Verification Testing of MassMotion 10.0 for Evacuation Modelling

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1 Introduction

1.1 Context

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

MassMotion replicates the built environment as a series of geometrical components (e.g. floors, ramps, stairs, escalators, doors, barriers and portals). Agents (or occupants of the 3-dimensional space) are

- introduced into the geometry of the built environment via entry portals;
- interact with the geometry components, and agents; and
- depart from the geometry via exit portals,

in accordance with user specified evacuation scenarios.

MassMotion implements a theoretical (conceptual) model simulating human behaviour in an evacuation event. The data and underlying theories which MassMotion employs are those based on general human behaviour observed during circulation. 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. As such, human behaviour during an evacuation and normal circulation are (generally) comparable.

1.2 Purpose and Scope

This report documents the verification testing of MassMotion for evacuation modelling. It has been developed by Arup Fire engineers in association with the Oasys MassMotion development team. 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).

1.3 Test Summary

The verification testing has been conducted to demonstrate that the theory is correctly implemented within MassMotion (and that the model predictions 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. 1238;
- 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 1238 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 during an evacuation:

- pre-evacuation behaviour;
- travel speed;
- physicality;
- decision making;
- crowd dynamics.

Note that four 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 2.7 - Elevator Usage;
- 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

Table 1: Summary of MassMotion Verification Tests

All the verification tests investigated passed the stated acceptance criteria.

It was noted that Test 8 demonstrated a high sensitivity of the prediction to small changes in the input parameter. See Section 8 where additional information is provided.

Results from the verification tests indicate that MassMotion is able to predict the expected results for those cases tested.

1.4 Automated Testing

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

- Gitlab Runner 11.9.1 - 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 Test 1: Corridor Walking Speeds

2.1 Test Description

The test is in accordance with IMO 1238 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.

2.2 Aim of Test

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

2.3 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 $3 m/s^2$. 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 1.

2.4 Test Results

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

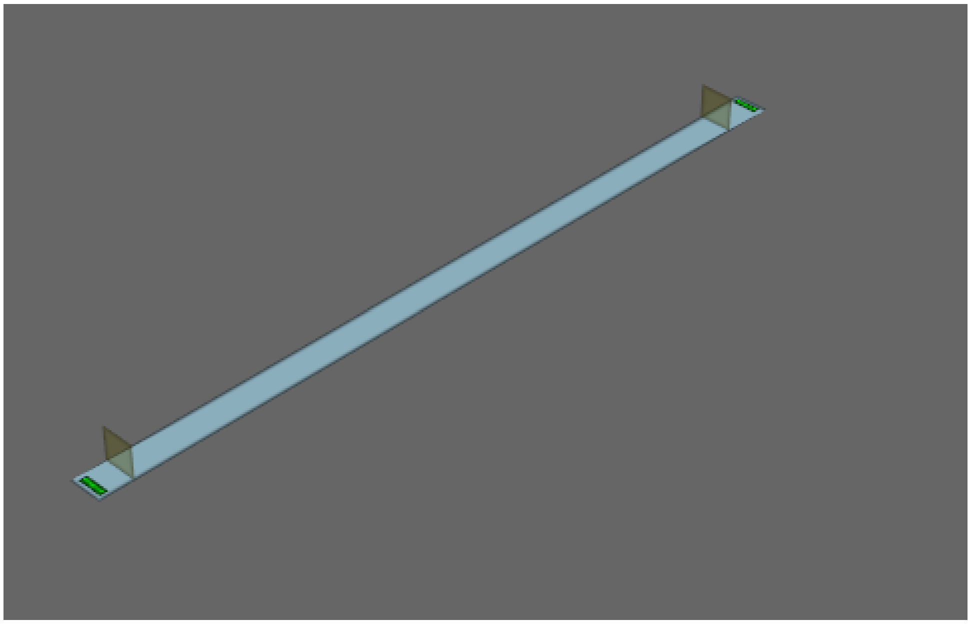


Figure 1: Test 1 Physical Environment

2.5 Conclusion

The IMO 1238 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.

The predictions 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

3 Test 2&3: Stair Walking Speeds

3.1 Test Description

The tests are in accordance with IMO 1238 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 1238 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 1238 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 2.

Stair Incline (degrees)	**Upward Stair Factor (%)**	**Downward Stair Factor (%)**
Less than 27	42.5	57.4
Between 27 and 32	42.5 - 37.8 (interpolate)	57.4 - 49.8 (interpolate)
Greater than 32	37.8	49.8

Table 2: MassMotion Default Agent Attributes for Stairs

Three stairs, each with a different incline (as defined in Table 3), 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 3: Test 2 Stair Inclines (and Dimension) Adopted

3.2 Aim of Tests

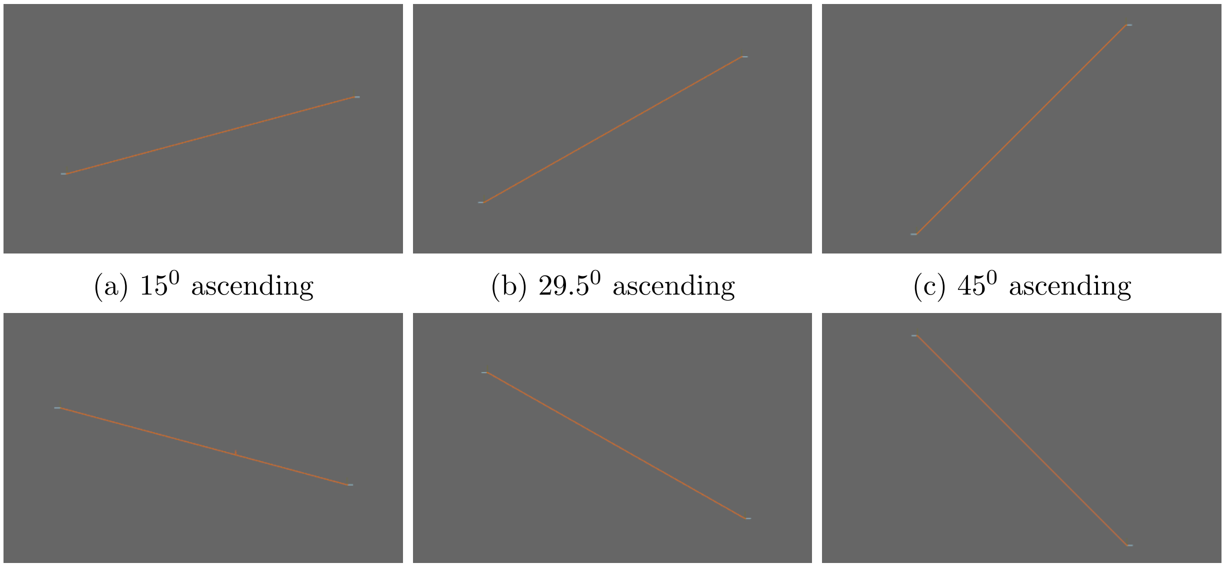
The purpose of the test is to demonstrate that an agent can move up or down a stair at a pre-defined constant walking speed.

3.3 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 3). 2 simulations are used for each incline angle, once for ascending and once for

descending.

A 2m wide floor was created at each end of each stair. A portal was created on each floor. (See Figures 2 and 3.)



(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 2: Test 2 Stair Layouts

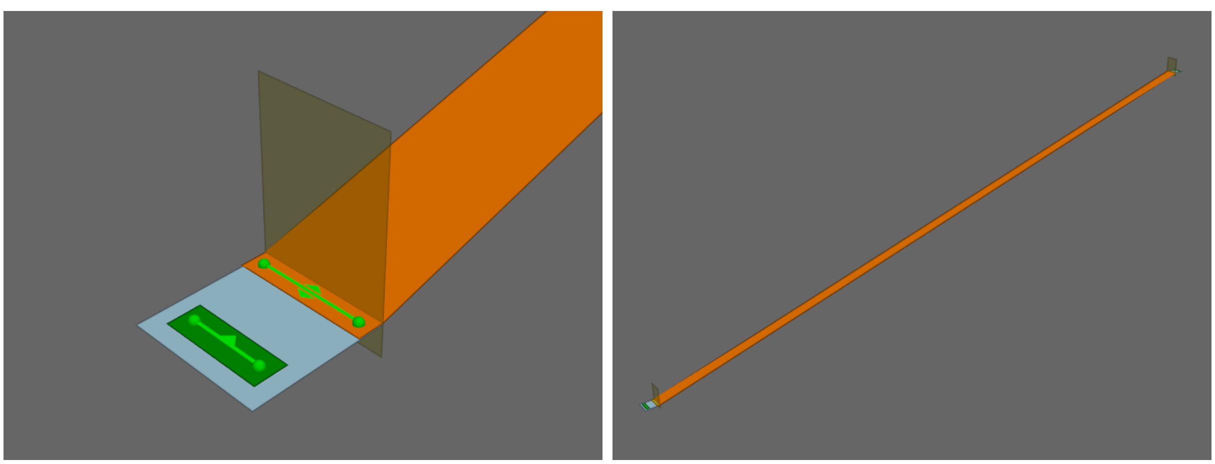


Figure 3: Test 2 Physical environment, 15^o ascending.

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 4.)

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.

3.4 Test Results

The MassMotion predictions and results are documented in Table 4.

Test	Stair Incline	Preferred Level Terrain Walking Speed (m/s)	Expected Stair Travel Time (s)	Measured Stair Travel Time (s)
2	15.000000 ascending	2.272767	100	99.600000
2	29.500000 ascending	2.167760	100	99.800000
2	45.000000 ascending	1.870653	100	100.200000
3	15.000000 descending	1.682798	100	100.200000
3	29.500000 descending	1.623798	100	100.200000
3	45.000000 descending	1.419893	100	100.000000

Table 4: Tests 2&3 MassMotion Results

3.5 Conclusion

The NIST 1822 Test 2.2 has been conducted using MassMotion.

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

Status: Pass.

4 Test 4: Exit Flow Rates

4.1 Test Description

This test comprises of two parts:

Part 1: A test in accordance with IMO 1238 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.

4.2 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.

4.3 Simulation Setup

An 8m x 5m primary floor with a 1000mm 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.

A cordon line is located at the link.

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 1000mm link is defined to have a capped flow rate of 1.33people/s. Figure 4 shows the initial setup with agents starting on the primary floor.

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

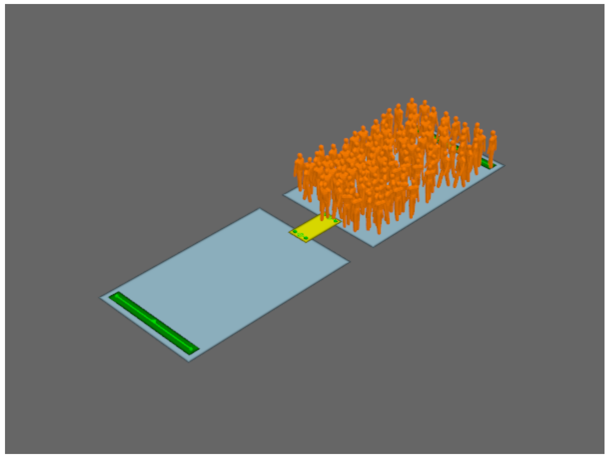


Figure 4: Test 4 Part 1 Physical Environment.

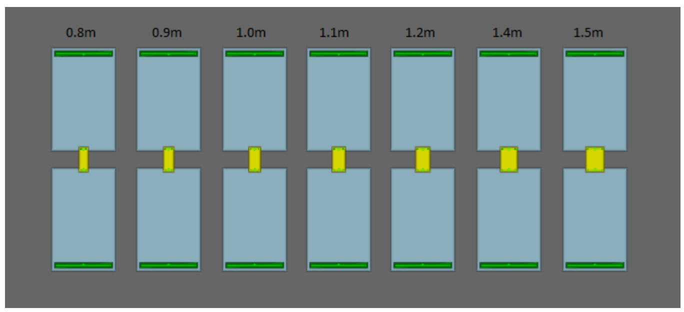


Figure 5: Test 4 Part 2 Sensitivity Cases.

4.4 Test Results

Part 1: Figure 6 illustrates the time averaged flow rate at the link.

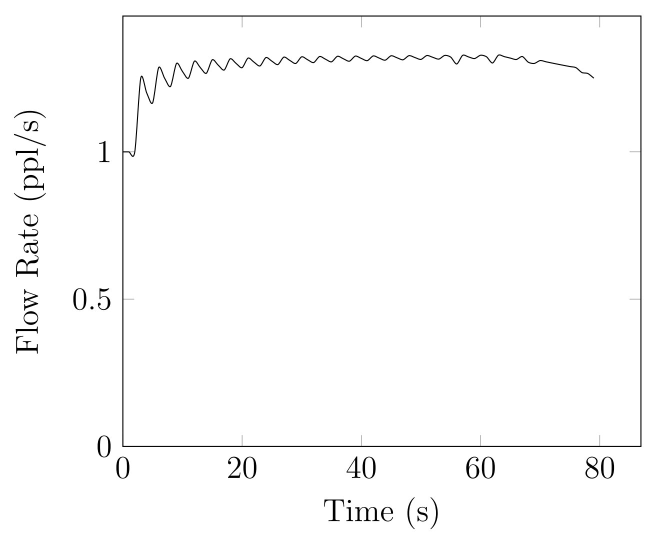


Figure 6: Test 4 Part 1 Average Flow Rate (People/s)

The overall average flow rate (100 people / 80 s exit time) is 1.25 people/s. The highest average flow rate is 1.32813 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 1.31026 people/s, ie. 98.5157 % 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 7 illustrates the time averaged flow rate at the link for varying link widths.

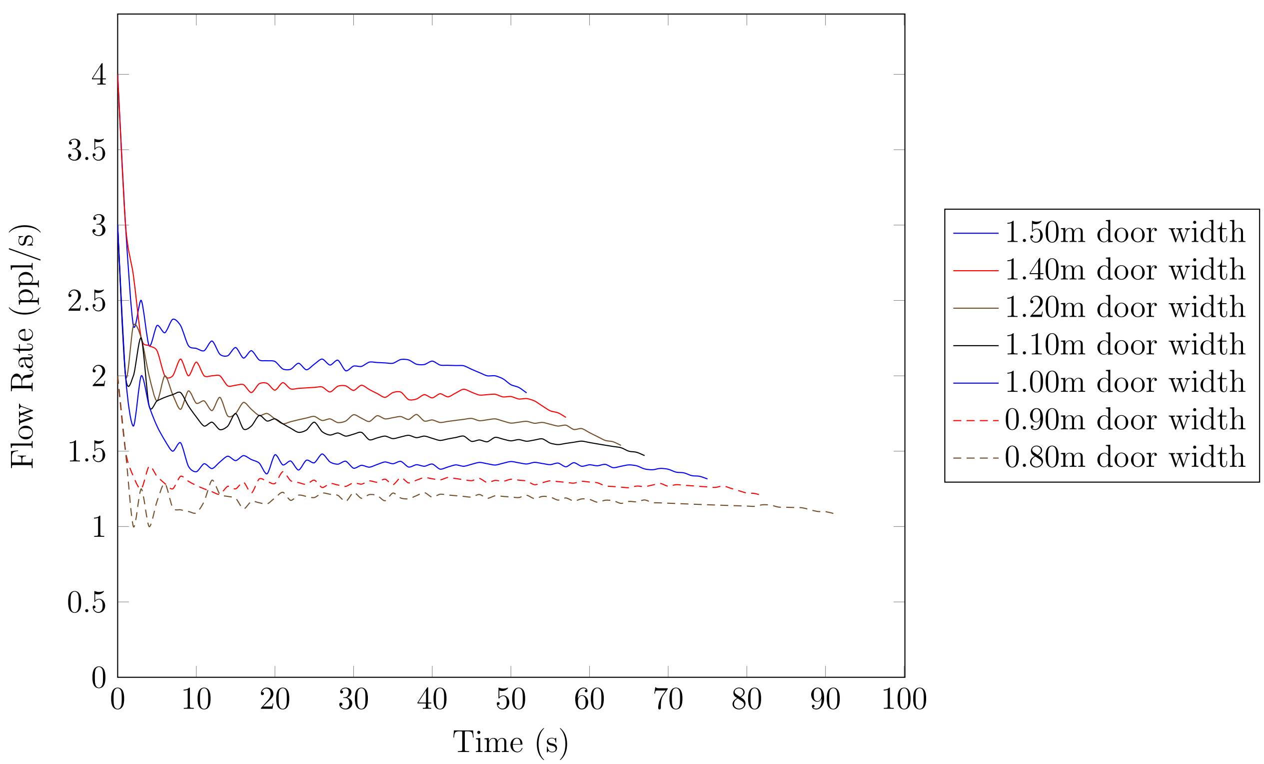


Figure 7: Test 4 Part 2 Average Flow Rate (People/s)

The MassMotion predictions illustrated in Figure 7 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 1.42708 people/m/s.

