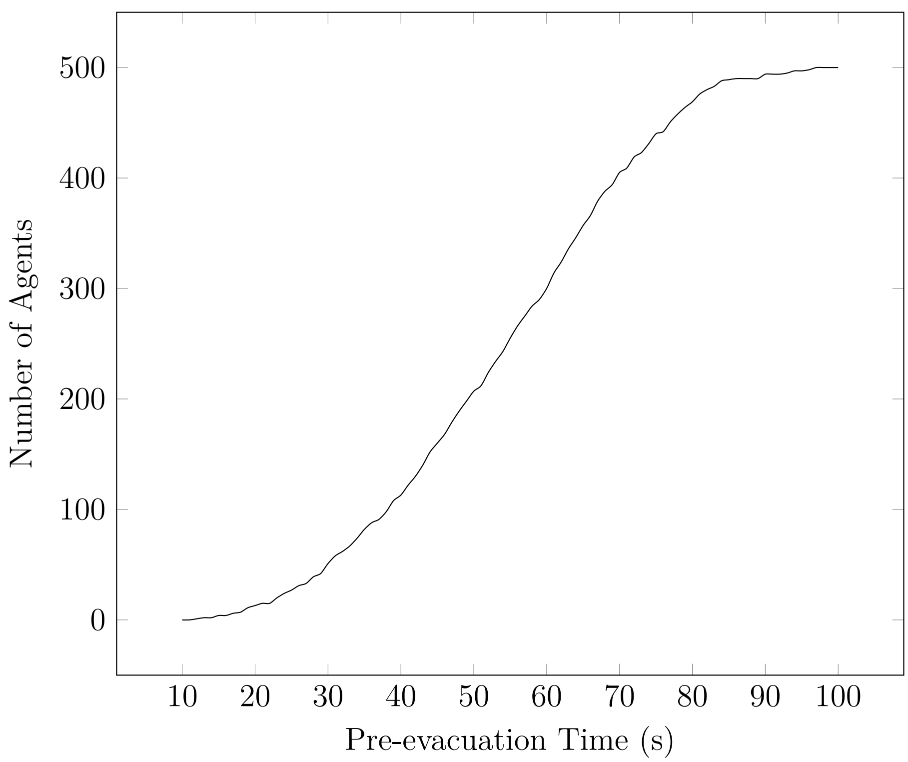


Figure 13: Test 1 Normal Distribution Cumulative Graph

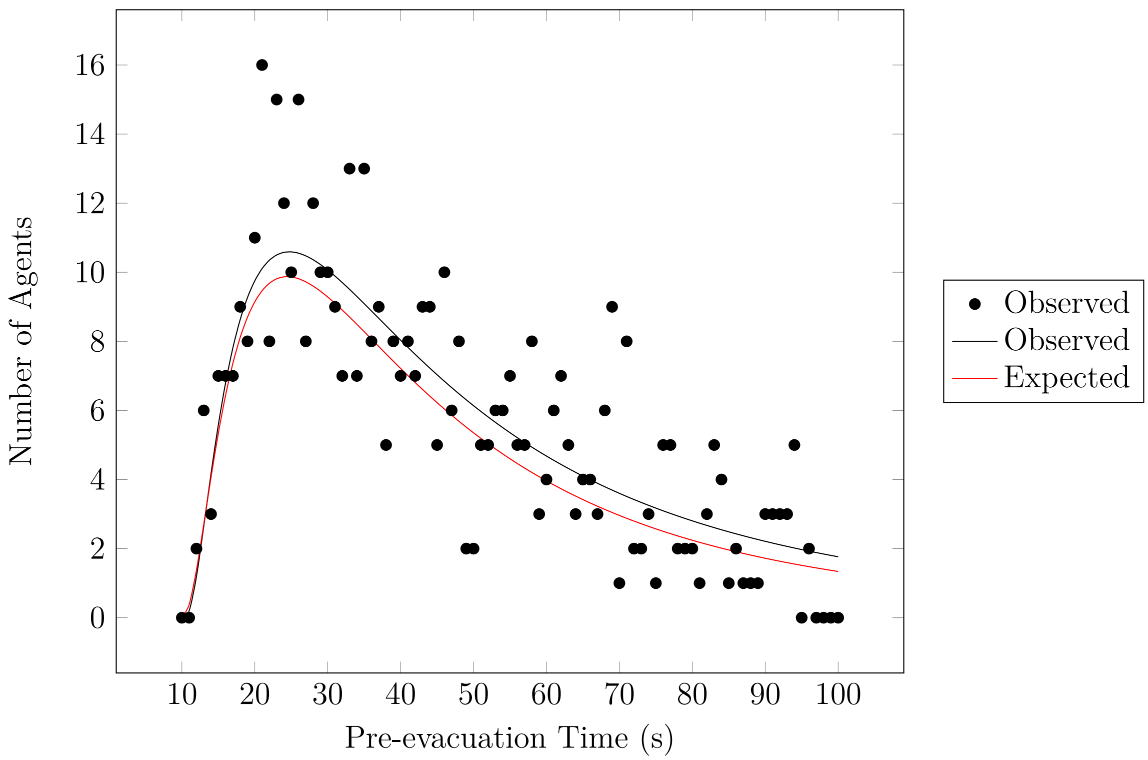


Figure 14: Test 1 Log-normal Distribution Histogram

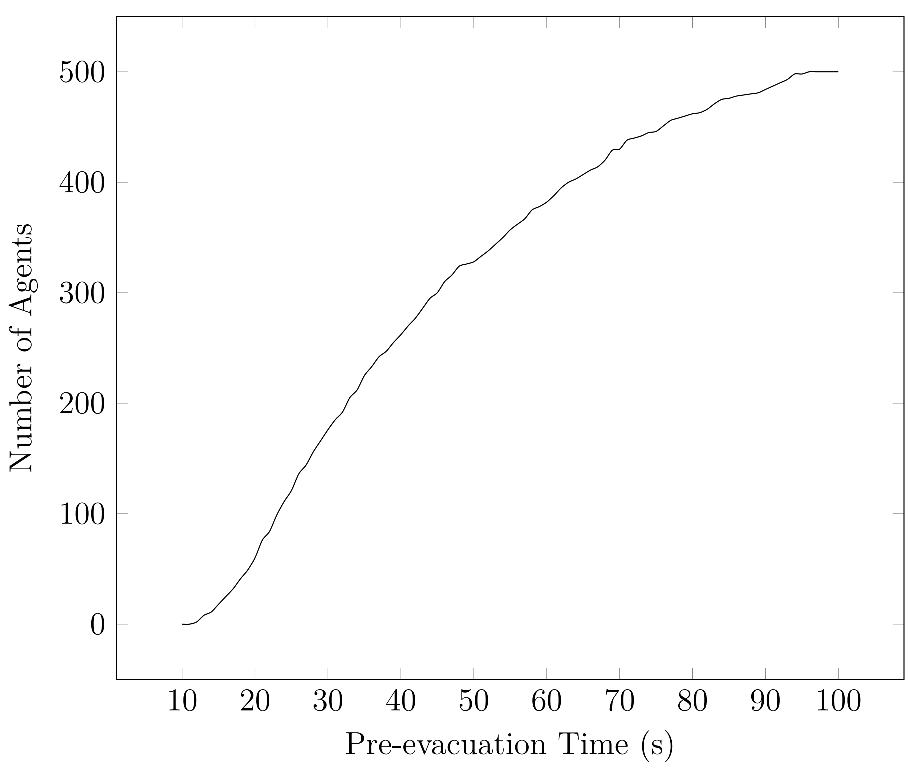


Figure 15: Test 1 Log-normal Distribution Cumulative Graph

5 Test 2: Walking speed in a corridor

5.1 Objective

Assess consistency between user walking speed assignment in a corridor and model representation.

5.2 Geometry

A corridor 2m wide and 45m long.

The MassMotion geometry consists of:

- one floor,
- an entrance portal on the floor,
- an exit portal on the floor.

Note that within MassMotion, agents accelerate/decelerate to the preferred walking speed at a default rate of $3m/s^2$. An agent requires a minimum of 0.333m in order to accelerate from rest to a speed of 1.0m/s. In order to simulate an agent traveling at 1.0m/s over a distance of 40m, a 45m floor is used.The scene is constructed as follows:

- Floor length is set at 45m,
- Two cordon lines are placed along the corridor exactly 40m apart,
- The portals are offset from the cordon lines by a minimum of 0.333m to allow for the acceleration/deceleration of the agent.

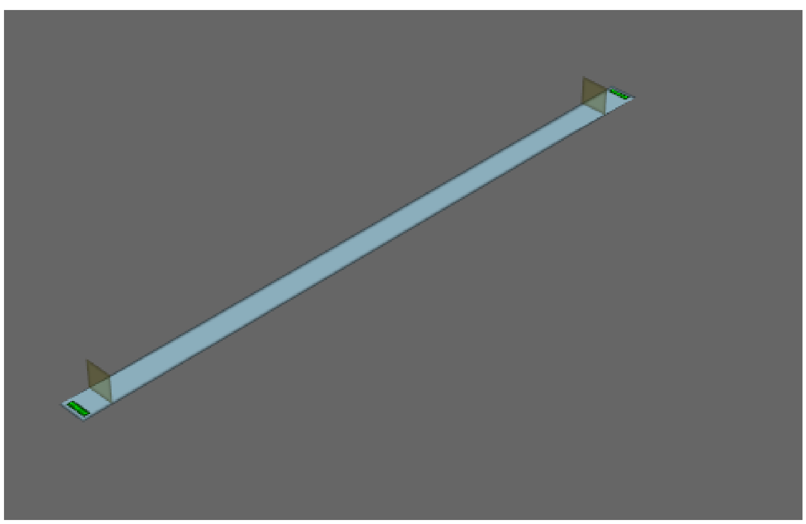


Figure 16: Test 2 Physical Environment

5.3 Scenario(s)

One occupant with an assigned walking speed of 1m/s walking along the corridor.

5.4 Expected result

The occupant should cover the distance of the corridor in 40s.

5.5 Test method

The test method is a quantitative verification of model results, i.e., the difference between the expected result and the simulation results.

5.6 User action

A single agent is spawned with a speed of 1m/s going from entrance to exit. Cordons are placed at either end of the floor and the time it takes for the agent to travel between them is measured.

5.7 Test Result

The time taken for the simulated agent to travel the 40m between the cordon lines is 40.000000s. This is consistent with a constant walking speed of 1m/s.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

6 Test 3: Walking speed on stairs

6.1 Objective

Assess consistency between user walking speed assignment on stairs and model representation.

6.2 Geometry

The MassMotion geometry, for each test case, consists of:

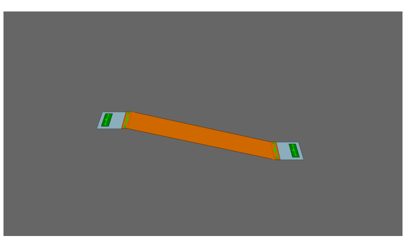
- a stair 2m wide and 10m long measured along the incline (down the center line),
- a 2m wide floor at each end of the stair, and
- a portal on each floor.

6.3 Scenario(s)

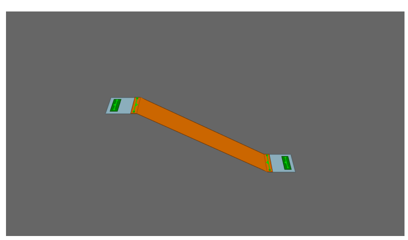
Four scenarios, each with a different incline or stair type (as defined in Table 9), are considered. Inclines close to 27^o and 32^o are avoided to ensure inclines are well within the ranges outlined in Table 10.

Stair Type	Incline (degrees)	Length (m)	Height (m)	Traverse (m)
Straight run	15.0	10.0	2.512	9.373
Straight run	29.5	10.0	4.924	8.704
Straight run	45.0	10.0	7.071	7.071
Spiral	15.0	10.0	2.588	9.373

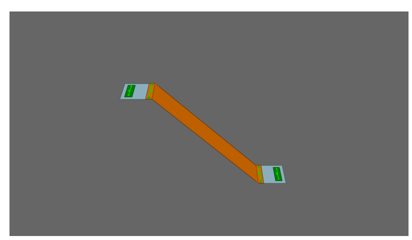
Table 9: Test 3 Stair Inclines (and Dimension) Adopted



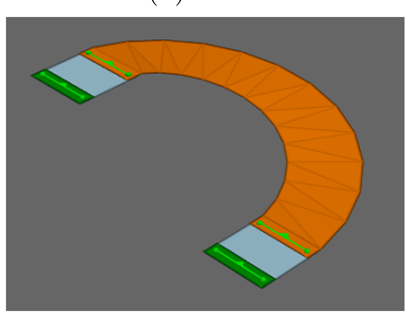
(a) 15^0



(b) 29.5^0



(c) 45^0



(d) Custom rise angle of 15^0

Figure 17: Test 3 Stair Layouts

The spiral stair is configured to have an inner radius of 2.2m and an outer radius of 4.2m to ensure the stair center line is 10m long.

In all four scenarios, one occupant with a walking speed of 1m/s (upwards or downwards) is walking along the stair incline.

6.4 Expected result

The occupant is expected to cover the distance in 10s (upwards or downwards).

6.5 Test method

The test method is a quantitative verification of model results, i.e., the difference between the expected result and the simulation results.

6.6 User action

MassMotion applies a factor to the preferred level terrain walking speed of an agent to determine the agent's preferred (horizontal) speed on a stair. The factors are based on the stair incline and direction of travel (up/down) and are outlined in Table 10.

Stair Incline (degrees)	Upward Stair Factor (%)	Downward Stair Factor (%)
Less than 27	42.6	57.3
Between 27 and 32	42.6 - 37.7 (interpolate)	57.3 - 49.8 (interpolate)
Greater than 32	37.7	49.8

Table 10: Test 3 MassMotion Default Agent Attributes for Stairs

An agent's preferred level terrain walking speed, S_{PLT}, is calculated from

$$S_{PLT} = \frac{\text{Speed on Stair} \times \cos(\text{Stair Incline Angle})}{\text{Stair Speed Reduction Factor (\%)} \times 0.01}$$

Simulations for each straight run incline angle (15^o, 29.5^o and 45^o) and the spiral stair are executed once with agents ascending and once with agents descending. This produces 8 simulations in total, each with a 10m long and 2m wide stair (see Table 9). For the ascending scenarios, agents are generated at an entry portal at the base of the stair and given a goal at the top of the stair. For the descending scenarios, agents are generated at an entry portal at the top of the stair and given a goal at the bottom of the stair. Cordon lines are placed at the base and the top of each stair to measure agent journey times.

6.7 Test Result

The MassMotion results are documented in Table 11. When walking on a spiral stair, a MasMotion agent tends to align itself with the inner edge of the stair. As a result, agent travel distance along the stair might be shorter than the 10m as measured along the stair center line. This could lead to stair travel times less than 10 seconds.

Test	Stair Type	Stair Incline	Preferred Level Terrain Walking Speed (m/s)	Expected Stair Travel Time (s)	Measured Stair Travel Time (s)
ascending	straight run	15.00	2.27	10	9.80
ascending	straight run	29.50	2.17	10	10.00
ascending	straight run	45.00	1.87	10	10.00
descending	straight run	15.00	1.68	10	10.00
descending	straight run	29.50	1.62	10	10.00
descending	straight run	45.00	1.42	10	10.00
ascending	spiral	15.00	2.27	10	9.80
descending	spiral	15.00	1.68	10	9.40

Table 11: Test 3 MassMotion Results

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

7 Test 4: Movement around a corner

7.1 Objective

Assess consistency between space usage in a corner and model representation.

7.2 Geometry

A corner is represented in accordance with Figure 18.

