Verification Testing of MassMotion 11.8 for IMO Circ 1533 / NIST TN 1822

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 development 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 IMO Circ 1533 / NIST TN 1822, 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).

Tests 1-14 represent a standard set of evacuation modelling verification tests performed in accordance with:

- International Maritime Organisation (IMO) Circ. 1533 Appendix 2 (2016);
- National Institute of Standards (NIST) Technical Note 1822.

Sensitivity testing has been applied to some of the verification tests to demonstrate the sensitivity of the prediction to changes in input parameters.

Additionally, testing of aspects of the model not included within the IMO 1533 and NIST Technical Note 1822 verification tests has been conducted in tests 15 and 16.

The verification tests (presented in Appendix A) are classified into the following aspects of human behaviour:

- pre-movement behaviour;
- travel speed;
- physicality;
- decision making;

- crowd dynamics.

Note that three of the tests specified in NIST 1822 cannot be completed within MassMotion as the software does not currently have functionality to explicitly/directly represent the requirements.

- Test 2.5 - Reduced Visibility versus Walking Speed;
- Test 2.6 - Occupant Incapacitation;
- Test 2.9 - Group Behaviour.

The full range of verification tests undertaken is presented in Table 1.

ID	Title	Category	NIST /IMO	Sensi- tivity	Status
1	Corridor Walking Speeds	Speed	Yes	No	Pass
2&3	Stair Walking Speeds	Speed	Yes	Yes	Pass
4	Exit Flow Rates	Crowd	Yes	Yes	Pass
5	Pre-evacuation Time	Pre-evacuation	Yes	No	Pass
6	Movement Around Corners	Physicality / Crowd	Yes	No	Pass
7	Assignment of Parameters	Decision	Yes	No	Pass
8	Counter-flow	Crowd	Yes	No	Pass (See Test)
9	Crowd Exit Usage	Decision	Yes	No	Pass
10	Exit Allocation	Decision	Yes	No	Pass
11	Stair Congestion	Crowd	Yes	No	Pass
12	Movement Disabilities	Physicality / Crowd	Yes	Yes	Pass
13	Affiliation	Decision	Yes	No	Pass
14	Dynamic Availability of Exits	Decision	Yes	No	Pass
15	Stair Merging	Crowd	No	Yes	Pass
16	Stair Flows	Crowd	No	Yes	Pass
17	Elevator Usage	Crowd	Yes	No	Pass

Table 1: Summary of MassMotion Verification Tests

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.

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.

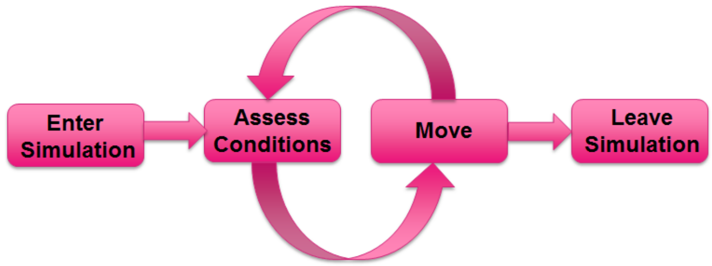

Figure 1: MassMotion Reflexive Movement Process

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)	$(0° < X < 27°)$: 42.5 $(27° \leq X \leq 32°)$: 42.5 – 37.8 $(X > 32°)$: 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 $27° \leq X \leq 32°$.)
	Stair (Down – Stair Angle X) Impact on Agent Speed (% of Preferred Horizontal Terrain Walking Speed)	$(0° < X < 27°)$: 57.4 $(27° \leq X \leq 32°)$: 57.4 – 49.8 $(X > 32°)$: 49.8	
	Ramp (Up – Ramp Angle X) Impact on Agent Speed (% of Preferred Horizontal Terrain Walking Speed)	$(0° < X < 5°)$: 100 $(5° \leq X \leq 10°)$:88.5 $(10° \leq X \leq 20°)$:88.5-75.0 $(20° < X)$: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).

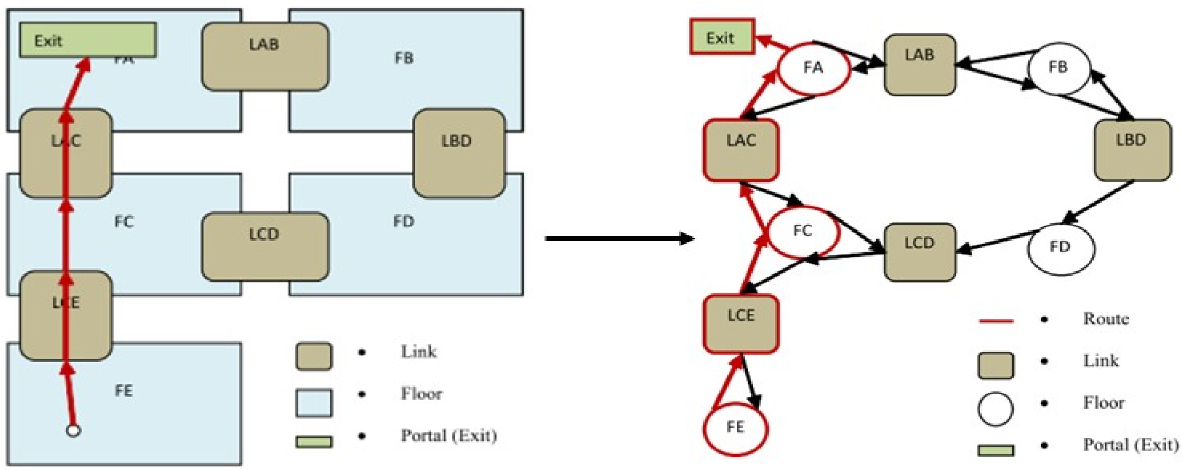

Figure 2: MassMotion Translation of a Floor / Link System into a Network

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).

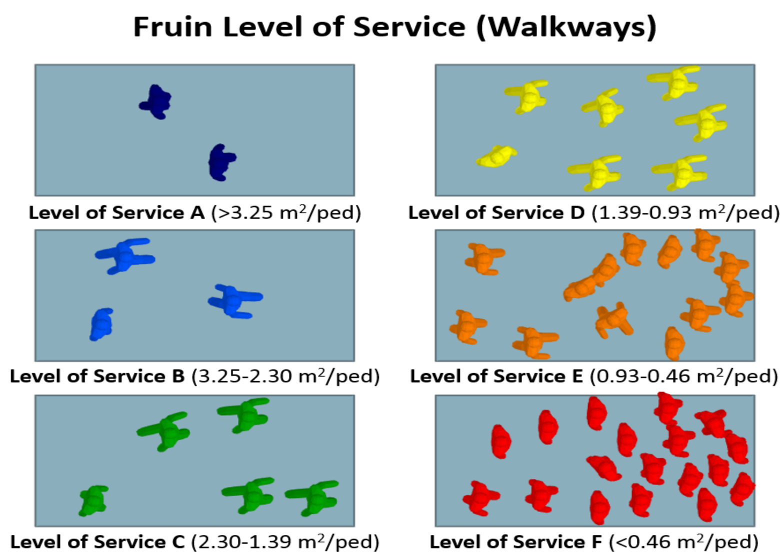

Figure 3: Illustration of Fruin 'Levels of Service (Walkways)'

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].

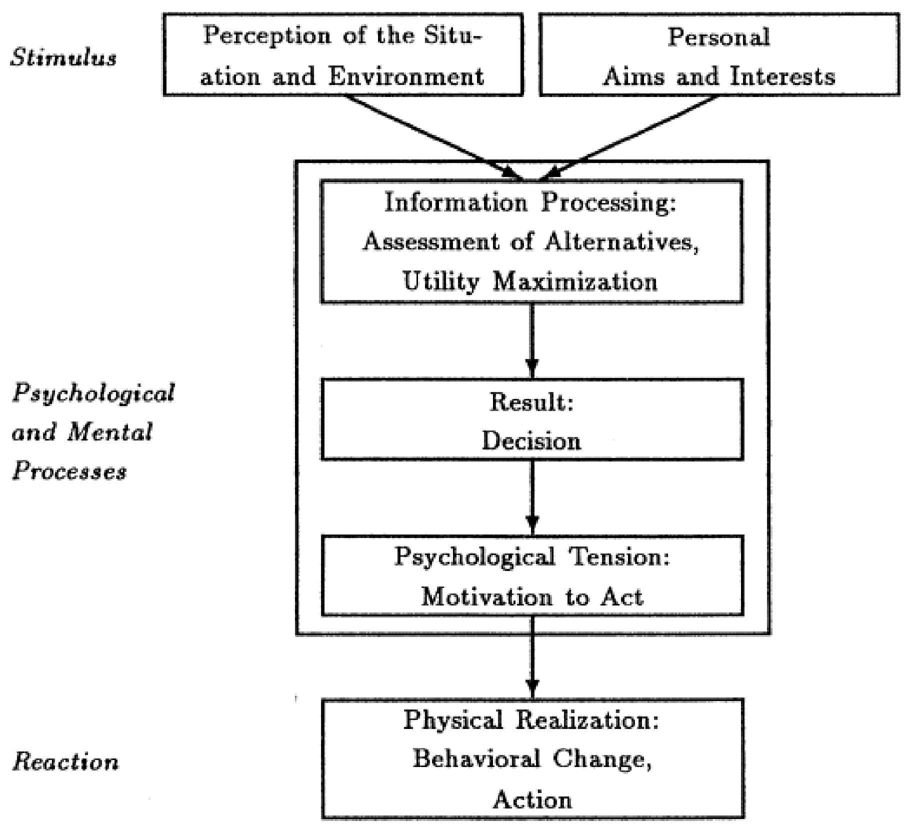

Figure 4: Schematic Representation of Processes Leading to Behavioural Changes

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

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4 Test 1: Corridor Walking Speeds

4.1 Test Description

The test is in accordance with IMO 1533 Test 1 and NIST 1822 Test 2.1.

This test is used to verify that the model is able to represent an agent maintaining an assigned speed over time. (This is a critical aspect during the calculation of the Required Safe Egress Time of a building.)

The test utilises a walking speed that is representative of the walking speed of an adult (1m/s) and a length of corridor that is sufficient to test if the assigned agent speed is maintained over time.

4.2 Aim of Test

The purpose of the test is to demonstrate that an agent can move along a corridor at a constant walking speed.

4.3 Simulation Setup

The geometry consists of:

- a corridor 2m wide by 45m long;
- an entry portal at one end of the corridor;
- an exit portal at the other end of the corridor.

A journey was simulated where the agent travels from the entry portal to the exit portal.

The agent was assigned a preferred walking speed of 1.0m/s.

Within MassMotion, agents accelerate / decelerate to the preferred walking speed at a default rate of $3m/s^2$. To achieve a walking speed of 1.0m/s, the agent needs to travel 0.333m to reach the desired walking from a standing start. Two cordon lines are located along the corridor and separated exactly 40m from each other. The portals are offset from the cordon lines by a minimum of 0.333m to allow for the acceleration / deceleration of the agent.

The model is shown in Figure 5.

4.4 Test Results

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

4.5 Conclusion

The IMO 1533 Test 1 and NIST 1822 Test 2.1 has been conducted using MassMotion.

The procedures for the test stated in the IMO and NIST guidance are identical and only one simulation was considered.

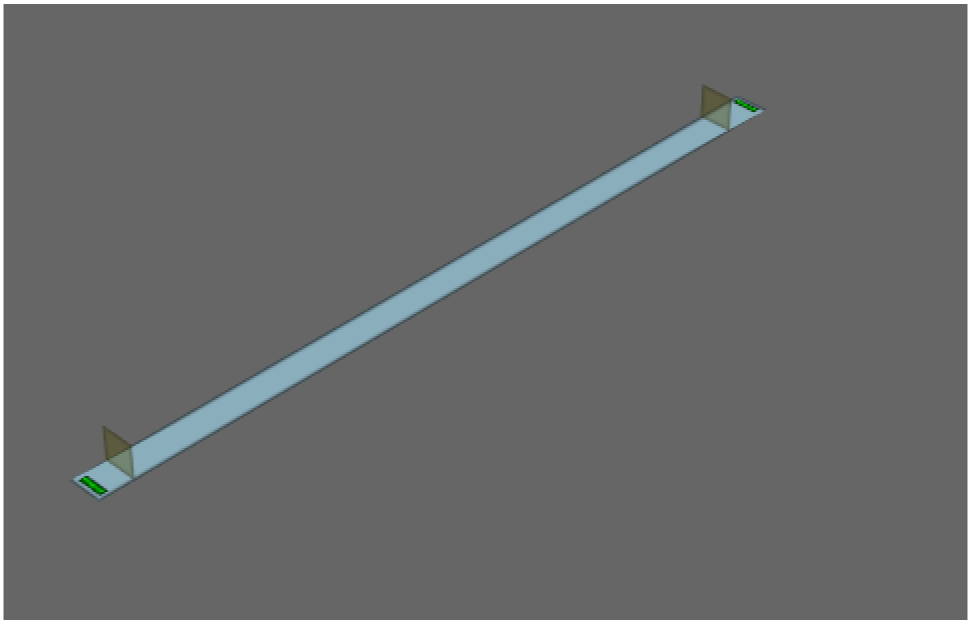


Figure 5: Test 1 Physical Environment

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters of the model.

Status: Pass

5 Test 2&3: Stair Walking Speeds

5.1 Test Description

The tests are in accordance with IMO 1533 Tests 2 and 3 and NIST 1822 Test 2.2.

The purpose of the test is to demonstrate that agents can move up or down a stair at a constant walking speed of 1 m/s.

The IMO 1533 tests state that a 10m stair should be used; the NIST 1822 test states that a 100m stair should be used. In all other respects, the tests are identical. Furthermore, both tests use the same MassMotion agent model. On this basis, the NIST 1822 Test 2.2 has been undertaken; it is considered that this test is suitable for demonstrating that the intent of IMO 1533 Test 2 and 3 is satisfied.

MassMotion applies a factor to the preferred level terrain walking speed of the agent to derive the preferred (horizontal) speed of the agent on the stairs. The default factors adopted in MassMotion are outlined in Table 7.

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 7: MassMotion Default Agent Attributes for Stairs

Three stairs, each with a different incline (as defined in Table 8), were assessed. Inclines close to 27^o and 32^o were avoided in order to avoid calculation rounding and potential migration of the factor into adjacent ranges.

Incline (degrees)	Length (m)	Height (m)	Traverse (m)
15.0	100.0	25.882	96.593
29.5	100.0	49.242	87.036
45.0	100.0	70.711	70.711

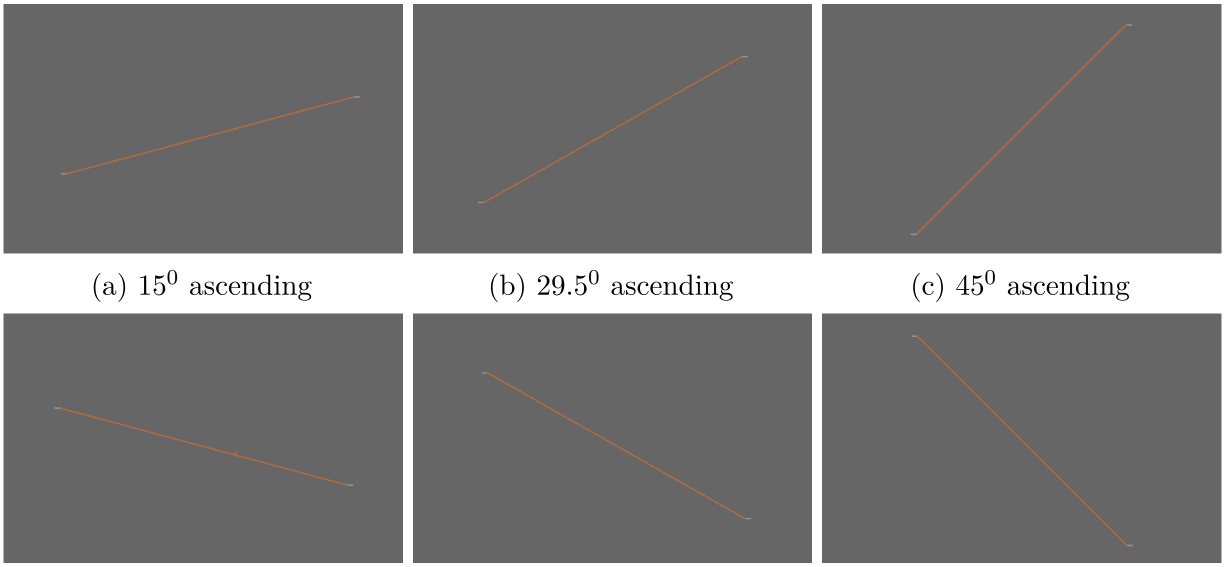
Table 8: Test 2 Stair Inclines (and Dimension) Adopted

5.2 Aim of Tests

The purpose of the test is to demonstrate that an agent can move up or down a stair at a pre-defined constant walking speed.

5.3 Simulations Setup

6 simulations are created, each with a 100m long and 2m wide stair with inclines of 15^o, 29.5^o and 45^o, (See Table 8). 2 simulations are used for each incline angle, once for ascending and once for descending.



(a) 15^0 ascending (b) 29.5^0 ascending (c) 45^0 ascending

(d) 15^0 descending (e) 29.5^0 descending (f) 45^0 descending

Figure 6: Test 2 Stair Layouts

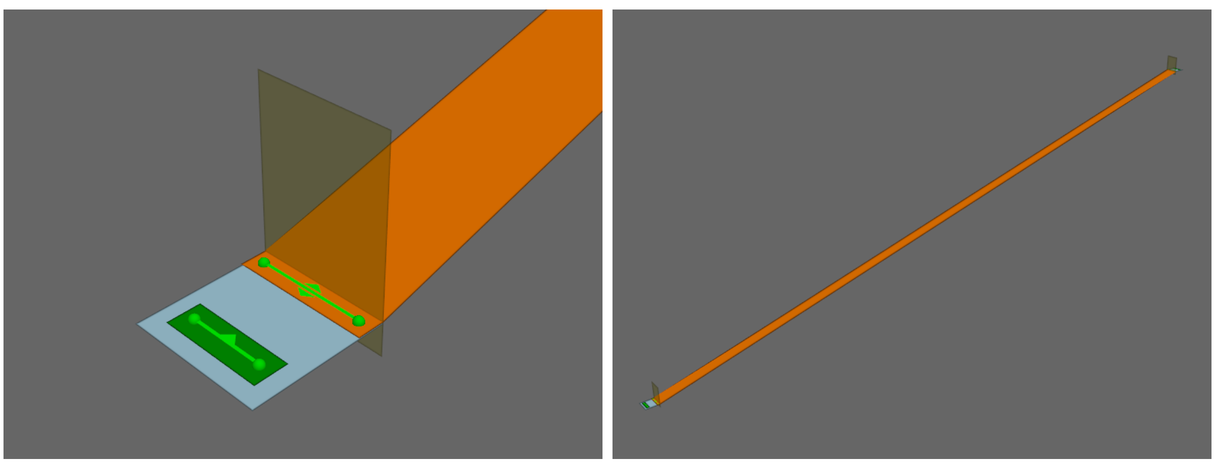


Figure 7: Test 2 Physical environment, 15^o ascending.

A 2m wide floor was created at each end of each stair. A portal was created on each floor. (See Figures 6 and 7.)

The test requires that agents walk at a constant speed of 1m/s up / down each stair. MassMotion derives the preferred horizontal walking speed on the stair from the product of the preferred level terrain (horizontal) walking speed and the factor appropriate to the stair incline and the direction of travel (up / down). Therefore, the agent preferred level terrain (horizontal) walking speed, S_{PLT}, is calculated from

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

(See Table 9.)

The agent attributes (e.g. constant speed) and 'journey' event were defined.

For Test 2, agents are generated by entry portals at the base of the stairs and the goal is set as the exit portals at the top of the stairs. For Test 3, agents are generated by entry portals at the top of the stairs and the goal is set as the exit portals at the base of the stairs.

Cordon lines at the base and top of each stair were created to monitor the agent journey times.

5.4 Test Results

The MassMotion results and results are documented in Table 9.

Test	**Stair Incline**	**Preferred Level Terrain Walking Speed (m/s)**	**Expected Stair Travel Time (s)**	**Measured Stair Travel Time (s)**
2	15.00 ascending	2.27	100	99.80
2	29.50 ascending	2.17	100	100.00
2	45.00 ascending	1.87	100	100.20
3	15.00 descending	1.68	100	100.00
3	29.50 descending	1.62	100	100.00
3	45.00 descending	1.42	100	100.00

Table 9: Tests 2&3 MassMotion Results

5.5 Conclusion

The NIST 1822 Test 2.2 has been conducted using MassMotion.