Table 5 shows how this average flow rate per unit width relates to the flow rates predicted by MassMotion.

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	1.43	1.14	1.21
0.90	1.43	1.28	1.31
1.00	1.43	1.43	1.41
1.10	1.43	1.57	1.60
1.20	1.43	1.71	1.70
1.40	1.43	2.00	1.93
1.50	1.43	2.14	2.11

Table 5: Test 4 Average Flow Rate per Unit Width Estimates

The average flow rate of 1.42708 people/m/s is slightly higher than values reported in other studies. Fruin indicates that the maximum flow rate per unit of width 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).

The predicted 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 6 and Figure 8.

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%	-14.0%
0.90	-10.0%	-7.1%
1.00	0.0%	0.0%
1.10	10.0%	13.5%
1.20	20.0%	20.3%
1.40	40.0%	37.1%
1.50	50.0%	49.7%

Table 6: Test 4 Increase in Uncapped Flow Rate by Increase in Link Width

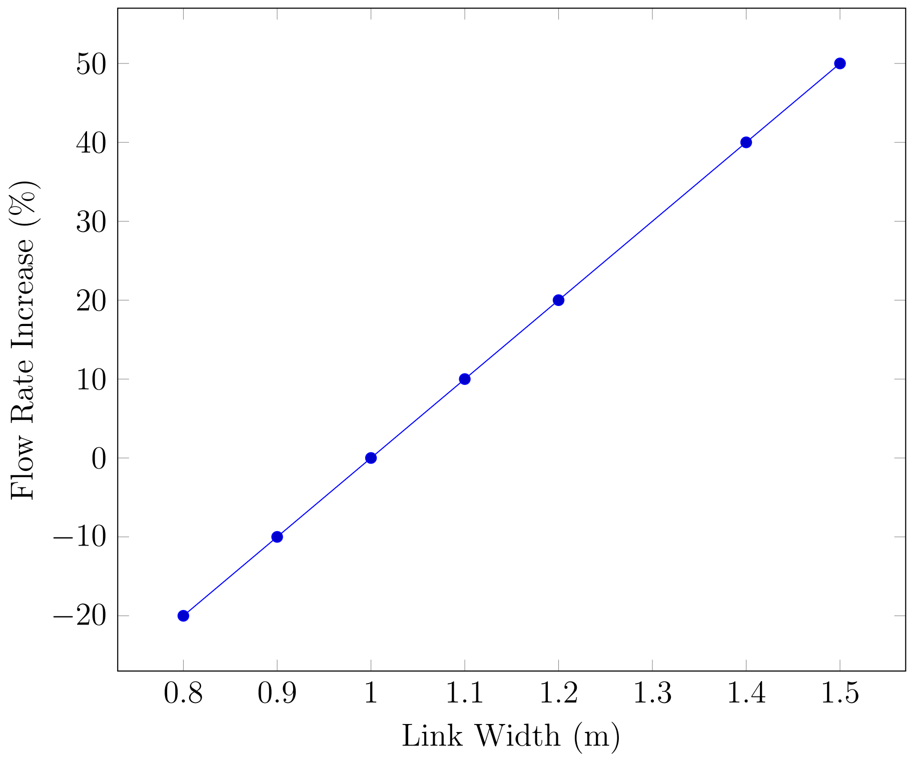


Figure 8: Test 4 Part 2 Flow Rate Increase by Link Width

4.5 Conclusion

The IMO 1238 Test 4 and NIST 1822 Test 5.2 have been conducted using MassMotion.

The predictions 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.

4.6 Recommendations

A sensitivity test has been undertaken. The modeller should make careful consideration of the use of uncapped flows in areas which are known to be subject to flow restrictions (extending to the impact of assigned walking speeds and pedestrian density upon simulation predictions). (Further work is required to explore the impact of uncapped flow rates.)

5 Test 5: Pre-evacuation Time

5.1 Test Description

The test is in accordance with IMO 1238 Test 5 and NIST 1822 Test 1.1.

Ten persons are located on a 8m x 5m floor having a 1.0 mm link (located centrally on the 5m wall). Pre-evacuation times are imposed randomly from a 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 1238 and NIST 1822 tests have identical physical environments. The IMO 1238 test specifies a uniform distribution of pre-evacuation times while the 1822 test further requires normal and log-normal distributions.

5.2 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.

5.3 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

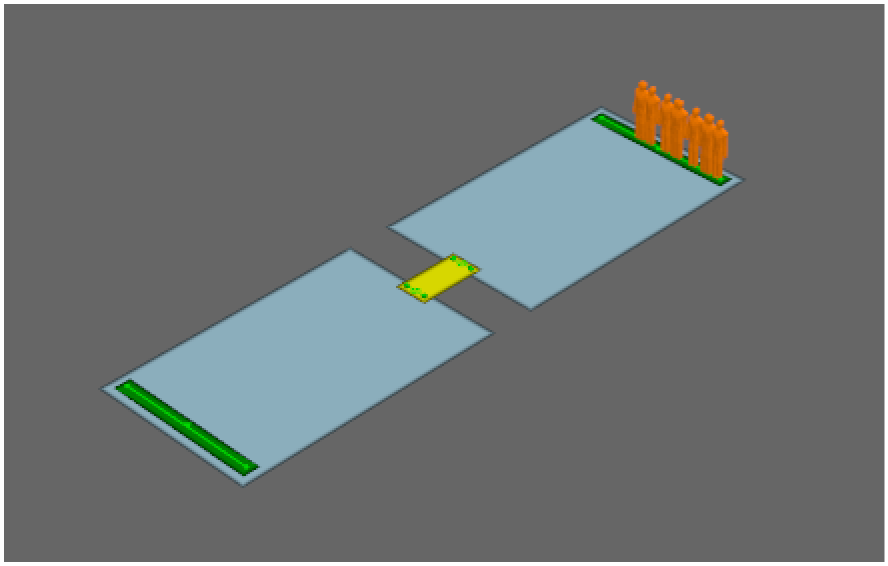


Figure 9: Test 5 Physical Environment.

- 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).

5.4 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 7. Histograms and cumulative distribution plots of pre-evacuation times for each distribution are shown in Figures 10 to 17.

Distribution	Minimum	Maximum	Average (Mean)	Standard Deviation
Uniform	10.200000	100.000000	54.962000	25.277073
Triangular	12.000000	97.800000	54.876000	17.851329
Normal	10.600000	99.400000	54.982000	18.719362
Log-normal	12.800000	99.400000	43.502000	21.891287