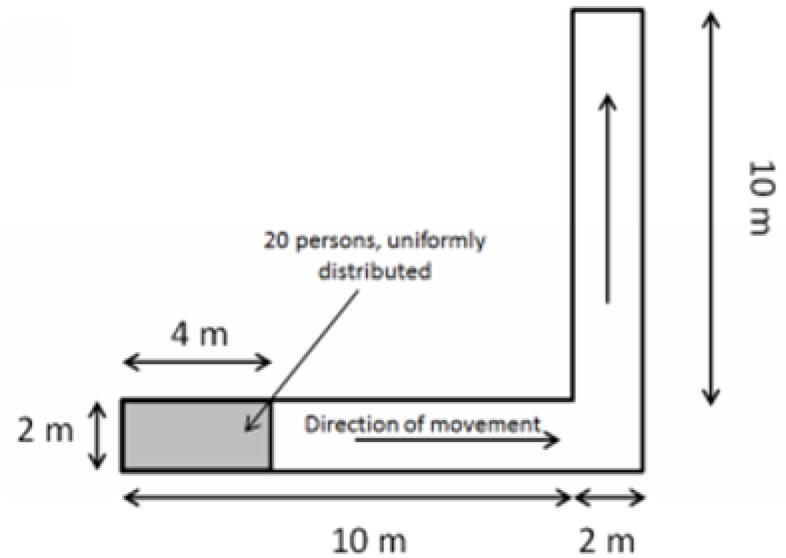


Figure 18: Test 4 Geometric Layout.

The MassMotion geometry, consists of:

- an L-shaped floor that is 2m wide and 12m long on each side,
- a 2m by 4m entry portal, and
- an exit portal.

7.3 Scenario(s)

Twenty occupants are uniformly distributed in one end of the hallway (in a space measured 2m by 4m). They have pre-evacuation time equal to 0 and a walking speed of 1 m/s.

7.4 Expected result

The occupants are expected to successfully navigate around the corner without penetrating the boundaries.

7.5 Test method

The test method is a qualitative or quantitative verification of the occupant movement. The analysis is performed by observing the travel path walked by the occupants.

7.6 User action

The entrance portal on the floor is set to uniformly distribute 20 agents inside portal in accordance with the above scenario.

The flow rates entering and exiting the corner is measured via cordon transition as depicted in Figure 19.

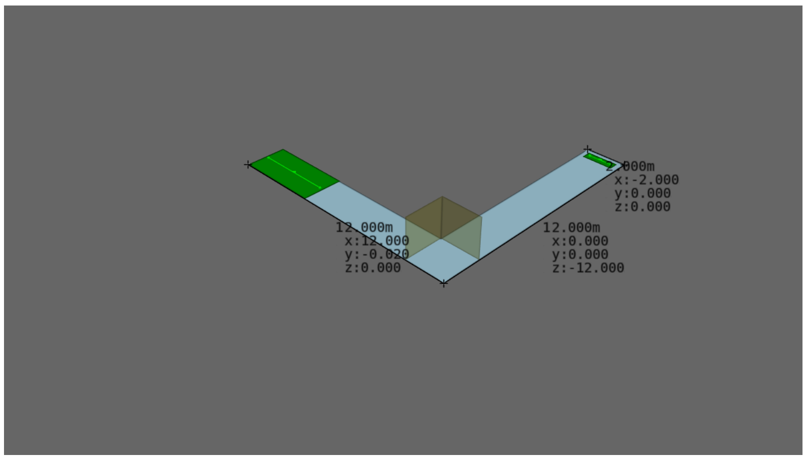


Figure 19: Test 4 Flow rate measurement.

7.7 Test Result

Figure 20 illustrates the simulated agent journeys at key times during the simulation.

The predicted agent co-ordinate positions sampled per second is illustrated in Figure 21.

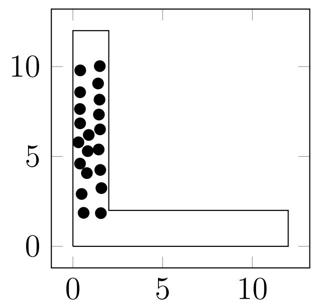
These demonstrate that:

- the agents navigate the corner within the designated boundaries;
- there are two distinct agent paths (particularly after the corner).

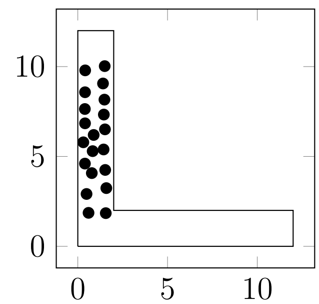
No significant difference between entering and exiting flow rates at the corner is measured.

- Entering flow rate: 1.052632 per second;
- Exiting flow rate: 0.952381 per second.

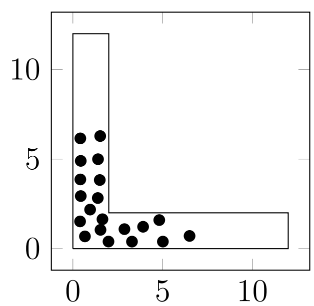
The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.



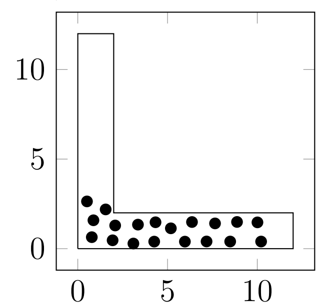
(a) Time 1s - All 20 agents entered simulation within the 2m x 4m entry portal.



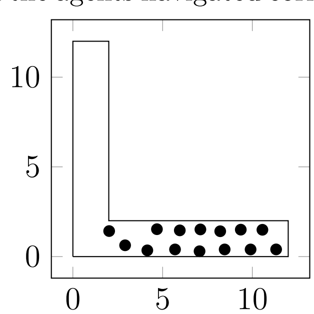
(b) Time 6s - First agent reaches the corner at this time (approximately).



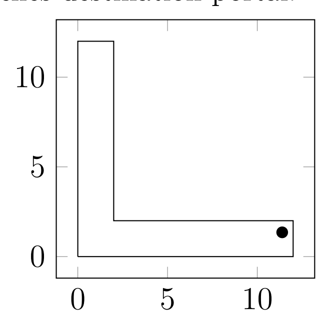
(c) Time 11s - Approximately half the agents navigated corner.



(d) Time 16s - First agent reaches destination portal.



(e) Time 21s - The last agent navigates the corner.



(f) Time 32s - The last agent leaves the simulation at the destination portal.

Figure 20: Test 4 Agent Movement Around Corners

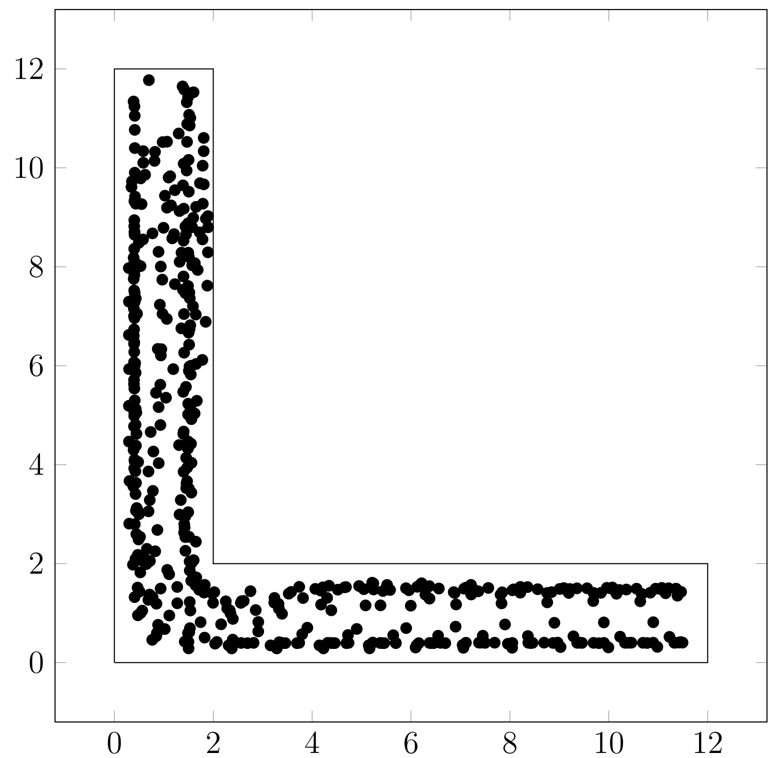


Figure 21: Test 4 MassMotion Agent Co-ordinate Positions

8 Test 5: Assigned occupant demographics

8.1 Objective

Assess consistency between occupant demographics assignment and model representation.

8.2 Geometry

A square room of size 100 m by 100 m.

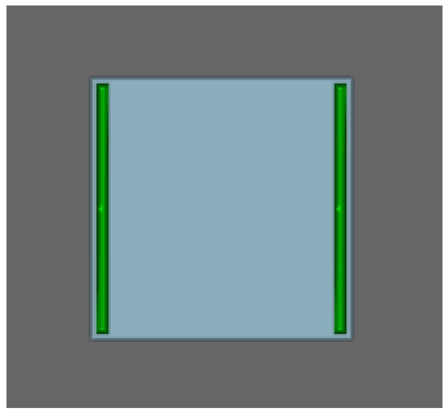


Figure 22: Test 5 Physical Environment

8.3 Scenario(s)

100 occupants, all 30 - 50 years old, are placed randomly in the room. Walking speeds are assigned randomly using a uniform probability distribution ranging from 0.25m/s to 1.9m/s.

8.4 Expected result

Show that the assigned walking speed distribution is consistent with the distribution specified in the scenario.

8.5 Test method

The test method is a quantitative verification of model assignments, i.e. the analysis of the walking speeds simulated by the evacuation model. In relation to the type of distribution under consideration, the model tester should identify a suitable quantitative method to evaluate the differences among the simulated and assigned distributions.

8.6 User action

Demographic characteristics were taken from the occupant group of 30 - 50 year olds identified in Lord et al. (2005). 40 simulations, each with a different random seed, are run to verify the simulation of occupant demographic.

8.7 Test Result

The simulation is run 40 times and the preferred horizontal terrain walking speed of the 100 agents is recorded. The minimum, maximum and mean values are summarized in Table 12.

	Expected	**Observed**
Minimum	0.25	0.25
Maximum	1.90	1.90
Mean	1.07	1.07
Variance	0.23	0.23

Table 12: Test 5 Preferred Horizontal Terrain Walking Speed

Figure 23 illustrates the number of agents assigned preferred horizontal terrain walking speeds, divided into 20 'buckets' and the expected distribution curve.

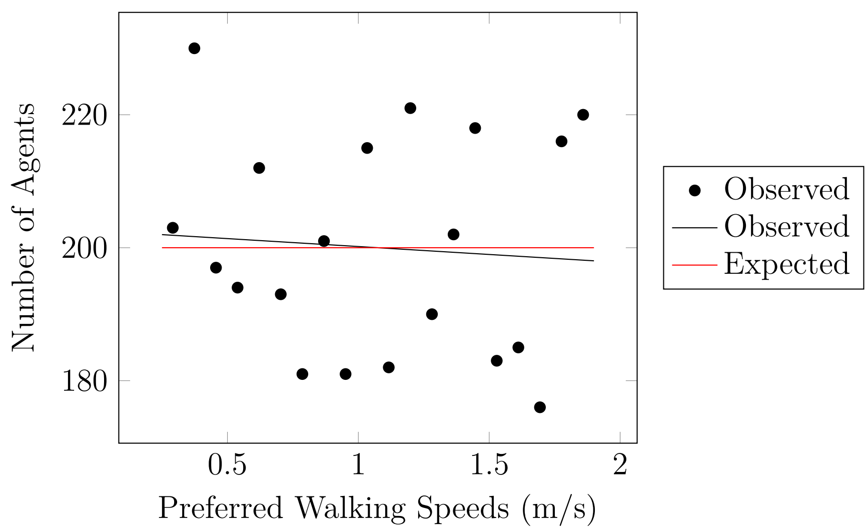


Figure 23: Test 5 Assigned Preferred Horizontal Terrain Walking Speeds

A chi-squared test with 20 buckets is used to check for uniform distribution and yields a test statistic of 25.17 . This is less than the critical value of 32.852 for a 97.5 % confidence. From this we conclude that the distribution of agent walking speeds is as specified in the simulation setup.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

9 Test 6: Counter-flows

9.1 Objective

Assess the qualitative abilities of models to represent counter-flows.

9.2 Geometry

The test is run on two models whose layout consist of two connected 10m x 10m rooms.

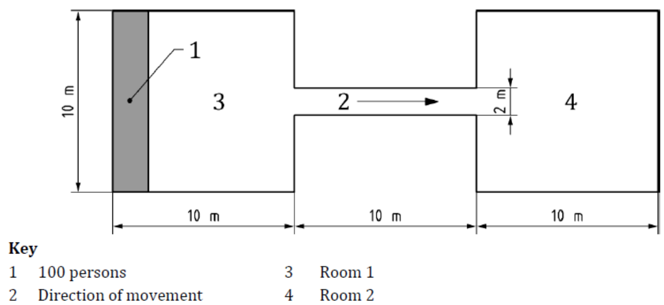
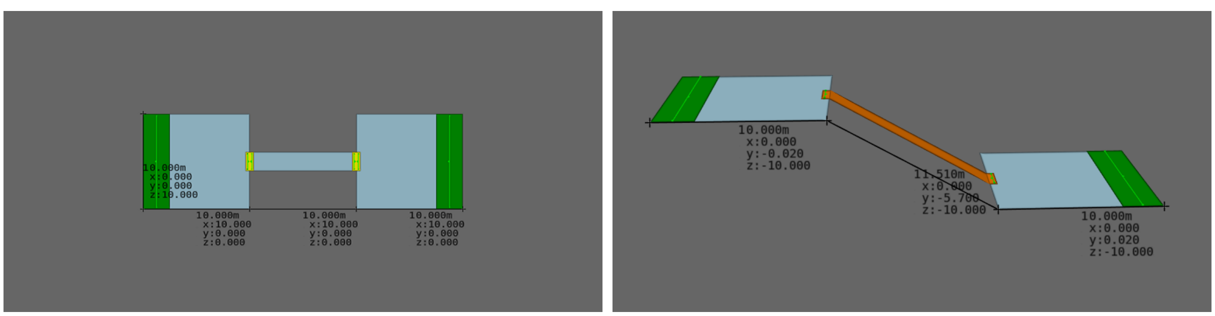


Figure 24: Test 6 Schematic geometric layout of the test (top view)

In model 1, the floors are connected via a 10m x 2m corridor starting and ending at the centre of one side of each room. In model 2, the floors are connected via a 10m x 2m stair starting and ending at the centre of one side of each room. The MassMotion models are illustrated in Figure 25.



(a) Floors Connected via a Corridor (b) Floors Connected via a Stair

Figure 25: Test 6 Physical Geometry

9.3 Scenario(s)

100 occupants with pre-evacuation time equal to 0s are placed along the portal. Walking speeds are assigned randomly using a uniform probability distribution ranging from 0.25m/s to 1.9 m/s.

Step 1: 100 occupants move from room 1 to room 2, where the initial distribution is such that the space of room 1 is filled from the left with maximum possible density.The time the last occupant enters room 2 is recorded.

Step 2 : Step one is repeated with an additional ten, fifty, and one hundred agents in room 2. These agents should have identical characteristics to those in room 1. Both crowds move simultaneously to the opposite room and the time for the last agents from room 1 to enter room 2 is recorded.

These scenarios are summarised in Table 13. Within MassMotion, the 'direction bias' agent parameter is used to resolve conflicts with other agents. The direction bias is defined by:

- the preferred direction, i.e. none, left or right (default); and
- the strength, i.e. weak or strong (default).

The 'direction bias' parameters adopted for each scenario are identified in Table 13. The direction bias is applied to agents originating on either floor. These scenarios test the sensitivity of the results with respect to the floor occupancy and the direction bias.

Note that these scenarios demonstrate high sensitivity of the prediction to small changes in the input parameter.

ID	Counterflow	Direction Bias Preference	Direction Bias Strength
1	0	Right	Strong
2	10	Right	Strong
3	50	Right	Strong
4	100	Right	Strong
5	100	Right	Weak
6	100	None	Not Applicable

Table 13: Test 6 Scenarios

9.4 Expected result

The recorded time increases as the number of agents in counter-flow increases.