The results indicate that MassMotion is able to reproduce the results stated in the NIST guidance given the configured parameters of the model.

Status: Pass.

6 Test 4: Exit Flow Rates

6.1 Test Description

This test comprises of two parts:

Part 1: A test in accordance with IMO 1533 Test 4 and NIST 1822 Test 5.2 to verify that the flow rate of a link / door is capped at an assigned value. (1.33 people/m/s is adopted for this study.)

Part 2: A sensitivity study to determine the peak unrestricted (non-capped) flow rates of a link / door for a variety of widths (800mm, 900mm, 1000mm, 1100mm, 1200mm, 1400mm, and 1500mm) predicted by the MassMotion model.

6.2 Aim of Tests

Part 1: The purpose of the test is to demonstrate that the capped flow rate at the link / door is not exceeded.

Part 2: The purpose of the test is to determine the sensitivity of the MassMotion model peak flow rate prediction as a function of link / door width.

6.3 Simulation Setup

An 8m x 5m primary floor with 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.

The total room occupancy is 100 agents. The pre-evacuation time is set to 0 seconds, and the preferred travel speeds are the MassMotion default speeds (between 0.65m/s and 2.05m/s).

Part 1: The 1m link is defined to have a capped flow rate of 1.33people/s. Figure 8 shows the initial setup with agents starting on the primary floor.

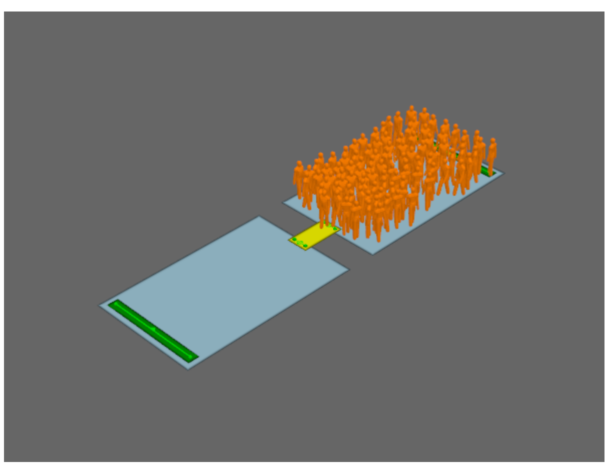


Figure 8: Test 4 Part 1 Physical Environment.

Part 2: 7 separate simulations are run, each identical to Part 1 apart from:

- the link flow rate is not capped;

- alternative link widths (800mm, 900mm, 1000mm, 1100mm, 1200mm, 1400mm, and 1500mm) are considered.

Figure 9 shows the layouts of each simulation for part 2. Note: each layout is in a separate simulation.

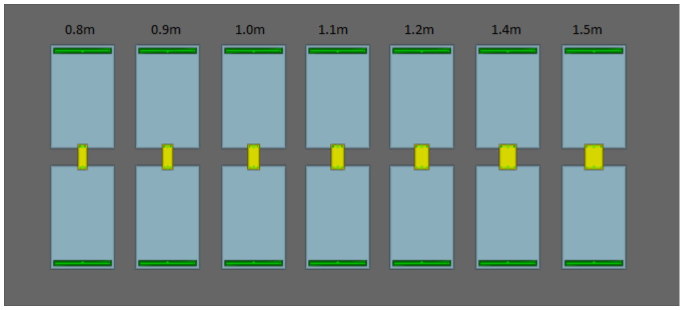


Figure 9: Test 4 Part 2 Sensitivity Cases.

6.4 Test Results

Part 1: Figure 10 illustrates the time averaged flow rate at the link.

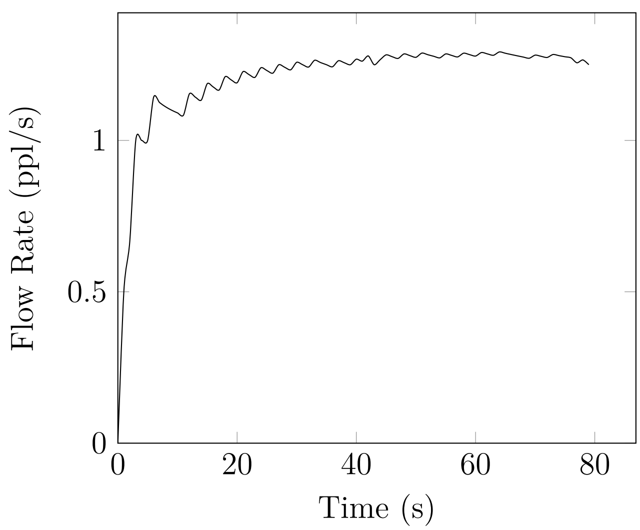


Figure 10: Test 4 Part 1 Average Flow Rate (People/s)

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 1.33 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.

It is possible for the time averaged flow rates to exceed 1.33people/s while the actual flow rate is correct. For example: a capping flow rate of 1.33 agents/second translates into a minimum delay between agents using the link of 0.75seconds, i.e. there must be at least 0.75seconds between consecutive agents moving through the link. If the first three agents pass through the link at 0.1s, 0.85s and 1.65s and the time averaging calculation uses 1s intervals, then:

- at 1s, the time average is calculated to be 2persons/s (the first and second agents have passed through the link);
- at 2s, the time average is calculated to be 1.5people/s.

Part 2: Figure 11 illustrates the time averaged flow rate at the link for varying link widths.

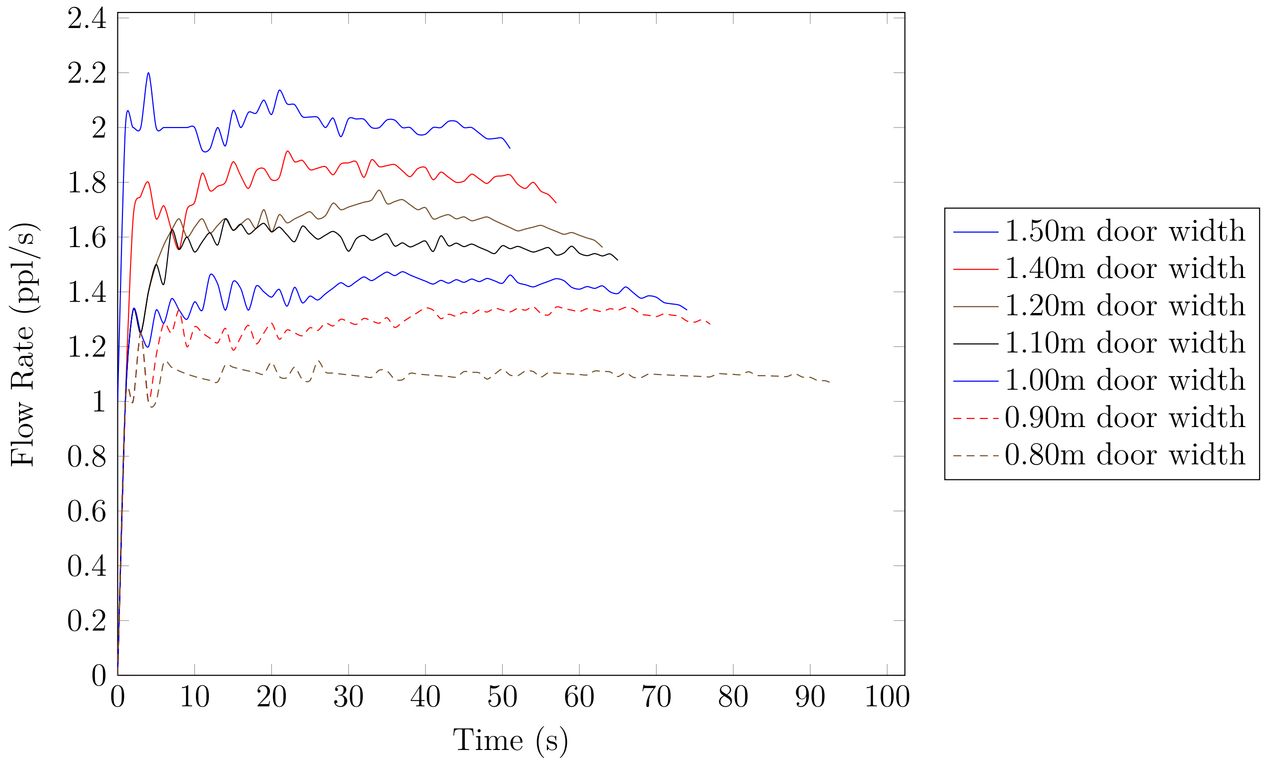


Figure 11: Test 4 Part 2 Average Flow Rate (People/s)

The MassMotion results illustrated in Figure 11 follow similar trends as in Part 1, with a gradually tapering flow rate. Some link widths also exhibit the flow rate averaging measurement calculation 'spike' previously described. The pre-evacuation time is represented appropriately, as the first person exits the room in the first second in each case.

The 'steady' flow rate was measured as the average flow rate at the halfway point between flow beginning and the final agent crossing the link. This should be sufficient to mitigate effects from the initial spike and the final tapering of flow.

The 'steady' flow rates for each link width are then divided by the width to find the flow rate per unit of width (people/m/s). The average of these flow rates per unit width is 1.40786 people/m/s.

Table 10 shows how this average flow rate per unit width relates to the flow rates predicted by MassMotion.

The average flow rate of 1.40786 people/m/s is slightly higher than values reported in other studies. Fruin indicates that the common peak flow rate per unit of width for a general public population is 82people/m/min $\approx$ 1.37 people/m/s. This can be explained in part by the initial spikes in flow rate and errors in time averaged flow rate calculations (explained in Part 1).

Door Width (m)	Average Flow Rate per Unit Width (people/m/s)	Average Flow Rate by Door Width (people/s)	MassMotion Predicted 'Steady' Flow Rate (people/s)
0.80	1.41	1.13	1.10
0.90	1.41	1.27	1.32
1.00	1.41	1.41	1.47
1.10	1.41	1.55	1.59
1.20	1.41	1.69	1.73
1.40	1.41	1.97	1.87
1.50	1.41	2.11	2.04

Table 10: Test 4 Average Flow Rate per Unit Width Estimates

The measured flow rates follow the expected trend in that there is an increase in flow rate with the increase in link width. This relationship is examined in Table 11 and Figure 12.

The increase in uncapped flow rate is approximately linearly proportional to increase in link width.

Door Width (m)	Increase in Width (%)	Increase in Flow Rate (%)
0.80	-20.0%	-25.1%
0.90	-10.0%	-10.1%
1.00	0.0%	0.0%
1.10	10.0%	7.8%
1.20	20.0%	17.2%
1.40	40.0%	26.7%
1.50	50.0%	38.2%

Table 11: Test 4 Increase in Uncapped Flow Rate by Increase in Link Width

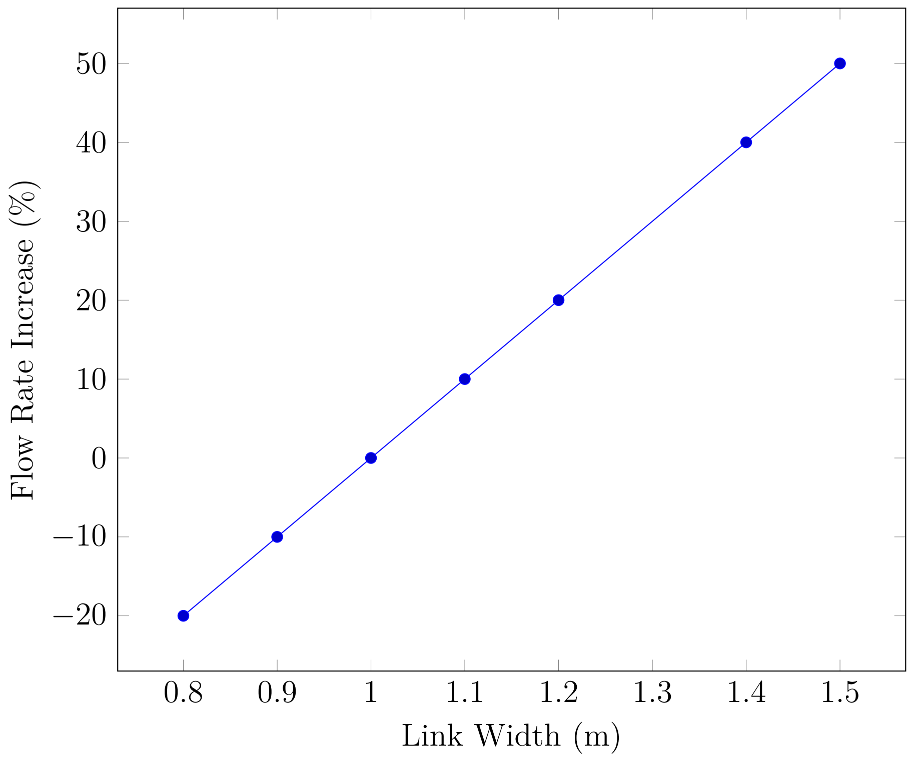


Figure 12: Test 4 Part 2 Flow Rate Increase by Link Width

6.5 Conclusion

The IMO 1533 Test 4 and NIST 1822 Test 5.2 have been conducted using MassMotion.

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters of the model.

Status: Pass.

7 Test 5: Pre-evacuation Time

7.1 Test Description

The test is in accordance with IMO 1533 Test 5 and NIST 1822 Test 1.1.

Ten persons are located on a 8m x 5m floor having a 1.0 m link (located centrally on the 5m wall). Pre-evacuation times are imposed randomly from a uniform probability distribution within a range from 10s to 100s.

The purpose of the test is to demonstrate that each occupant starts to move at the specified time.

The IMO 1533 and NIST 1822 tests have identical physical environments. The IMO 1533 test specifies a uniform distribution of pre-evacuation times while the 1822 test further requires normal and log-normal distributions.

7.2 Aim of Tests

This test considers the representation of the pre-evacuation time within the MassMotion evacuation model. The aim of the test is to verify that each occupant starts to move at the time specified and that the range of times for multiple agents are consistent with the distribution employed.

7.3 Simulations Setup

10 agents are created instantly at the beginning of the simulation by an evacuate event.

The MassMotion 'evacuate' event automatically creates a 'Wait' action (i.e .pre-evacuation time) followed by 'Seek Portal' and 'Exit' actions.

It is currently not possible to output the pre-evacuation time for each agent directly from MassMotion. Instead, the simulation is modified so that the pre-evacuation wait can be indirectly measured.

The evacuation event has its demand set to 'Instant' so that agents are created instantly at the beginning of the simulation. The movement type of the agent's initial floor is set to 'Virtual' so that agents finished their pre-evacuation wait are instantly moved to the link to the exit floor.

Thus, the time agents move to the link, an easy to output value, is exactly the pre-evacuation wait time.

The IMO 5 and NIST 1.1 tests specify a uniform distribution for pre-evacuation wait. The NIST test also requires any default pre-evacuation time distributions to be tested. The distributions with appropriate values selected for the test are described below:

- Uniform: Min = 10, Max = 100
- Triangular: Min = 10, Max = 100, Mode = 55
- Normal: Min = 10, Max = 100, Mean = 55, Std = 20
- Log-normal: Shift = 10, Max = 100, Mu = 3.516, Sigma = 0.901

50 simulation runs are performed for each distribution, each with a different random seed. The time agents move to the link are recorded (ie. 500 samples per distribution).

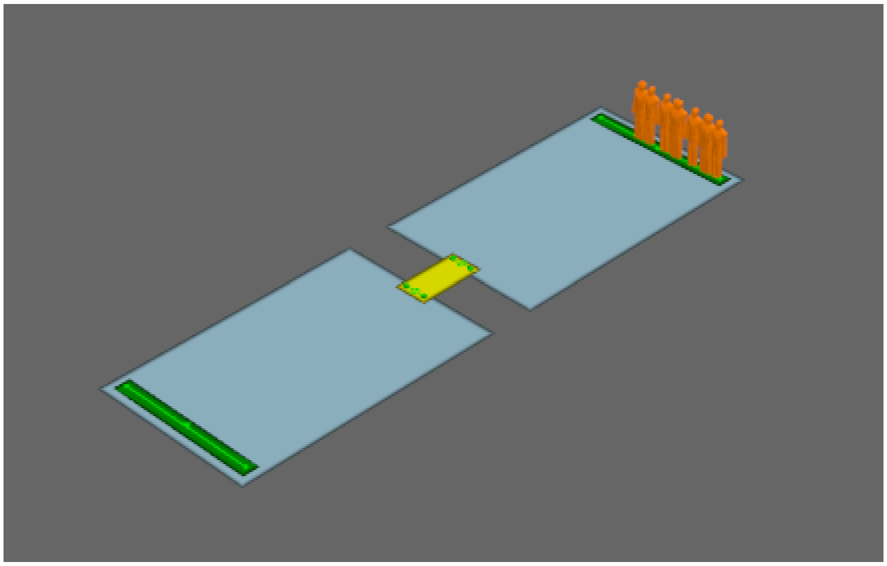


Figure 13: Test 5 Physical Environment.

7.4 Test Results

For each distribution type, 50 simulations of 10 agents are run and the pre-evacuation times are recorded.

The results are summarized in Table 12. Histograms and cumulative distribution plots of pre-evacuation times for each distribution are shown in Figures 14 to 21.

Distribution	Minimum	Maximum	Average (Mean)	Standard Deviation
Uniform	10.40	100.00	53.79	26.74
Triangular	14.00	97.20	54.21	19.02
Normal	12.40	97.60	54.45	17.50
Log-normal	12.40	96.60	43.59	21.45