Table 7: Test 5 Distribution Results Summary

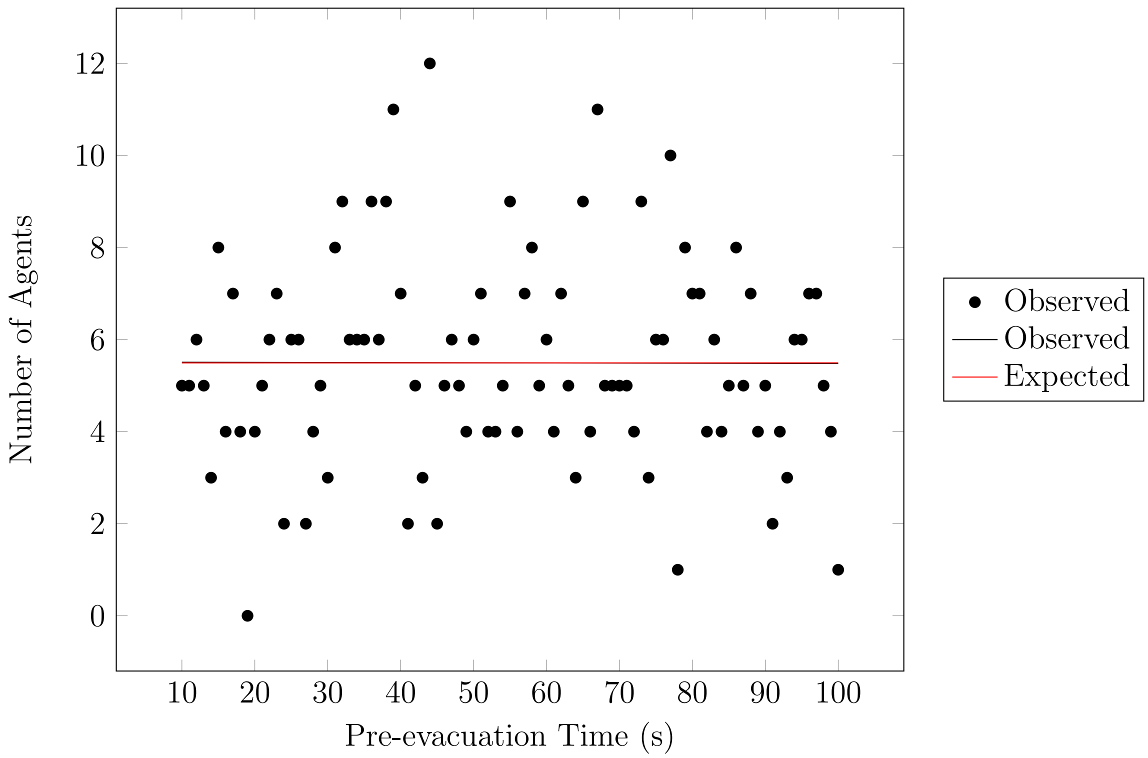


Figure 10: Test 5 Uniform Distribution Histogram

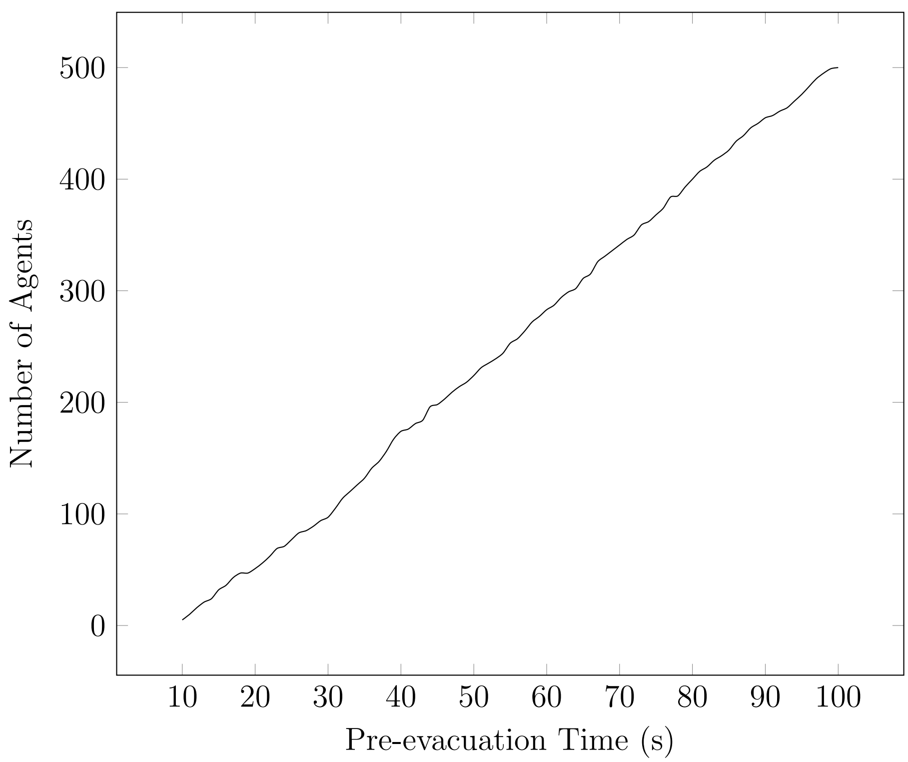


Figure 11: Test 5 Uniform Distribution Cumulative Graph

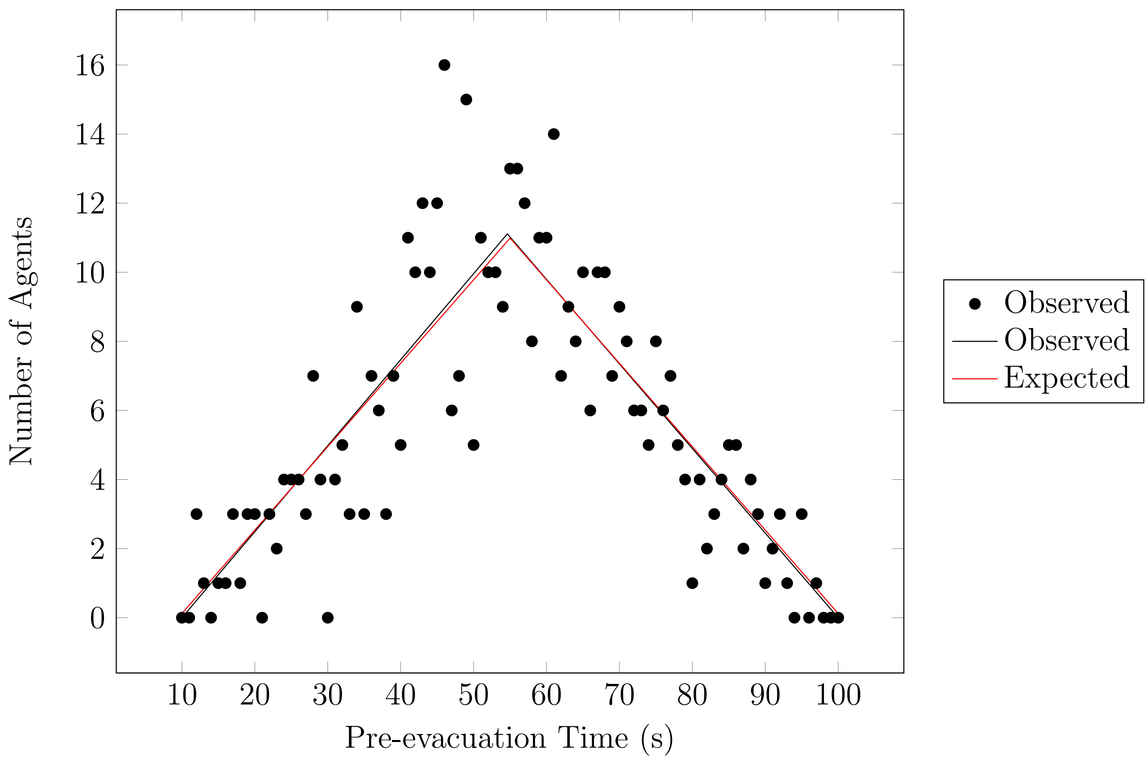


Figure 12: Test 5 Triangular Distribution Histogram

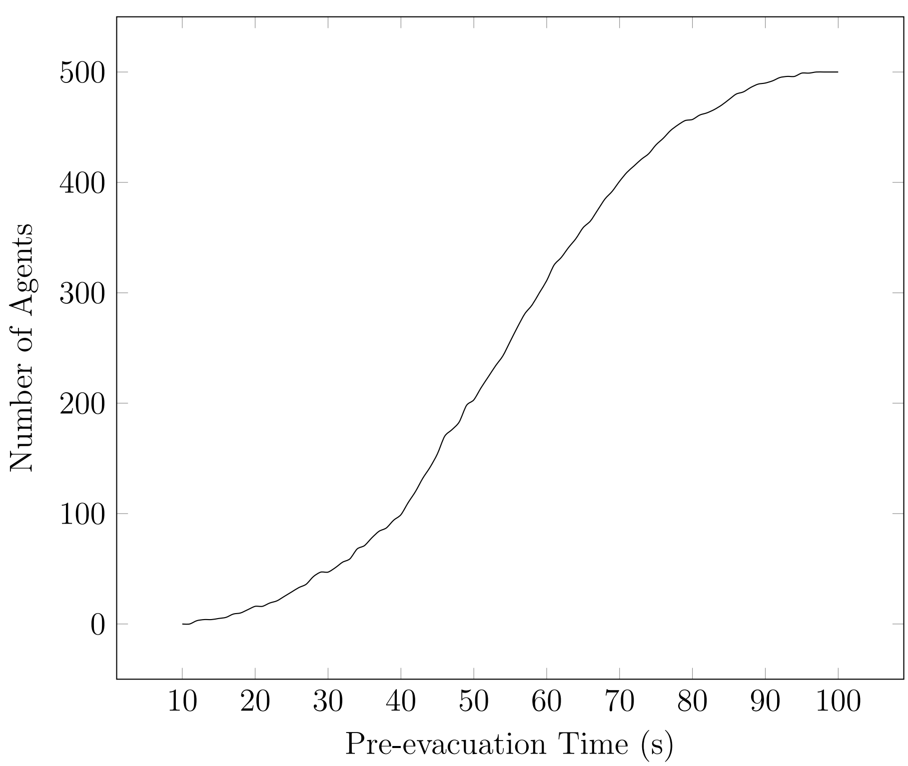


Figure 13: Test 5 Triangular Distribution Cumulative Graph

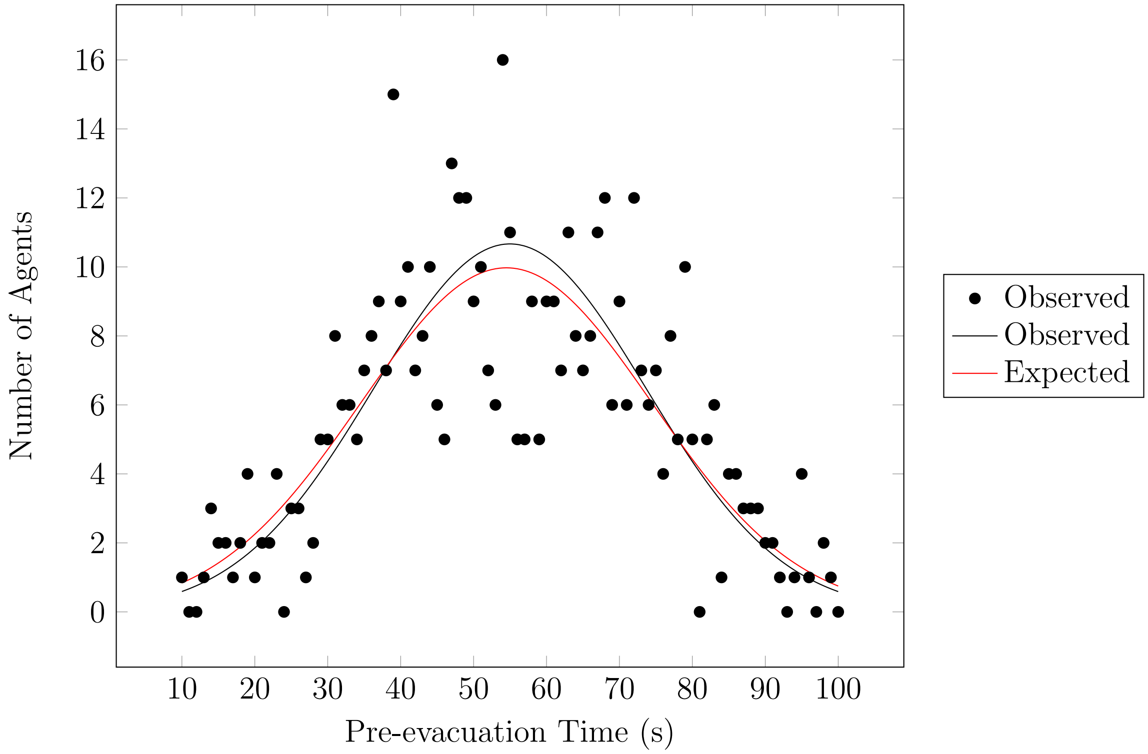


Figure 14: Test 5 Normal Distribution Histogram

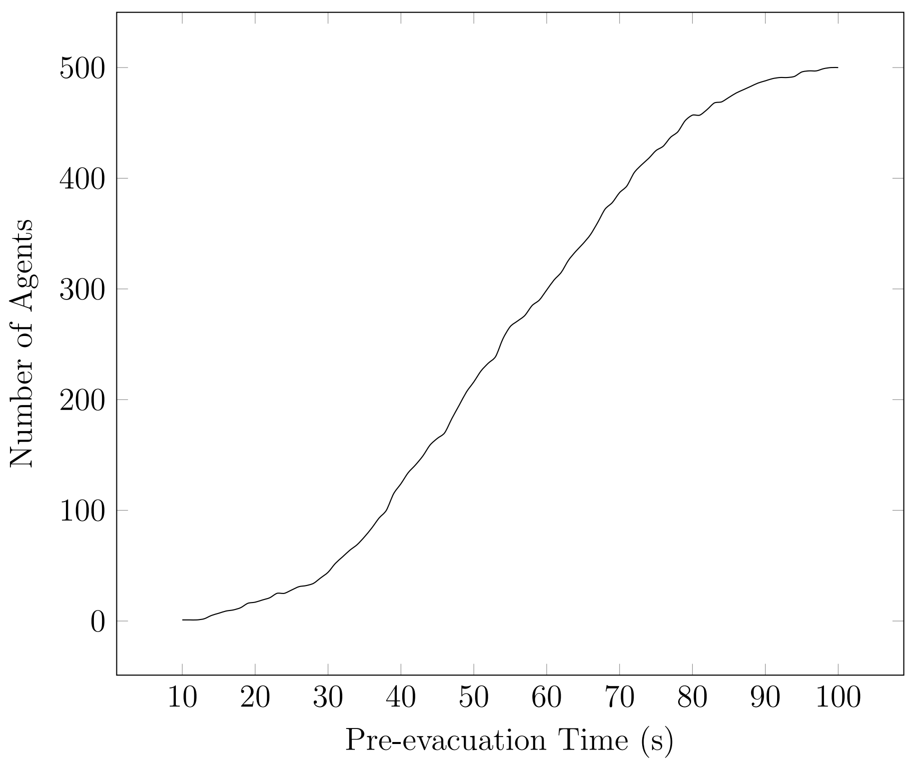


Figure 15: Test 5 Normal Distribution Cumulative Graph

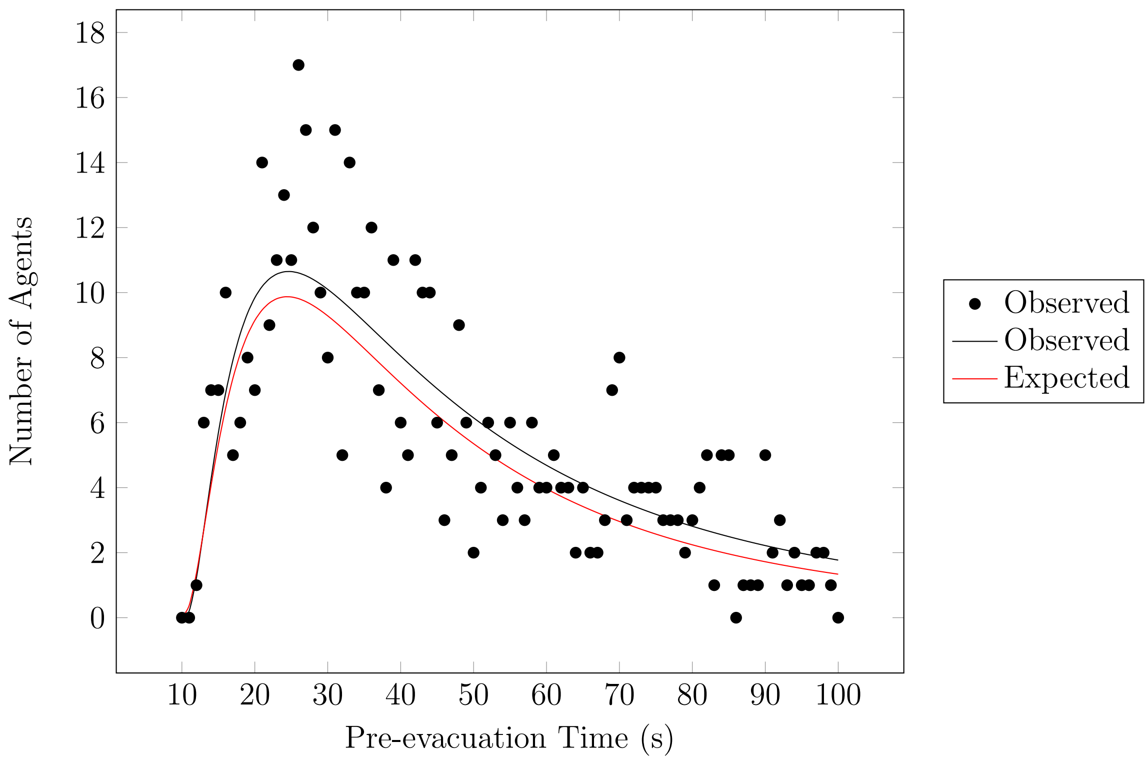


Figure 16: Test 5 Log-normal Distribution Histogram

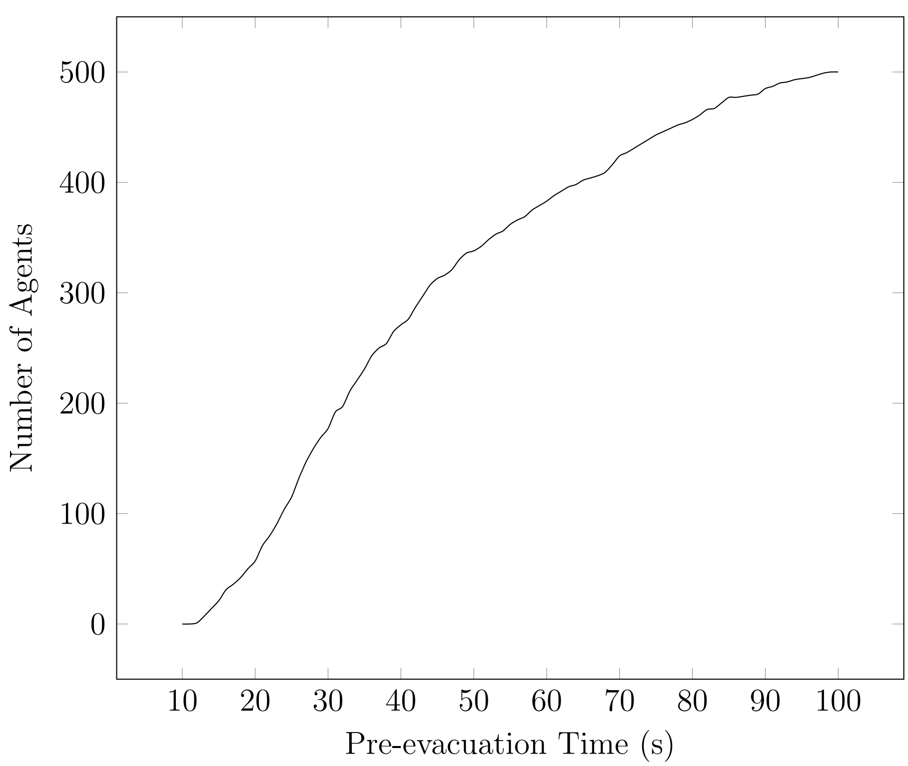


Figure 17: Test 5 Log-normal Distribution Cumulative Graph

5.5 Conclusion

The IMO 1238 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.

5.6 Recommendations

The use of random sampling from each of the four pre-evacuation time distributions results in some variability when reconstructing the pre-evacuation time distributions (and the standard deviations in particular) from the sampled data.

It is recommended that sensitivity testing extend the current test in order to understand the extent which this variation occurs and implications for each distribution type.

6 Test 6: Movement Around Corners

6.1 Test Description

The test is in accordance with IMO 1238 Test 6 and NIST 1822 Test 2.3.

The test is based on a right angle corridor having dimension as illustrated in Figure 18.

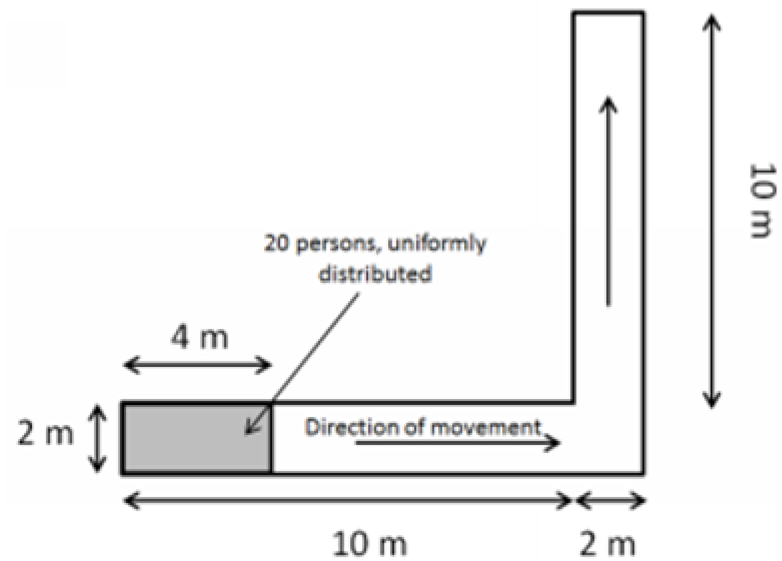


Figure 18: Test 6 Geometric Layout.

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.

6.2 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.

6.3 Simulation Setup

The geometrical layout of the IMO 1238 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 18).

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

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.

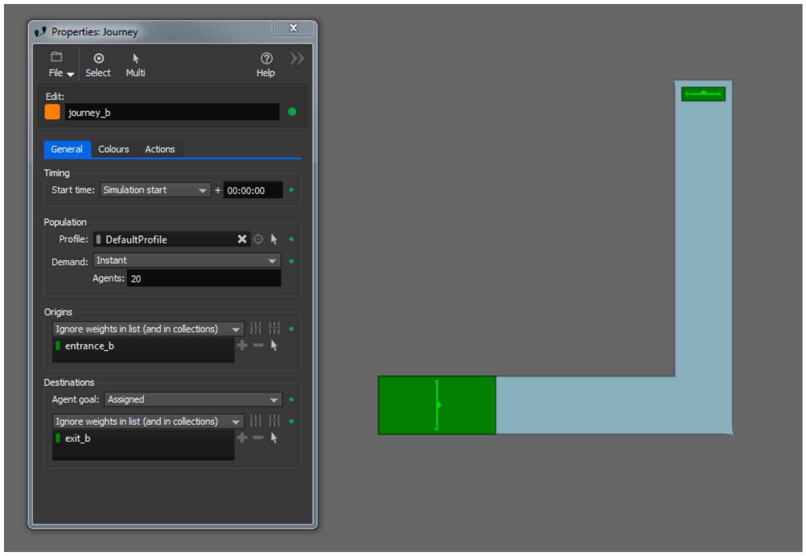


Figure 19: Test 6 Physical Environment and ‘Journey’ Properties.