9.5 Test method

The test method is a qualitative evaluation of the capabilities of the model of reproducing counter-flows. Model results need to be compared and the differences (expressed in terms of evacuation times) between the steps of the test are presented.

9.6 User action

The preferred horizontal terrain walking speeds is derived from Lord et al., 2005 guidelines and assigned randomly from a uniform probability distribution within the minimum and maximum speeds for the relevant population group as defined in Table 14.

Group	Minimum Speed (m/s)	Maximum Speed (m/s)
30-50 years old	0.25	1.9
>50 years old	0.25	1.5

Table 14: Lord et al., 2005 Preferred Horizontal Terrain Walking Speed

9.7 Test Result

Tables 15 and 16 list the times when the last agent from the left floor enters the right floor.

Scenario	Time when last agent from left floor enters right floor (s)
1	109.80
2	134.80
3	210.40
4	268.40
5	lock-up
6	lock-up

Table 15: Test 6 Clearance time for agents leaving the left room via the corridor

Scenario	Time when last agent from left floor enters right floor (s)
1	221.60
2	254.20
3	309.80
4	333.20
5	lock-up
6	lock-up

Table 16: Test 6 Clearance time for agents leaving the left room via the stair

Scenarios 1, 2, 3 and 4 demonstrate that the time at which the last agent originating in the left floor enters the right floor increases with the increase in agents originating in the right floor.

Scenarios 4 demonstrate that lock-up does not occur when 'strong' directional bias is assigned to agents originating on either side of the counter-flow.

Scenario 5 demonstrates that lock-up occurs even when 'weak' directional bias is assigned to agents originating on either side of the counter flow.

Scenario 6 demonstrates that lock-up occurs when directional bias is not assigned to agents originating on either side of the counter-flow.

Below Figures illustrate the simulation results at key times for the above scenarios. Note that the agents starting in the left room are coloured **red** while those starting in the right room are coloured **blue**.

Figures 26 to 31 show the impact of horizontal counter-flow on simulation result.

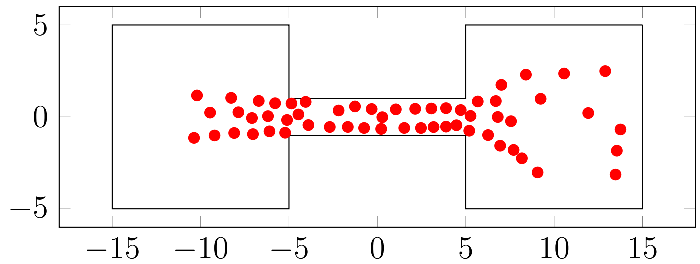


Figure 26: Test 6 Horizontal Counter-flow Scenario 1 Agent Positions (at 47 seconds)

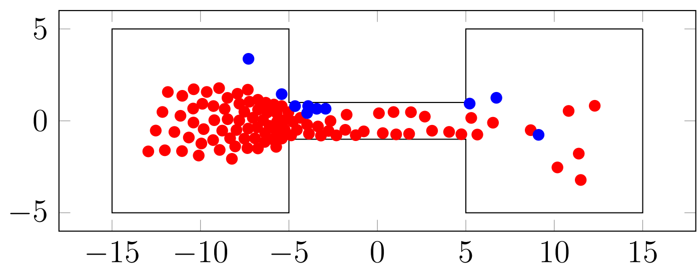


Figure 27: Test 6 Horizontal Counter-flow Scenario 2 Agent Positions (at 25 seconds)

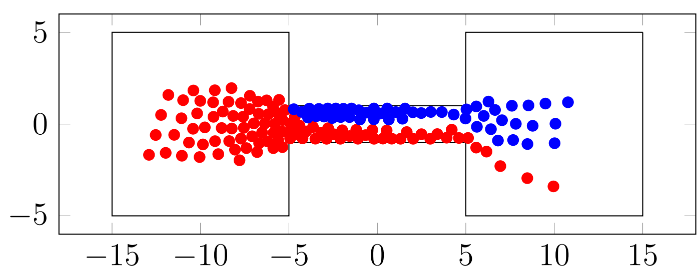


Figure 28: Test 6 Horizontal Counter-flow Scenario 3 Agent Positions (at 25 seconds)

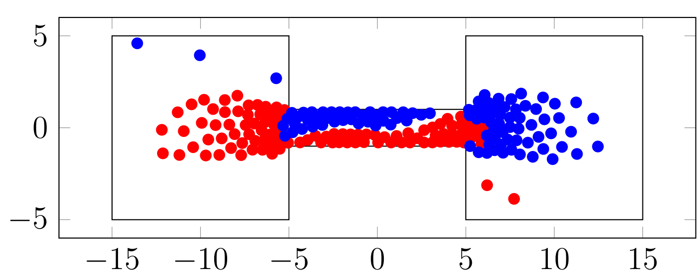


Figure 29: Test 6 Horizontal Counter-flow Scenario 4 Agent Positions (at 38 seconds)

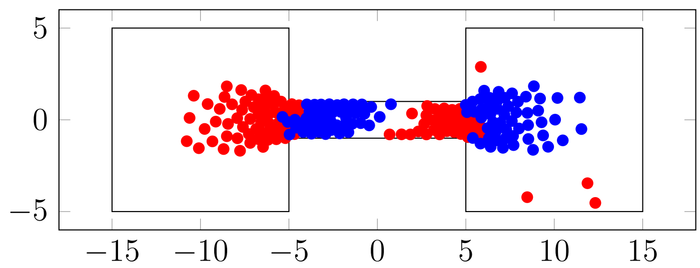


Figure 30: Test 6 Horizontal Counter-flow Scenario 5 Agent Positions (at 57 seconds)

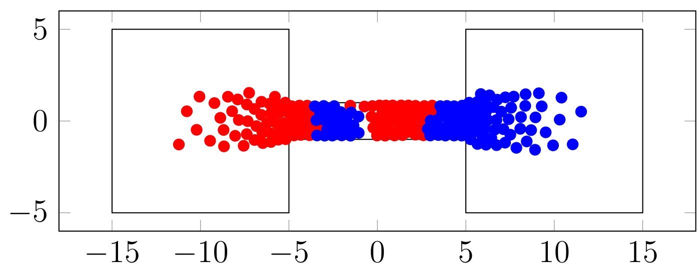


Figure 31: Test 6 Horizontal Counter-flow Scenario 6 Agent Positions (at 54 seconds)

Figures 32 to 37 show the impact of vertical counter-flow on simulation result.

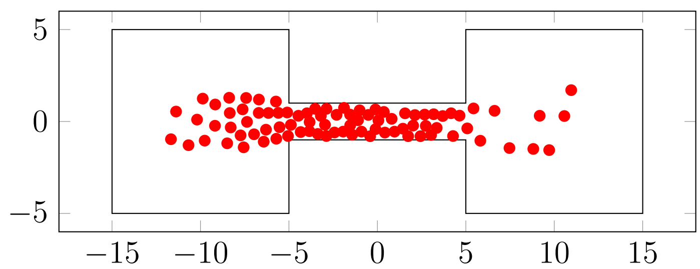


Figure 32: Test 6 Vertical Counter-flow Scenario 1 Agent Positions (at 47 seconds)

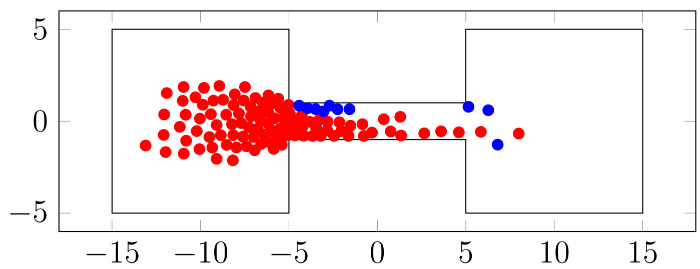


Figure 33: Test 6 Vertical Counter-flow Scenario 2 Agent Positions (at 25 seconds)

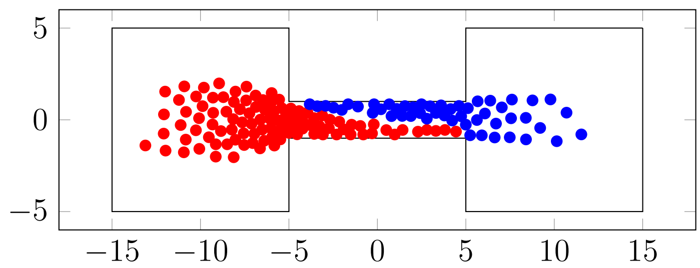


Figure 34: Test 6 Vertical Counter-flow Scenario 3 Agent Positions (at 25 seconds)

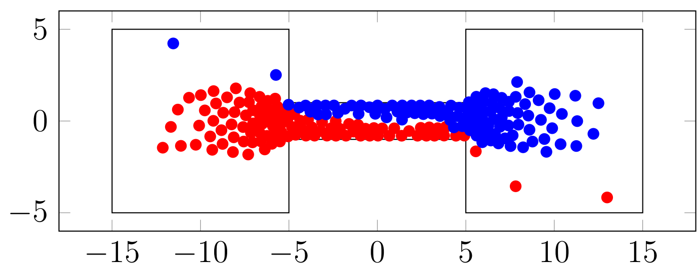


Figure 35: Test 6 Vertical Counter-flow Scenario 4 Agent Positions (at 38 seconds)

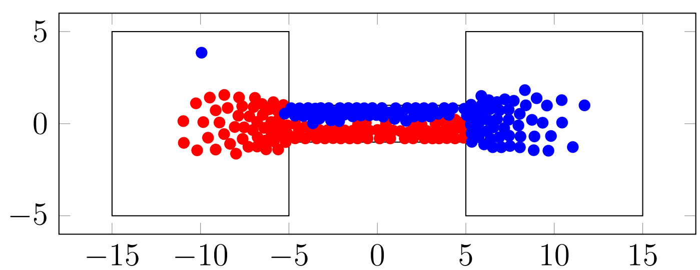


Figure 36: Test 6 Vertical Counter-flow Scenario 5 Agent Positions (at 57 seconds)

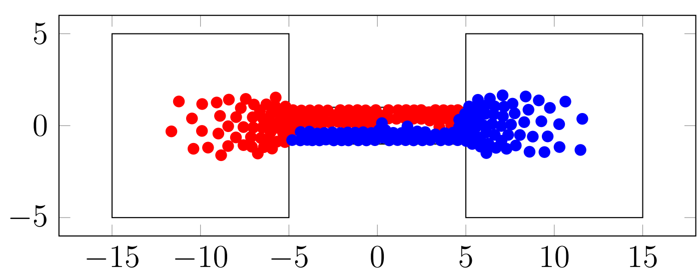


Figure 37: Test 6 Vertical Counter-flow Scenario 6 Agent Positions (at 54 seconds)

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

10 Test 7: People with movement disabilities

10.1 Objective

Assess model representation of people with disabilities in terms of their reduced mobility and increased space usage.

10.2 Geometry

Two rooms at different heights, namely room 1 (1m above the ground level) and room 2 (at ground level) are connected by a 12m x 1.5m ramp. A 1m wide exit is located at the end of room 2 (see Figure 38). Note that in Figure 38, as captured from ISO/DIS 20414, the leading agent in zone 1 is marked as disabled occupant in both scenarios. This is contrary to the description of scenario 2 that requires all occupants in zone 1 to have the same able-bodied characteristics.

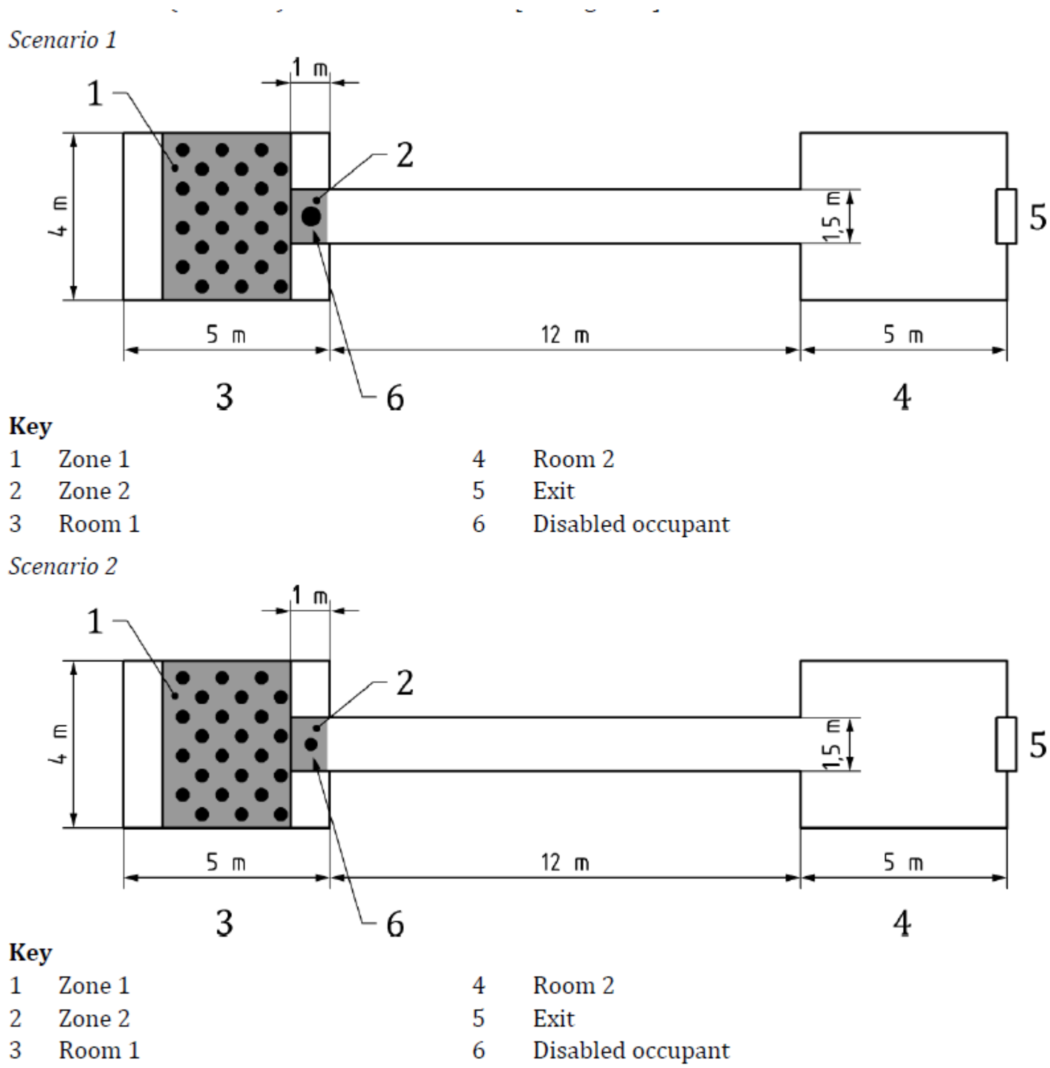


Figure 38: Test 7 Geometric Layout

The MassMotion model is illustrated in Figure 39. The 1m height difference between the two rooms results in 4.764deg rise angle for the ramp connecting the rooms.

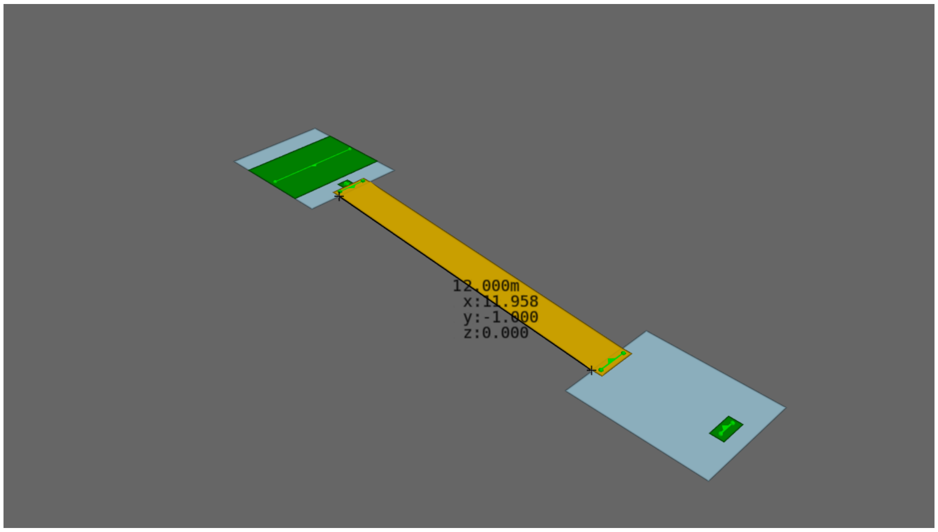


Figure 39: Test 7 Physical Environment.