Table 12: Test 5 Distribution Results Summary

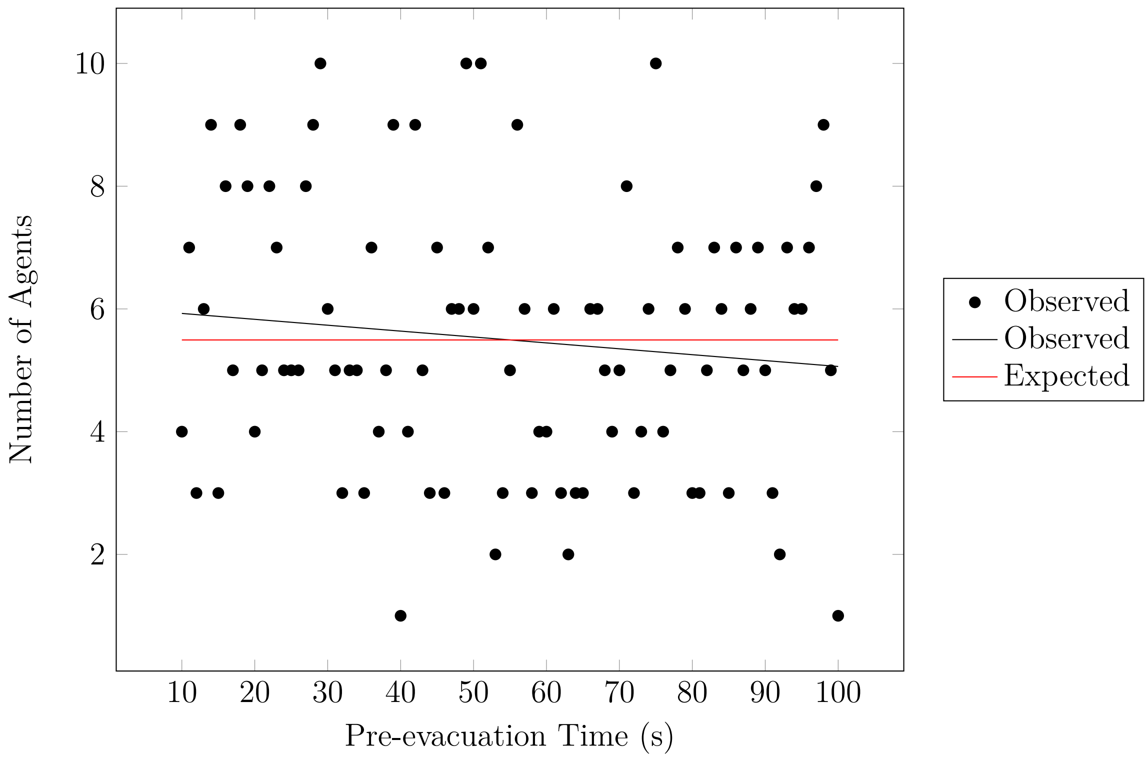


Figure 14: Test 5 Uniform Distribution Histogram

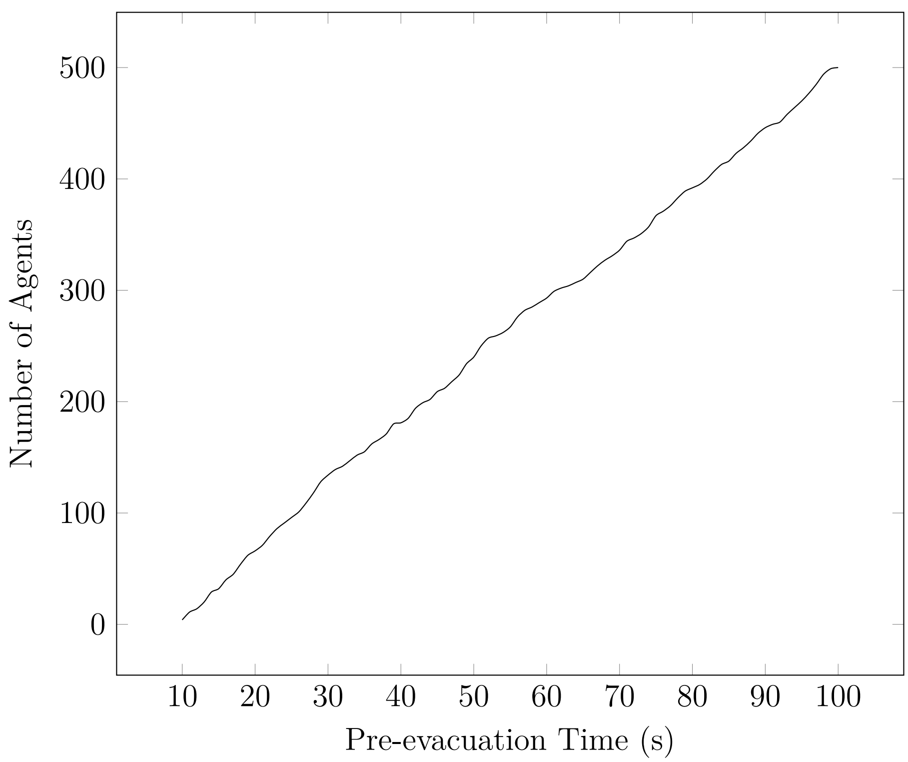


Figure 15: Test 5 Uniform Distribution Cumulative Graph

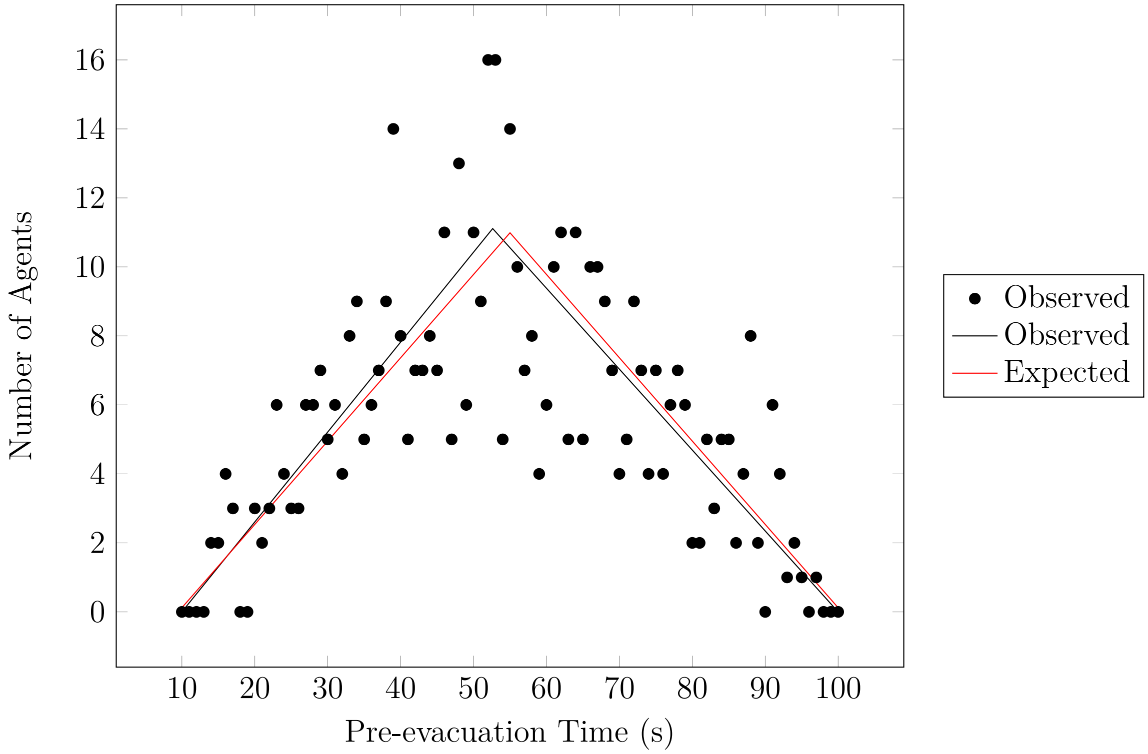


Figure 16: Test 5 Triangular Distribution Histogram

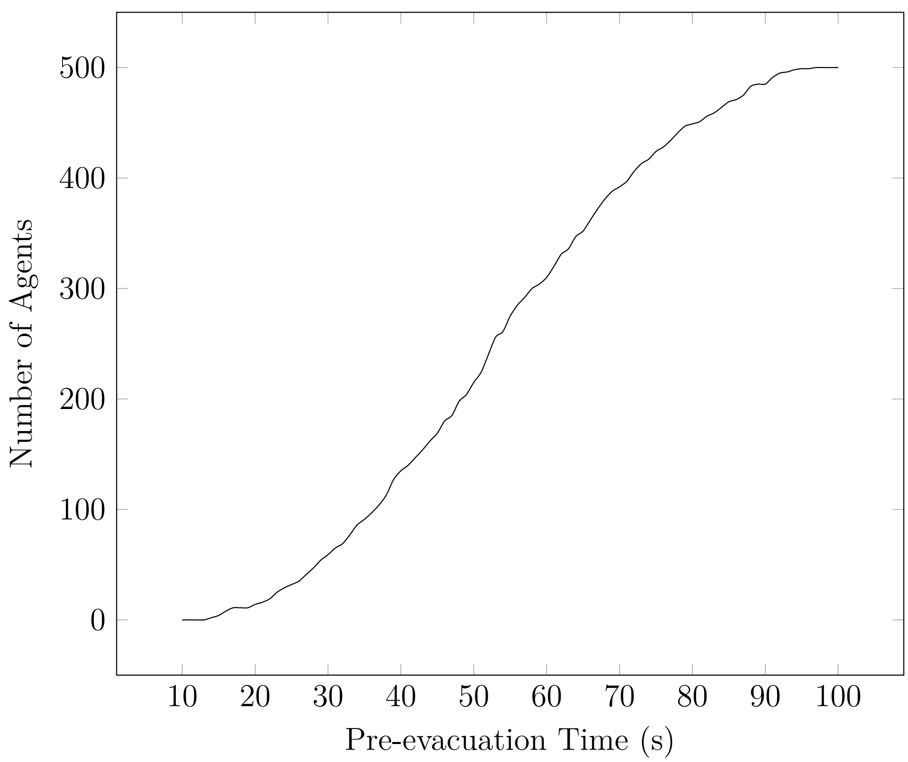


Figure 17: Test 5 Triangular Distribution Cumulative Graph

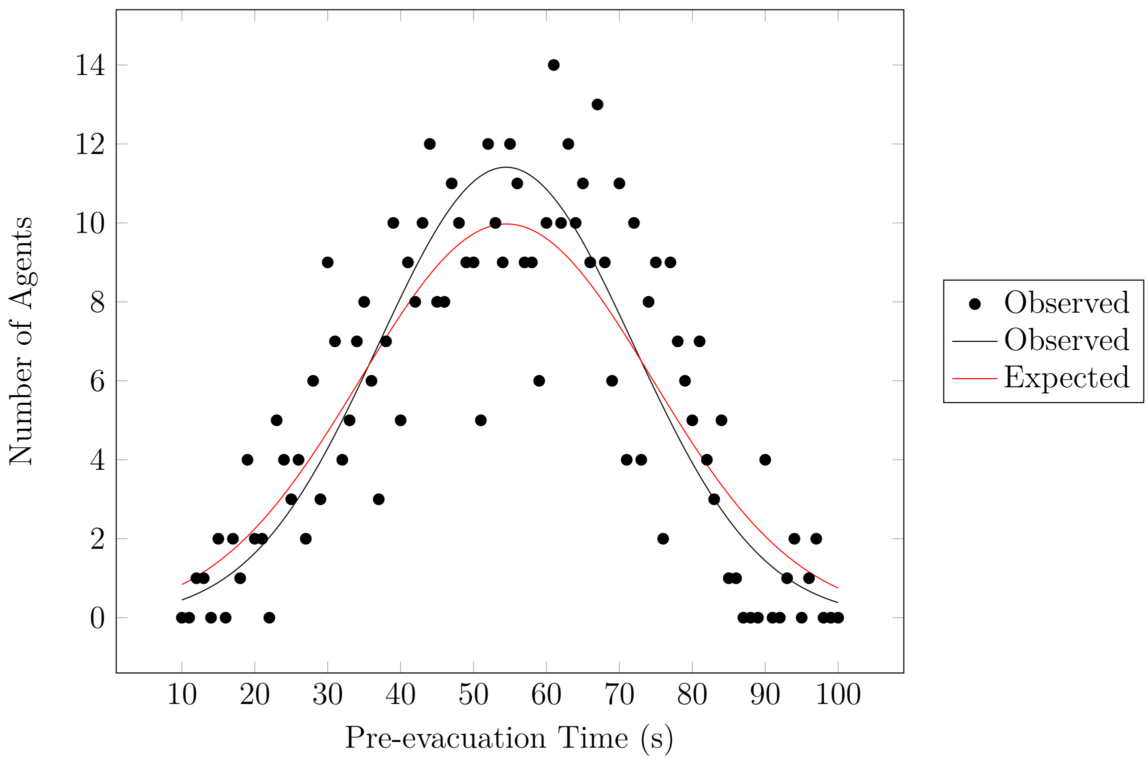


Figure 18: Test 5 Normal Distribution Histogram

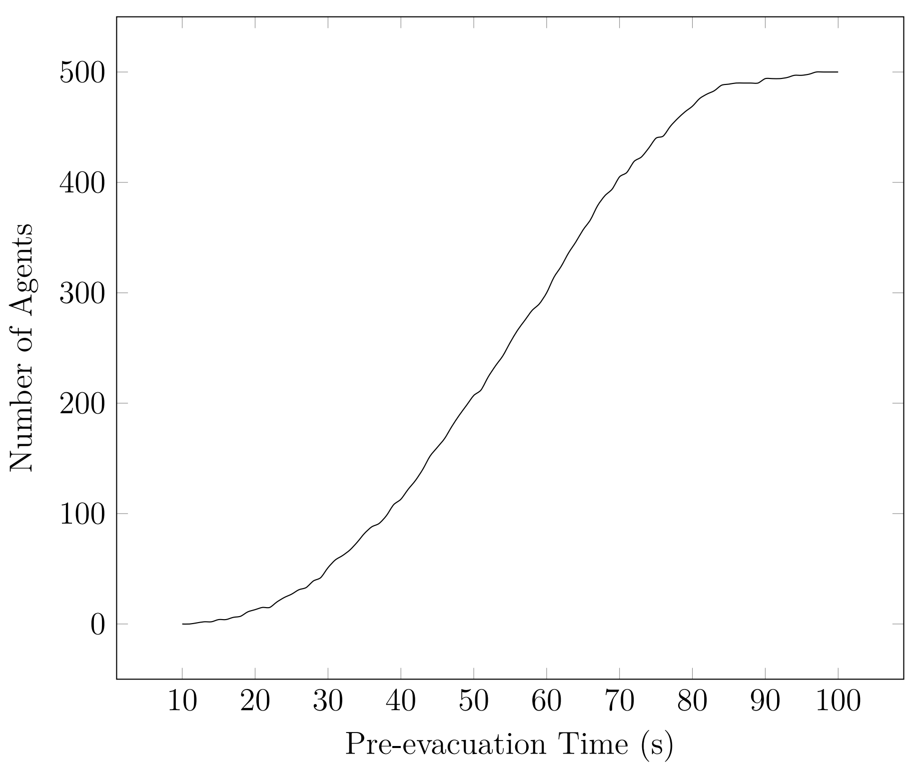


Figure 19: Test 5 Normal Distribution Cumulative Graph

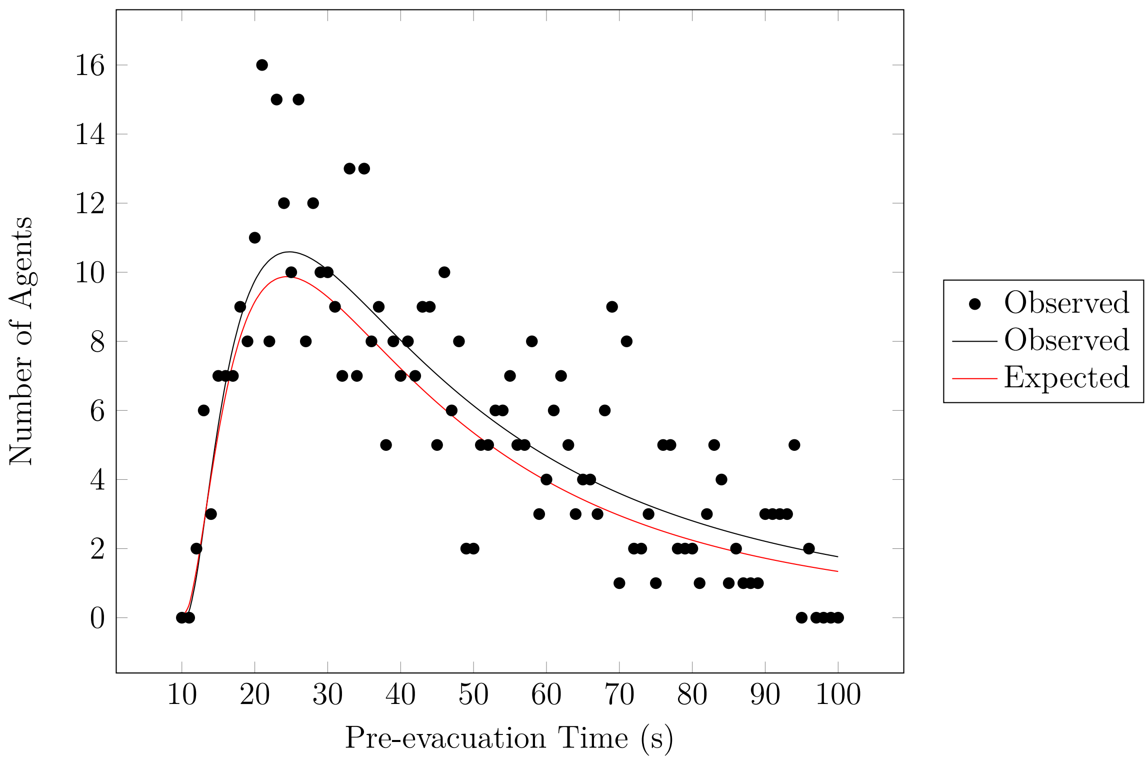


Figure 20: Test 5 Log-normal Distribution Histogram

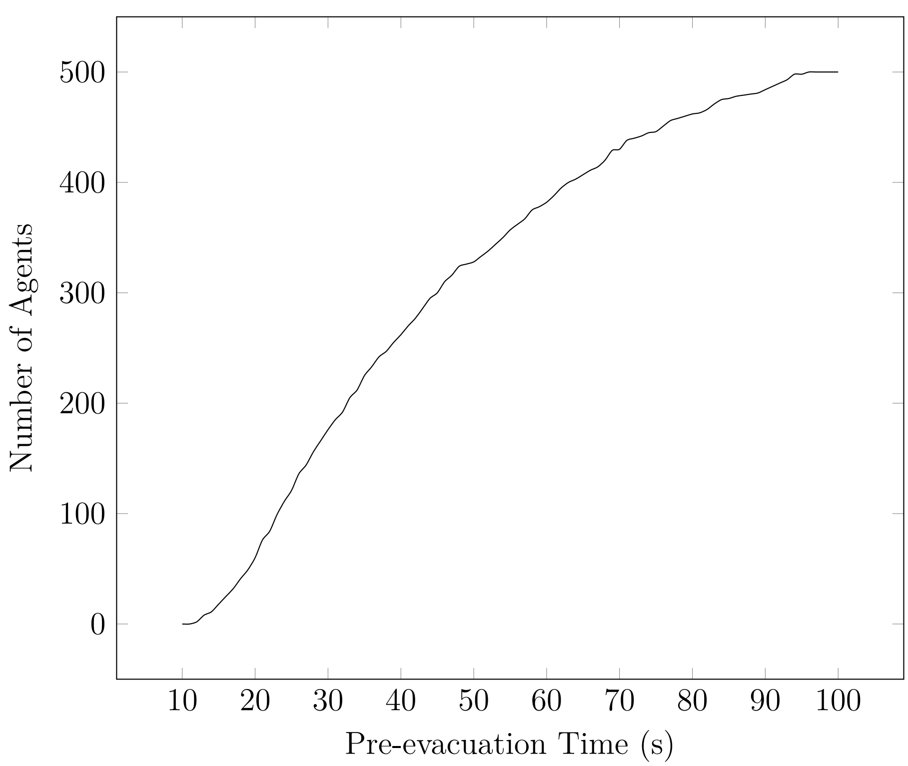


Figure 21: Test 5 Log-normal Distribution Cumulative Graph

7.5 Conclusion

The IMO 1533 Verification Test 5 and NIST Verification test 1.1 has been conducted in the MassMotion evacuation model.

Results from the test indicate MassMotion is able to produce comparable results to those stated in the IMO and NIST guidance given the configured parameters of the model.

Status: Pass.

8 Test 6: Movement Around Corners

8.1 Test Description

The test is in accordance with IMO 1533 Test 6 and NIST 1822 Test 2.3.

The test is based on a right angle corridor having dimension as illustrated in Figure 22.

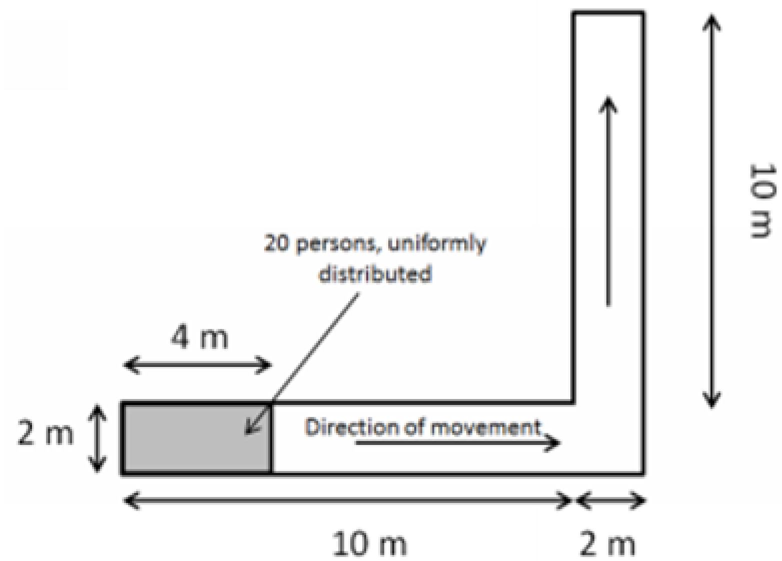


Figure 22: Test 6 Geometric Layout.

Twenty persons, uniformly distributed and having immediate pre-evacuation times and a preferred horizontal terrain walking speed of 1 m/s, occupy one end of the corridor.

The test is a qualitative verification of the agent movement, performed by observing the agent travel path.

8.2 Aim of Test

The purpose of the test is to verify that the twenty agents approach the corner and successfully navigate around it without penetrating the boundaries of the physical environment.

8.3 Simulation Setup

The geometrical layout of the IMO 1533 Test 6 and NIST 1822 Test 2.3 are identical.

A single geometry floor area was created, consisting of a 2m x 4m area appended to a 2m x 8m area and a 2m x 10m area at a 90^o angle to the first floor (as Figure 22).

An entry portal was assigned to the 2m x 4m floor with the agent placement set to 'Inside Portal'.

An exit portal was created at the end of the corridor remote from the entry portal.

An agent profile with constant preferred horizontal walking speed of 1m/s and having no direction bias was created.

A population of 20 agents (with the agent profile described) was uniformly distributed across the 2m x 4m area at the beginning of the simulation.