6.4 Test Results

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

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

These demonstrate that:

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

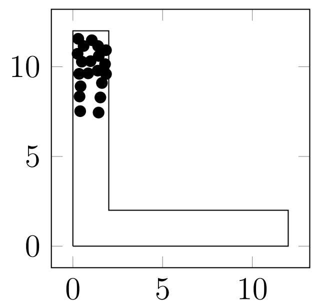
6.5 Conclusion

IMO 1238 Verification Test 6 and NIST 1822 Test 2.3 have been conducted within MassMotion.

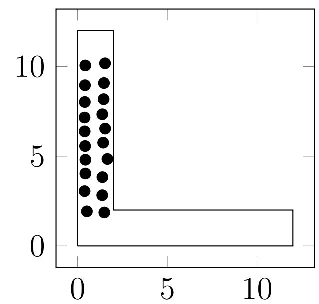
Analysis of the test results indicated that all 20 agents navigated the corner geometry without penetrating the boundaries.

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

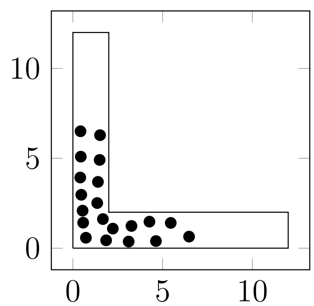
Status: Pass



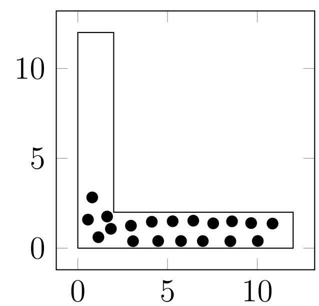
(a) Time 1s - All 20 agents entered simulation within the 2m x 4m entry portal.



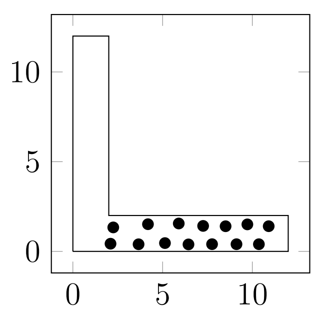
(b) Time 6s - First agent reaches the corner at this time (approximately).



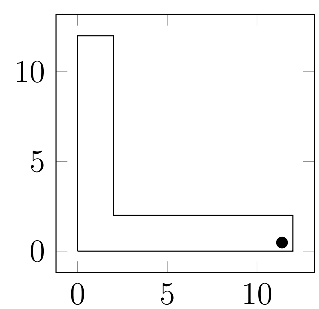
(c) Time 11s - Approximately half the agents navigated corner.



(d) Time 17s - First agent reaches destination portal.



(e) Time 20s - The last agent navigates the corner.



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

Figure 20: Test 6 Agent Movement Around Corners

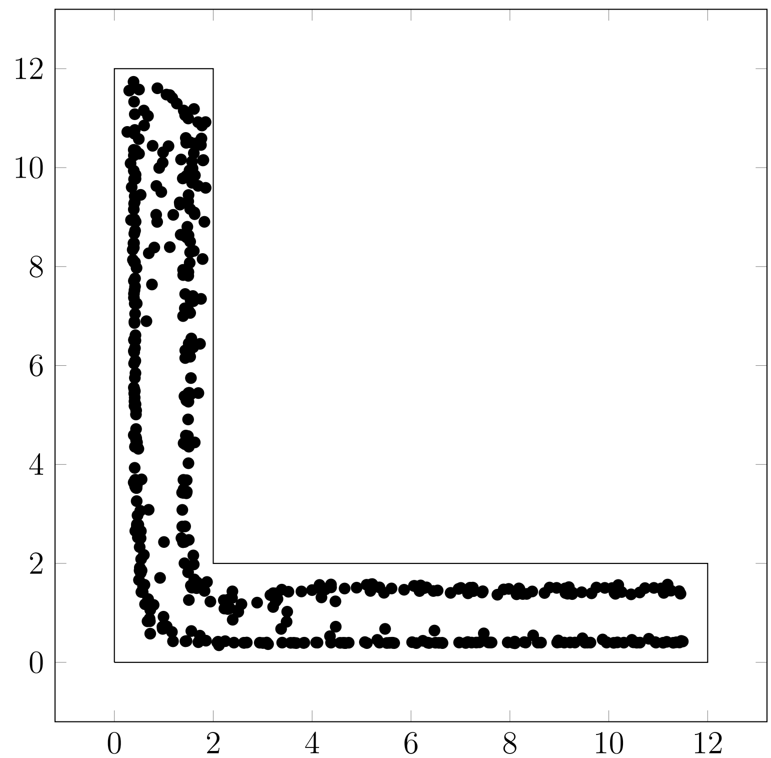


Figure 21: Test 6 MassMotion Agent Co-ordinate Positions

7 Test 7: Assignment of Parameters

7.1 Test Description

The test is in accordance with IMO 1238 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 1238 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.

7.2 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).

7.3 Simulation Setup

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

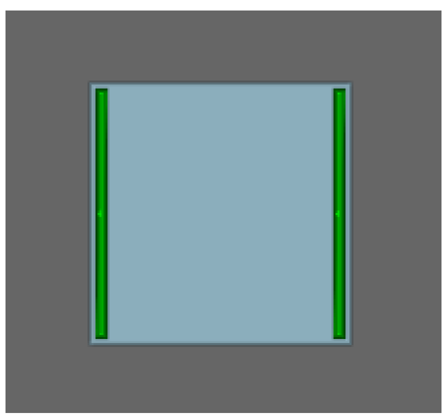


Figure 22: Test 7 Physical Environment

An IMO 1238 '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.

7.4 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 8.

	Expected	Observed
Minimum	0.97	0.971893
Maximum	1.62	1.619812
Mean	1.295	1.296990
Variance	0.035208	0.034052

Table 8: Test 7 Preferred Horizontal Terrain Walking Speed

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

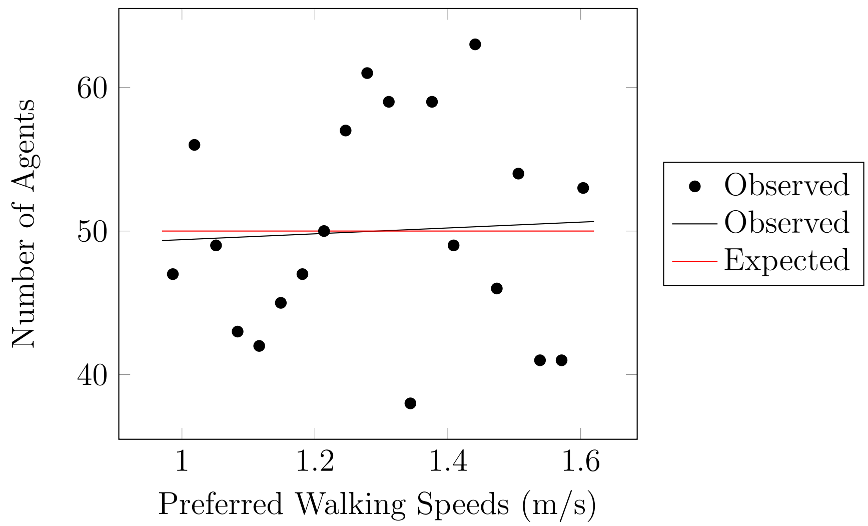


Figure 23: Test 7 Assigned Preferred Horizontal Terrain Walking Speeds

A chi-squared test with 20 buckets is used to check for uniform distribution and yields a test statistic of 20.84 . 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.

7.5 Conclusion

IMO 1238 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 predictions 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

8 Test 8: Counter-flow

8.1 Test Description

The test is in accordance with IMO 1238 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 1238 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 24.

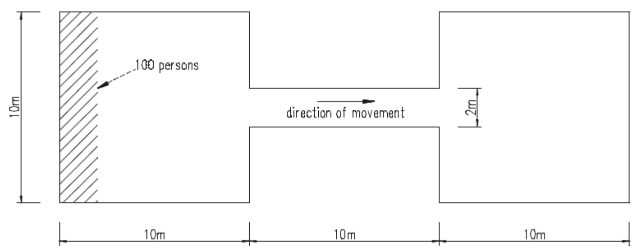


Figure 24: Test 8 Geometric Layout.

Six further scenarios, summarised in Table 9, are considered. There scenarios test the sensitivity of the predictions with respect to the floor occupancy and the direction bias.

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 9: Test 8 Scenarios

8.2 Aim of Test

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

8.3 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.

2000mm 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 1238 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 10.

Group	IMO 1238 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 10: IMO 1238 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 9. The direction bias is applied to agents originating on either floor.

The MassMotion model of Scenario 1 is illustrated in Figure 25.

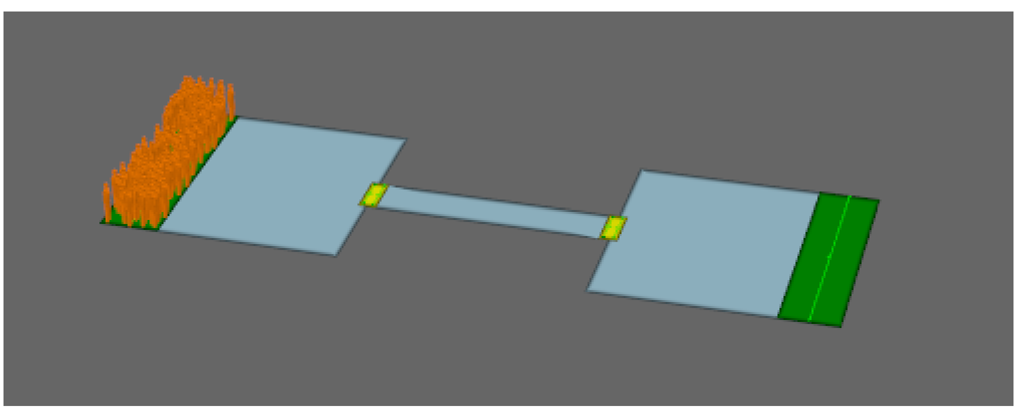


Figure 25: Test 8 Physical Geometry and Agent Population for Scenario 1.

8.4 Test Results

Table 11 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	63.000000
2	110.000000
3	129.000000
4	455.000000
5	240.400000
6	lock-up
7	lock-up

Table 11: 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 26 to 32 illustrate the simulation predictions 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**.

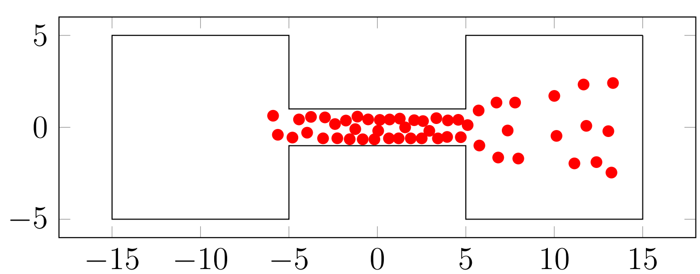


Figure 26: Test 8 Scenario 1 Agent Positions (at 47 seconds)

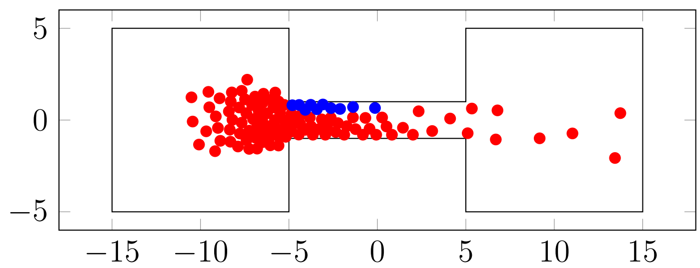


Figure 27: Test 8 Scenario 2 Agent Positions (at 25 seconds)

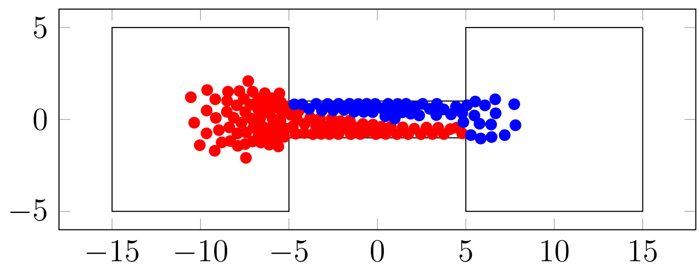


Figure 28: Test 8 Scenario 3 Agent Positions (at 25 seconds)

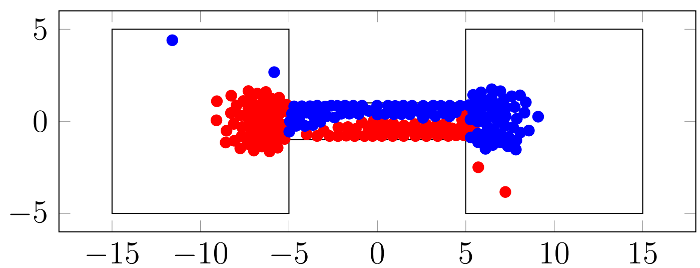


Figure 29: Test 8 Scenario 4 Agent Positions (at 38 seconds)

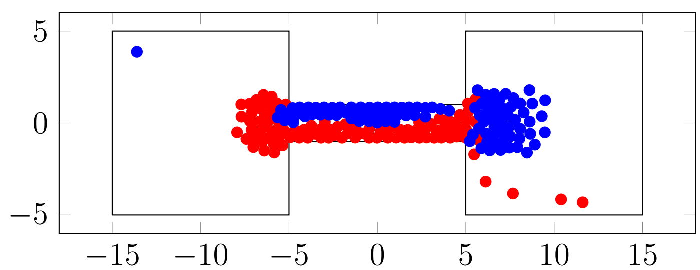


Figure 30: Test 8 Scenario 5 Agent Positions (at 53 seconds)

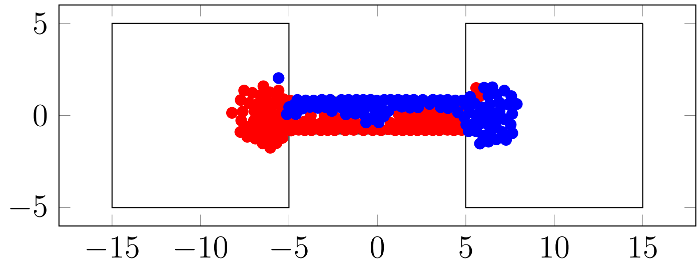


Figure 31: Test 8 Scenario 6 Agent Positions (at 57 seconds)

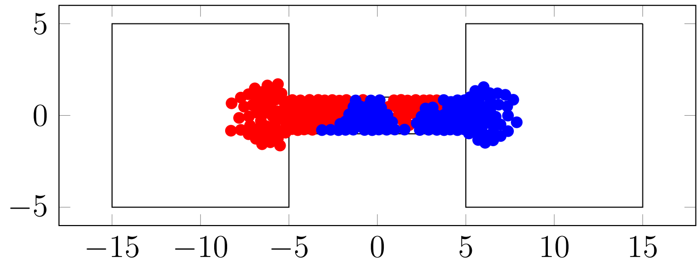


Figure 32: Test 8 Scenario 7 Agent Positions (at 54 seconds)

8.5 Conclusion

IMO 1238 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 predictions 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’).

9 Test 9: Crowd Exit Usage

9.1 Test Description

The test is in accordance with IMO 1238 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 33.