10.3 Scenario(s)

Two scenarios are considered:

- Scenario 1: Room 1 is populated with 24 occupants in zone 1 and 1 disabled occupant in zone 2. Zone 1 occupants have default body size assumed by the model and are assumed to have preferred horizontal terrain walking speed of 1.25 m/s. The disabled occupant in zone 2 is assumed to have preferred horizontal walking speed equal to 0.8 m/s and 0.4 m/s on the ramp. The disabled occupant is also assumed to occupy an area larger than half the width of the ramp (0.75m) (e.g., a wheelchair user). All occupants have to reach the exit in room 2.
- Scenario 2: Re-run the test and populate zone 2 with an occupant having the same characteristics of the other 24 occupants in zone 1 (i.e.no disabled occupants are simulated). All occupants have to reach the exit in room 2.

10.4 Expected result

It takes longer for zone 1 occupants to reach the exit in scenario 1 than in scenario 2.

10.5 Test method

The test is a qualitative verification of emergent behaviours. The tester should qualitatively evaluate if the model is able to simulate disabled occupants and their possible impact on the evacuation times.

10.6 User action

The only deviation from the test description concerns the speed of the mobility impaired agent. MassMotion applies the same factor (in this case 1) to the preferred horizontal terrain walking speed of all the agents (‘able-bodied’ and ‘mobility impaired’) when on the ramp. The preferred horizontal terrain walking speed of the mobility impaired agent is, therefore, set to 0.4m/s (slower than that defined in the test description) such that the resultant speed on the ramp is 0.4m/s.

The movement of the mobility impaired agent is slower (compared to the test description) on the horizontal floors: overtaking is possible on the horizontal floors and, therefore, the slower movement of the mobility impaired agent should have limited impact.

10.7 Test Result

Figure 40 illustrates the MassMotion results when the mobility impaired agent of Scenario 1 (coloured in blue) is still on the ramp.

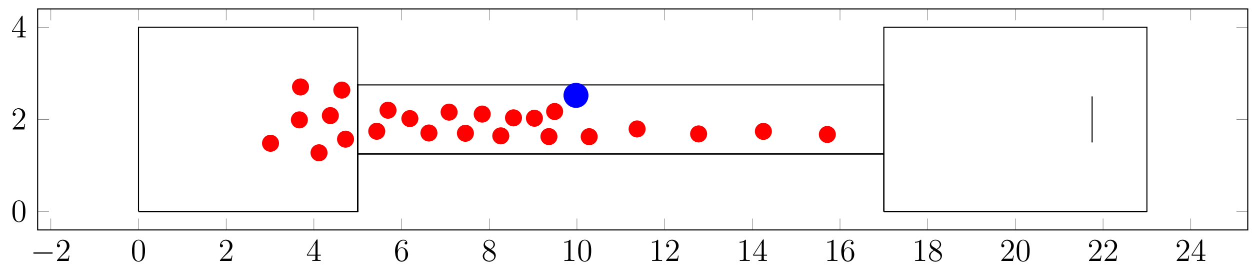


Figure 40: Test 7 Scenario 1 Agent Positions 12s into the Simulation (0.375m impaired agent radius)

For Scenario 1, the agents originating in Zone 1 have been impeded by the mobility impaired agent of Zone 2.

Figure 41 shows the MassMotion prediction for Scenario 2. The agent originating in Zone 2 is coloured blue.

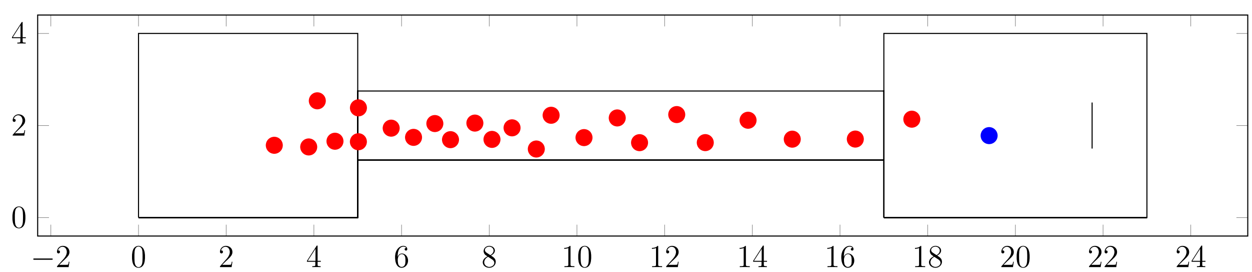


Figure 41: Test 7 Scenario 2 Agent Positions 12s into the Simulation

For Scenario 2, the able-bodied agent of Zone 2 has the same preferred walking speed as the agents originating in Zone 1 and therefore:

- is in advance of the agents originating in Zone 1 in moving towards the exit portal;
- has travelled down the ramp and is well into Room 2 while mobility impaired agent is still on the ramp.

In undertaking theses simulations, it was noted that the presence of the slower agent impeded the exit rate of other agents.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

11 Test 8: Exit route allocation

11.1 Objective

Assess consistency between exit route allocation assignment and model representation.

11.2 Geometry

The geometric layout (Figure 42) represents a corridor section with rooms.

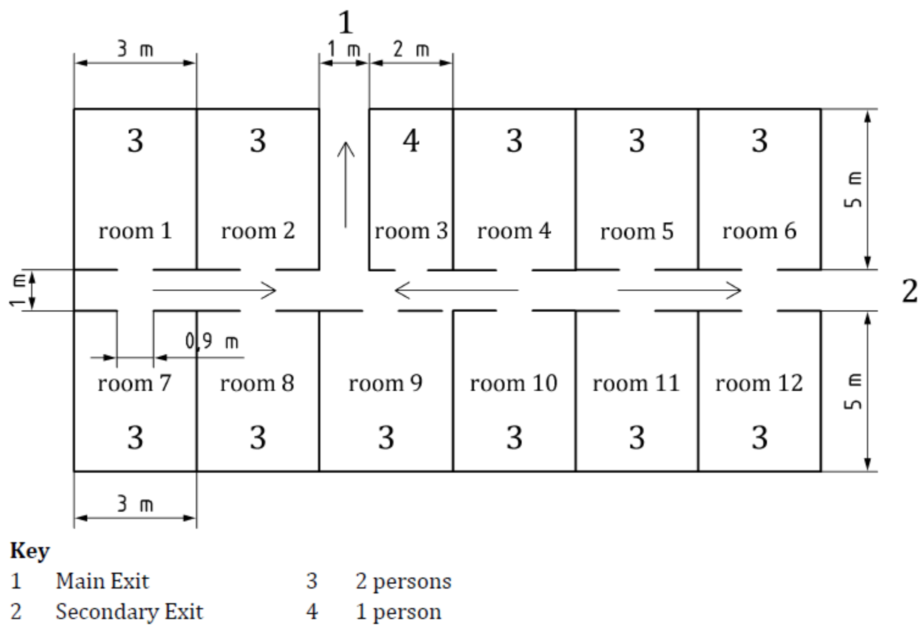


Figure 42: Test 10 Configuration of Corridor

The MassMotion model is shown in Figure 43.

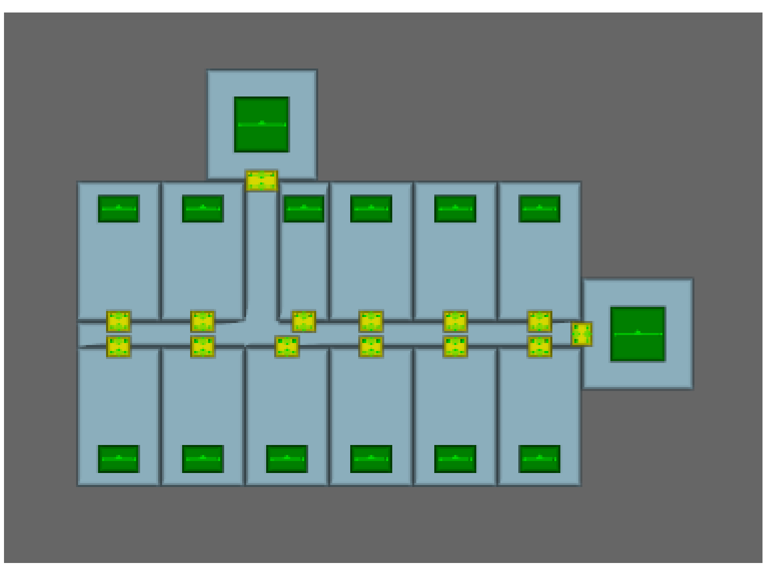


Figure 43: Test 8 Physical Environment

Floors are used to represent the 12 rooms, one corridor, and two destinations. Entry portals are created in each room. Exit portals are created at the destinations.

11.3 Scenario(s)

23 occupants with pre-evacuation times equals to 0s are placed across the rooms as shown in figure 42. The occupants' walking speed are assigned randomly using a uniform probability distribution ranging from 0.25m/s to 1.9m/s, in accordance with the expected demographics of the population of the building(s) (see Lord et al. (Lord et al., 2005) '30 – 50 Years Old Occupant Group'). The occupants in room 1, 2, 3, 4, 7, 8, 9, and 10 are allocated to the main exit. All the remaining occupants are allocated to the secondary exit.

11.4 Expected result

The allocated occupants move to the corresponding exits.

11.5 Test method

The test method is a qualitative verification of the ability of the model to represent exit route allocation.

11.6 User action

Two scenarios are considered:

- Scenario 1 - as defined above;
- Scenario 2 - The MassMotion exit selection algorithm (based on route cost) is applied to the agents.

11.7 Test Result

Table 17 summarizes the MassMotion results for Scenarios 1 and 2.

The MassMotion results indicate:

- Scenario 1 - all agents used the allocated exit;
- Scenario 2 - some agents from room 4 and room 10 chose to use the secondary exit (while all other agents adopted the same exit as in Scenario 1).

The agent behaviour identified in the latter is a function of the travel distance and cost associated with accessing the corridor leading to the main exit.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

		Scenario 1		Scenario 2	
Number	**Persons**	**Main**	**Secondary**	**Main**	**Secondary**
1	2	2	0	2	0
2	2	2	0	2	0
3	1	1	0	1	0
4	2	2	0	0	2
5	2	0	2	0	2
6	2	0	2	0	2
7	2	2	0	2	0
8	2	2	0	2	0
9	2	2	0	2	0
10	2	2	0	0	2
11	2	0	2	0	2
12	2	0	2	0	2

Table 17: Test 8 Number of Room Occupants Using Each Exit

12 Test 9: Dynamic availability of exit

12.1 Objective

Assess consistency between the assigned dynamic availability of exit and model representation.

12.2 Geometry

A 10m by 15m room with two exits (1m wide) available on the 15m walls of the room. The exists are equally distant from the 10m long wall (see Figure 44).

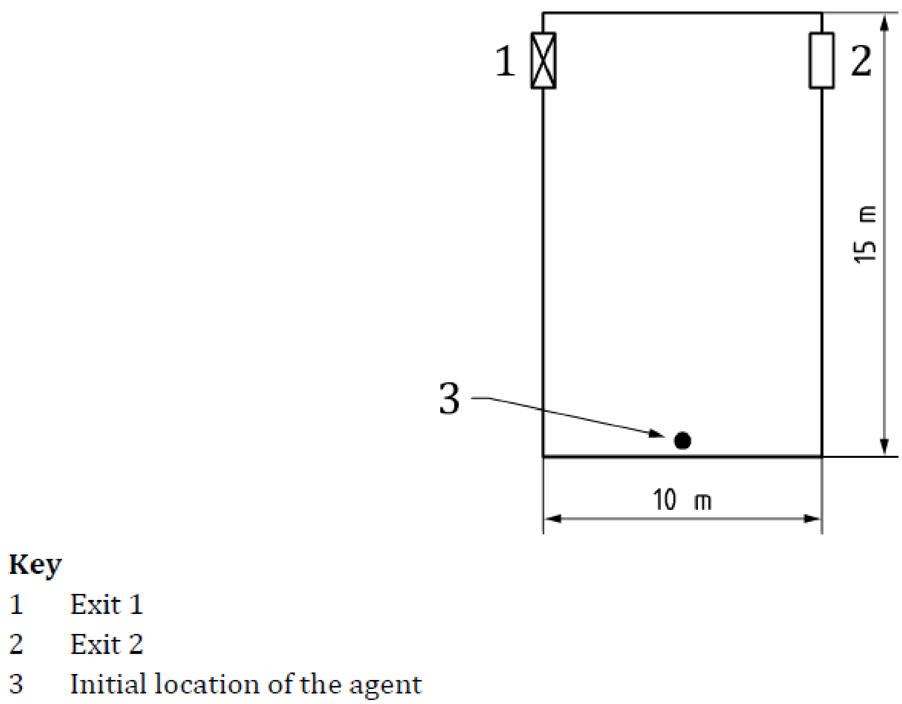


Figure 44: Test 9 Geometric Layout

The MassMotion model (Figure 45) consists of:

- 3 floors (the room and 2 destination areas);
- 2 links (to connect the room to the destination areas at the exits);
- 1 entry portal (associated with the room);
- 2 exit portals (associated with the destination areas).

12.3 Scenario(s)

One occupant with pre-evacuation time equals to 0s is assigned constant preferred walking speed of 1 m/s is placed at the entrance inside the room as shown in Figure 44. Exit 1 becomes unavailable after 1s of simulation time. Check the exit usage for both Exit 1 and Exit 2.

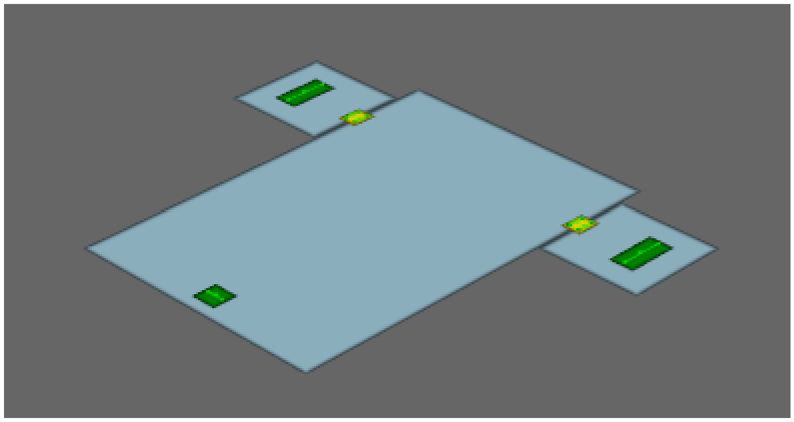


Figure 45: Test 9 Physical Environment.

12.4 Expected result

The expected result is that Exit 1 is not used by the occupant.

12.5 Test method

The model capabilities are analyzed in this test using a quantitative evaluation of the results in terms of exit usage

12.6 User action

The scenario is considered with the following MassMotion parameters set for the simulation:

- The agent is assigned both exist portals as its destination. It is instructed to continuously evaluate route costs throughout the simulation and seek the portal with lowest cost route.
- Links to Exit 1 and Exit 2 are enabled to be used as 'Gates' with their default state configured to be closed.
- 'Gate Access' event for Exit 1 to keep it open from 0s to 1s in the simulation to force the agent to prefer Exit 1 initially.
- 'Gate Access' event for Exit 2 to keep it open from 1s to simulation end.

12.7 Test Result

Agent route map is illustrated in Figure 46. The agent route map result is consistent with anticipated behaviours.