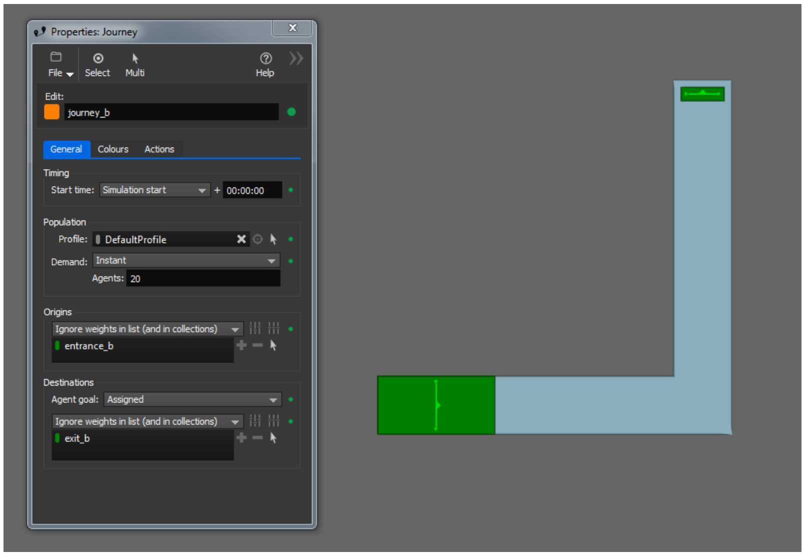


Figure 23: Test 6 Physical Environment and 'Journey' Properties.

8.4 Test Results

Figure 24 illustrates the simulated agent journeys at key times during the simulation

The predicted agent co-ordinate positions sampled per second is illustrated in Figure 25.

These demonstrate that:

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

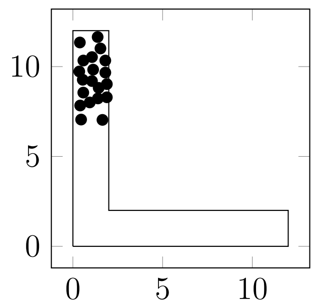
8.5 Conclusion

IMO 1533 Verification Test 6 and NIST 1822 Test 2.3 have been conducted within MassMotion.

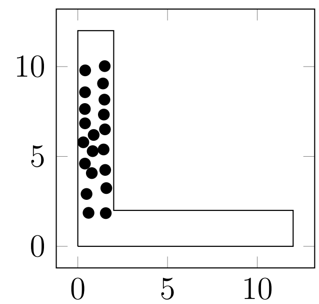
Analysis of the test results indicated that all 20 agents navigated the corner geometry without penetrating the boundaries.

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters of the model.

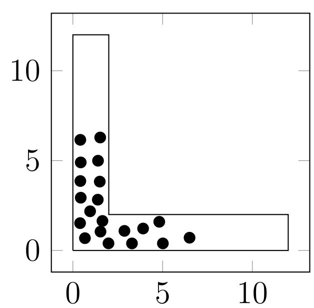
Status: Pass



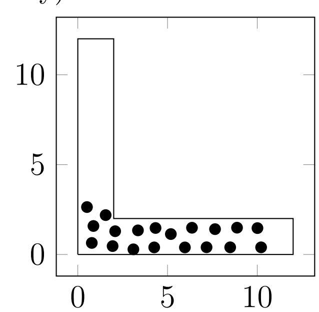
(a) Time 1s - All 20 agents entered simulation within the 2m x 4m entry portal.



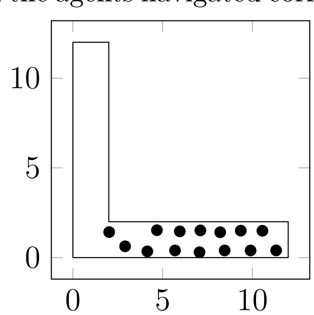
(b) Time 6s - First agent reaches the corner at this time (approximately).



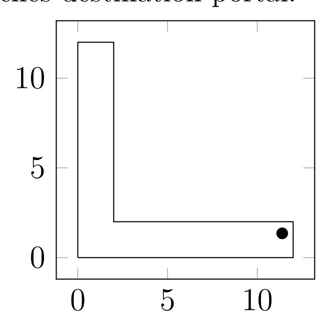
(c) Time 11s - Approximately half the agents navigated corner.



(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 24: Test 6 Agent Movement Around Corners

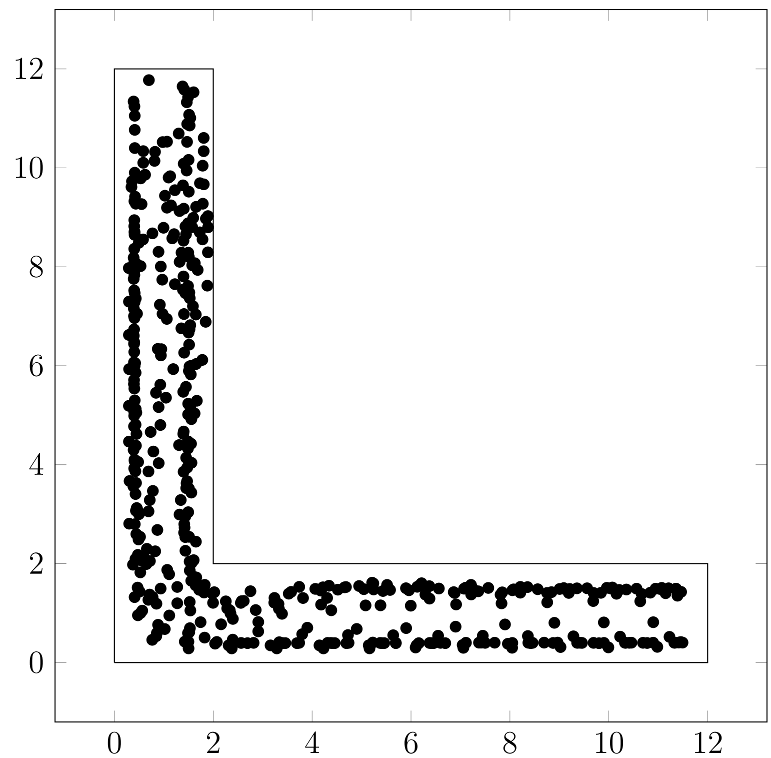


Figure 25: Test 6 MassMotion Agent Co-ordinate Positions

9 Test 7: Assignment of Parameters

9.1 Test Description

The test is in accordance with IMO 1533 Test 7 and NIST 1822 Test 2.4.

The test assigns a preferred horizontal terrain walking speed to a population of 100 agents. The preferred horizontal terrain walking speeds are selected at random from a uniform probability distribution (ranging from 0.97m/s to 1.62m/s - see IMO 1533 population panel 'Males 30-50'). The aim is to confirm that the assigned preferred horizontal terrain walking speed is consistent with the uniform probability distribution.

9.2 Aim of Test

The purpose of the test is to demonstrate that MassMotion is able to correctly assign agent demographic parameters (including the preferred horizontal terrain walking speed).

9.3 Simulation Setup

The physical environment consists of a single 10m x 10m floor with portals on either end.

Please note that NIST 1822 Test 2.4 specifies a 100 m x 100 m space. Given agent population in this test a space of 10m x 10m has been modelled.

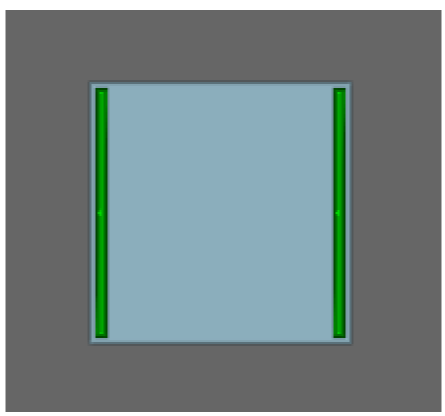


Figure 26: Test 7 Physical Environment

An IMO 1533 'Males 30-50' agent profile was created.

A 'journey' event with a population of 1000 agents was created using the profile, going from one portal on the floor to the other.

All other parameters not identified above were assigned the MassMotion default values.

9.4 Test Results

The simulation is run and the preferred horizontal terrain walking speed of agents of the 1000 agents is recorded. The minimum, maximum and mean values are summarized in Table 13.

	Expected	**Observed**
Minimum	0.97	0.97
Maximum	1.62	1.62
Mean	1.29	1.30
Variance	0.04	0.04

Table 13: Test 7 Preferred Horizontal Terrain Walking Speed

Figure 27 illustrates the number of agents assigned preferred horizontal terrain walking speeds, divided into 20 ‘buckets’ and the expected distribution curve.

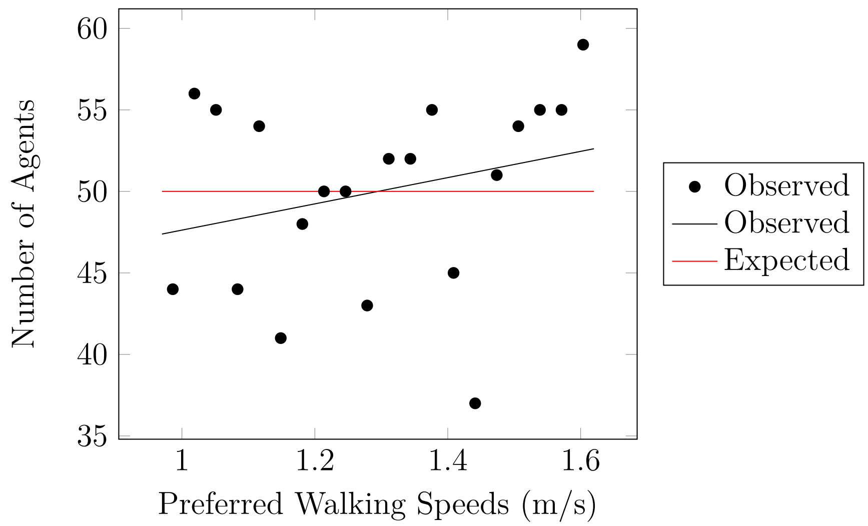


Figure 27: Test 7 Assigned Preferred Horizontal Terrain Walking Speeds

A chi-squared test with 20 buckets is used to check for uniform distribution and yields a test statistic of 13.16 . This is less than the critical value of 30.144 for a 95% confidence.

From this we conclude that the distribution of agent walking speeds is as specified in the simulation setup.

9.5 Conclusion

IMO 1533 Test 7 and NIST 1822 Test 2.4 have been conducted within MassMotion.

The procedures for the test stated in the IMO and NIST guidance are identical and only one simulation was considered.

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters of the model.

Status: Pass

10 Test 8: Counter-flow

10.1 Test Description

The test is in accordance with IMO 1533 Test 8 and NIST 1822 Test 2.8.

Two 10m x 10m floors are connected via a 10m x 2m floor (corridor) connected to the centre of one side of each floor at the mid-points of one of its boundaries.

The test assigns a preferred horizontal terrain walking speed to a population of 100 agents. The preferred horizontal terrain walking speeds are selected at random from a uniform probability distribution (ranging from 0.97m/s to 1.62m/s - see IMO 1533 population panel 'Males 30-50'). The agents are located at a preferred density of 4persons/m^2 at the side of the floor of one of the rooms remote from the corridor.

Scenario 1 requires the agents to pass through the corridor to an exit from the second floor remote from the corridor, as illustrated in Figure 28.

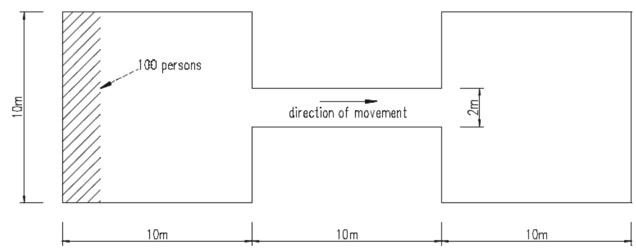


Figure 28: Test 8 Geometric Layout.

Six further scenarios, summarised in Table 14, are considered. 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 (Males)	Right	Strong
3	50 (Males)	Right	Strong
4	100 (Males)	Right	Strong
5	100 (Females)	Right	Strong
6	100 (Males)	Right	Weak
7	100 (Males)	None	Not Applicable

Table 14: Test 8 Scenarios

10.2 Aim of Test

The purpose of the test verify the ability of MassMotion to simulate counter-flow and its possible impact on evacuation time.

10.3 Simulation Setup

Two 10m x 10m floors are connected via a 10m x 2m floor (corridor) connected to the centre of one side of each floor at the mid-points of one of its boundaries.

2m links connect the corridor to the floors at each end.

An 'entry' portal is used to fill a 2.5m x 10m region of the left floor with 100 persons at a density of 4persons/m2. A matching 'exit' portal is created at the far right boundary of the right floor. (Counterflow agents will be have their 'entry' and 'exit' portals reversed.)

The preferred horizontal terrain walking speeds is derived from the IMO 1533 guidelines (based on random assignment from a uniform probability distribution within the minimum and maximum speeds for the relevant population group as defined in Table 15.

Group	IMO 1533 Population	Minimum Speed (m/s)	Maximum Speed (m/s)
Females	Females 30-50	0.71	1.19
Males	Males 30-50	0.97	1.62

Table 15: IMO 1533 Preferred Horizontal Terrain Walking Speed

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 14. The direction bias is applied to agents originating on either floor.

The MassMotion model of Scenario 1 is illustrated in Figure 29.

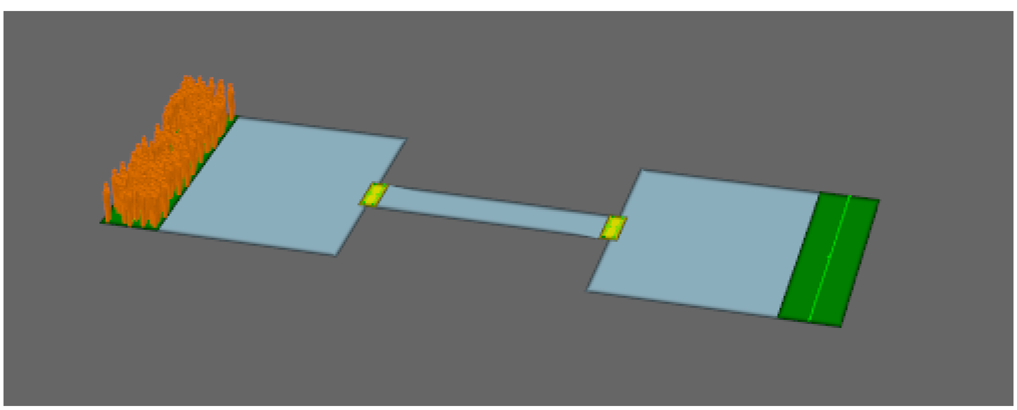


Figure 29: Test 8 Physical Geometry and Agent Population for Scenario 1.

10.4 Test Results

Table 16 lists 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	63.00
2	102.20
3	239.20
4	277.60
5	221.60
6	lock-up
7	lock-up

Table 16: Test 8 Clearance time for agents from the left floor

The agents in scenarios 6 and 7 do not actually complete their journey's and are instead 'locked-up' by congestion.

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 and 5 demonstrate that lock-up does not occur when 'strong' directional bias is assigned to agents originating on either side of the counter-flow.

Scenarios 5 demonstrates that a counterflow with a different speed does not prevent counter flows from navigating around each other.

Scenario 6 demonstrates that lock-up occurs even when 'weak' directional bias is assigned to agents originating on either side of the counter flow.

Scenario 7 demonstrates that lock-up occurs when directional bias is not assigned to agents originating on either side of the counter-flow.

Figures 30 to 36 illustrate the simulation results at key times for the seven scenarios considered. Note that the agents starting in the left room are coloured **red** while those starting in the right room are coloured **blue**.

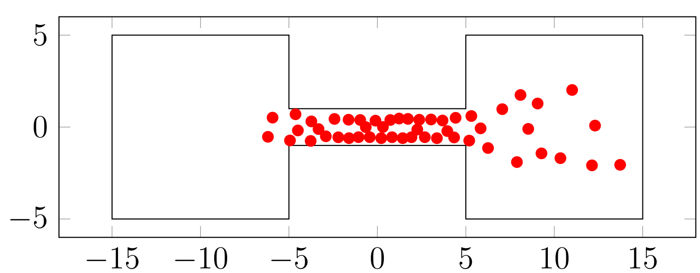


Figure 30: Test 8 Scenario 1 Agent Positions (at 47 seconds)

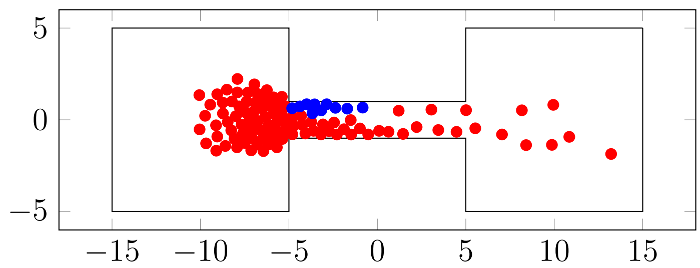


Figure 31: Test 8 Scenario 2 Agent Positions (at 25 seconds)

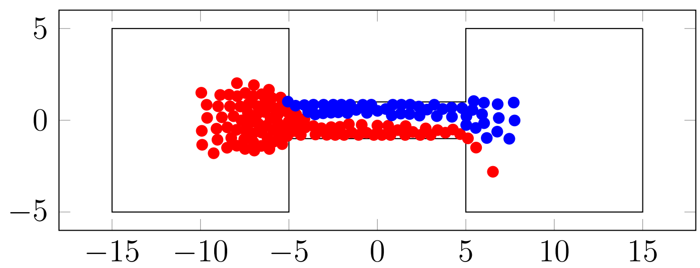


Figure 32: Test 8 Scenario 3 Agent Positions (at 25 seconds)

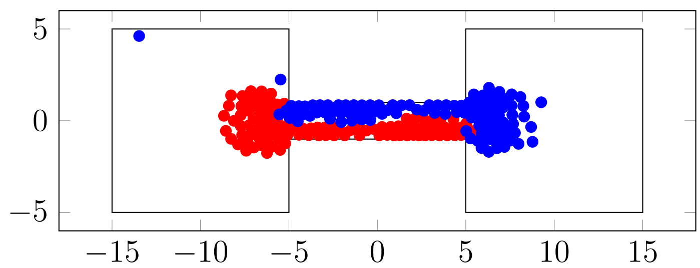


Figure 33: Test 8 Scenario 4 Agent Positions (at 38 seconds)

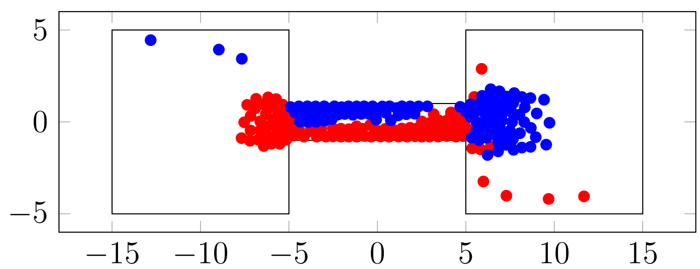


Figure 34: Test 8 Scenario 5 Agent Positions (at 53 seconds)

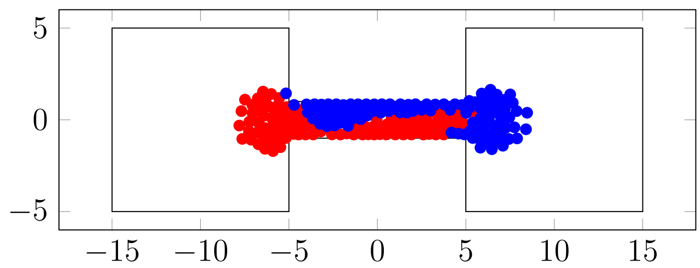


Figure 35: Test 8 Scenario 6 Agent Positions (at 57 seconds)

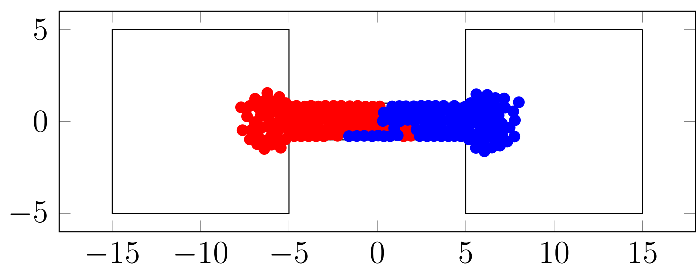


Figure 36: Test 8 Scenario 7 Agent Positions (at 54 seconds)

10.5 Conclusion

IMO 1533 Test 8 and NIST 1822 Test 2.8 have been conducted within MassMotion.