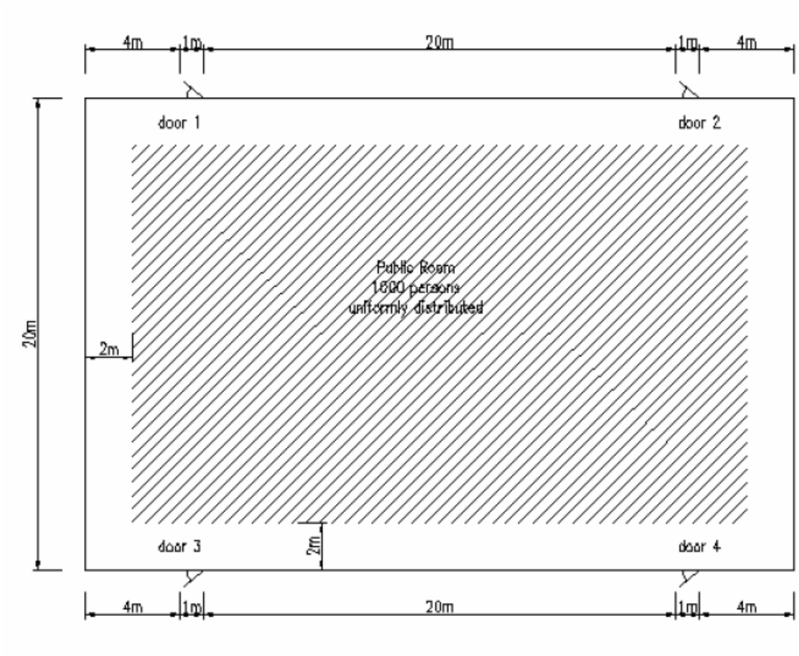


Figure 33: Test 9 Geometric Layout.

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.

9.2 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.

9.3 Simulation Setup

The MassMotion physical environment (showing floors (5), entry portals (1), links (4), and exit portals (4)) is illustrated in Figures 34 and 35.

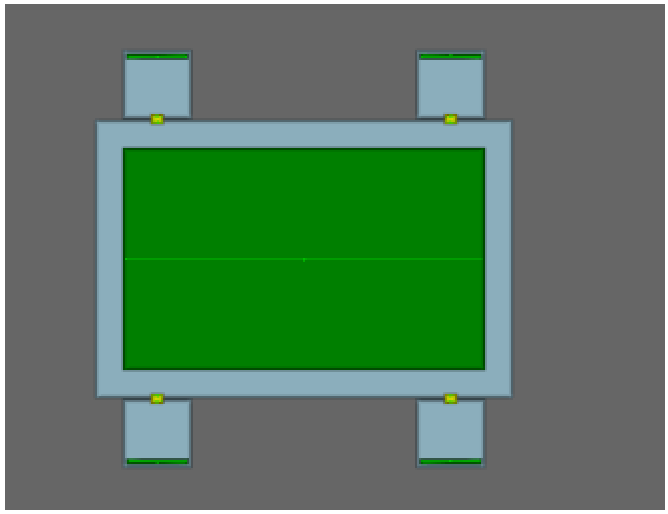


Figure 34: Test 9 Physical Environment.

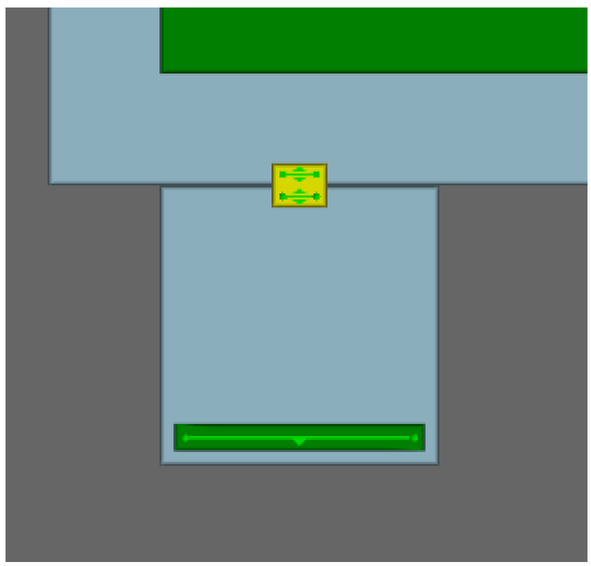


Figure 35: Test 9 Door 3 as a Mass Motion Link.

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

In Scenario 2, links 1 and 2 are disabled, preventing agents from using them to evacuate (Figure 36). Links 3 and 4 are unchanged.

An IMO 1238 '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.

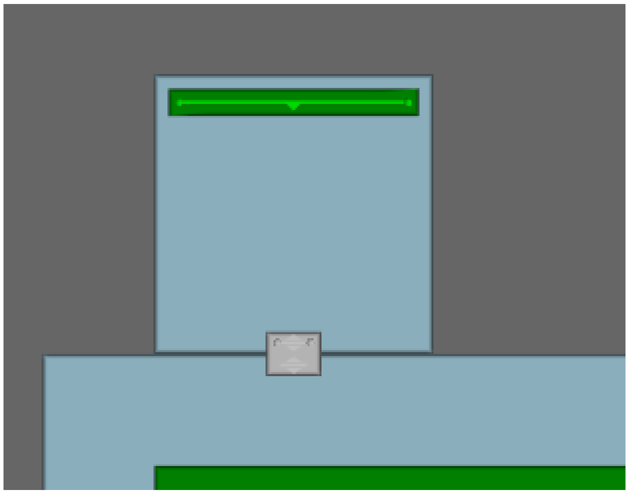


Figure 36: Test 9 Scenario 2 Door 1 as a Disabled Mass Motion Link.

9.4 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 12 and Figure 37.

	Minimum (s)	**Maximum (s)**	**Mean (s)**
Scenario 1 (Exits 1, 2, 3 and 4)	168.000000	178.000000	170.500000
Scenario 2 (Exits 3 and 4)	316.000000	333.000000	323.400000

Table 12: Test 9 Total Evacuation Time Predictions

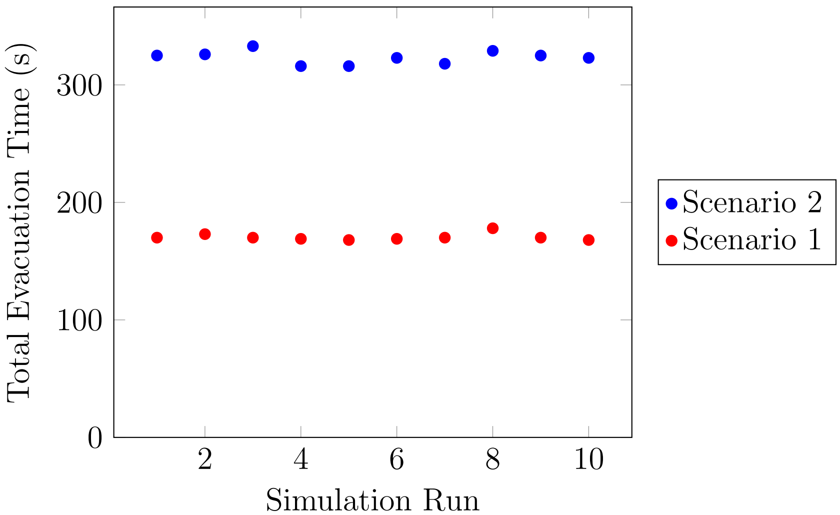


Figure 37: Test 9 Predicted Exit Times

Typical agent queuing at the relevant exits is illustrated in Figure 38 for Scenario 1 and Figure 39 for Scenario 2.

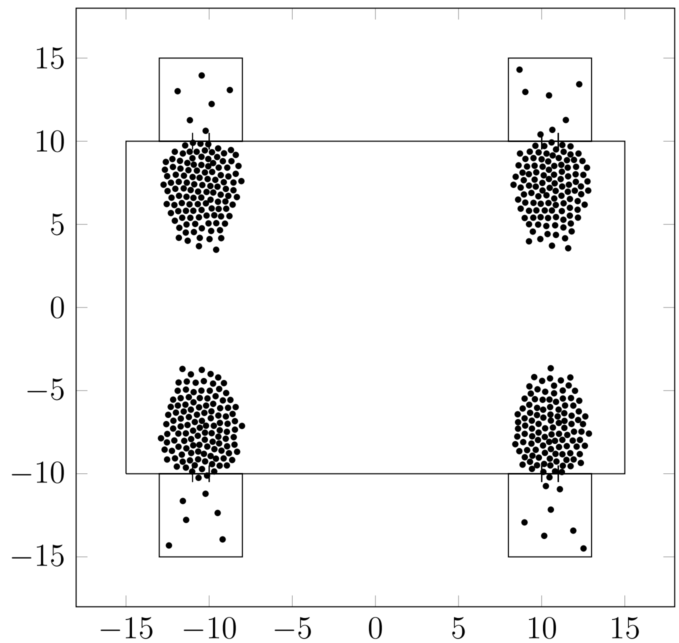


Figure 38: Test 9 Scenario 1 Typical Result

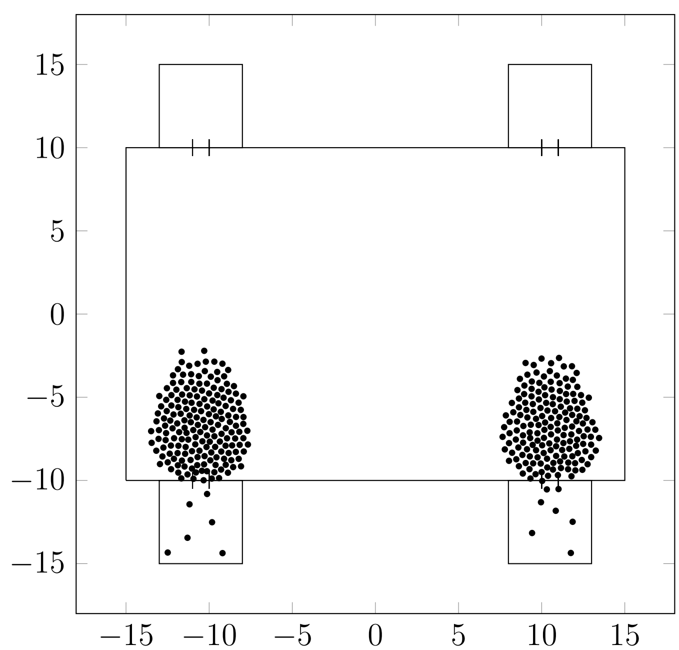


Figure 39: Test 9 Scenario 2 Typical Result

The total evacuation time for Scenario 2 is approximately twice (the mean is x1.90) 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.

9.5 Conclusion

IMO 1238 Test 9 has been conducted within MassMotion.

The predictions 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

10 Test 10: Exit Allocation

10.1 Test Description

The test is in accordance with IMO 1238 Test 10 and NIST 1822 Test 3.1.

The geometric layout (Figure 40) represents a cabin corridor.

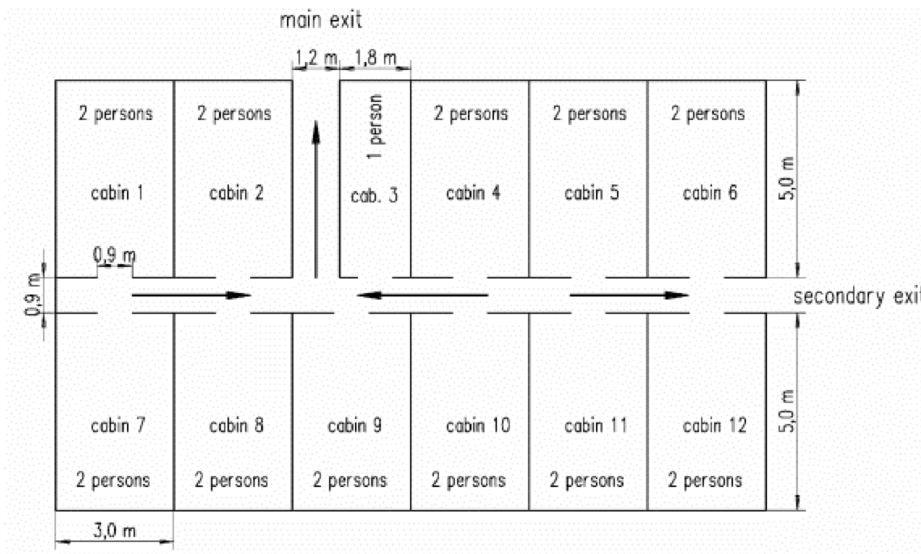


Figure 40: Test 10 Configuration of Cabin Corridor

The cabins are populated as shown in Figure 40. 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 1238 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 1238 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.

10.2 Aim of Tests

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

10.3 Simulations Setup

The physical environment is shown in Figure 41.

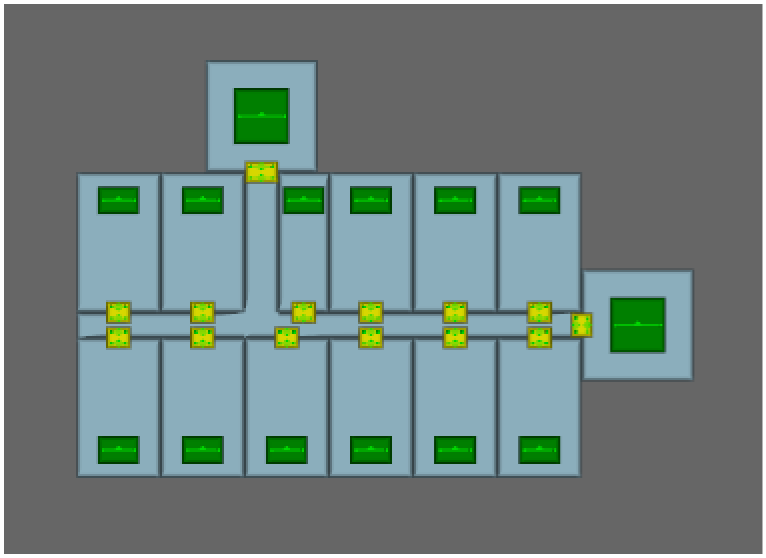


Figure 41: Test 10 Physical Environment

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.

10.4 Test Results

Table 13 summarises the MassMotion predictions 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	0	2
5	2	0	2	0	2
6	2	0	2	0	2
7	2	2	0	2	0
8	2	2	0	2	0
9	2	2	0	2	0
10	2	2	0	1	1
11	2	0	2	0	2
12	2	0	2	0	2

Table 13: Test 10 Number of Cabin Occupants Using Each Exit

The MassMotion predictions 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 adoped 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.

10.5 Conclusion

IMO 1238 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 predictions 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.

11 Test 11: Stair Congestion

11.1 Test Description

The test is in accordance with IMO 1238 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 42.

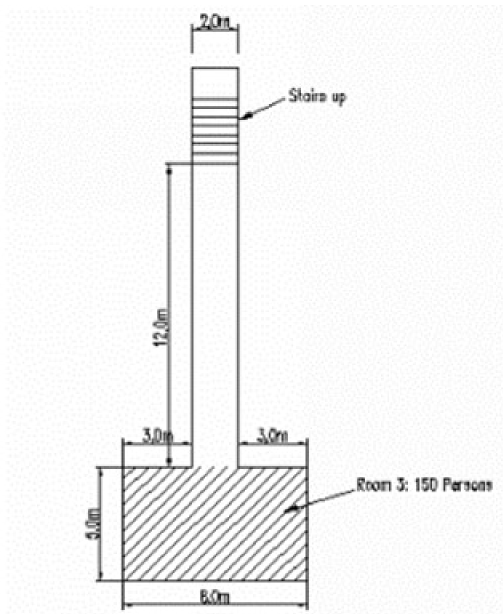


Figure 42: Test 11 Layout.

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.

11.2 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.

11.3 Simulations Setup

Four distinct geometry elements were created:

- 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 1238 ‘Males 30-50’ compatible agent profile was created.