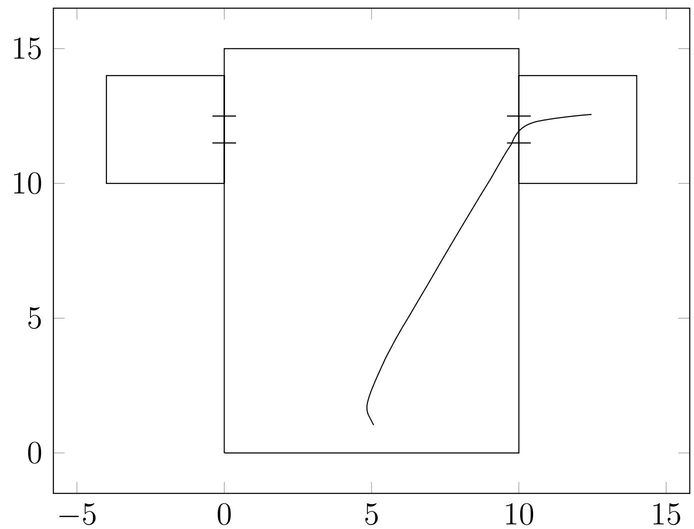


Figure 46: Test 9 Simulated Agent Route Map

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

13 Test 10: Congestion in front of a flight of stairs

13.1 Objective

Assess ability of models to represent congestion in front of a flight of stairs.

13.2 Geometry

A room connected to a stair via a corridor (see Figure 47 for room, stair, and corridor dimensions).

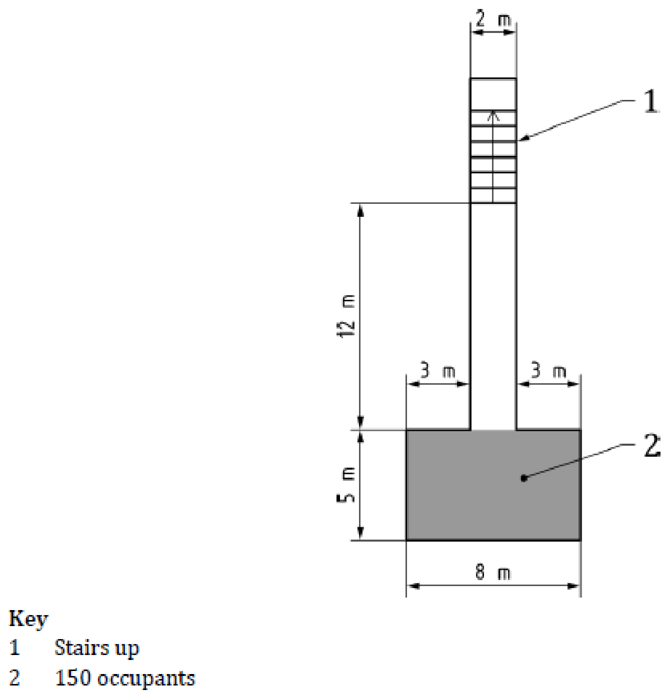


Figure 47: Test 10 Layout.

Figure 48 shows the setup of the physical environment in MassMotion. The MassMotion model consists of

- an 8m x 5m floor (room);
- a 12m x 2m floor (corridor);
- a link connecting the room to the corridor;
- a 3m x 2m (1.73m height, 30 degree incline) stair;
- a destination floor;
- entry and exit portals in the room and on the destination floor respectively.

13.3 Scenario(s)

The room is populated with 150 occupants with pre-evacuation times equal to 0s. The occupants' walking speed is assigned randomly using a uniform probability distribution ranging from 0.25m/s

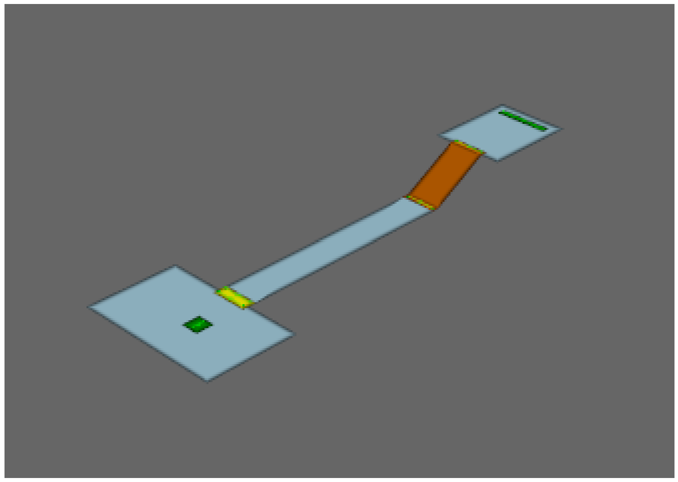


Figure 48: Test 10 Physical Environment

to 1.9m/s, in accordance with the expected demographics of the population of the building(s) (see Lord et al. (Lord et al., 2005) '30 – 50 Years Old Occupant Group').

13.4 Expected result

Congestion appears at the exit from the room, which produces a steady flow in the corridor with the formation of congestion at the base (i.e.the bottom) of the stairs given the different flow characteristics of the corridor and the stair.

13.5 Test method

The test method is a qualitative verification of model results in terms of congestions in consecutive parts of the room and corridor during the simulation.

13.6 User action

Agents are created instantly at the beginning of the simulation and are distributed in the room. Their journey is set to start from the room to the head of the stair.

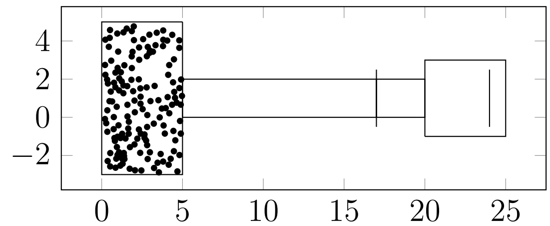
13.7 Test Result

The MassMotion results are illustrated in figures 49. Qualitative assessment of the simulation results illustrates the ability of MassMotion to replicate congestion:

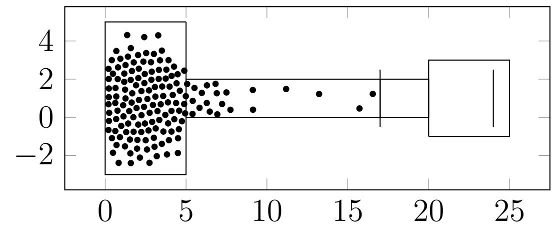
- at the exit from the room;
- at the end of the corridor adjacent to the stair.

The extent of the congestion at the latter is a function of the direction of the stair and the initial room population.

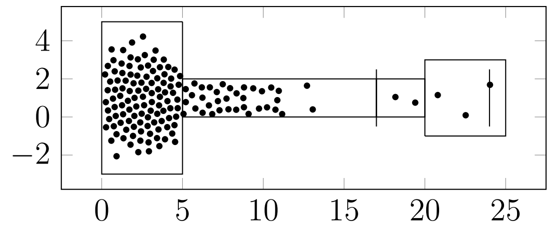
The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.



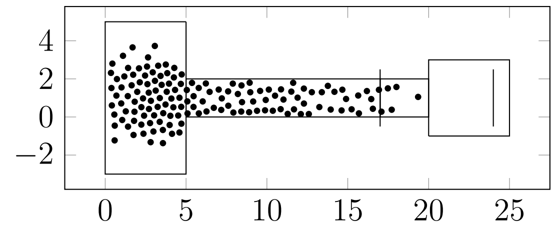
(a) Time 0s - The room is populated by 150 agents distributed uniformly.



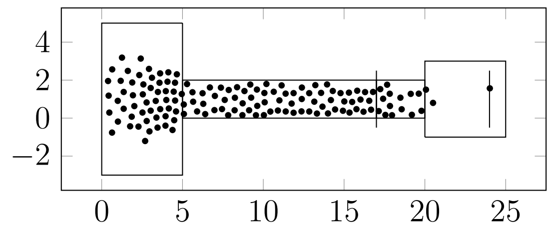
(b) Time 8s - First agent reaches foot of the stair.



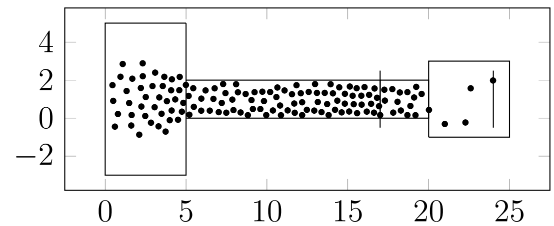
(c) Time 15s - First agent leaves simulation after reaching head of the stair.



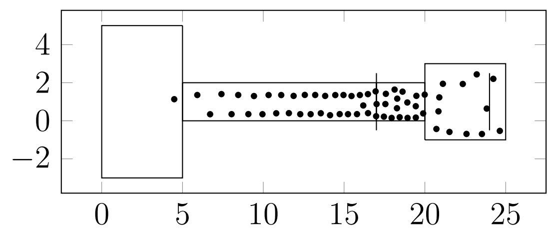
(d) Time 26s - Half of the agents have left room.



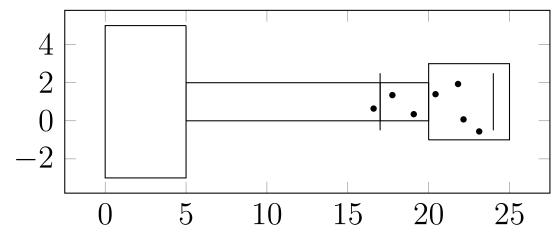
(e) Time 36s - Two thirds of the agents have left room.



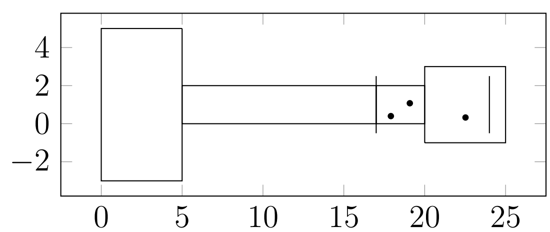
(f) Time 41s - Three quarters of the agents have left room.



(g) Time 90s - All agents have left the room.



(h) Time 167s - The last of the agents are leaving the corridor to ascend the stair.



(i) Time 180s - The last agent leaves the simulation after reaching the head of the stair.

Figure 49: Test 10 Result (150 Persons, Stair Up)

14 Test 11: Maximum exit/door flow rates

14.1 Objective

Assess consistency between maximum exit/door flow rates assignment and model representation.

14.2 Geometry

An 8m by 5m room with a 1m exit located centrally on the 5m wall.

The MassMotion model consists of an 8m by 5m primary floor that is connected via a 1m link (located centrally on the 5m wall) to a secondary floor. An entry portal is located (remote from the link) within the primary floor. An exit portal is located (remote from the link) within the secondary floor. Figure 50 shows the initial setup with agents starting on the primary floor.

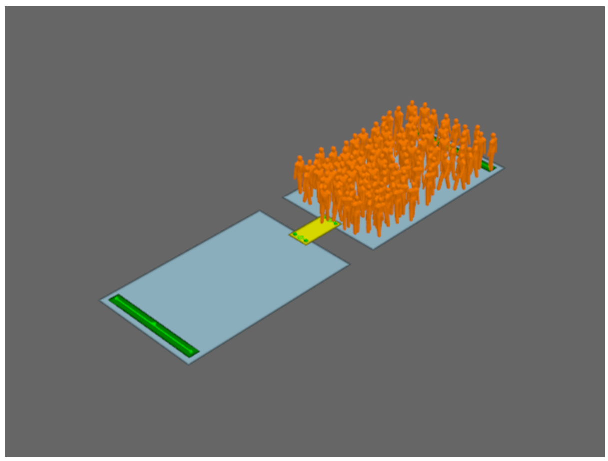


Figure 50: Test 11 Physical Environment.

14.3 Scenario(s)

100 occupants with pre-evacuation times equals to 0s are placed across the primary room. The occupants' walking speed is assigned randomly using a uniform probability distribution ranging from 0.25m/s to 1.9m/s, in accordance with 30-50 years old occupant group identified in Lord et al. (2005).

14.4 Expected result

The flow rate at the exit over the entire period should not exceed a pre-defined maximum threshold.

14.5 Test method

The test method is a quantitative evaluation of model results, i.e. the comparison between the results produced by the model and the maximum flow rate.

14.6 User action

The 1m link is defined to have a capped flow rate of 1.33people/s.

14.7 Test Result

Figure 51 illustrates the time averaged flow rate at the link.

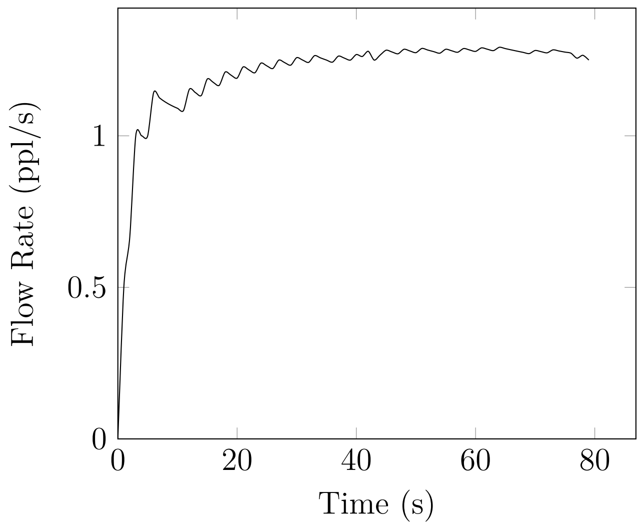


Figure 51: Test 11 Average Flow Rate (People/s)

The overall average flow rate (100 people / 80 s exit time) is 1.25 people/s. The highest average flow rate is 1.29231 people/s, which is below the specified limit of 1.330000 people/s.

The mean value of the time averaged flow from 20s to 80 s is 1.26455 people/s, ie. 95.0786 % of the value defined as the capped flow.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

15 Test 12: Stair flow rates

15.1 Objective

Assess qualitative consistency between stair flow rate assignment and model representation.

15.2 Geometry

Two floors at different levels are connected by a stair (height = 3m; diagonal = 4.24 m; angle = 45°). Five stair widths (1.0m, 1.2m, 1.4m, 1.6m and 1.8m) are considered (see x in Figure 52).

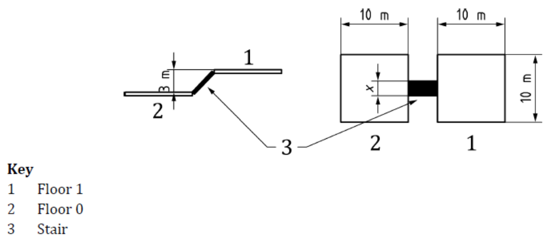


Figure 52: Test 12 Geometric Layout.

The MassMotion model for each test case, consists of:

- 2 floors (10m x 10m);
- 1 stair connecting the floors (height = 3m, length = 3m, diagonal = 4.24m, angle = 45^0);
- an entrance portal on one floor, set to distribute agents on the portal area.
- an exit portal on the other floor.

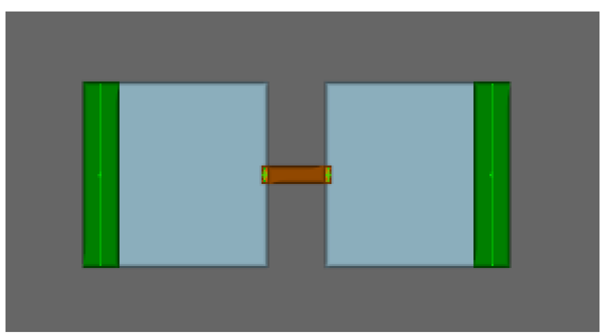


Figure 53: Test 12 Physical Environment (1.0m width)

15.3 Scenario(s)

Two scenarios are considered:

- Scenario 1 (Stair Down) - the flow goes from the upper floor to the lower floor.
- Scenario 2 (Stair Up) - the flow from the lower floor to the upper floor.

For each scenario/stair width combination, 100 occupants with pre-evacuation times equals to 0s are uniformly distributed in one of the two sides of the stairs. The occupants preferred horizontal terrain walking speeds are set to 1m/s.