'Lock-up' (where agents are unable to transfer from one floor to the other) occurred in those cases where the flow comprises of a large numbers of agents having a 'direction bias' strength defined as 'weak' or no direction bias at all. MassMotion **is not** verified for use when large numbers of agents are involved in counter-flow situations and the 'directional bias' is defined to be 'weak' or 'none'.

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters of the model. (Specifically, that the time for the last agent originating in left floor to enter the right floor increases with the number of agents in the counter-flow.). MassMotion **is** verified for use when large numbers of agents are involved in counter-flow situations and the 'directional bias' is defined to be 'strong'.

Status: Pass. (Conditional - Subject to Appropriate Setting of 'Direction Bias').

11 Test 9: Crowd Exit Usage

11.1 Test Description

The test is in accordance with IMO 1533 Test 9.

The test considers a 30m x 20m floor having 4 x 1000mm exits. 1000 agents are uniformly distributed over the central 26m x 16m of the floor. See Figure 37.

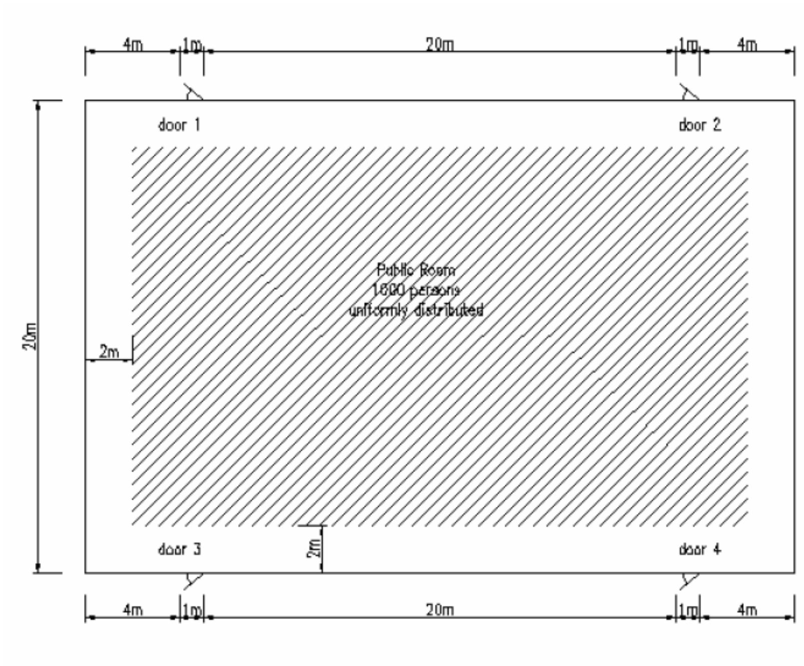


Figure 37: Test 9 Geometric Layout.

Two scenarios are considered:

- Scenario 1 - all 4 exits are open;
- Scenario 2 - only exits '3' and '4' are open;

The test examines the MassMotion exit selection algorithm.

11.2 Aim of Test

The purpose of the test is to verify that agents will assess the exit conditions (location, size, business) and choose an appropriate exit.

11.3 Simulation Setup

The MassMotion physical environment (showing floors (5), entry portals (1), links (4), and exit portals (4)) is illustrated in Figures 38 and 39.

In Scenario 1, all links have default settings and are available as routes for agent evacuations.

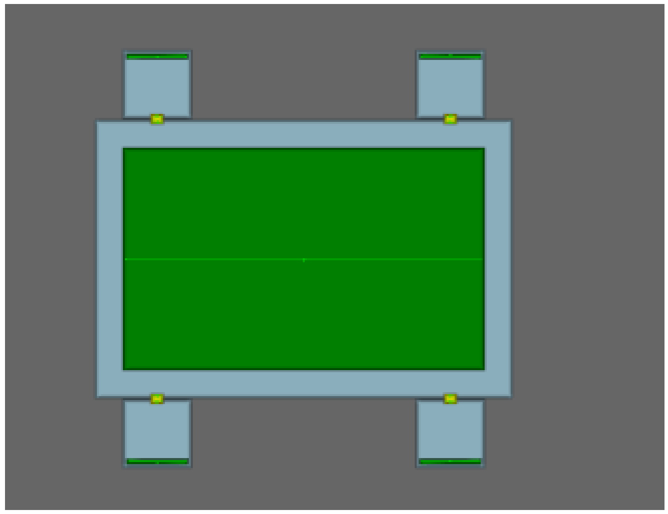


Figure 38: Test 9 Physical Environment.

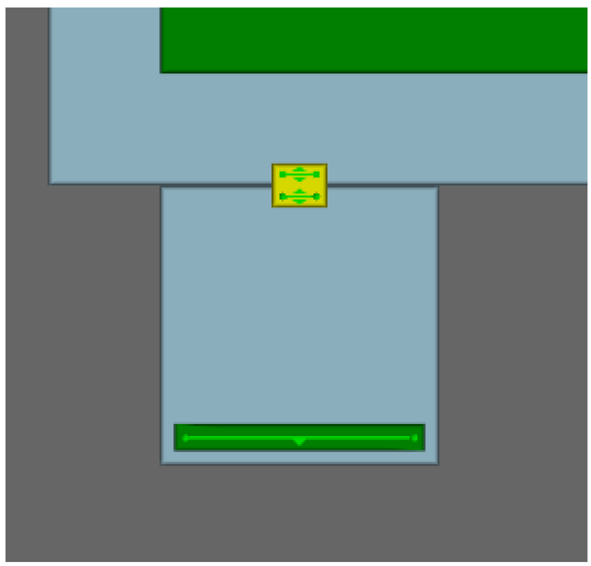


Figure 39: Test 9 Door 3 as a Mass Motion Link.

In Scenario 2, links 1 and 2 are disabled, preventing agents from using them to evacuate (Figure 40). Links 3 and 4 are unchanged.

An IMO 1533 'Males 30-50' agent profile was created with a speed uniformly distributed from 0.97m/s to 1.62m/s.

The entry portal covers the central 26m x 16m area of the main floor and is set to distribute agents over its entire area.

An 'Evacuation' event was setup to create 1000 agents on the entry portal with the 'Males 30-50' profile and zero pre-evacuation time.

All other parameters not identified above were assigned the MassMotion default values.

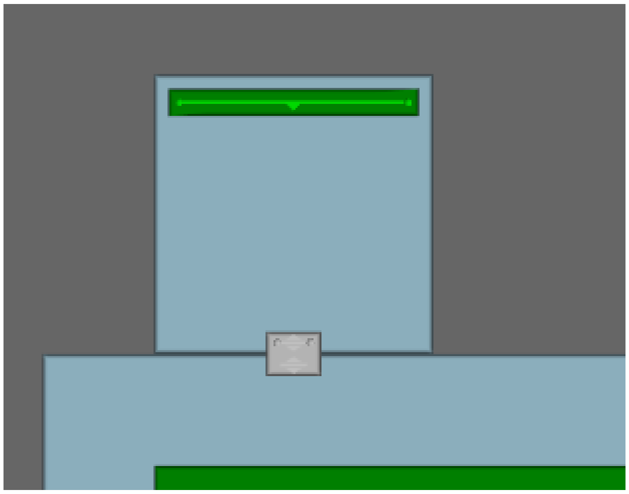


Figure 40: Test 9 Scenario 2 Door 1 as a Disabled Mass Motion Link.

11.4 Test Results

10 simulations were undertaken for both Scenario 1 and Scenario 2. A summary of the predicted total evacuation time from the simulations is provided in Table 17 and Figure 41.

	Minimum (s)	**Maximum (s)**	**Mean (s)**
Scenario 1 (Exits 1, 2, 3 and 4)	167.00	174.00	169.20
Scenario 2 (Exits 3 and 4)	319.00	337.00	325.90

Table 17: Test 9 Total Evacuation Time Predictions

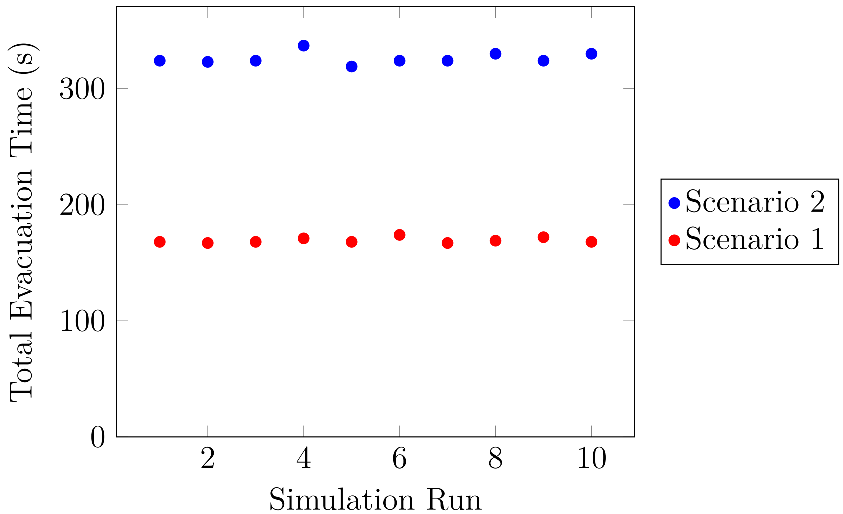


Figure 41: Test 9 Predicted Exit Times

Typical agent queuing at the relevant exits is illustrated in Figure 42 for Scenario 1 and Figure 43 for Scenario 2.

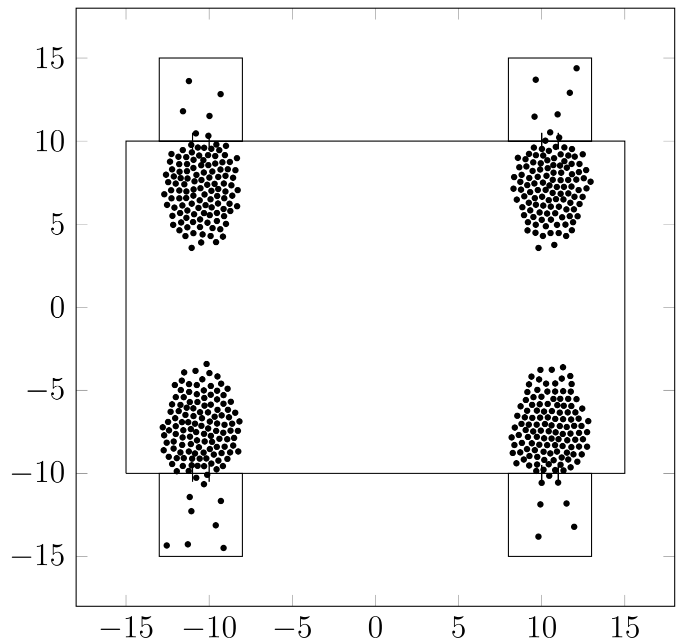


Figure 42: Test 9 Scenario 1 Typical Result

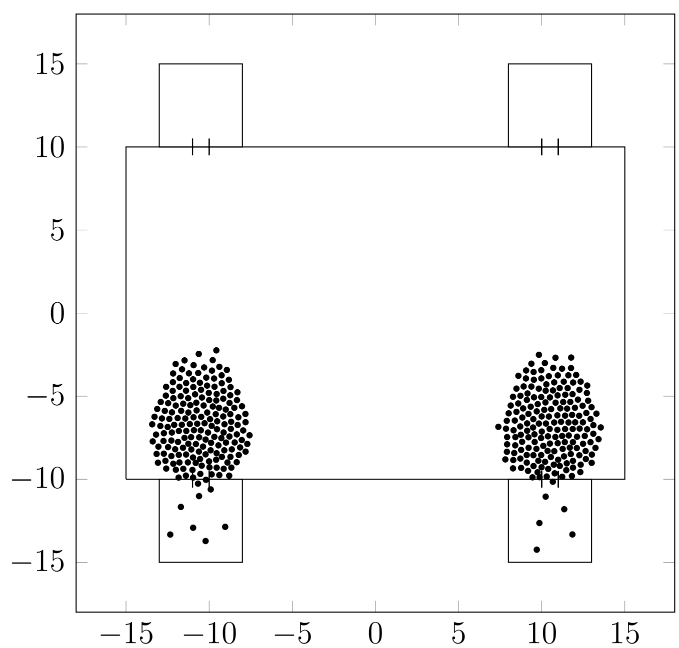


Figure 43: Test 9 Scenario 2 Typical Result

The total evacuation time for Scenario 2 is approximately twice (the mean is x1.93) that of Scenario 1.

The total evacuation time is expected to be slightly less than double within MassMotion, as flow rates across a link (door) increase as a function of crowd density. The crowding in Scenario 2 is higher and so flow rates will be slightly above those in scenario 1.

11.5 Conclusion

IMO 1533 Test 9 has been conducted within MassMotion.

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters of the model.

The flow rate is slightly higher in situations with increased crowding. If this is not desired, then a fixed flow rate limit can be imposed on the links.

Status: Pass

12 Test 10: Exit Allocation

12.1 Test Description

The test is in accordance with IMO 1533 Test 10 and NIST 1822 Test 3.1.

The geometric layout (Figure 44) represents a cabin corridor.

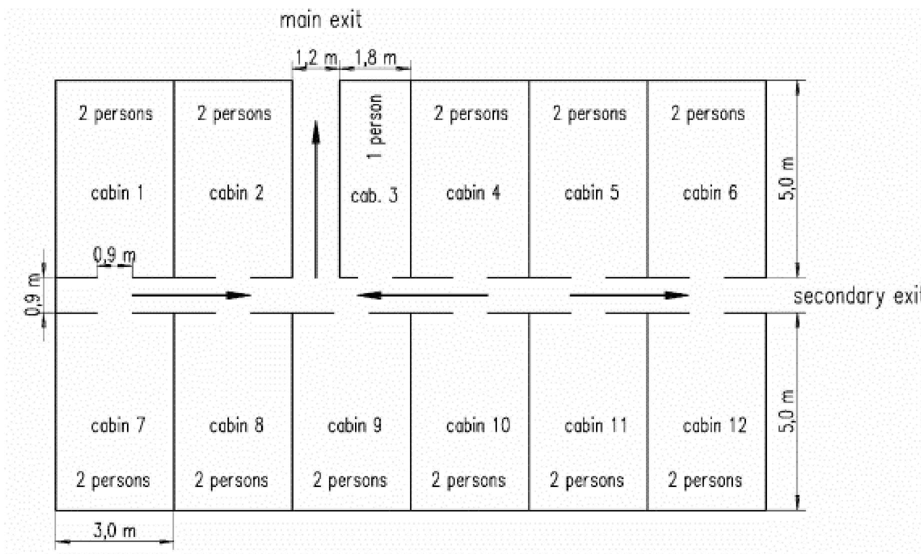


Figure 44: Test 10 Configuration of Cabin Corridor

The cabins are populated as shown in Figure 44. The agents are created at the beginning of the simulation with zero pre-evacuation time (ie. instantaneous movement). The preferred horizontal terrain walking speeds are selected at random from a uniform probability distribution (ranging from 0.97m/s to 1.62m/s - see IMO 1533 population panel 'Males 30-50').

The agents in cabins 1, 2, 3, 4, 7, 8, 9, and 10 are allocated to the main exit.

The agents (blue) in cabins 5, 6, 11 and 12 are allocated to the secondary exit.

Two scenarios are considered:

- Scenario 1 - IMO 1533 Test 10 and NIST 1822 Test 3.1 - as defined above.
- Scenario 2 - The MassMotion exit selection algorithm (based on route cost) is applied to the agents.

This test is qualitative.

12.2 Aim of Tests

The purpose of the test is to provide qualitative verification of the ability of MassMotion to represent exit route allocation.

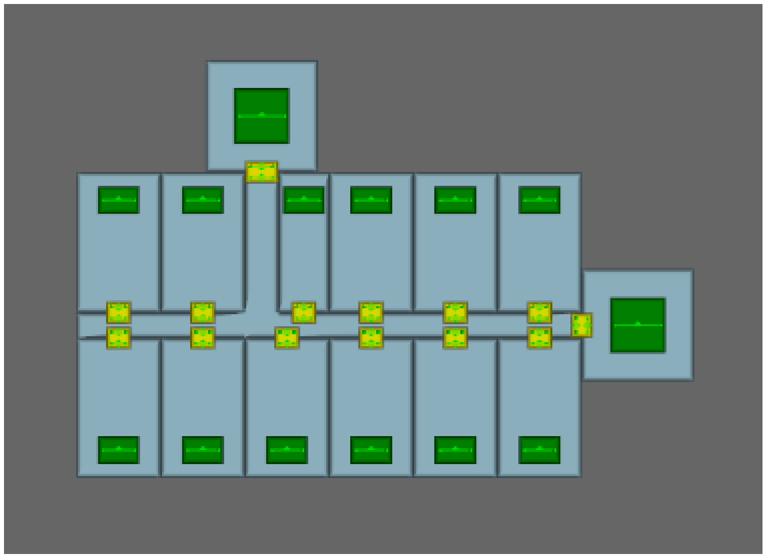


Figure 45: Test 10 Physical Environment

12.3 Simulations Setup

The physical environment is shown in Figure 45.

Floors were created to represent the cabins (12), corridor (1) and destinations (2).

Entry portals were created in each cabin. Exit portals were created at the destinations.

12.4 Test Results

Table 18 summarises the MassMotion results for Scenarios 1 and 2.

		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	1	1
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 18: Test 10 Number of Cabin Occupants Using Each Exit

The MassMotion results indicate:

- Scenario 1 - all agents used the allocated exit;

- Scenario 2 - some agents from Cabin 4 and Cabin 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.

12.5 Conclusion

IMO 1533 Test 10 and NIST 1822 Test 3.1 have been conducted within MassMotion.

The Scenario 1 prediction identifies that the agents exiting the simulation do so at the allocated exit.

The results indicate that MassMotion is able to reproduce the results stated in the IMO and NIST guidance given the configured parameters (allocated exit) of the model.

Status: Pass.

13 Test 11: Stair Congestion

13.1 Test Description

The test is in accordance with IMO 1533 Test 11 and NIST 1822 Test 5.1.

An 8m x 5m floor (room) is connected via a 12m x 2m floor (corridor) to a 3m x 2m (1.73m height, 30 degree incline) stair. See Figure 46.

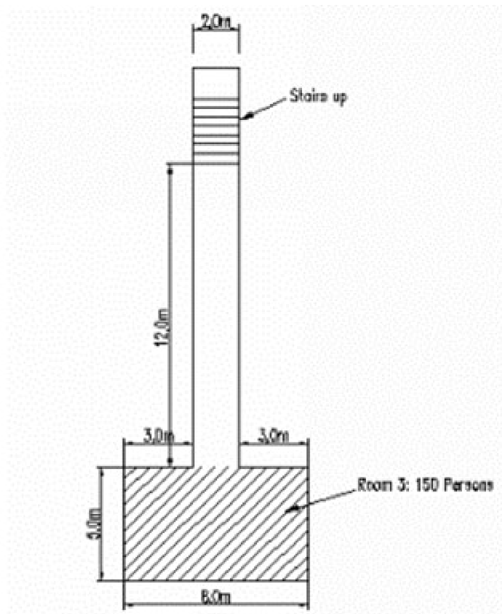


Figure 46: Test 11 Layout.

Four scenarios are to be considered:

- Scenario 1 - 150 persons, stair up;
- Scenario 2 - 100 persons, stair up;
- Scenario 3 - 150 persons, stair down;
- Scenario 4 - 100 persons, stair down.

13.2 Aim of Tests

The purpose of the test is to verify that MassMotion is able to predict congestion at the exit of the room and at the base of the stair.

13.3 Simulations Setup

Though IMO/NIST suggest geometry element of size 8m by 5m for this test, below four distinct geometry elements were created for sensitivity testing.

- an 8m x 5m floor (room);
- a 12m x 2m floor (corridor);

- a 3m x 2m (1.73m height, 30 degree incline) stair;
- a destination floor.

A link was used to connect the room to the corridor.

An exit portal was created on the destination floor.

An entry portal was created in the room, set to distribute agents on the room floor.

An IMO 1533 ‘Males 30-50’ compatible agent profile was created.

In all four scenarios, the journey is from the room to the head (stair up) or foot (stair down) of the stair. Agents are created instantly at the beginning of the simulation.

Figures 47 and 48 show the setup of the physical environment in MassMotion.