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

Figures 43 and 44 show the setup of the physical environment in MassMotion.

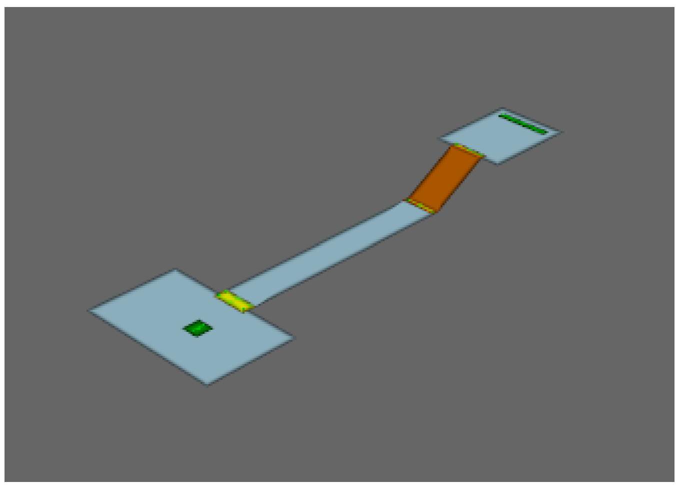


Figure 43: Test 11 Scenario 1&2 Physical Environment

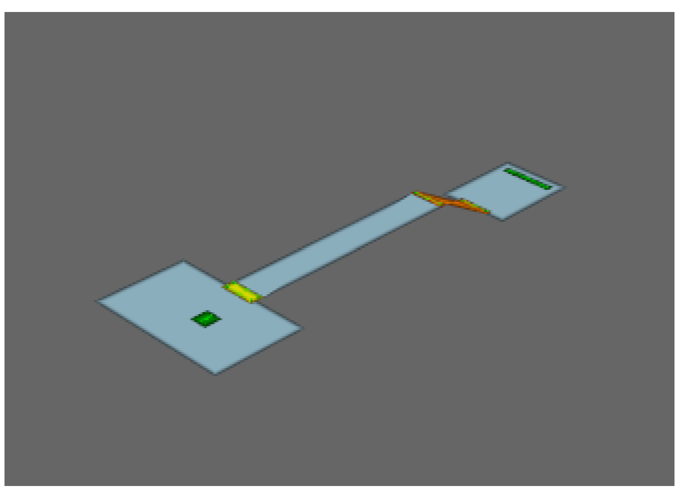


Figure 44: Test 11 Scenario 3&4 Physical Environment

11.4 Test Results

The MassMotion predictions are illustrated in figures 45, 46, 47 and 48.

11.5 Conclusion

IMO 1238 Test 11 and NIST 1822 Test 5.1 has been conducted within MassMotion.

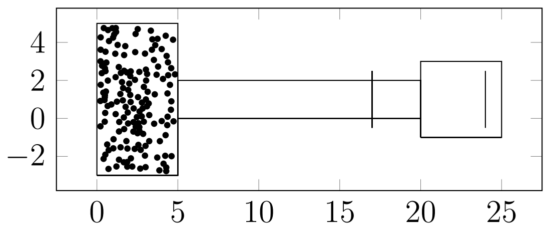
Qualitative assessment of the simulation predictions illustrate the ability of MassMotion to replicate congestion:

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

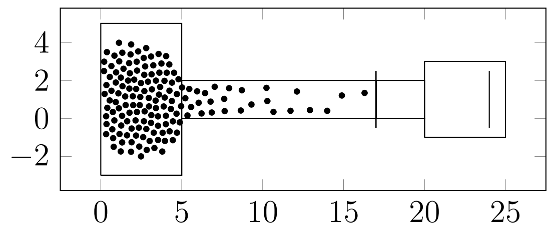
The extent of the congestion at the latter is a function of the direction of the stair and the initial room population. Greater congestion is noted for an upward stair than for a downward stair and an increased population leads to increased congestion.

The predictions 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.

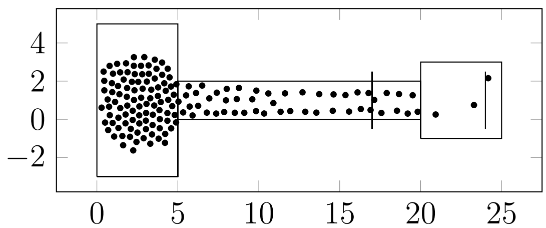
Status: Pass.



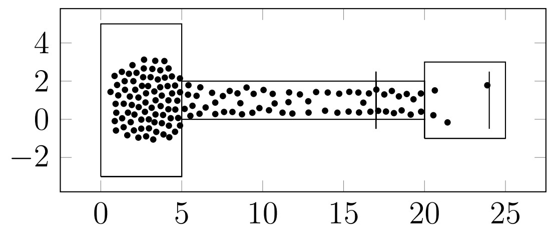
(a) The room is populated by 150 agents distributed uniformly.



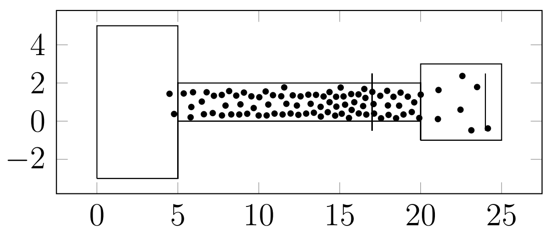
(b) Time 9s - First agent reaches foot of the stair.



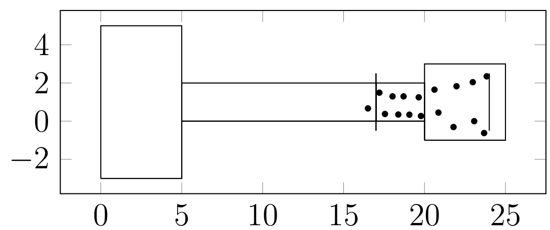
(c) Time 19s - First agent leaves simulation after reaching head of the stair.



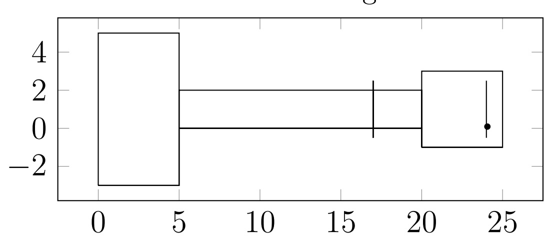
(d) Time 26s - Half of the agents have left room.



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

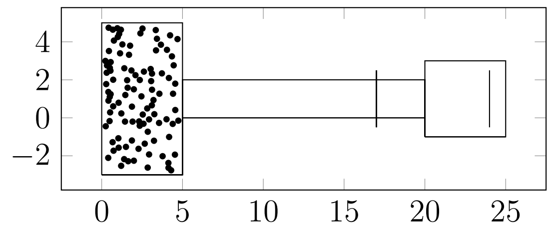


(f) Time 96s - The last of the agents are leaving the corridor to ascend the stair.

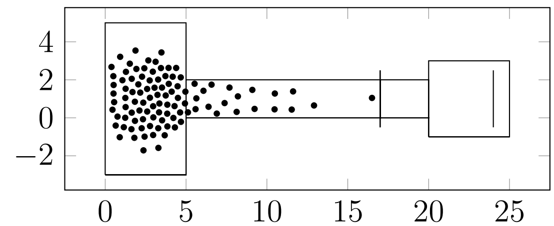


(g) Time 109s - The last agent leaves the simulation after reaching the head of the stair.

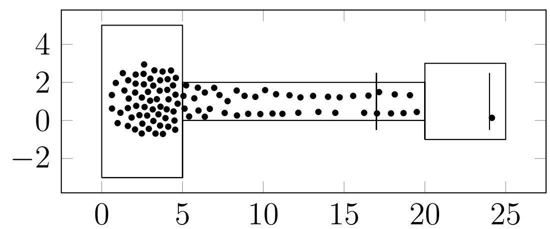
Figure 45: Test 11 Scenario 1 Results (150 Persons, Stair Up)



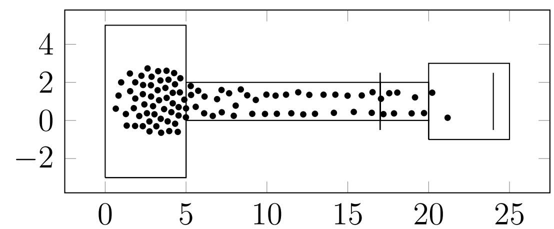
(a) The room is populated by 100 agents distributed uniformly.



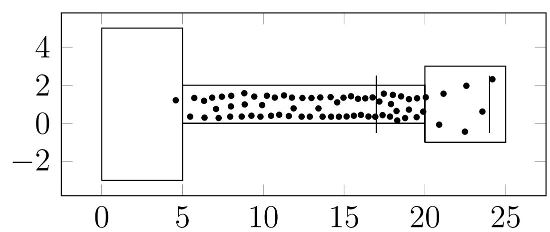
(b) Time 8s - First agent reaches the foot of the stair.



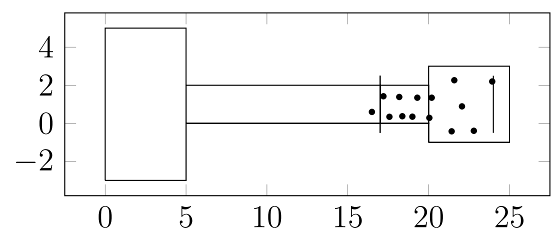
(c) Time 16s - First agent leaves simulation after reaching head of the stair.



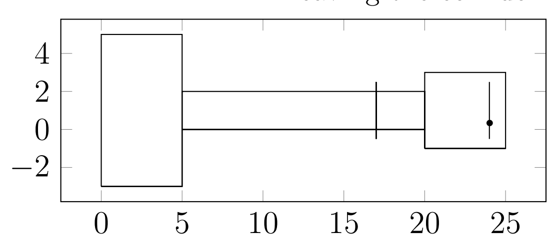
(d) Time 18s - Half of the agents have left room.



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

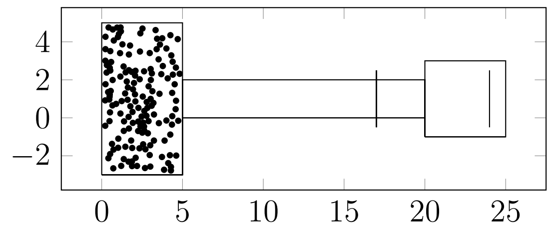


(f) Time 69s - The last of the agents are leaving the corridor to ascend the stair.

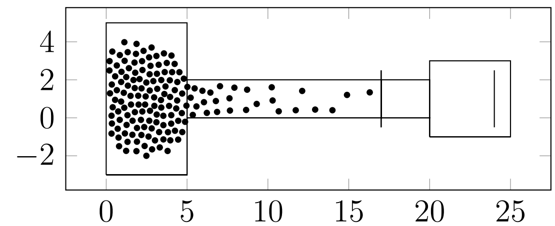


(g) Time 82s - The last agent leaves the simulation after reaching the head of the stair.

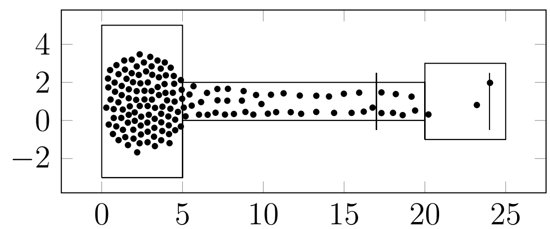
Figure 46: Test 11 Scenario 2 Results (100 Persons, Stair Up)



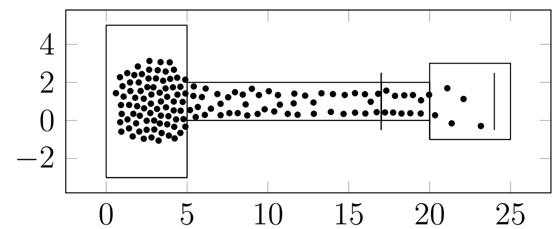
(a) The room is populated by 150 agents distributed uniformly.



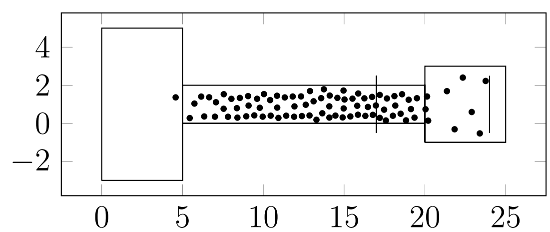
(b) Time 9s - First agent reaches head of the stair.



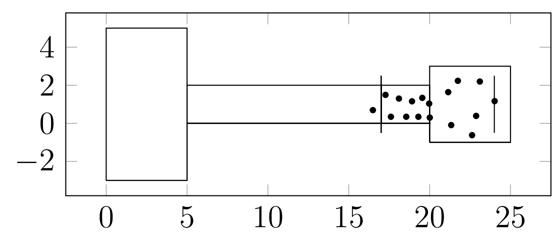
(c) Time 17s - First agent leaves simulation after reaching foot of the stair.



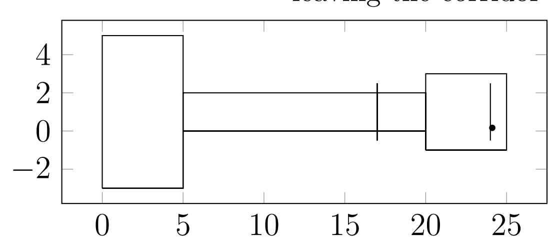
(d) Time 26s - Half of the agents have left room.



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

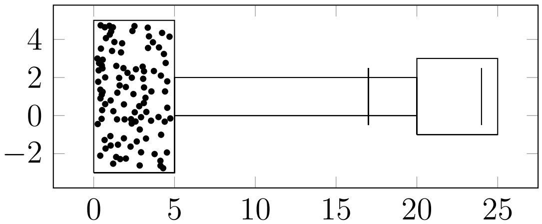


(f) Time 94s - The last of the agents are leaving the corridor to descend the stair.

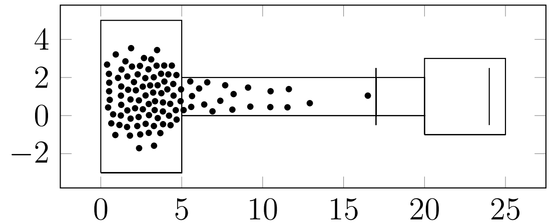


(g) Time 105s - The last agent leaves the simulation after reaching the foot of the stair.

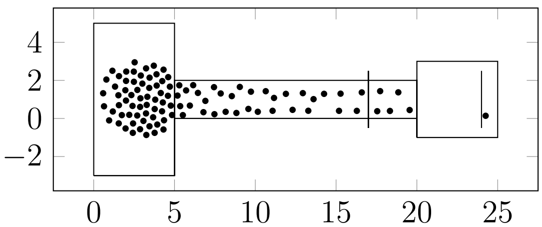
Figure 47: Test 11 Scenario 3 Results (150 Persons, Stair Down)



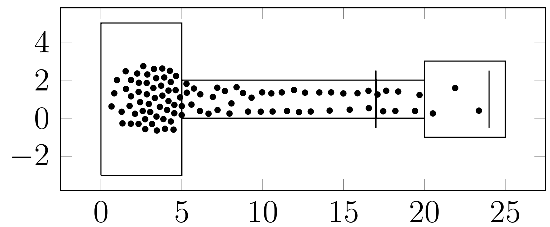
(a) The room is populated by 100 agents distributed uniformly.