15.4 Expected result

An increase in stair width should correspond to an increase in the agent flow rate.

15.5 Test method

The test method is a quantitative verification of average flow rates on stairs in the different configurations (stair down and stair up) and different stair widths.

15.6 User action

Each scenario is run 5 times with different stair widths (1.0m, 1.2m, 1.4m, 1.6m, 1.8m). In each run 100 agents were created at the start of the simulation traveling from the entrance portal to the exit portal.The flow rates are measured at the point where the agents enter the stairs (ie. at the top in Scenario 1 and at the bottom in Scenario 2).

15.7 Test Result

The floor clearance times are summarised in Table 18.

Scenario	Stair Direction	Stair Width	Clearance Time (s)
1	Down	1.0m	103
1	Down	1.2m	91
1	Down	1.4m	79
1	Down	1.6m	71
1	Down	1.8m	66
2	Up	1.0m	106
2	Up	1.2m	92
2	Up	1.4m	81
2	Up	1.6m	72
2	Up	1.8m	66

Table 18: Test 12 Entrance Floor Clearance Times

The average flow rate through each stair as a function of time is illustrated in Figures 54 and 55.

The average flow rate is calculated by time-averaging the number of agents entering the stairs in rolling 10s intervals.

The overall average flow rates are calculated as the total occupancy divided by the total exit time and listed in Table 19 and illustrated in Figure 56. As shown, the flow rates in both scenarios increases roughly linearly with the increases in stair width.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

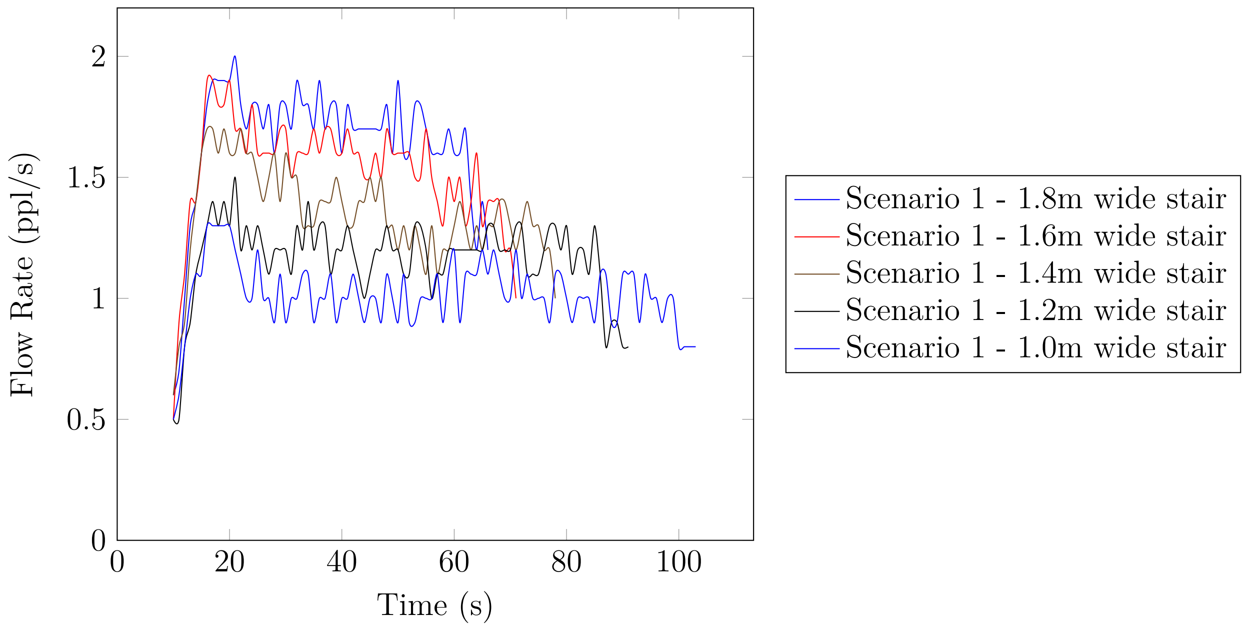


Figure 54: Test 12 Scenario 1 Average Flow Rates Through the Stair (Down)

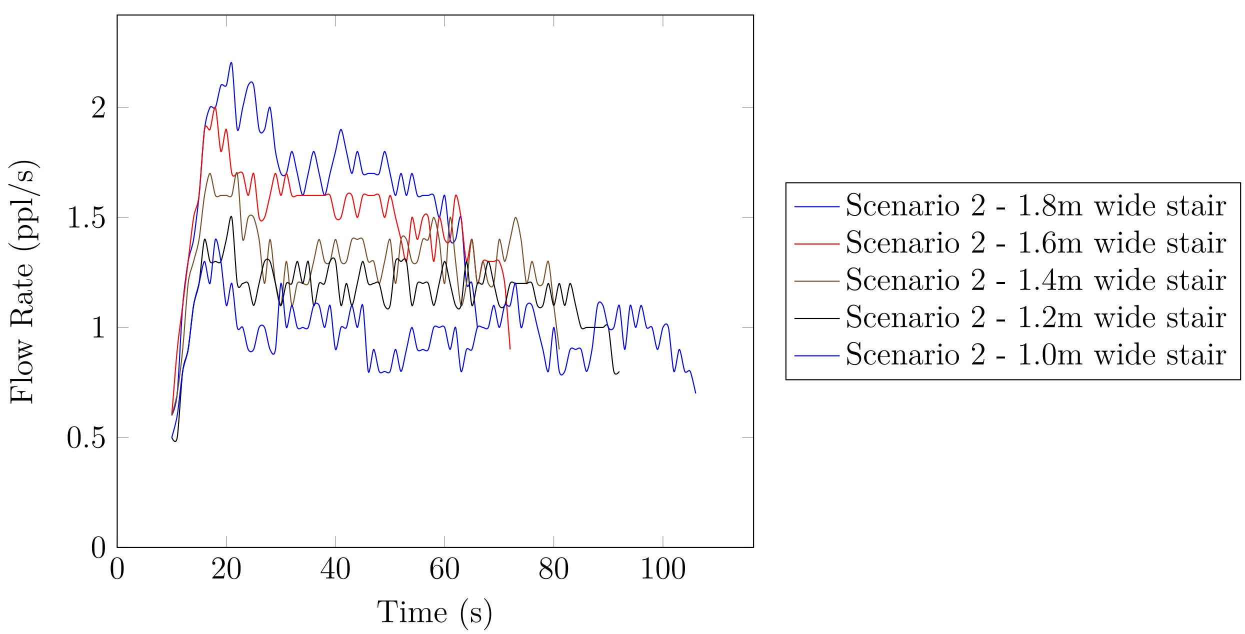


Figure 55: Test 12 Scenario 2 Average Flow Rates Through the Stair (Up)

Scenario	**Stair Direction**	**Stair Width**	**Overall Average Flow Rate**
1	Down	1.0m	0.96
1	Down	1.2m	1.09
1	Down	1.4m	1.27
1	Down	1.6m	1.39
1	Down	1.8m	1.49
2	Up	1.0m	0.93
2	Up	1.2m	1.08
2	Up	1.4m	1.22
2	Up	1.6m	1.37
2	Up	1.8m	1.49

Table 19: Test 12 Overall Average Flow Rates

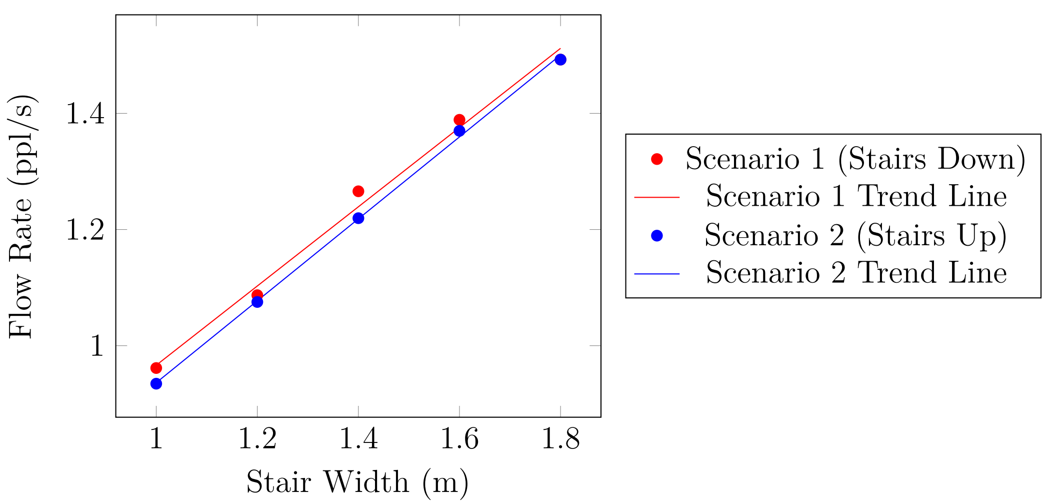


Figure 56: Test 12 Overall Average Flow Rates

16 Test 13: Relationship between walking speed, uni-directional flow and density

16.1 Objective

Assess qualitative consistency between the relationship between walking speed, uni-directional flow and density assignment and model representation.

16.2 Geometry

A corridor is represented in accordance to Figure 57 and it is divided in three zones, namely zone 1 (white), zone 2 (light gray) and zone 3 (white).

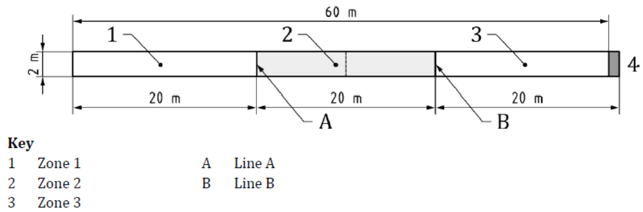


Figure 57: Test 13 Geometric Layout.

The MassMotion model consists of one floor measuring 2m x 60m. Exit portal is located at one end of the floor. Figure 58 shows the initial setup.

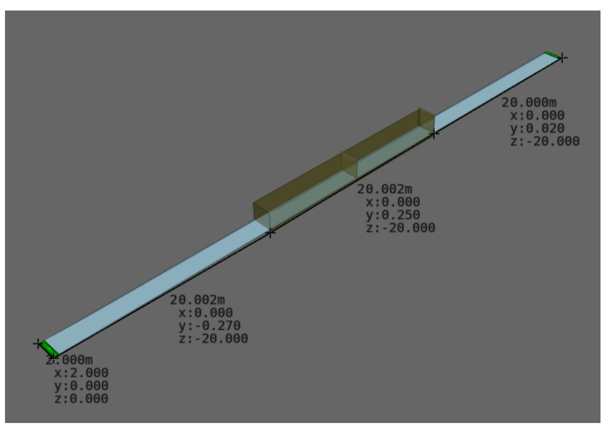


Figure 58: Test 13 Physical Environment.

16.3 Scenario(s)

60 occupants with pre-evacuation time equals to 0s are uniformly distributed in the entire corridor (zone 1, 2 and 3). The occupants' preferred horizontal terrain walking speed is set to 1 m/s.

Step 1: 60 occupants (= 60 / 120: the initial density is 0.5 [people/m2] in the corridor) move towards the exit. Place the last occupant in zone 2 near line A and measure the time that it takes from line A to line B and estimate the associated walking speed. Measure the average occupant flows in line B (with a time interval decided by the tester) starting from the beginning of the simulation until the last occupant in zone 2 arrives to Line B. People densities in zone 2 are recorded when the last occupant in zone 2 reaches the centre of zone 2.

Step 2: Step one is repeated with

- 120 occupants (= 120 / 120: the initial density is 1.0[people/m2] in the entire corridor),
- 240 occupants (= 240 / 120: the initial density is 2.0[people/m2] in the entire corridor),
- 360 occupants (= 360 / 120: the initial density is 3.0[people/m2] in the entire corridor),
- 480 occupants (= 480 / 120: the initial density is 4.0[people/m2] in the entire corridor).

16.4 Expected result

The relationship between walking speeds and people densities in Zone 2 as well as the flows in line A vs people densities in Zone 2 are plotted and compared with the underlying assumptions used in the evacuation model.

Note: There is a discrepancy between the scenario and the expected result in the ISO spec. The scenario requires flow rate to be measured across line B while expected result requires plot of flow rate across line A vs people densities in Zone 2. The implementation follows scenario description.

16.5 Test method

The test method is a qualitative verification of the occupant movement.

16.6 User action

The entrance portal is configured to uniformly distribute agents on the floor at the start of the simulation. Agents that are born in zone 2 are given a token so they can be tracked throughout the simulation.

Flow rate across line B is measured via a cordon at line B with a time interval of 1s.

People density in zone 2 is measured by obtaining population count in the volume stretching between line A and line B. A cordon is placed in the middle of zone 2 to identify the moment in time when the last occupant in zone 2 reaches the centre of zone 2.

16.7 Test Result

Figures 59 and 60 show the impact of people density on walking speed and flow rate. Figure 59 shows that the average walking speed through zone 2 decreases as the density in zone 2 increases. Figure 60 shows that the flow rate across line B increases as the density in zone 2 increases. The rate of increase in flow rate decreases as the density increases.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

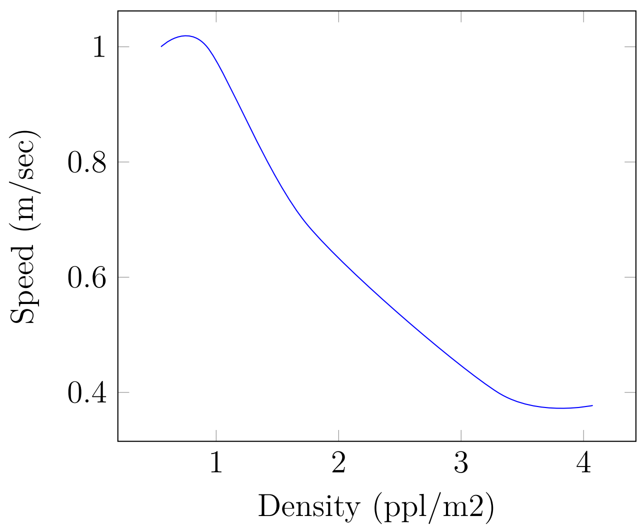


Figure 59: Test 13 Density vs Speed in Zone 2

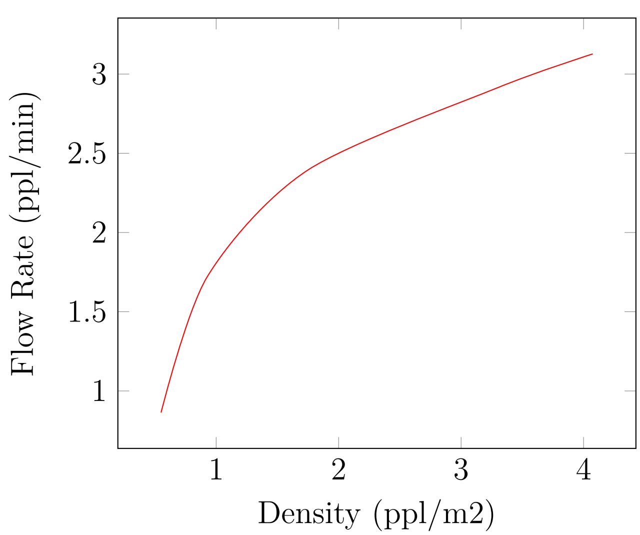


Figure 60: Test 13 Density vs Flow Rate in Zone 2

17 Test 14: Group behaviour

17.1 Objective

Assess the ability of the model to represent group behaviour in terms of the attempt of the group to maintain proximity.

17.2 Geometry

N/A

17.3 Scenario(s)

N/A

17.4 Expected result

N/A

17.5 Test method

N/A

17.6 User action

Although simulating group behaviour can be accomplished using the MassMotion SDK, the capability does not currently exist in the MassMotion desktop application.

17.7 Test Result

N/A

18 Test 15: Social influence on exit choice

18.1 Objective

Assess ability of the model to represent social influence on exit choice.