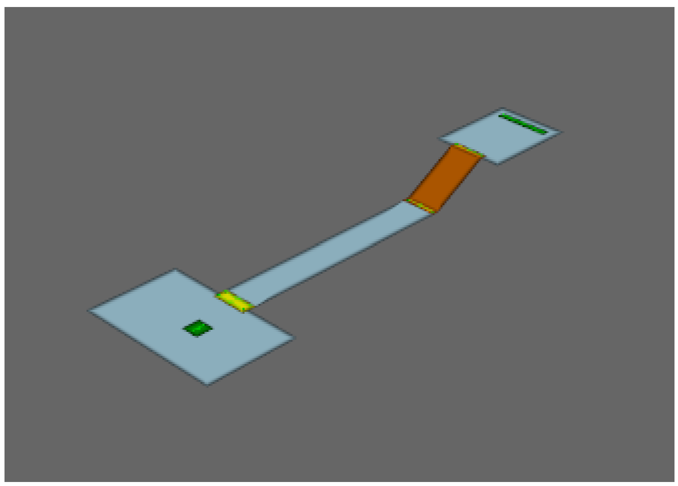


Figure 47: Test 11 Scenario 1&2 Physical Environment

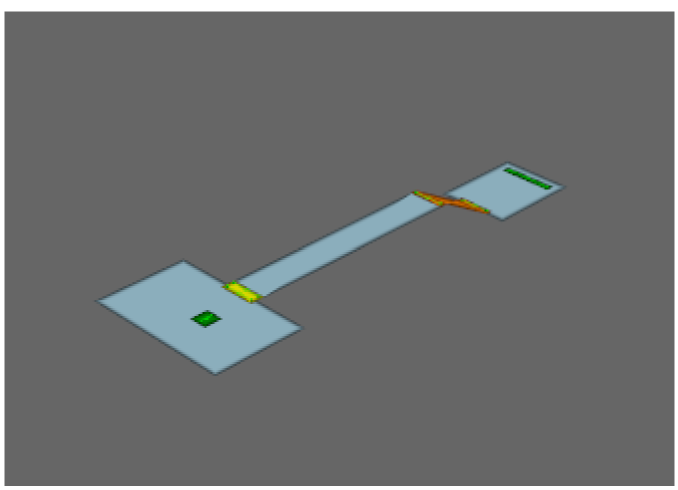


Figure 48: Test 11 Scenario 3&4 Physical Environment

13.4 Test Results

The MassMotion results are illustrated in figures 49, 50, 51 and 52.

13.5 Conclusion

IMO 1533 Test 11 and NIST 1822 Test 5.1 has been conducted within MassMotion.

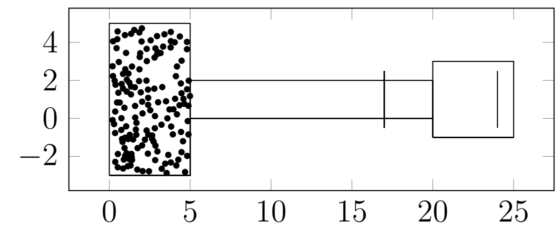
Qualitative assessment of the simulation results illustrate the ability of MassMotion to replicate congestion:

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

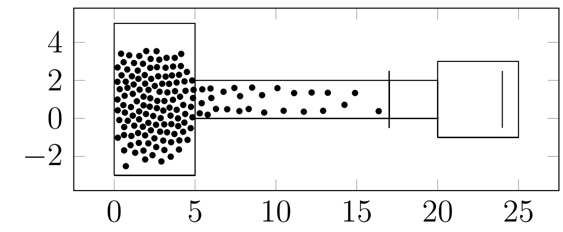
The extent of the congestion at the latter is a function of the direction of the stair and the initial room population. Greater congestion is noted for an upward stair than for a downward stair and an increased population leads to increased congestion.

The results indicate that MassMotion is able to reproduce the results (in the form of the qualitative nature of the congestion, i.e. its location and extent) stated in the IMO and NIST guidance given the configured parameters of the model.

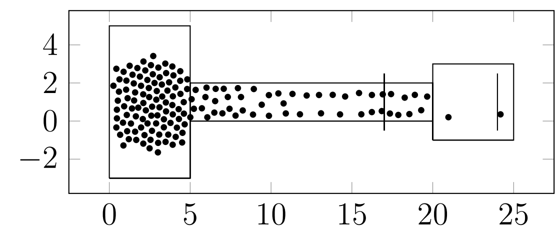
Status: Pass.



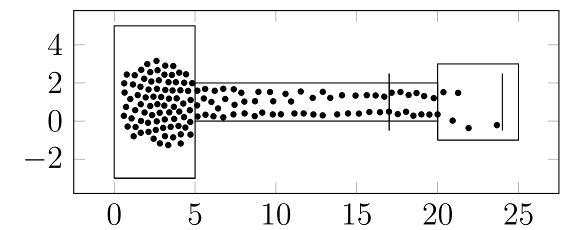
(a) The room is populated by 150 agents distributed uniformly.



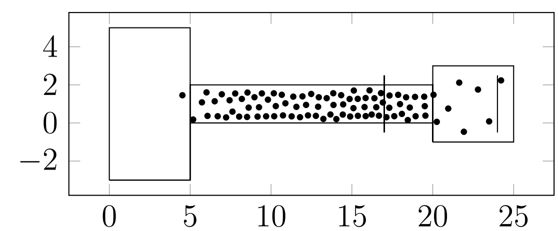
(b) Time 9s - First agent reaches foot of the stair.



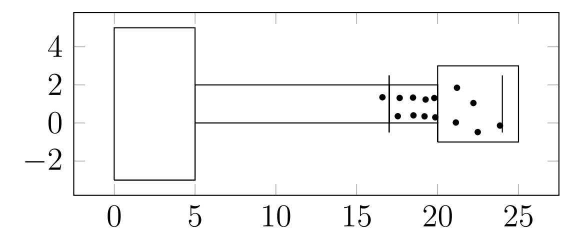
(c) Time 18s - First agent leaves simulation after reaching head of the stair.



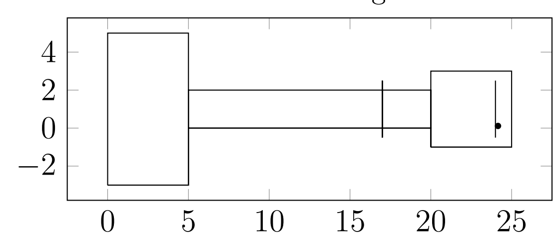
(d) Time 25s - Half of the agents have left room.



(e) Time 56s - All agents have left the room.

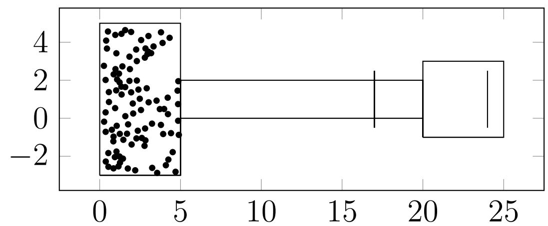


(f) Time 95s - The last of the agents are leaving the corridor to ascend the stair.

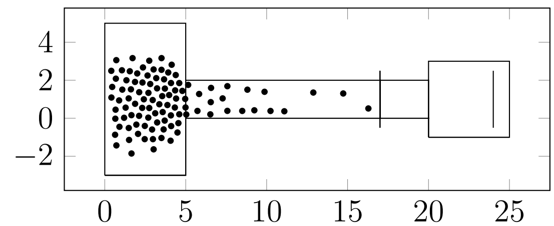


(g) Time 108s - The last agent leaves the simulation after reaching the head of the stair.

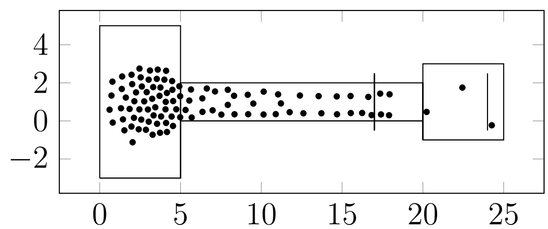
Figure 49: Test 11 Scenario 1 Results (150 Persons, Stair Up)



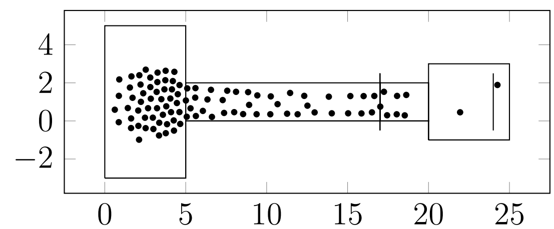
(a) The room is populated by 100 agents distributed uniformly.



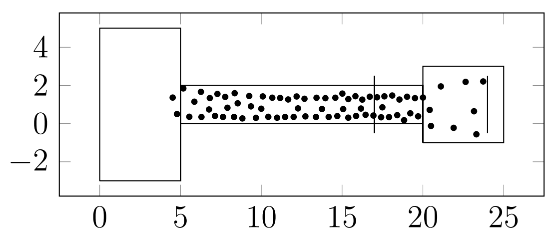
(b) Time 8s - First agent reaches the foot of the stair.



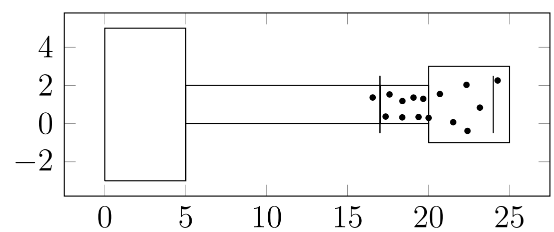
(c) Time 16s - First agent leaves simulation after reaching head of the stair.



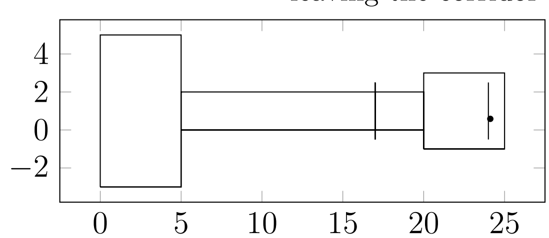
(d) Time 18s - Half of the agents have left room.



(e) Time 38s - All agents have left the room.

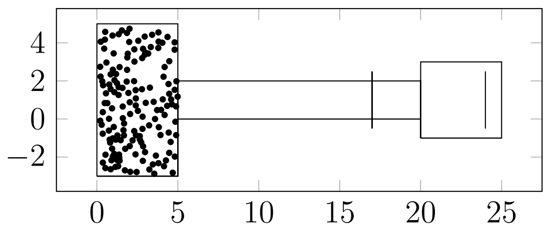


(f) Time 69s - The last of the agents are leaving the corridor to ascend the stair.

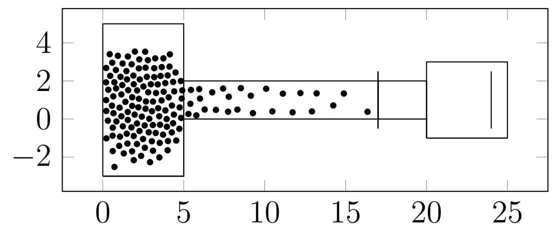


(g) Time 81s - The last agent leaves the simulation after reaching the head of the stair.

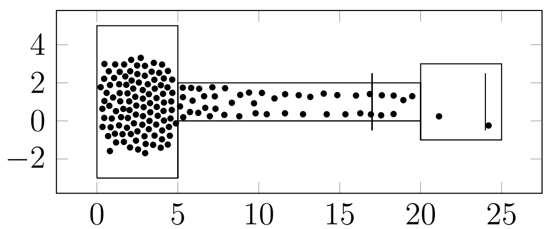
Figure 50: Test 11 Scenario 2 Results (100 Persons, Stair Up)



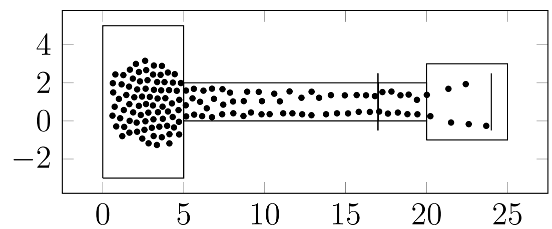
(a) The room is populated by 150 agents distributed uniformly.



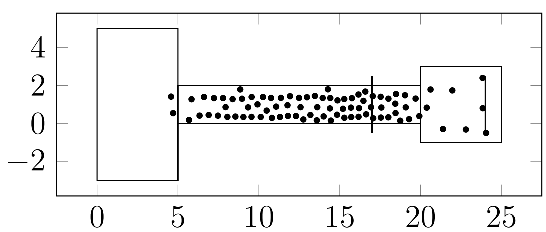
(b) Time 9s - First agent reaches head of the stair.



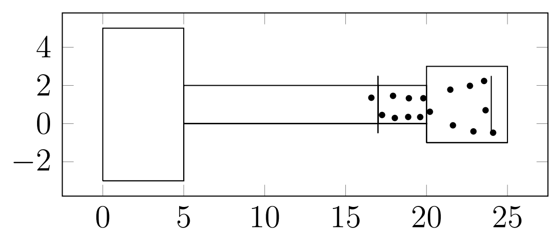
(c) Time 16s - First agent leaves simulation after reaching foot of the stair.



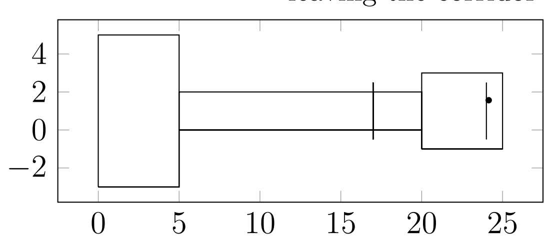
(d) Time 25s - Half of the agents have left room.



(e) Time 57s - All agents have left the room.

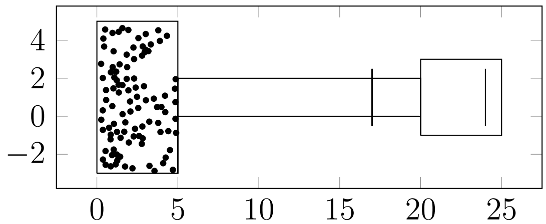


(f) Time 93s - The last of the agents are leaving the corridor to descend the stair.

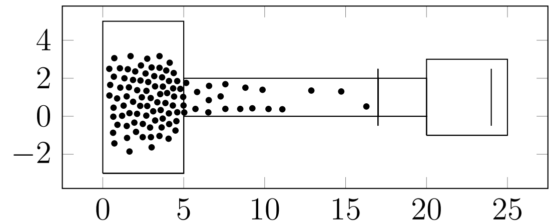


(g) Time 105s - The last agent leaves the simulation after reaching the foot of the stair.

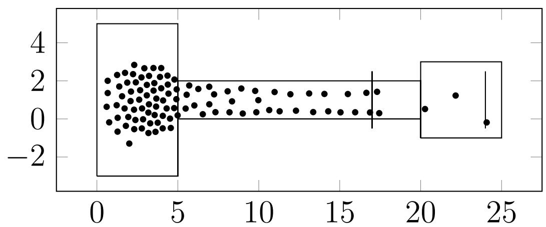
Figure 51: Test 11 Scenario 3 Results (150 Persons, Stair Down)



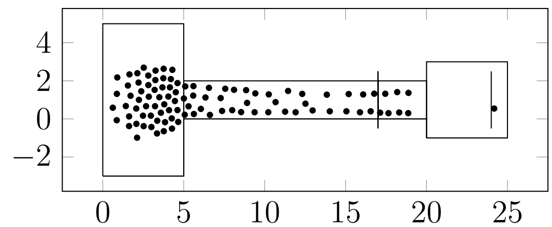
(a) The room is populated by 100 agents distributed uniformly.



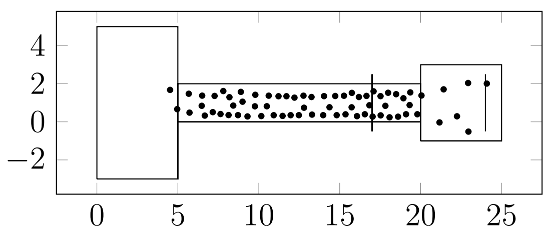
(b) Time 8s - First agent reaches head of the stair.



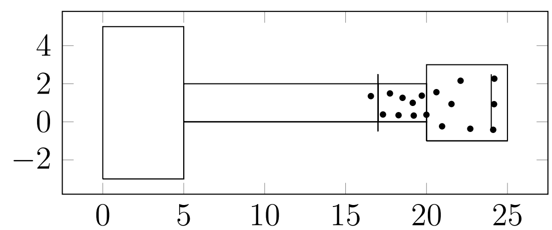
(c) Time 15s - First agent leaves simulation after reaching foot of the stair.



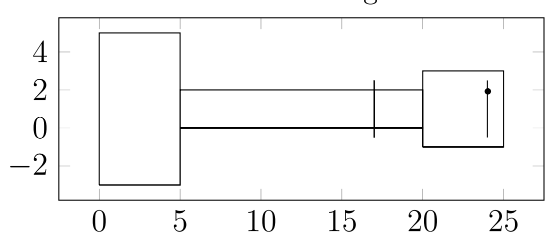
(d) Time 18s - Half of the agents have left room.



(e) Time 39s - All agents have left the room.



(f) Time 67s - The last of the agents are leaving the corridor to descend the stair.



(g) Time 78s - The last agent leaves the simulation after reaching the foot of the stair.

Figure 52: Test 11 Scenario 4 Results (100 Persons, Stair Down)

14 Test 12: Movement Disabilities

14.1 Test Description

The test is in accordance with NIST 1822 Test 2.10. There is no associated IMO 1533 test.

Two 5m x 4m floors (rooms) at different elevations are connected by a 2m x 1.5m ramp. Room 1 is located 1m above ground level while Room 2 is located at ground level. A 1m exit is located at the boundary of Room 2 remote from the ramp. See Figure 53.

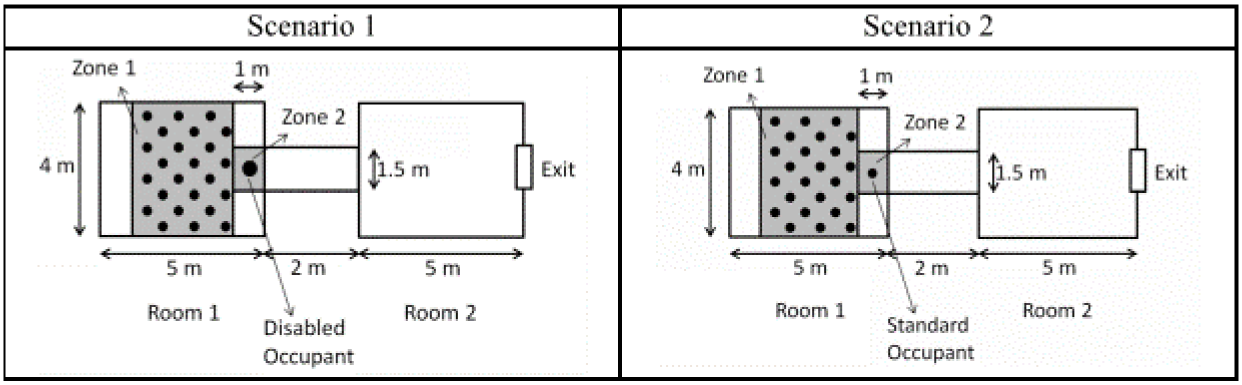


Figure 53: Test 12 Geometric Layout

A 3m x 4m area of Room 1 located 1m from the ramp, (Zone 1) is populated by 24 agents having:

- the default body size (0.5m diameter);
- a preferred horizontal terrain walking speed of 1.25 m/s.

Two scenarios are considered:

- Scenario 1 - A 1m x 1.5m area of Room 1 (Zone 2) immediately adjacent to the ramp is populated by a 'mobility impaired' agent having:
  - a body size greater than half the width of the ramp (i.e. >0.75m), e.g. a wheelchair user;
  - a preferred horizontal terrain walking speed of 0.8m/s;
  - a preferred ramp walking speed of 0.4m/s.
- Scenario 2 - Differs from Scenario 1 only in that the single agent of Zone 2 has the same agent attributes as those in Zone 1 (ie. no mobility impaired agents are included).

All agents leave the simulation via the exit from Room 2.

14.2 Aim of Test

The purpose of the test is to verify that MassMotion is able to predict that the flow of agents is restricted by the presence of a mobility impaired agent (being relatively larger and slower) in a confined space.

14.3 Simulation Setup

The only deviation from the test description concerns the speed of the mobility impaired agent. MassMotion applies the same factor (in this case 100%) to the preferred horizontal terrain walking speeds 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.

A sensitivity test for the width of the mobility impaired agent has been undertaken for Scenario 1:

- 0.25m - physically unrealistic for an adult (the agent is too small);
- 1.0m - satisfies the requirement of the test;
- 1.5m - the width of the ramp;
- 2.0m - physically unrealistic (greater than the width of the ramp).

While the 0.25m and 2.0m widths are physically unrealistic, they are included for comparative purposes.

Figure 54 shows the simulation setup within MassMotion.