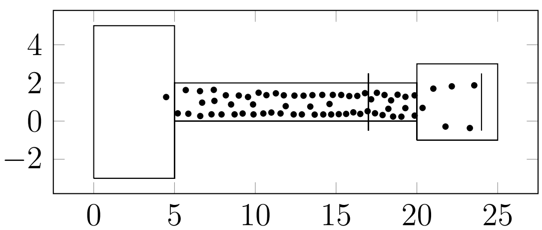
(b) Time 8s - First agent reaches head of the stair.



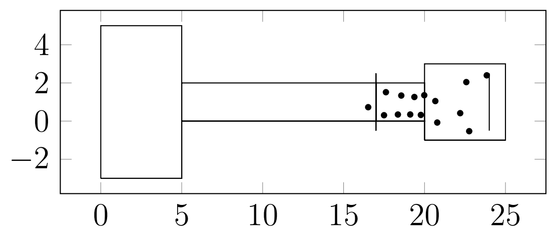
(c) Time 15s - First agent leaves simulation after reaching foot of the stair.



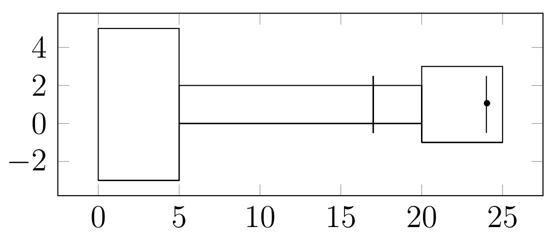
(d) Time 18s - Half of the agents have left room.



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



(f) Time 68s - The last of the agents are leaving the corridor to descend the stair.



(g) Time 79s - The last agent leaves the simulation after reaching the foot of the stair.

Figure 48: Test 11 Scenario 4 Results (100 Persons, Stair Down)

12 Test 12: Movement Disabilities

12.1 Test Description

The test is in accordance with NIST 1822 Test 2.10. There is no associated IMO 1238 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 1000mm exit is located at the boundary of Room 2 remote from the ramp. See Figure 49.

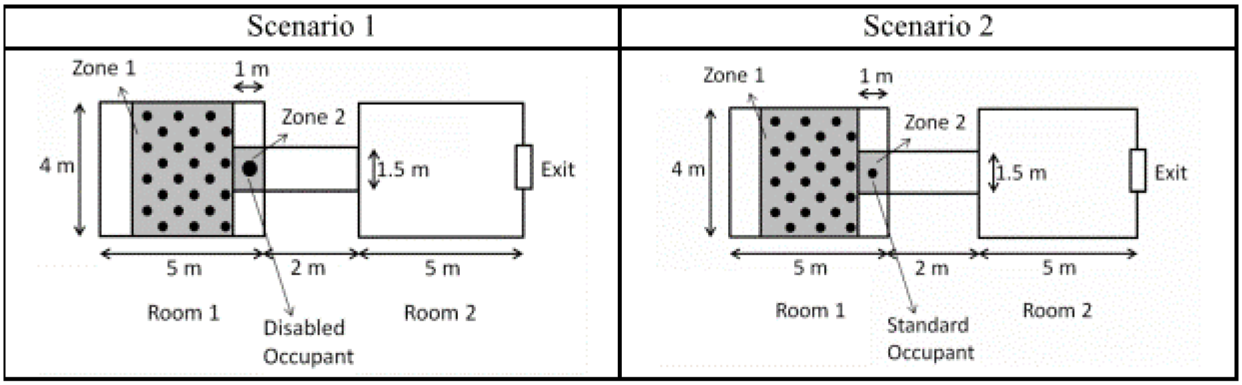


Figure 49: Test 12 Geometric Layout

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.

12.2 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.

12.3 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 50 shows the simulation setup within MassMotion.

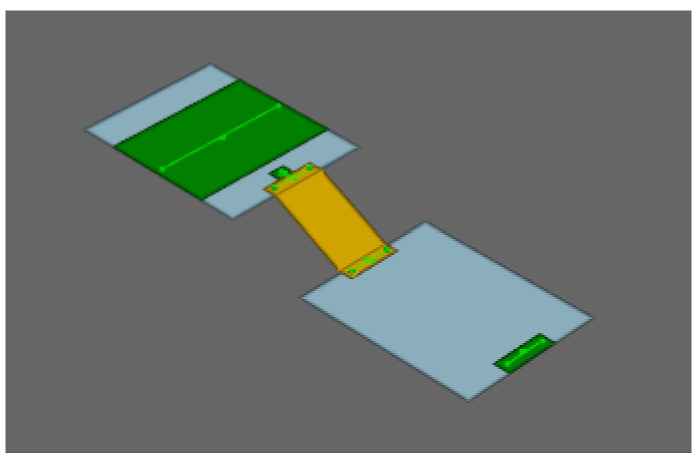


Figure 50: Test 12 Physical Environment.

12.4 Test Results

Figures 51, 52, 53 and 54 illustrates the MassMotion predictions when the mobility impaired agents of Scenario 1 are still on the ramp. Figure 55 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.

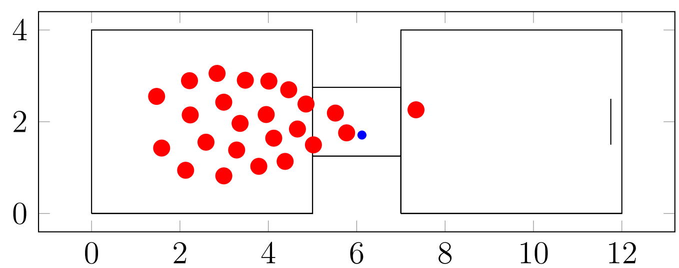


Figure 51: Test 12 Scenario 1 Simulation (0.25m impaired agent radius)

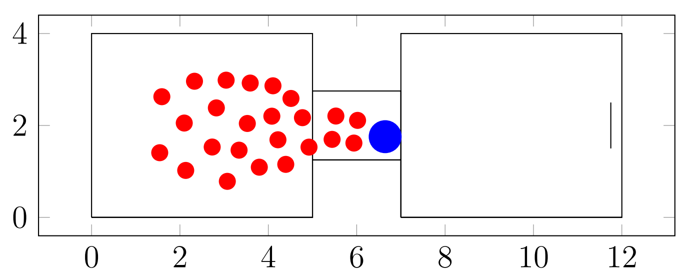


Figure 52: Test 12 Scenario 1 Simulation (1.0m impaired agent radius)

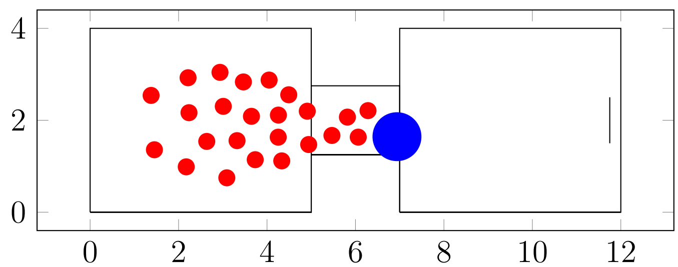


Figure 53: Test 12 Scenario 1 Simulation (1.5m impaired agent radius)

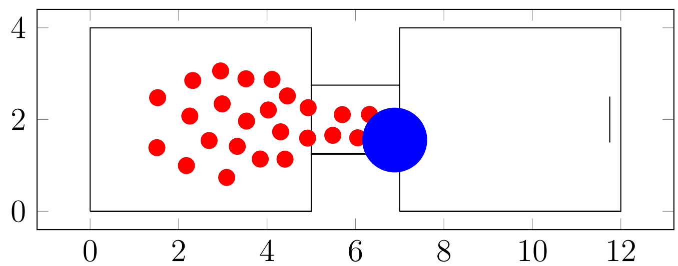


Figure 54: Test 12 Scenario 1 Simulation (2.0m impaired agent radius)

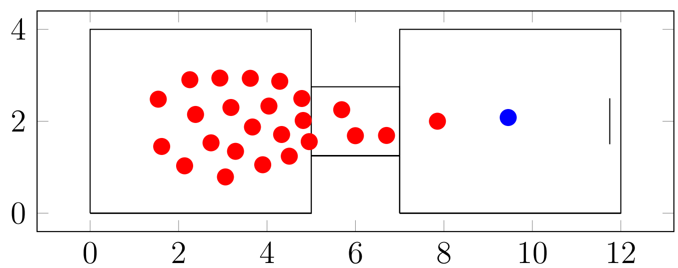


Figure 55: Test 12 Scenario 2 Simulation

12.5 Conclusion

NIST 1822 Test 2.10 has been conducted within MassMotion.

The predictions 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.

13 Test 13: Affiliation

13.1 Test Description

The test is in accordance with NIST 1822 Test 3.3. There is no associated IMO 1238 test.

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

A 15m x 10m floor (room) has two 1000mm exits located (See Figure 56):

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

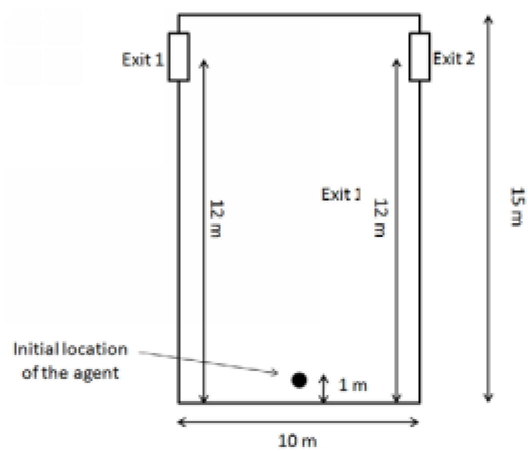


Figure 56: Test 13 Geometric Layout

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 2, ie. Exit 1 is favoured by the agent.

13.2 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.

13.3 Simulation Setup

The MassMotion physical environment (Figure 57) 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).

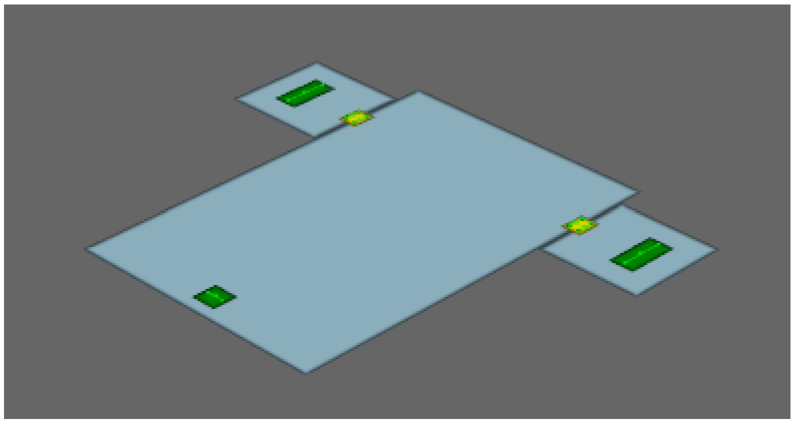


Figure 57: Test 13 Physical Environment.

The agent was assigend 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 14.

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

Table 14: Test 13 Exit Weights

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

13.4 Test Results

The frequency of usage of each exit over the 100 simulations is summarized in Table 15.

This demonstrates that the MassMotion predictions 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	-	57	43
2	A	71	29
2	B	99	1

Table 15: Test 13 MassMotion Exit Usage

13.5 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.

14 Test 14: Dynamic Availability of Exits

14.1 Test Description

The test is in accordance with NIST 1822 Test 4.1. There is no associated IMO 1238 test.

A 15m x 10m floor (room) has two 1000mm exits located (See Figure 58):

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

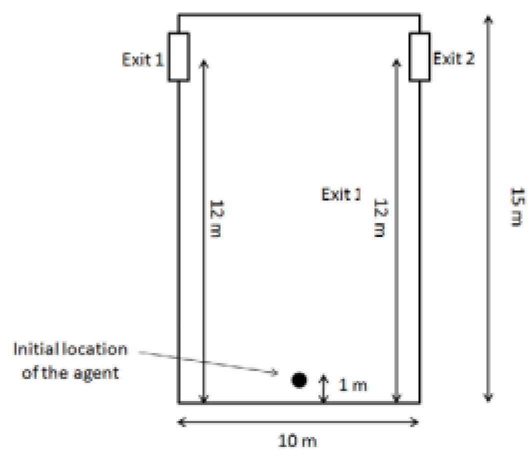


Figure 58: Test 14 Geometric Layout

Both Exit 1 and Exit 2 are available initially. After 1 second, Exit 1 becomes unavailable

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

14.2 Aim of Test

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

14.3 Simulation Setup

The MassMotion physical environment (Figure 59) 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).

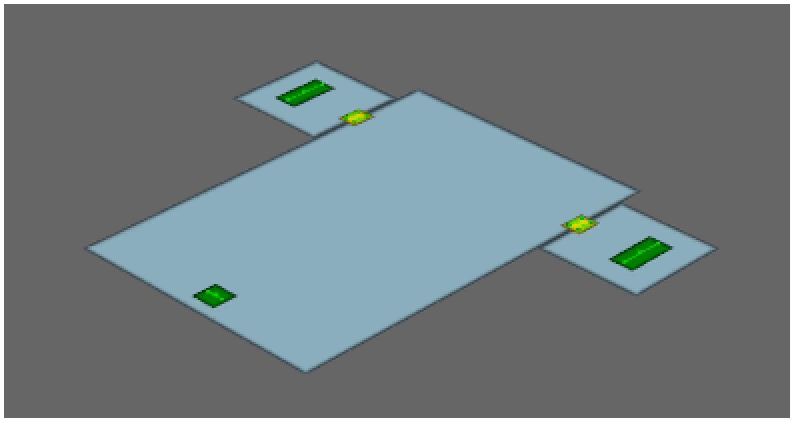


Figure 59: Test 14 Physical Environment.

Two scenarios are considered with the following parameters set for the simulation:

- Profile:
  - Preferred horizontal walking speed = constant;
  - Value = 1m/s.
- Journey:
  - Demand = Instant;
  - Agent count = 1;
  - Entry portal (weight = 1);
  - Exit portal 1 (weight = 0.5);
  - Exit portal 2 (weight = 0.5).
- Links to Exits 1&2:
  - Enabled to be used as a 'Gate';
  - Cost of waiting = 100000 (ie. a big cost).
- 'Open Gate' event for Exit 1
  - Scenario 1 - Gate to be open from 0s to 2s 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.

14.4 Test Results

Agent route maps are illustrated in Figure 60 (Scenario 1) and Figure 61 (Scenario 2).

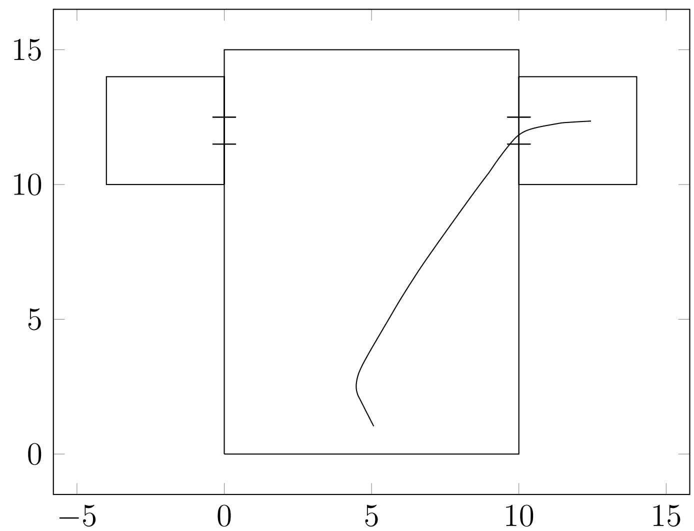


Figure 60: Test 14 Scenario 1 Predicted Agent Route Map

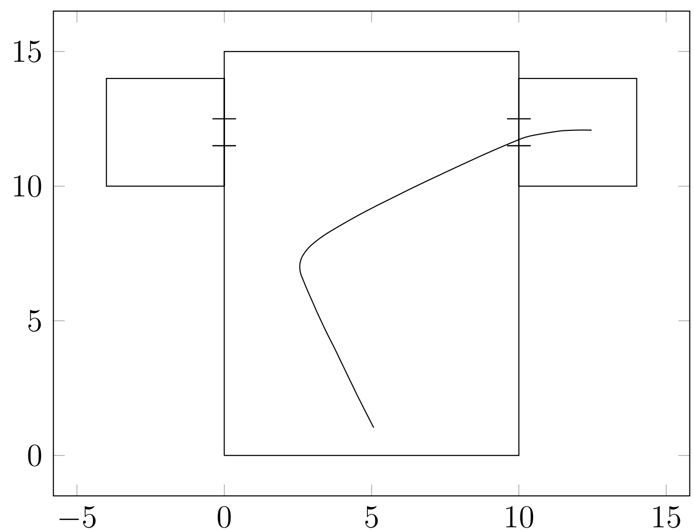


Figure 61: Test 14 Scenario 2 Predicted Agent Route Map

The agent route map predictions are consistent with anticipated behaviours.