18.2 Geometry

N/A

18.3 Scenario(s)

N/A

18.4 Expected result

N/A

18.5 Test method

N/A

18.6 User action

Although simulating social influence on choice of exit can be accomplished using the MassMotion SDK, the capability does not currently exist in the MassMotion desktop application.

18.7 Test Result

N/A

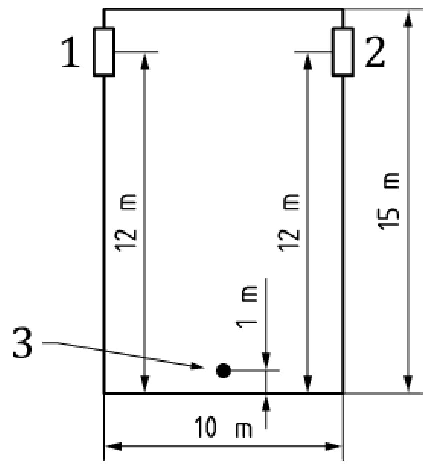
19 Test 16: Affiliation to familiar exits

19.1 Objective

Assess ability of the model to represent affiliation to familiar exits.

19.2 Geometry

A 10m by 15m room with two exits (1m wide) available on the 15m walls of the room. The exits are equally distant from the 10m long wall at the end of the room (see Figure 61).



Key
1 Exit 1
2 Exit 2
3 Initial location of the agent

Figure 61: Test 16 Geometric Layout

The MassMotion model (Figure 62) consists of:

- 3 floors (the room and 2 destination areas);
- 2 links (to connect the room to the destination areas at the exits);
- 1 entry portal (associated with the room);
- 2 exit portals (associated with the destination areas).

19.3 Scenario(s)

Two scenarios are considered:

- Scenario 1: One occupant with pre-evacuation time equals to 0s and a constant walking speed equal to 1m/s is placed in the room as shown in Figure 61 (the black dot represents the occupant which is 1m away from the 10m long wall on the bottom). The occupant is assumed to be unfamiliar with the exits.

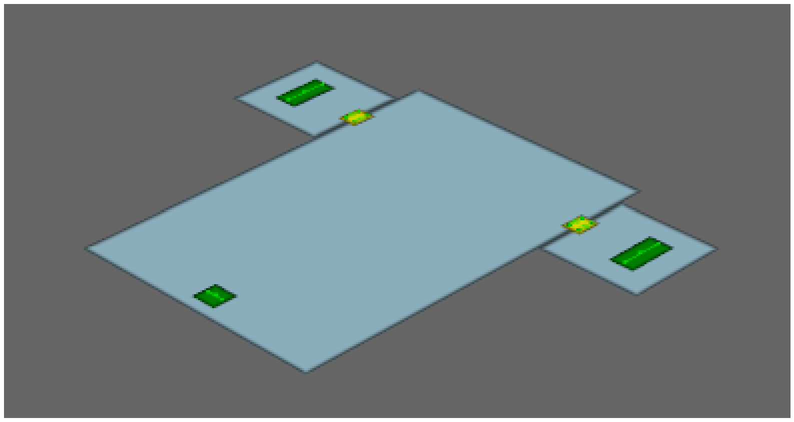


Figure 62: Test 16 Physical Environment.

- Scenario 2: One occupant with pre-evacuation time equals to 0s and a constant walking speed equal to 1m/s is placed in the room as shown in Figure 61 (the black dot represents the occupant which is 1m away from the 10m long wall on the bottom). The occupant is affiliated with Exit 2, i.e. Exit 2 is the favoured exit chosen by the occupant if all the other conditions affecting choice are the same for all exits.

Run each scenario several times until a stable percentage of exit usage for both exits i.e., exit usage does not vary more than 1% is reached. The occupant should always be placed in the same position among different runs and its position should be equidistant to both exits. Annotate the exit usage for the two exits.

19.4 Expected result

The expected result is that the usage of exit 2 in scenario 2 is higher than the exit 2 usage in scenario 1.

19.5 Test method

The evaluation method of this test is a quantitative evaluation of model results in terms of exit usage.

19.6 User action

The MassMotion journey is configured to assign the occupant one of the two available exits as its goal. The occupants affiliation to familiar exits is modeled by assigning weights to the available exits. The weights indicate the likelihood that the occupant is assigned to an exit in the simulation. The exit weights for the two scenarios are as defined in Table 20.

	Weight (%)	
Scenario	**Exit 1**	**Exit 2**
1	50	50
2	25	75

Table 20: Test 16 Exit Weights

100 simulations are undertaken for both scenarios.

19.7 Test Result

The frequency of usage of each exit over the 100 simulations is summarized in Table 21. This demonstrates that the MassMotion results for exit usage (and, therefore, the probability of exit usage) follow the weights applied to the exits as input.

	Usage (%)	
Scenario	**Exit 1**	**Exit 2**
1	48	52
2	27	73

Table 21: Test 16 MassMotion Exit Usage

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

20 Test 17: Route choice

20.1 Objective

Assess consistency between the horizontal route choice method and model representation.

20.2 Geometry

A two floor structure as shown in Figure 63. Start area and target area are connected by two flights of stairs (gray) and a corridor on the ground floor (dark gray in Figure 63) and by a (longer) corridor (white in Figure 63) on the upper floor.

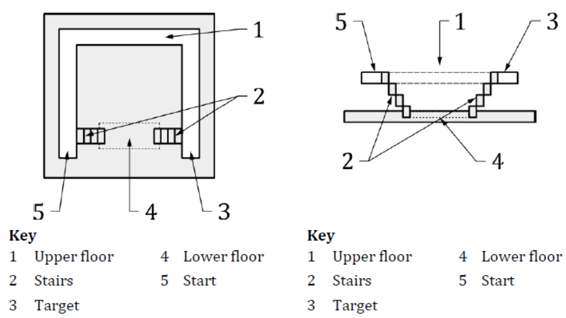


Figure 63: Test 17 Geometric Layout.

The MassMotion model consists of:

- One floor representing the ground level;
- Three floors connected by two links representing the upper level structure;
- Two flights of stairs connecting the lower and the upper structures;
- One entry portal associated with the start area;
- One exit portals associated with the target area.

20.3 Scenario(s)

Place one occupant in the start area and assign it to the target.

20.4 Expected result

Occupant adopts the shortest path using the lower floor in their journey or they use the longer path on the upper floor. The path should match the underlying route choice implemented in the evacuation model (i.e., most appropriate route given the route choice selection algorithm).

20.5 Test method

The test method is a qualitative verification of the adopted behaviour in terms of route choice.

20.6 User action

A single agent is created at the beginning of the simulation and placed at the entry portal. The agent is given the exit portal as a destination and left to evaluate route costs and make its own choice about the most suitable route. Two scenarios are considered:

- Scenario 1: The two upper floors perpendicular to the stairs are each 12m long.

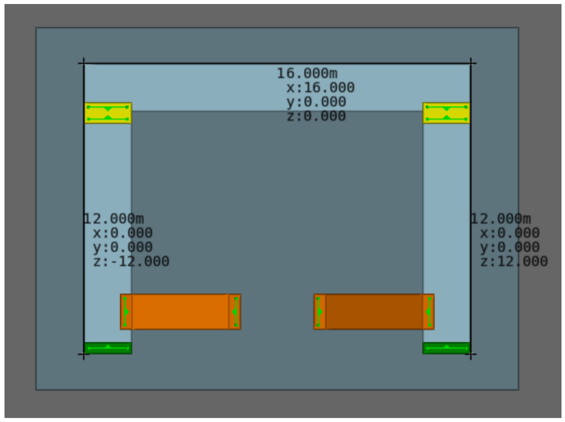


Figure 64: Test 17 The Long Path Using the Upper Floor is Used.

- Scenario 2: The two upper floors perpendicular to the stairs are each 24m long.

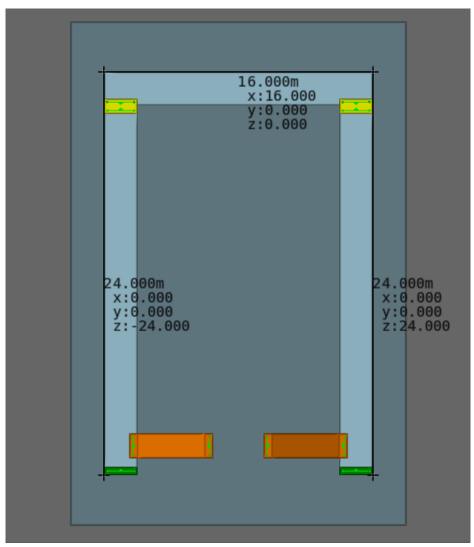


Figure 65: Test 17 The Short Path Using the Lower Floor is Used

In both scenarios, the height difference between the two levels is 2.5m. The location of the flights of stairs relative to the portals as well as their geometry are kept the same between the two scenarios.

20.7 Test Result

Figures 66 and 66 illustrate the route taken by the agent in each of the scenarios. In both cases, the occupant is evaluating the cost of available routes and choosing the route with the lowest cost. The cost of a route is a function of both horizontal and vertical displacement. In scenario 1 the upper floor route is 24m longer horizontally than the stair route. The stair route has a non-zero vertical cost. The upper floor route has the lower total cost and is chosen by the agent.

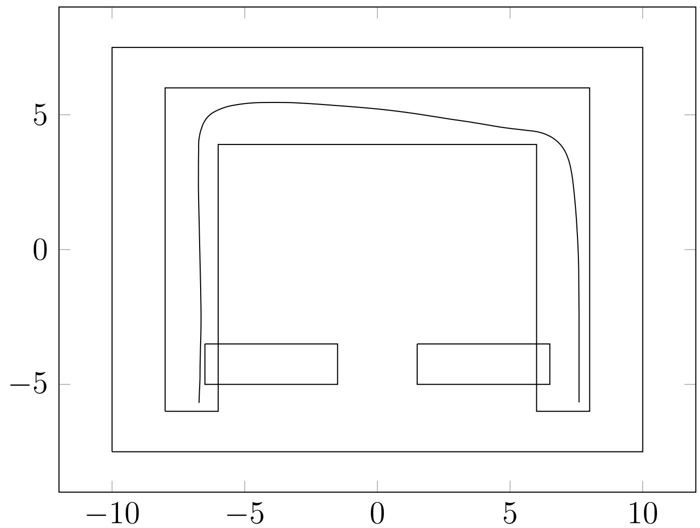


Figure 66: Test 17 Simulated Agent Route Map - Scenario One

In scenario 2 the upper floor route is 48m longer horizontally than the stair route. This increased horizontal distance results in the upper floor route having a larger total cost than the stair route and the stair route is chosen by the agent.

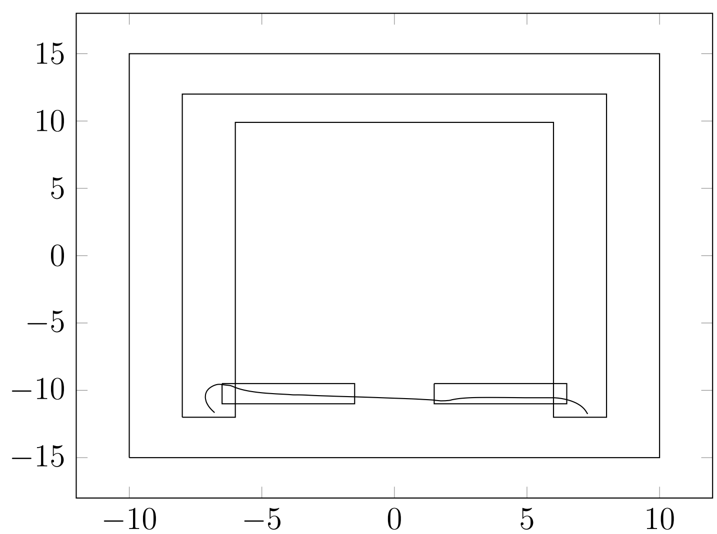


Figure 67: Test 17 Simulated Agent Route Map - Scenario Two

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

21 Test 18: Reduced visibility vs walking speed

21.1 Objective

Assess consistency between the assigned impact of reduced visibility on walking speed and model representation.

21.2 Geometry

N/A

21.3 Scenario(s)

N/A

21.4 Expected result

N/A

21.5 Test method

N/A

21.6 User action

Although simulating the impact of reduced visibility on walking speed can be accomplished using the MassMotion SDK, the capability does not currently exist in the MassMotion desktop application.

21.7 Test Result

N/A

22 Test 19: Occupant incapacitation

22.1 Objective

Assess consistency between the assigned occupant incapacitation calculation method and model representation.

22.2 Geometry

N/A

22.3 Scenario(s)

N/A

22.4 Expected result

N/A

22.5 Test method

N/A

22.6 User action

Although simulating occupant incapacitation can be accomplished using the MassMotion SDK, the capability does not currently exist in the MassMotion desktop application.

22.7 Test Result

N/A

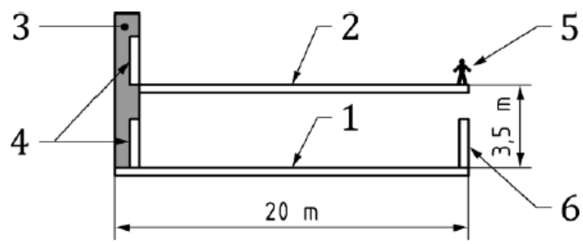
23 Test 20: Lift usage

23.1 Objective

Assess consistency between the elevator usage assignment and model representation.

23.2 Geometry

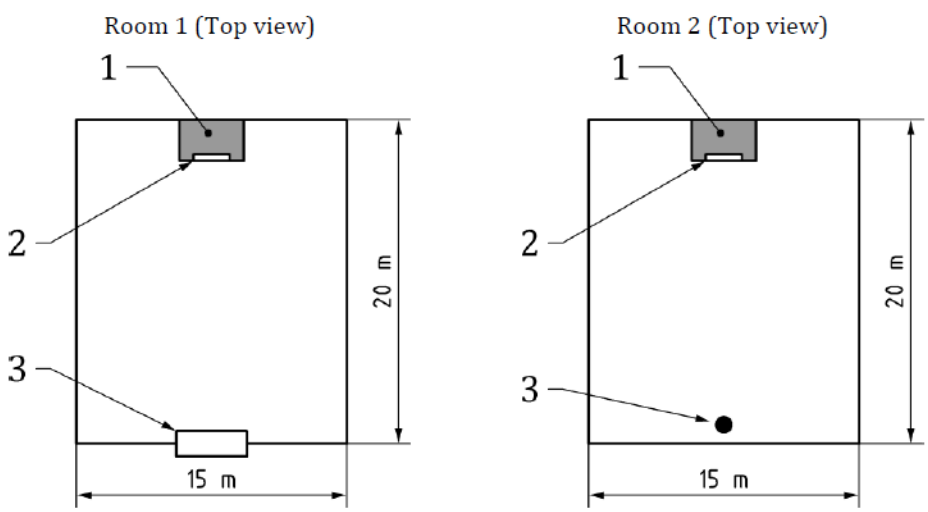
Construct two rooms, namely room 1 and room 2, placed at different heights having a floor to floor inter - distance equal to 3.5m (see Figures 68 and 69). Place a lift connecting the two rooms in accordance to Figures 68 and 69. Insert a 1m wide exit in room 1.



Key

1 Room 1
2 Room 2
3 Elevator shaft
4 Elevator door
5 Initial location of the agent
6 Exit

Figure 68: Test 20 Geometric Layout - Side View.



Key

1 Elevator
2 Elevator door
3 Exit

Key

1 Elevator
2 Elevator door
3 Initial location of the agent

Figure 69: Test 20 Geometric Layout - Top View.

The MassMotion model consists of two 15m x 20m floors connected via one or more elevators. Entry and exit portals are located at one end of each floor respectively.

23.3 Scenario(s)

Two scenarios are considered. In each scenario one or more lifts connect rooms 1 and 2. Lifts are the only egress component available for evacuation. Lifts begin at room 1, can be called to room 2 to pick up an agent, and then carry the occupant to room 1. Each lift has a maximum capacity of one so can only carry one agent at a time. The two scenarios are as follows:

- Scenario 1: One lift connects room 1 and room 2 (See Figure 70). A single occupant with an unimpeded walking speed of 1m/s and pre - evacuation time equals to 0s is placed in room 2.
- Scenario 2: Two lifts connect room 1 and room 2 (See Figure 71). Three occupants with an unimpeded walking speed of 1m/s and pre-evacuation time equal to 0s are placed in room 2.