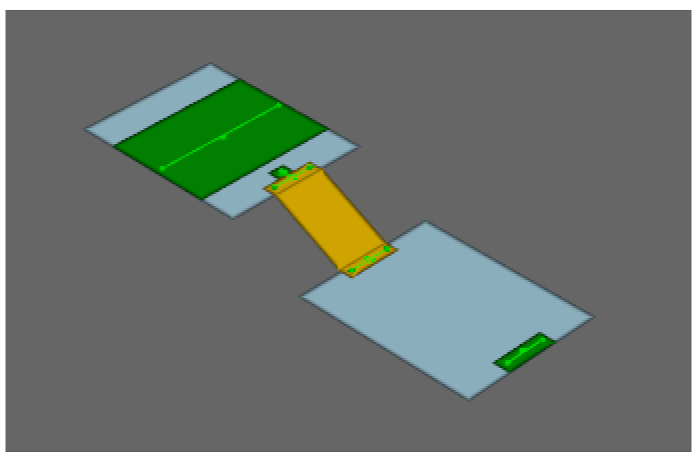


Figure 54: Test 12 Physical Environment.

14.4 Test Results

Figures 55, 56, 57 and 58 illustrates the MassMotion results when the mobility impaired agents of Scenario 1 are still on the ramp. Figure 59 shows the MassMotion prediction for Scenario 2. The agent originating in Zone 2 is coloured blue.

For Scenario 1, the agents originating in Zone 1 have been impeded by the 1.0m, 1.5m and 2.0m mobility impaired agent of Zone 2, to the extend that they were unable to overtake whilst on the ramp.

Agents originating in Zone 1 were able to overtake the 0.25m mobility impaired agent whilst on the ramp. This does not always occur with every simulation seed, and is dependent on initial positions of agents.

For Scenario 2, the able-bodied agent of Zone 2 has the same preferred walking speed as the agents originating and 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 agents are still on the ramp.

In undertaking theses simulations, it was noted that:

- in all cases, the presence of the slower agent impeded the exit rate of other agents;
- the actual size of the slower agent had less effect than the random variations within a simulation (as a function of the initial positions of the agents);
- in some cases, faster agents were able to pass the slower agent before it reached the ramp.

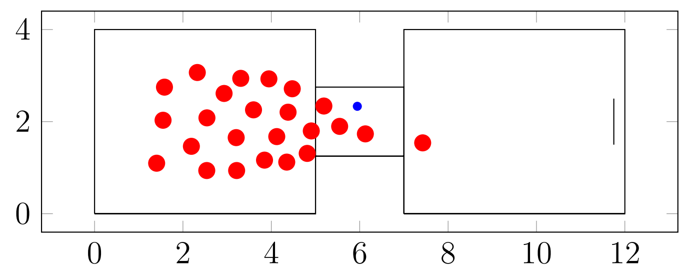


Figure 55: Test 12 Scenario 1 Simulation (0.125m impaired agent radius)

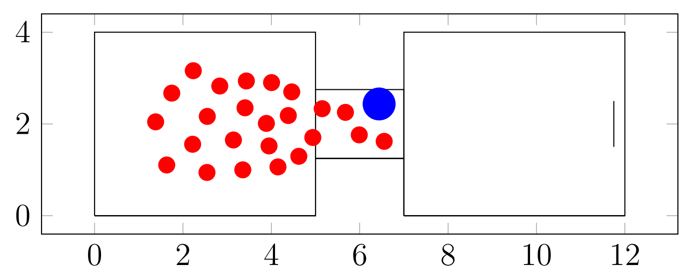


Figure 56: Test 12 Scenario 1 Simulation (0.5m impaired agent radius)

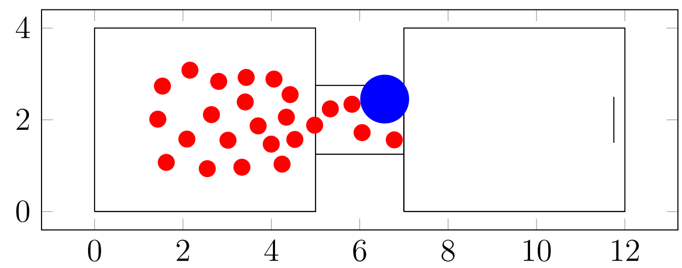


Figure 57: Test 12 Scenario 1 Simulation (0.75m impaired agent radius)

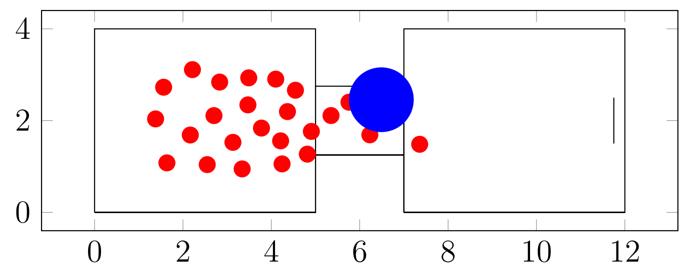


Figure 58: Test 12 Scenario 1 Simulation (1.0m impaired agent radius)

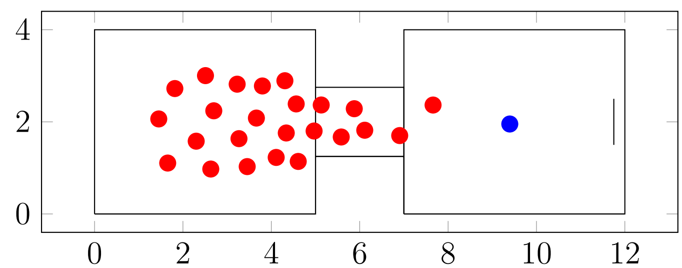


Figure 59: Test 12 Scenario 2 Simulation

14.5 Conclusion

NIST 1822 Test 2.10 has been conducted within MassMotion.

The results indicate that MassMotion is able to reproduce the results (in the form of the qualitative nature of the impedance of faster agents by a slower agent in a confined environment) stated in NIST guidance given the configured parameters of the model.

Status: Pass.

15 Test 13: Affiliation

15.1 Test Description

The test is in accordance with NIST 1822 Test 3.3. There is no associated IMO 1533 test.

Within this test the term 'Affiliation' refers to familiarity / preference for a particular exit.

A 15m x 10m floor (room) has two 1m exits located (See Figure 60):

- on opposing 15m walls;
- such that the centre of the exit is 12m from one of the 10m walls.

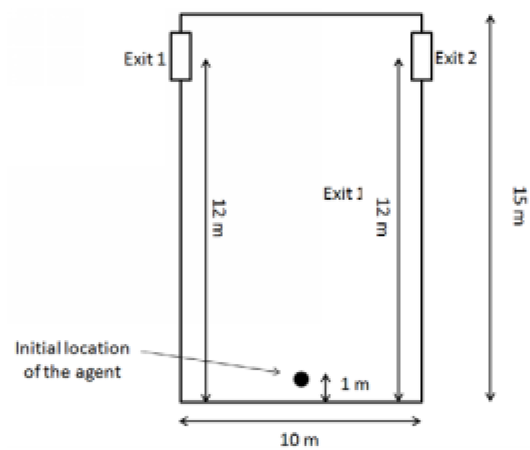


Figure 60: Test 13 Geometric Layout

Two scenarios for the evacuation of a single agent (initially at the centre of the 10m wall remote from the exits) are considered:

- Scenario 1 - the agent is unfamiliar with both exits;
- Scenario 2 - the agent is not affiliated (familiar) with Exit 1, ie. Exit 2 is favoured by the agent.

15.2 Aim of Test

The purpose of the test is to demonstrate that an agent's increased familiarity with a given exit can be represented and configured within MassMotion.

15.3 Simulation Setup

The MassMotion physical environment (Figure 61) consists of:

- 3 floors objects (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).

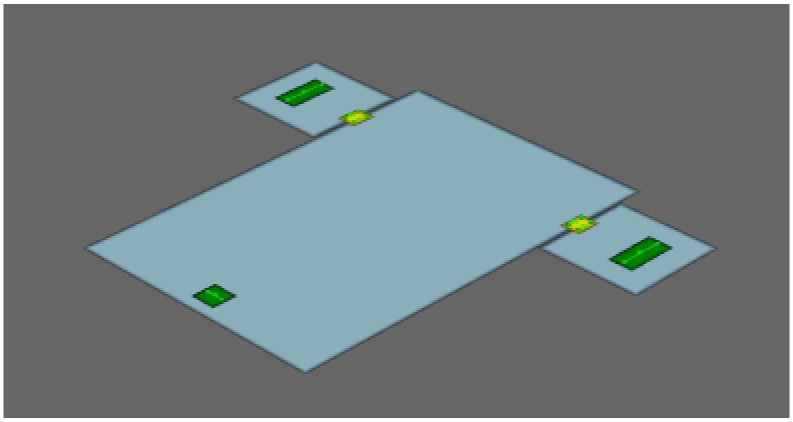


Figure 61: Test 13 Physical Environment.

The agent was assigned as preferred horizontal terrain walking speed of 1m/s at the start of the simulation.

All other parameters were as per MassMotion defaults.

For Scenario 2, a sensitivity test was undertaken to examine the extent to which Exit 1 is favoured.

The exit weights are as defined in Table 19.

		Weight (%)	
Scenario	**Case**	**Exit 1**	**Exit 2**
1	-	50	50
2	A	75	25
2	B	99	1

Table 19: Test 13 Exit Weights

100 simulations were undertaken for scenario and both cases of scenario 2.

15.4 Test Results

The frequency of usage of each exit over the 100 simulations is summarized in Table 20.

This demonstrates that the MassMotion results for exit usage (and, therefore, the probability of exit usage) follow the weightings applied to the exits as input.

		Usage (%)	
Scenario	**Case**	**Exit 1**	**Exit 2**
1	-	48	52
2	A	27	73
2	B	1	99

Table 20: Test 13 MassMotion Exit Usage

15.5 Conclusion

NIST 1822 Test 3.3 has been conducted within MassMotion.

Results from the test indicate MassMotion is able to reproduce the results stated in the NIST guidance given the configured parameters of the model.

Status: Pass.

16 Test 14: Dynamic Availability of Exits

16.1 Test Description

The test is in accordance with NIST 1822 Test 4.1. There is no associated IMO 1533 test.

A 15m x 10m floor (room) has two 1m exits located (See Figure 62):

- on opposing 15m walls;
- such that the centre of the exit is 12m from one of the 10m walls.

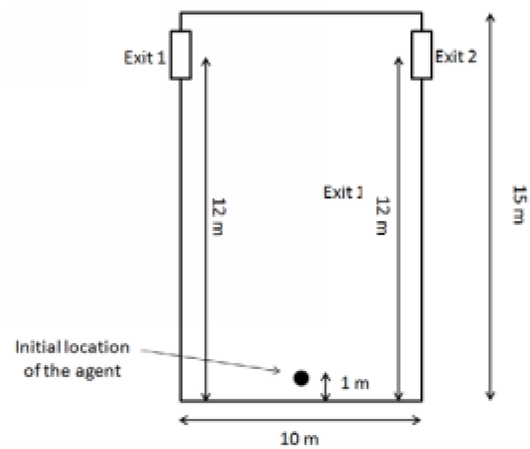


Figure 62: Test 14 Geometric Layout

At the start of the simulation only Exit 1 is available. After 1 second, Exit 1 becomes unavailable and at the same time Exit 2 becomes available.

Evacuation of a single agent (initially at the centre of the 10m wall remote from the exits) is considered.

16.2 Aim of Test

The purpose of the test is to demonstrate that MassMotion is able to represent the dynamic availability of exits.

16.3 Simulation Setup

The MassMotion physical environment (Figure 63) 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).

Two scenarios are considered with the following parameters set for the simulation. The scenarios differ in the length of the interval before the gates change between open and closed.

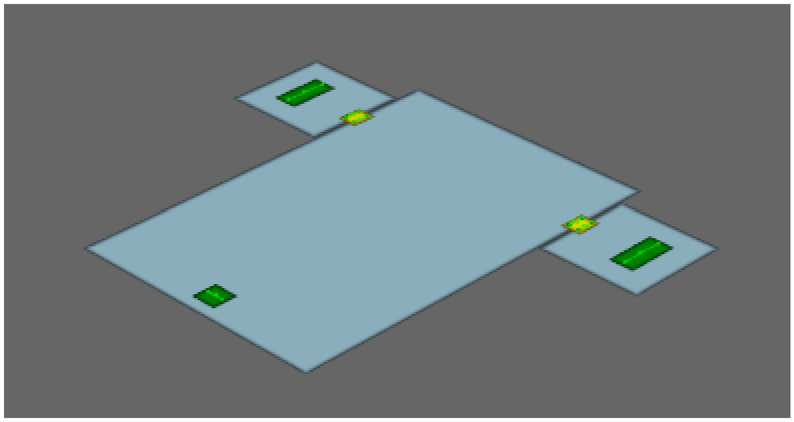


Figure 63: Test 14 Physical Environment.

- Profile:
  - Preferred horizontal walking speed = constant;
  - Value = 1m/s.
- Journey:
  - Demand = Instant;
  - Agent count = 1;
  - Entry portal (weight = 1);
  - 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 Exits 1&2:
  - Enabled to be used as a 'Gate'.
- 'Open Gate' event for Exit 1
  - Scenario 1 - Gate to be open from 0s to 1s simulation time;
  - Scenario 2 - Gate to be open from 0s to 7s simulation time.
- 'Open Gate' event for Exit 2
  - Gate to be closed from 0s to 1s simulation time (to force the agent to prefer Exit 1 initially);
  - Gate to be open from 1s to simulation end.

All other parameters were as per MassMotion defaults.

16.4 Test Results

Agent route maps are illustrated in Figure 64 (Scenario 1) and Figure 65 (Scenario 2).

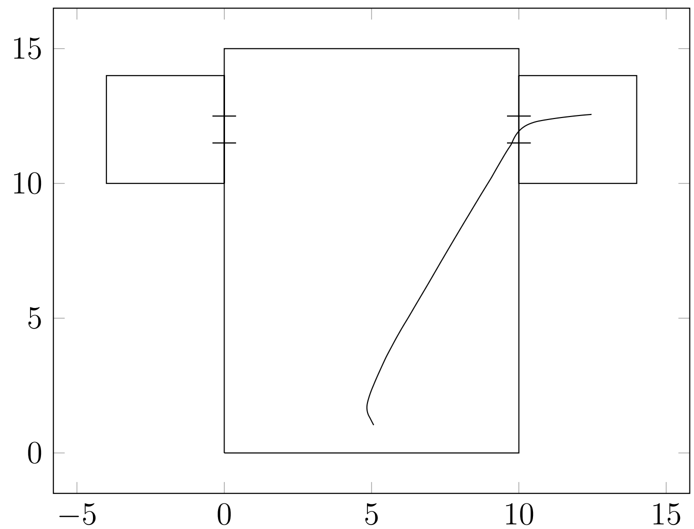


Figure 64: Test 14 Scenario 1 Simulated Agent Route Map

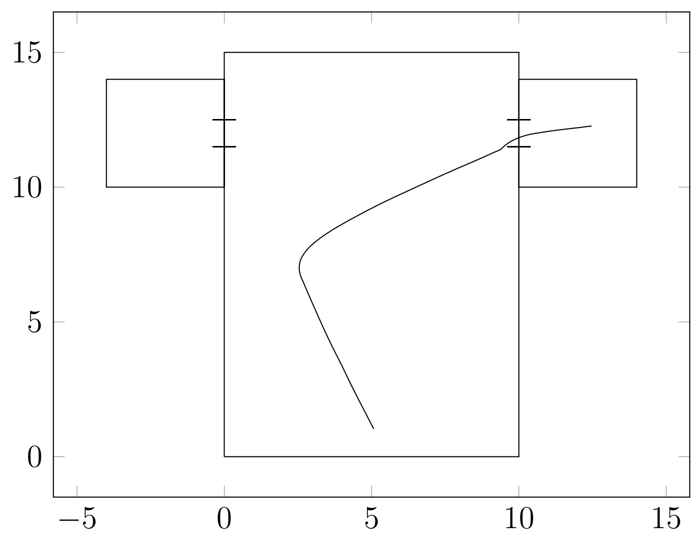


Figure 65: Test 14 Scenario 2 Simulated Agent Route Map

The agent route map results are consistent with anticipated behaviours.

16.5 Conclusion

NIST 1822 Test 4.1 has been conducted within MassMotion.

Results from the test indicate MassMotion is able to reproduce the results stated in the NIST guidance given the configured parameters of the model.

Status: Pass.

17 Test 15: Stair Merging

17.1 Test Description

This test investigates the ability of MassMotion to represent:

- the merging of flows in a stairwell; and
- to assess the effect of occupant densities on the merging of flows in a stairwell.

There is no associated IMO 1533 or NIST 1822 test.

The test is based on a 3-storey building (with open plan floor plates) and a single dog-leg stair accessed via landings, as illustrated in Figure 66.

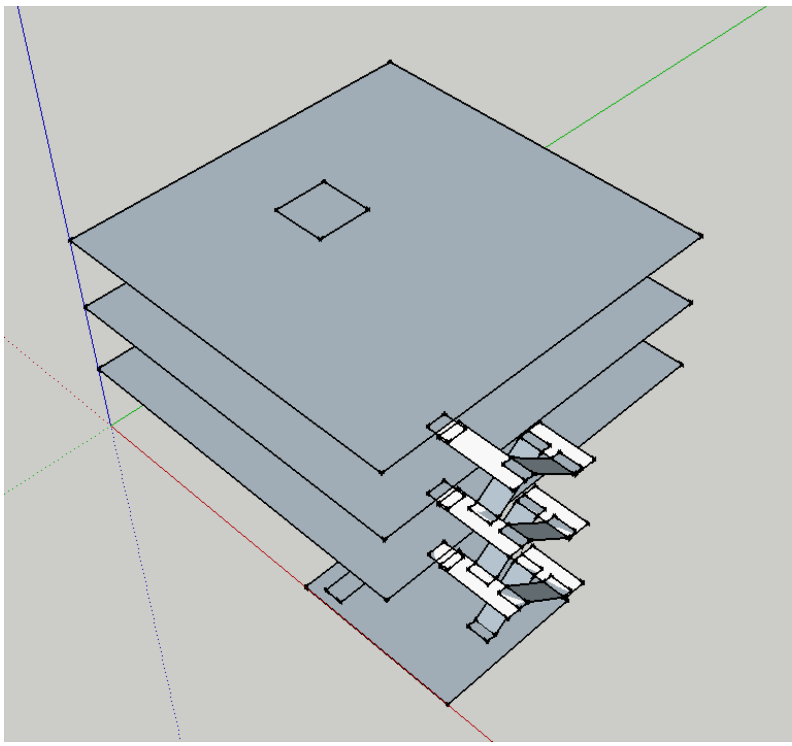


Figure 66: Test 15 Geometric Layout

Table 21 summarises the floor occupancies for each of the five scenarios considered in this study.

	Occupancy (agents)		
Scenario	**1st Floor**	**2nd Floor**	**3rd Floor**
1	100	0	0
2	100	100	0
3	100	400	0
4	100	600	0
5	100	200	200

Table 21: Test 15 Floor Occupancies

17.2 Aim of Tests

The purpose of the test is to verify that MassMotion is able to represent the merging of flows at an entry point on the stair.

17.3 Simulations Setup

The MassMotion model geometry includes (Figure 67):

- Three 20m x 20m upper floors and a 9m x 7.8m ground floor.
- a 1m wide link as an entry to each of the upper floors.
- Stairs:
  - 1.2m wide with flights spanning 2.5m horizontally and 2m vertically.
  - 4.2m x 1.2m landings at each floor.
  - 2.8m x 1.2m half-landings.
- Entry portals on the three upper floors.
- A 6.8m long exit portal at the ground floor level.