14.5 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.

15 Test 15: Stair Merging

15.1 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 1238 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 62.

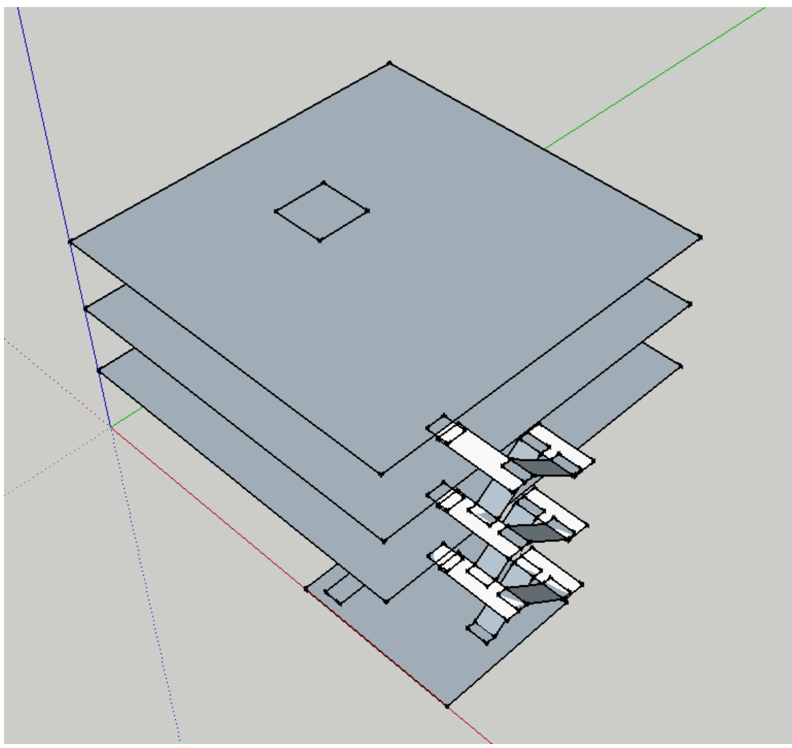


Figure 62: Test 15 Geometric Layout

Table 16 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 16: Test 15 Floor Occupancies

15.2 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.

15.3 Simulations Setup

The MassMotion model geometry includes (Figure 63):

- 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.

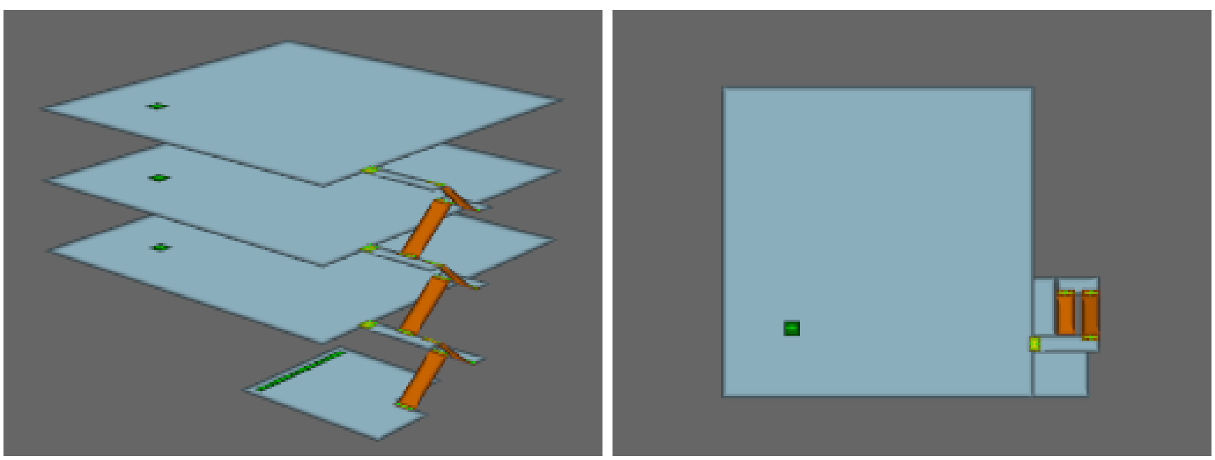


Figure 63: Test 15 Physical Environment.

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 predictions 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.

15.4 Test Results

The time required for agents to clear the first floor (above ground floor) is summarized in Table 17.

Scenario	Time (s)	% Change Relative to Scenario 1	% Change Relative to Scenario 2
1	80.200000	N/A	N/A
2	97.600000	121.695761	N/A
3	95.200000	118.703242	97.540984
4	101.000000	125.935162	103.483607
5	97.000000	120.947631	99.385246

Table 17: Test 15 First Floor Clearance Times

MassMotion predicts that in Scenario 1 (no stair merging), the first floor (above ground) will clear in 80.200000s.

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 97.000000s, 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.

15.5 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.

15.6 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).

16 Test 16: Stair Flows

16.1 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 1238 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 64).

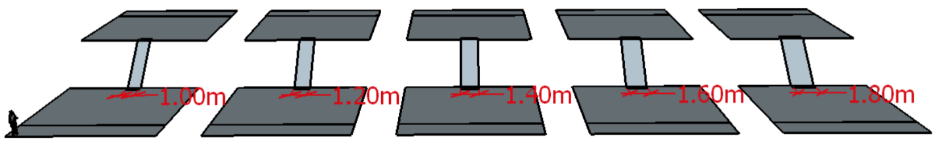


Figure 64: Test 16 Layout.

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

16.2 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.

16.3 Simulation Setup

Each scenario is run 5 times with different stair widths (1.0m, 1.2m, 1.4m, 1.6m, 1.8m). Table 18 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)	A	B	C	D	E

Table 18: Test 16 Test Cases

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

- 2 floors (8m x 8m);

- 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.

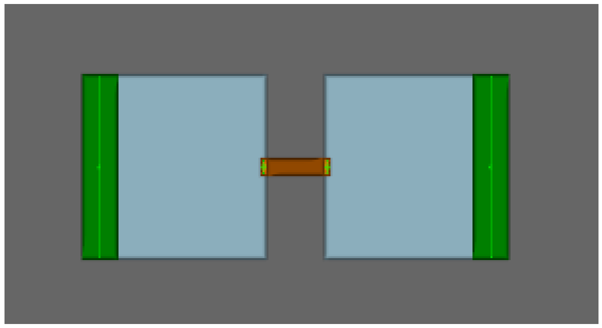


Figure 65: Test 16 Physical Environment (1.0m width)

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 measued at the point where the agents enter the stairs (ie. at the top in Scenario 1 and at the bottom in Scenario 2).

16.4 Test Results

The floor clearance times are summarised in Table 19.

Scenario	Case	Clearance Time (s)
1 (Stair Down)	A (1.0m width)	108
1 (Stair Down)	B (1.2m width)	95
1 (Stair Down)	C (1.4m width)	83
1 (Stair Down)	D (1.6m width)	73
1 (Stair Down)	E (1.8m width)	68
2 (Stair Up)	A (1.0m width)	110
2 (Stair Up)	B (1.2m width)	93
2 (Stair Up)	C (1.4m width)	85
2 (Stair Up)	D (1.6m width)	71
2 (Stair Up)	E (1.8m width)	68

Table 19: Test 16 Entrance Floor Clearance Times

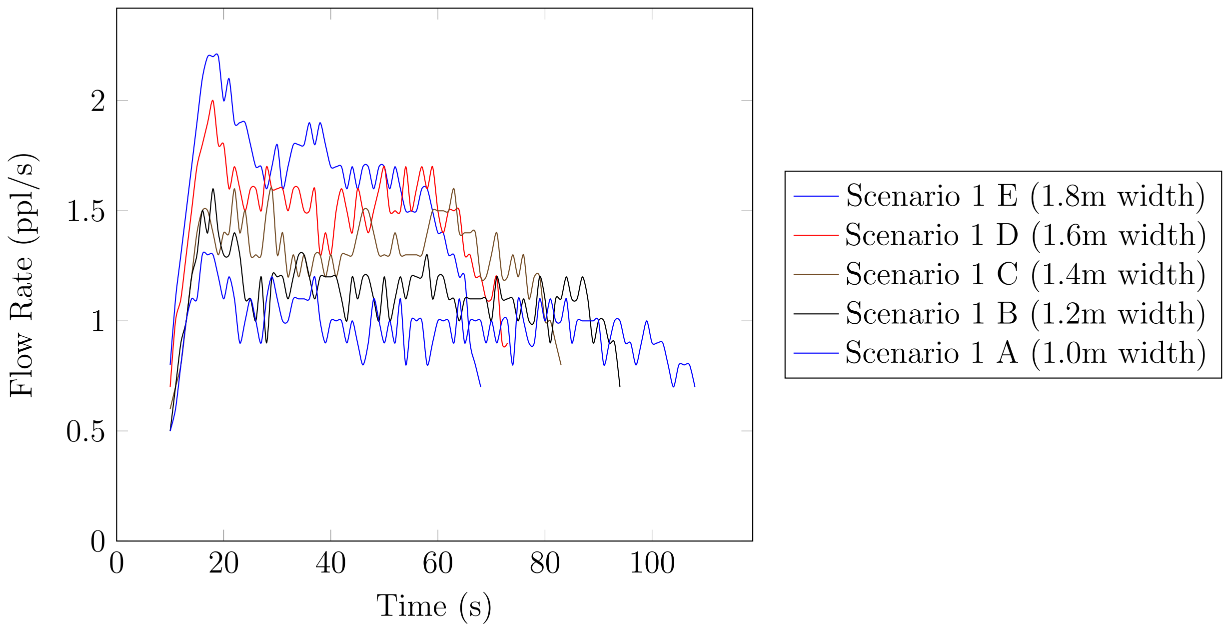


Figure 66: Test 16 Scenario 1 Average Flow Rates Through the Stair (Down)

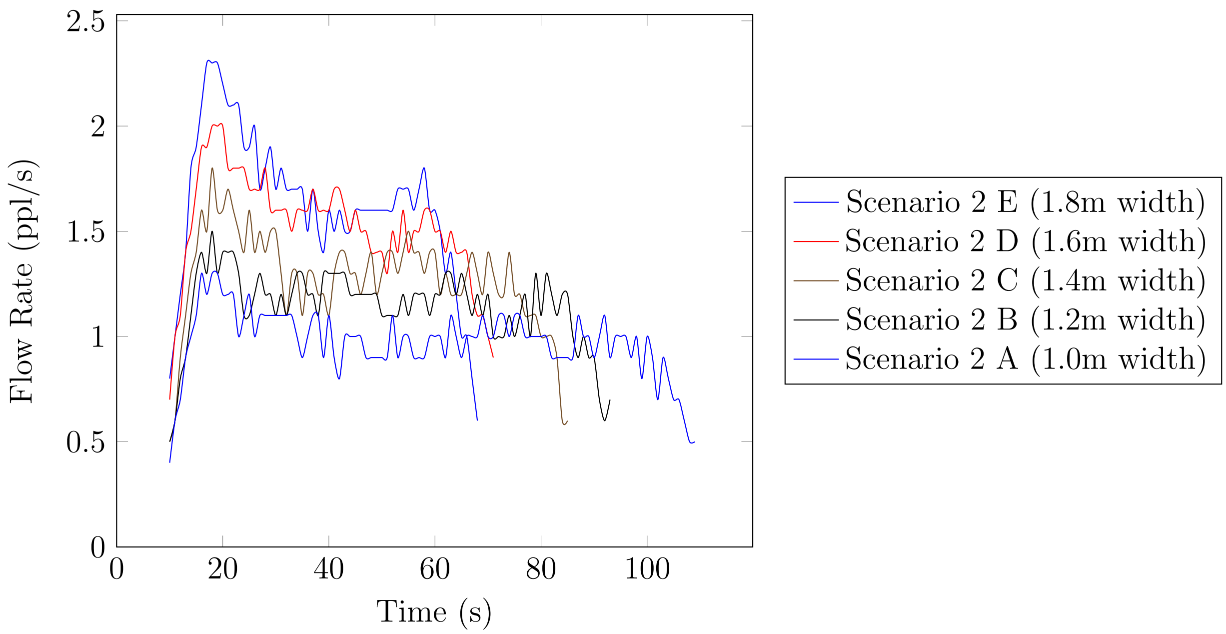


Figure 67: Test 16 Scenario 2 Average Flow Rates Through the Stair (Up)

The average agent flow rate through each stair as a function of time is illustrated in Figure 66 for Scenario 1 and 67 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 20 and illustrated in Figure 68. 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)	0.917431
1 (Stair Down)	B (1.2m width)	1.052632
1 (Stair Down)	C (1.4m width)	1.190476
1 (Stair Down)	D (1.6m width)	1.351351
1 (Stair Down)	E (1.8m width)	1.449275
2 (Stair Up)	A (1.0m width)	0.909091
2 (Stair Up)	B (1.2m width)	1.063830
2 (Stair Up)	C (1.4m width)	1.162791
2 (Stair Up)	D (1.6m width)	1.388889
2 (Stair Up)	E (1.8m width)	1.449275

Table 20: Test 16 Overall Average Flow Rates

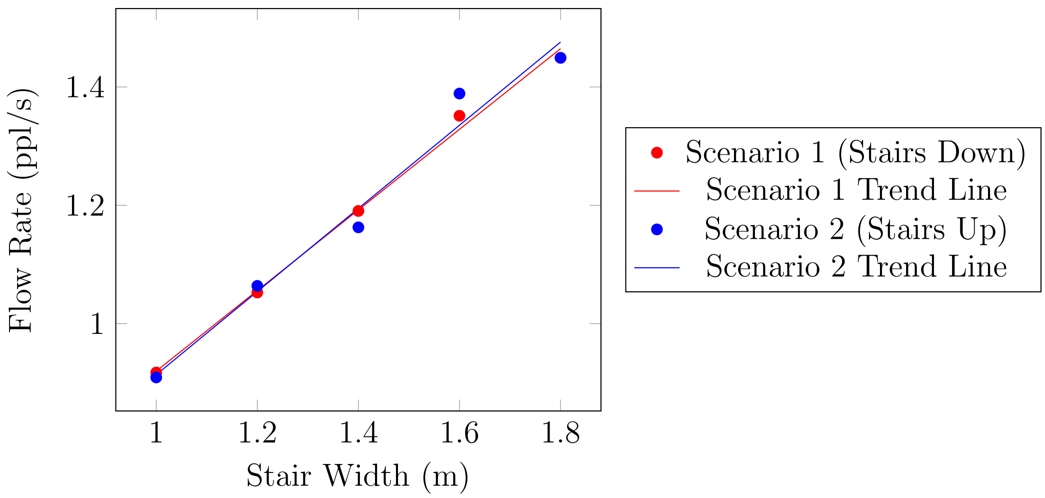


Figure 68: Test 16 Overall Average Flow Rates

16.5 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