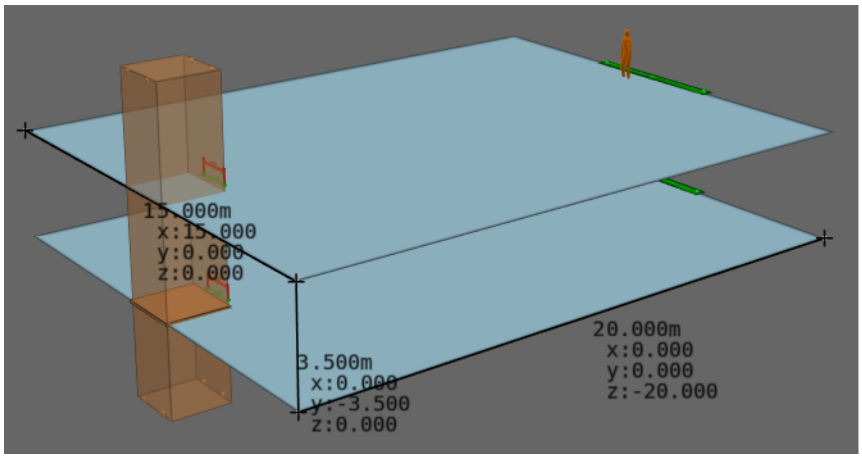


Figure 70: Test 20 Physical Environment for Scenario 1.

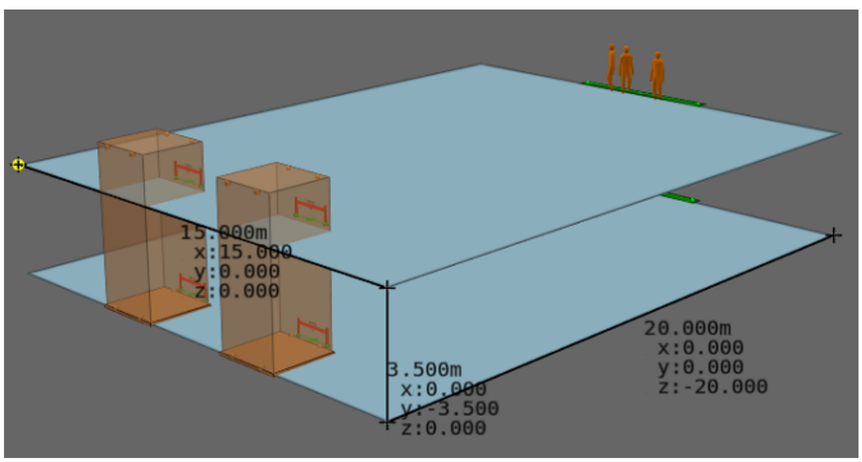


Figure 71: Test 20 Physical Environment for Scenario 2.

23.4 Expected result

Each occupant enters a lift in room 2. A lift will only carry one occupant at a time and will discharge that same occupant in room 1. Lifts will return to room 2 to pick up additional occupants as required until all agents have evacuated. If possible, this evaluation can be performed using the visualization tool of the model.

23.5 Test method

The test method is a qualitative verification of model assignment, i.e. the ability of the model to simulate evacuation using lifts.

23.6 User action

Lifts are configured with a maximum capacity of one and are given room 1 as the starting location. MassMotion default values are used to define lift kinematics :

- Maximum speed of 1m/s;
- Maximum acceleration of 1m/s^2;
- Constant jerk of 0.8 m/s^3;
- Door opening time of 1.9s;
- Door closing time of 2.9s.

23.7 Test Result

Figure 72 provides a visual plot of the path of the agents in both scenarios. The vertical rectangle represents the elevator. The plot shows agents moving across room 2, boarding a lift, traveling down, and then leaving the lift and crossing room 1 to the exit.

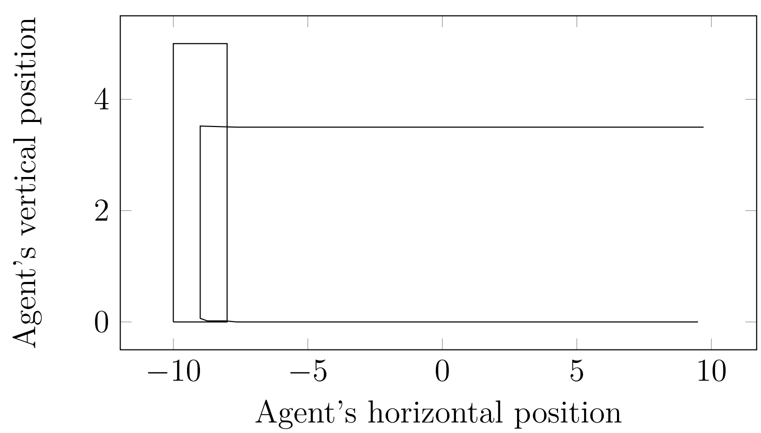


Figure 72: Test 20 Simulated Agent Route Map - Side View

Figure 73 shows a histogram of agent exit times from scenario 2. Two agents were able to board a lift immediately on arrival at room 2. Both lifts were then at capacity. The third agent had to wait for one elevator to carry an agent to room 1 and then return to room 2. The third agent's exit time is therefore delayed by 30 seconds.

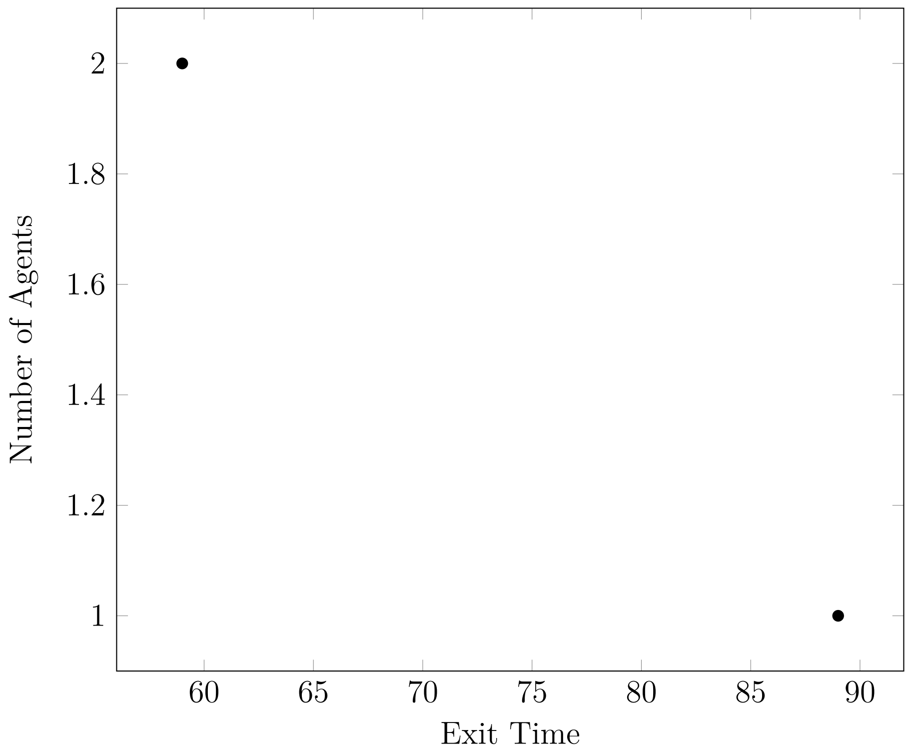


Figure 73: Test 20 Histogram of Simulated Agent Exit Times for Scenario 2

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

24 Test 21: Escalator usage

24.1 Objective

Assess consistency between the escalator usage assignment and model representation.

24.2 Geometry

Construct two floors at two different levels (floor 0 and floor 1) connected by an escalator (height = 3m, diagonal = 4.24m, angle = 45°, width of the escalator = 2m) as shown in Figure. 74.

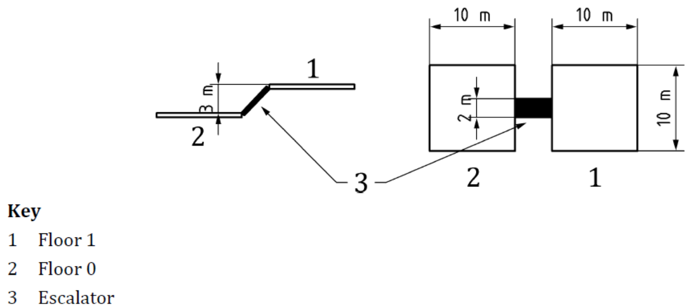


Figure 74: Test 21 Geometric Layout (top view on the left side and side view on the right side).

The MassMotion model for each test case, consists of:

- 2 floors (10m x 10m);
- 1 escalator connecting the floors (height = 3m, length = 3m, diagonal = 4.24m, angle = 45^0);
- an entrance portal on one floor, set to distribute agents on the portal area.
- an exit portal on the other floor.

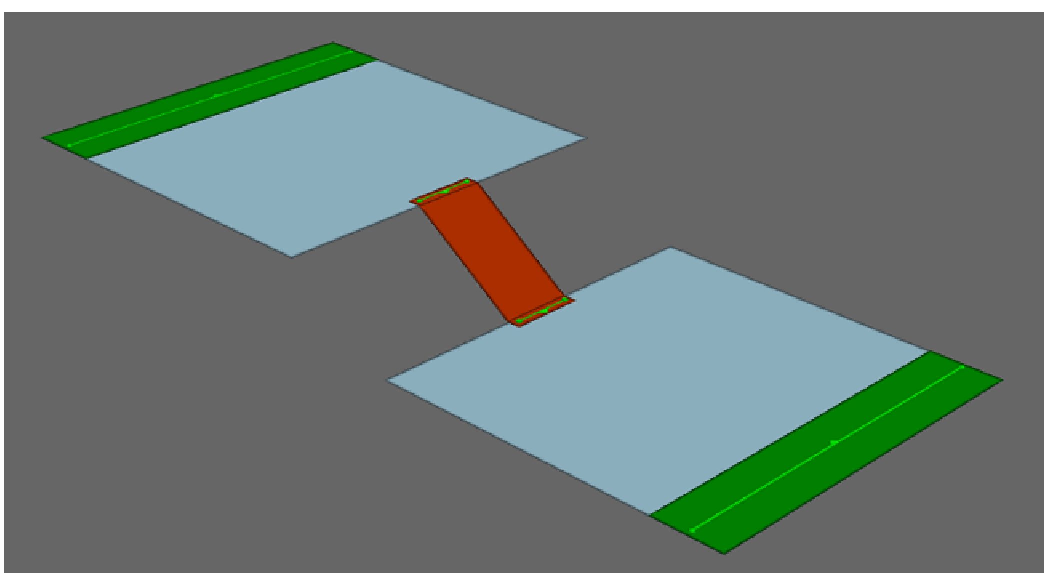


Figure 75: Test 21 Physical Environment

24.3 Scenario(s)

Two scenarios are considered:

- Scenario 1 (Escalator Down) - the flow goes from the upper floor to the lower floor.
- Scenario 2 (Escalator Up) - the flow from the lower floor to the upper floor.

In both scenarios, one occupant with pre-evacuation time equals to 0s and initial walking speed equals to 1m/s travels from one floor to the other using the escalator. A modified user defined speed on the escalators (different than 1m/s) is defined by the model tester.

24.4 Expected result

The final speed of the occupant on the escalator is modified to take into account the speed of the escalator.

24.5 Test method

The test method is a quantitative verification of speeds on escalators in the different configurations (escalator down and escalator up).

24.6 User action

The default MassMotion value of 0.65m/s is used for the escalator's tread speed.

24.7 Test Result

MassMotion does not allow agents to walk while riding an escalator. Thus, testing the ability of the model to simulate proportions of walkers/riders and side preference behaviour is out of the scope of this test.

While riding the escalator, regardless of the direction of travel, the agent's speed is set to match the horizontal component of the escalator's tread speed using the below formula.

$$\text{Speed on Escalator} = \text{Tread Speed along Incline} \times \cos(\text{Rise Angle})$$

An escalator tread speed of 0.65m/s and a rise angle of 45 degrees results in an adjusted horizontal speed of 0.45m/s. Agent speed is always measured along the horizontal. Therefore agents will travel with a speed of 0.45m/s when riding the escalator. Figures 76 and 77 show agent's walking speed throughout the simulation. The dip in the plot shows the agent's adjusted speed while riding the escalator.

The results indicate that MassMotion is able to reproduce the results stated in the ISO/DIS 20414:2020 guidance given the configured parameters of the model.

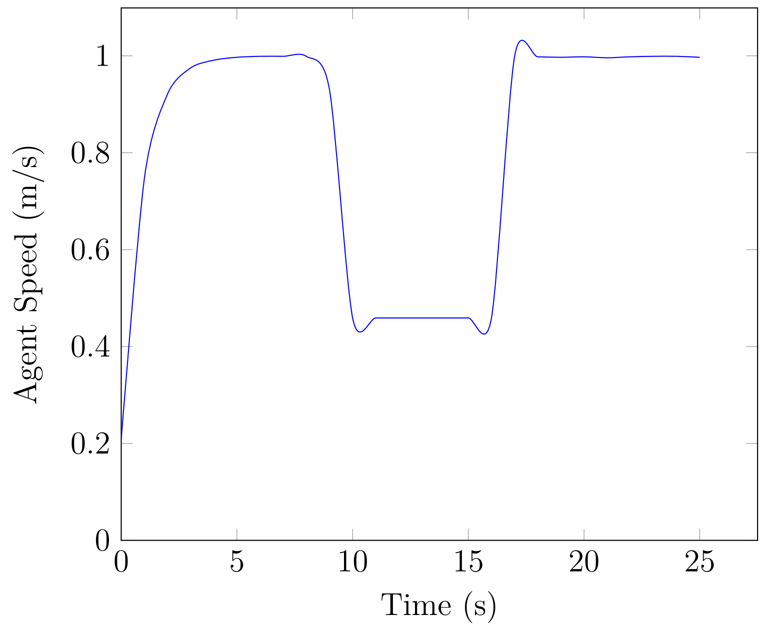


Figure 76: Test 21 Scenario One (Escalator Down) Agent Speed

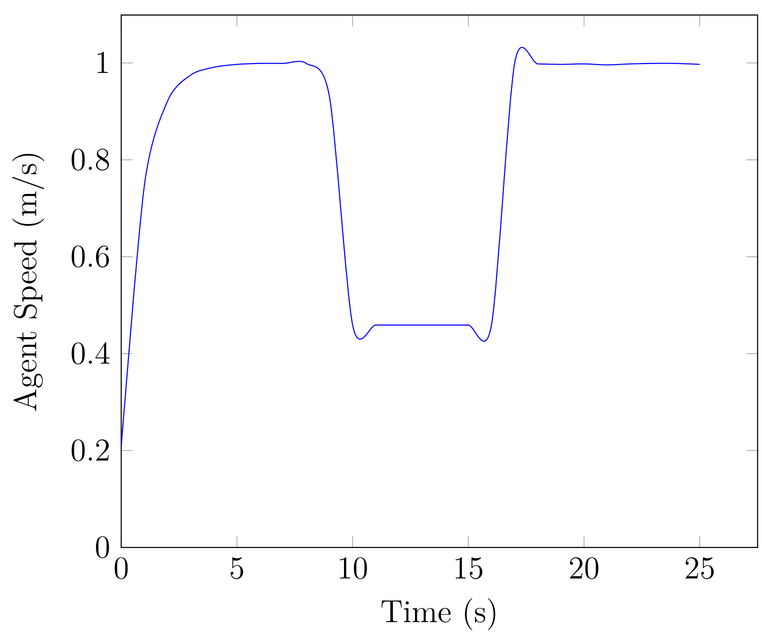


Figure 77: Test 21 Scenario Two (Escalator Up) Agent Speed