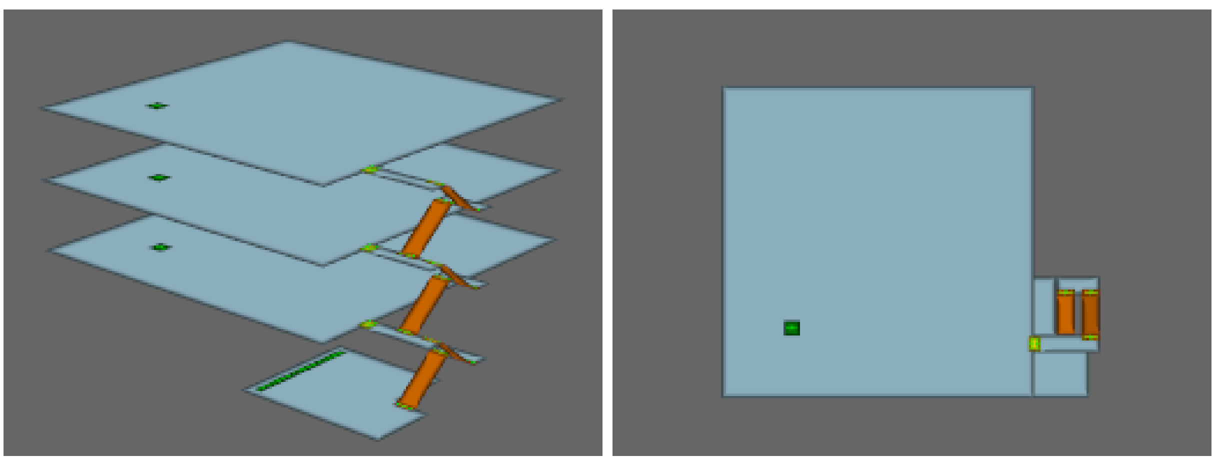


Figure 67: Test 15 Physical Environment.

The entry portals on each floor were defined so that the agents were randomly distributed across the whole floor.

The default agent attributes (eg. preferred horizontal terrain walking speed) and zero pre-evacuation times were assigned to all agents. Agents are created at the beginning of the simulation on the specified floors, headed toward the exit portal on the ground floor.

It was considered likely that the results would be dominated by queuing behaviour on the stairs (and, therefore, that the effect of random sampling on the prediction would not be significant). Only a single simulation was undertaken for each scenario.

Scenario	Total Evacuation Time (s)	% Increase in Time to Scenario 1	% Increase in Time to Scenario 2
1	77.80	N/A	N/A
2	91.80	117.99	N/A
3	93.80	120.57	102.18
4	92.40	118.77	100.65
5	95.40	122.62	103.92

Table 22: Test 15 First Floor Clearance Times

17.4 Test Results

The time required for agents to clear the first floor (above ground floor) is summarized in Table 22.

MassMotion predicts that in Scenario 1 (no stair merging), the first floor (above ground) will clear in 77.8 s.

Scenarios 2, 3 and 4 show that the time required for agents to clear the first floor is substantially increased when agents are introduced to the second floor. However, increasing the number of agents on the second floor (from 100 agents to 400 or 600) has little impact on the time taken for agents to evacuate from the first floor. This suggests that when a stair is fully utilised, merging (between the stream entering the stair and those already on the stair) occurs at a ratio of approximately 1:1 (in the configuration examined). Further testing is necessary to examine whether this rule holds in all cases.

In Scenario 5, the time required for agents to evacuate from the first floor is 95.40s, ie. similar to that for Scenarios 2, 3 and 4. It can be concluded that multiple floor merging flows does not affect the merging flow behaviour.

17.5 Conclusion

This test examined merging flows in a stairwell within MassMotion. It may be concluded that:

- merging flows can be represented in MassMotion;
- the delay to agents exiting a floor as a result of agents on the stair from floor(s) above (and by inference, the delay to agent on the stair as a result of agents entering from a floor below) can be represented by MassMotion; and.
- for the configuration under consideration in this test, that when a stair is fully utilised, merging (between the stream entering the stair and those already on the stair) occurs at a ratio of approximately 1:1.

Status: Pass.

17.6 Recommendations

It is recommended that further work is undertaken to ascertain to what extent the predictions are influenced by:

- assigned agent walking speeds;

- the relative pre-evacuation times (i.e. arriving at stairs at different times compared to the flow); and.
- the number of additional floors (above and below).

18 Test 16: Stair Flows

18.1 Test Description

This test investigates the flow rates on (downward and upward) stairs, with the aim of confirming that an increase in stair width leads to an increase in agent flow rates. There is no associated IMO 1533 or NIST 1822 test.

Two floors are connected by a stair (height = 3m, length = 3m, diagonal = 4.24m, angle = 45^0). Five stair widths (1.0m, 1.2m, 1.4m, 1.6m, 1.8m) are considered (Figure 68).

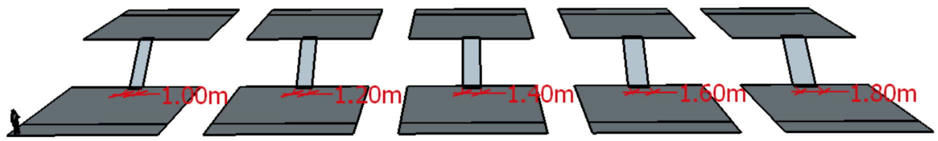


Figure 68: Test 16 Layout.

Two scenarios are considered:

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

The study utilises 100 agents (for each scenario / stair width combination) to estimate the flow rates on the stairs.

18.2 Aim of Test

The purpose of this test is to verify that MassMotion predicts an increase in agent flow rate as the stair width increases.

18.3 Simulation Setup

Each scenario is run 5 times with different stair widths (1.0m, 1.2m, 1.4m, 1.6m, 1.8m). Table 23 lists the test cases examined.

	Stair Width				
Scenario	**1.0m**	**1.2m**	**1.4m**	**1.6m**	**1.8m**
1 (Stair Down)	A	B	C	D	E
2 (Stair Up)	F	G	H	I	J

Table 23: Test 16 Test Cases

The MassMotion geometry, 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.

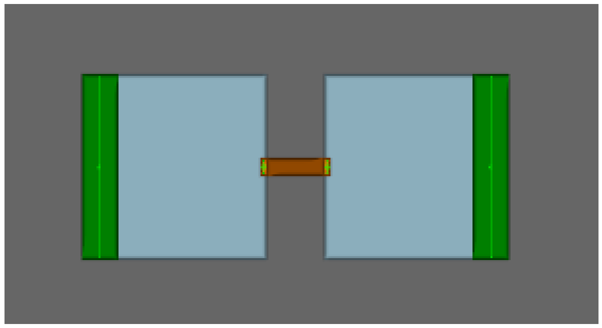


Figure 69: Test 16 Physical Environment (1.0m width)

A 'journey' event was created to generate 100 agents at the start of the simulation traveling from the entrance portal to the exit portal. The agents move from the entrance portal up or down a stair to the exit portal.

The occupant 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).

18.4 Test Results

The floor clearance times are summarised in Table 24.

Scenario	Case	Clearance Time (s)
1 (Stair Down)	A (1.0m width)	103
1 (Stair Down)	B (1.2m width)	91
1 (Stair Down)	C (1.4m width)	79
1 (Stair Down)	D (1.6m width)	71
1 (Stair Down)	E (1.8m width)	66
2 (Stair Up)	F (1.0m width)	106
2 (Stair Up)	G (1.2m width)	92
2 (Stair Up)	H (1.4m width)	81
2 (Stair Up)	I (1.6m width)	72
2 (Stair Up)	J (1.8m width)	66

Table 24: Test 16 Entrance Floor Clearance Times

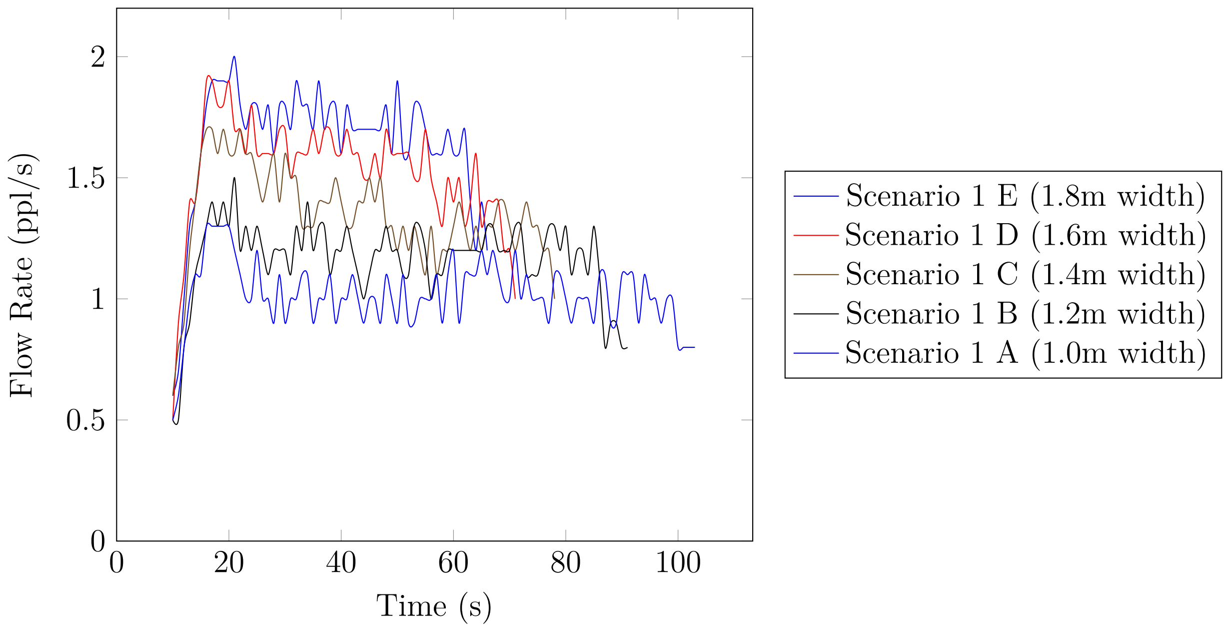


Figure 70: Test 16 Scenario 1 Average Flow Rates Through the Stair (Down)

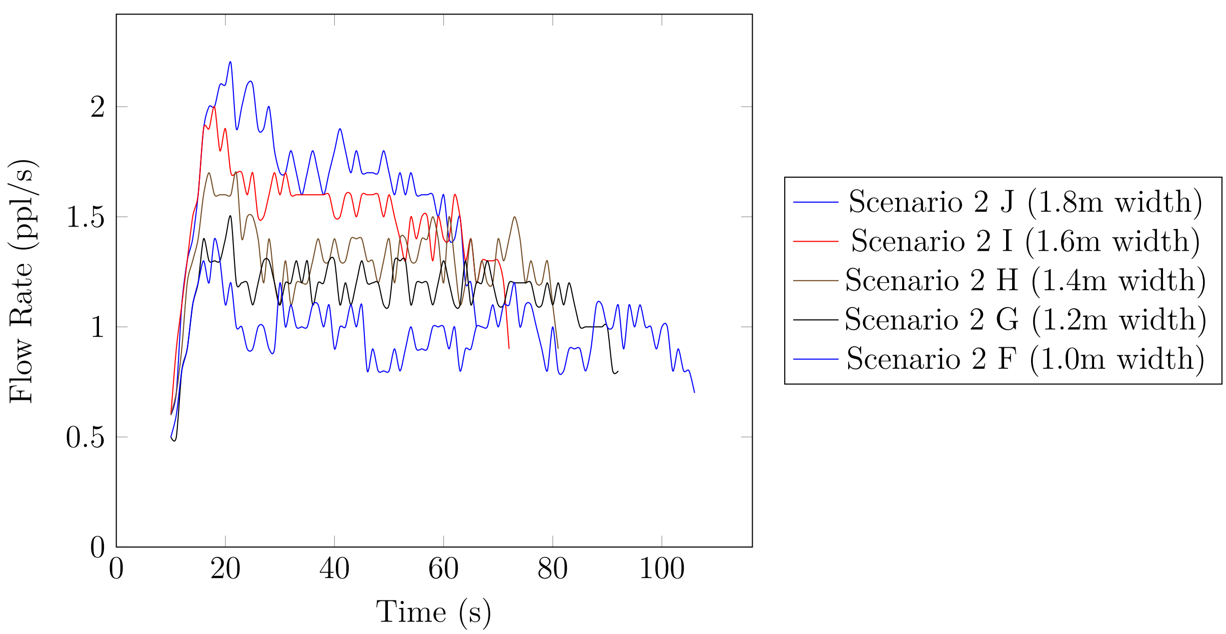


Figure 71: Test 16 Scenario 2 Average Flow Rates Through the Stair (Up)

The average agent flow rate through each stair as a function of time is illustrated in Figure 70 for Scenario 1 and 71 for Scenario 2. It 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 25 and illustrated in Figure 72. As shown, the flow rates in both scenarios increases roughly linearly with the increases in stair width.

Scenario	Case	Overall Average Flow Rate
1 (Stair Down)	A (1.0m width)	0.96
1 (Stair Down)	B (1.2m width)	1.09
1 (Stair Down)	C (1.4m width)	1.27
1 (Stair Down)	D (1.6m width)	1.39
1 (Stair Down)	E (1.8m width)	1.49
2 (Stair Up)	F (1.0m width)	0.93
2 (Stair Up)	G (1.2m width)	1.08
2 (Stair Up)	H (1.4m width)	1.22
2 (Stair Up)	I (1.6m width)	1.37
2 (Stair Up)	J (1.8m width)	1.49

Table 25: Test 16 Overall Average Flow Rates

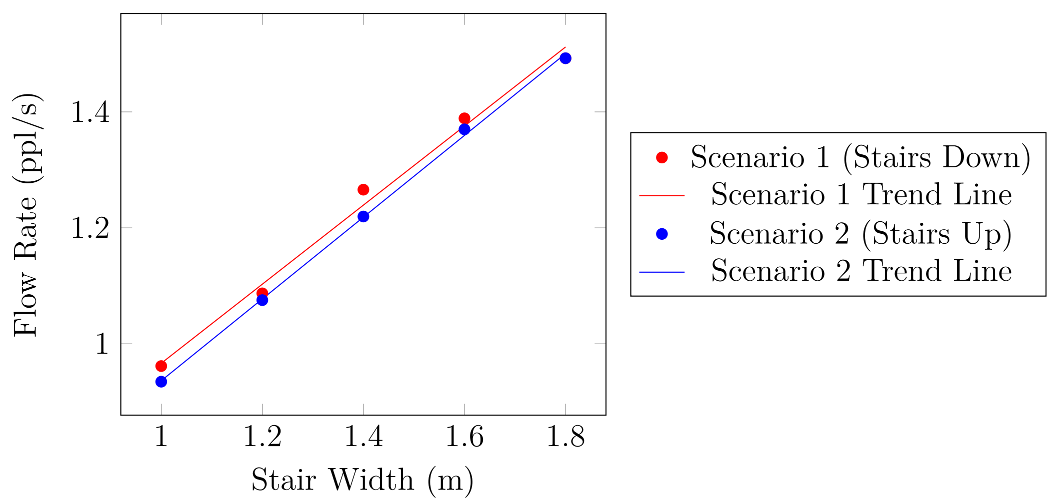


Figure 72: Test 16 Overall Average Flow Rates

18.5 Conclusion

This test examined flows in (downward and upward) stairs within MassMotion. It may be concluded that:

- the predicted agent flow rate increases almost linearly with increase in stair width for a fully utilised downward stair;
- the predicted agent flow rate increases almost linearly with increase in stair width for a fully utilised upward stair.

Status: Pass

19 Test 17: Elevator Usage

19.1 Test Description

The test is in accordance with NIST 1822 Test 2.7.

Two rooms, namely room 1 and room 2, are placed at different heights having a floor to floor inter-distance equal to 3.5m. A 1m wide exit is located in room 1. The rooms are connected via an elevator (see Figures 73 and 74).

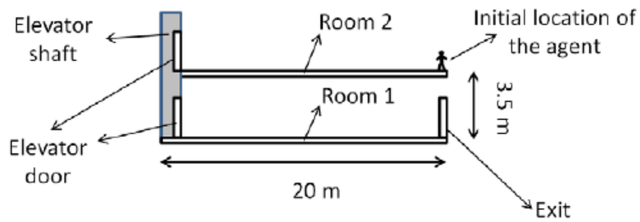


Figure 73: Test 18 Geometric Layout - Side View.

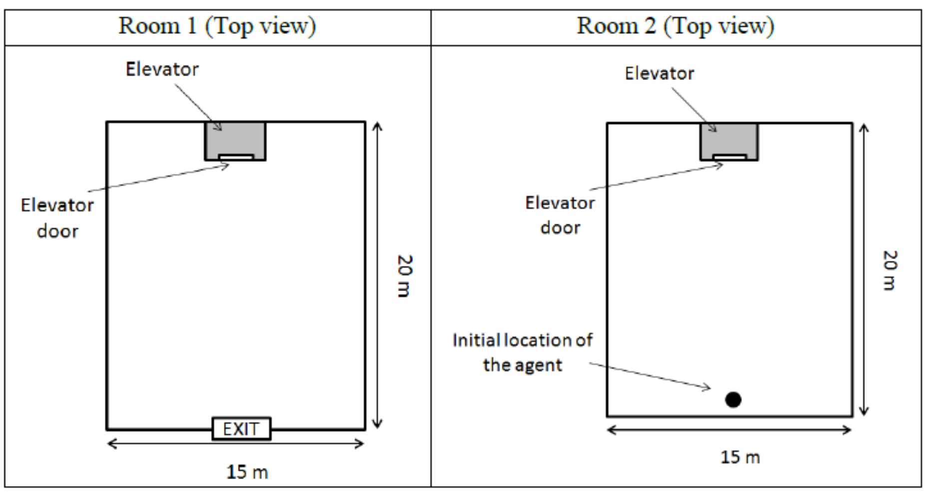


Figure 74: Test 18 Geometric Layout - Top View.

The MassMotion model consists of two floors connected via an elevator. Entry and exit portals are located at one end of each floor respectively.

19.2 Aim of Test

The purpose of this test is to verify the capability of MassMotion evacuation models in simulating evacuation using elevators.

19.3 Simulation Setup

A single occupant with an unimpeded walking speed of 1m/s and pre-evacuation time equals to 0s is placed in room 2 (See Figure 75). The elevator is the only egress component available for evacuation. The elevator begins at room 1, can be called to room 2 to pick up an agent, and then carry the occupant to room 1. The Elevator is configured with a maximum capacity of one and is given room 1 as the starting location. MassMotion default values are used to define elevator 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.

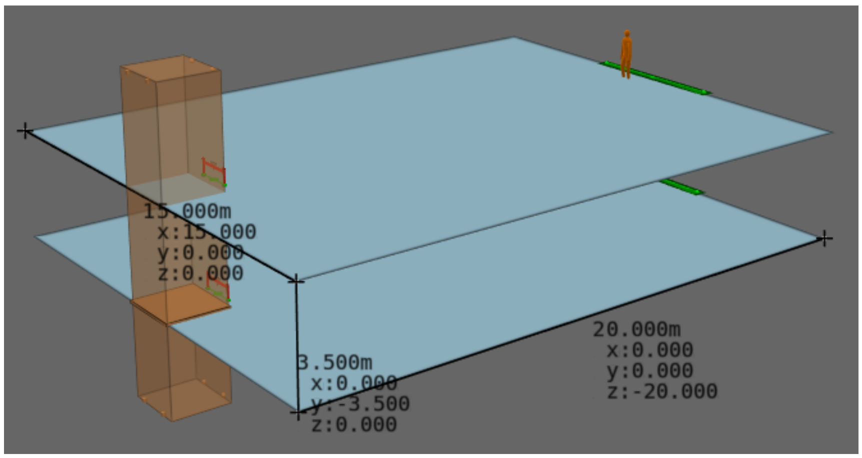


Figure 75: Test 18 Physical Environment.

19.4 Test Results

Figure 76 provides a visual plot of the path of the agent in the scenario. The vertical rectangle represents the elevator. The plot shows agent moving across room 2, boarding the elevator, traveling down, and then leaving the elevator and crossing room 1 to the exit.

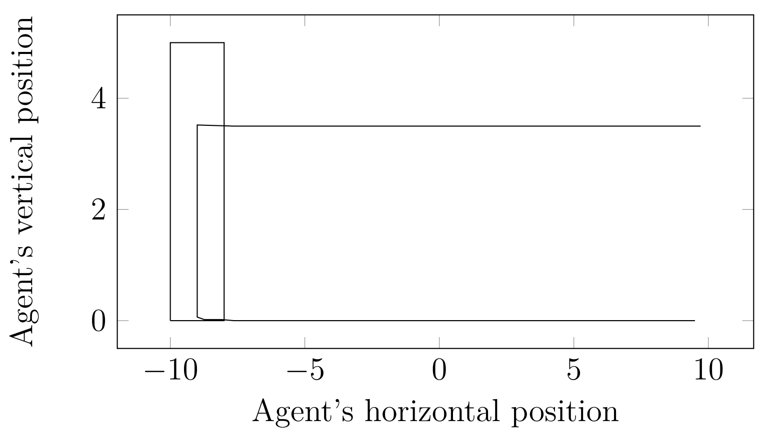


Figure 76: Test 18 Simulated Agent Route Map - Side View

19.5 Conclusion

NIST 1822 Test 2.7 has been conducted within MassMotion.

Results from the test indicate MassMotion is able to reproduce the results stated in the NIST guidance given the configured parameters of the model.

Status: Pass.