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# **Verification and Validation**

Pathfinder 2015.1

Release 0504 x64

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Users are warned that Pathfinder is intended for use only by those competent in the field of egress modeling. Pathfinder is intended only to supplement the informed judgment of the qualified user. The software package is a computer model that may or may not have predictive capability when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous conclusions. All results should be evaluated by an informed user.

## **Table of Contents**

1	INT	RODUCTION1
	1.1	SIMULATION MODES
	1.2	INERTIA
2	FUN	IDAMENTAL DIAGRAM AND FLOW RATE TESTS
	2.1	ZHANG AND SEYFRIED FUNDAMENTAL DIAGRAM EXPERIMENTS
	2.2	DOOR FLOW RATES
	2.3	CORRIDOR FLOW RATES
	2.4	CORRIDOR MERGING
	2.5	STAIRWAY MERGING
3	IMC	) TESTS1
	3.1	MOVEMENT SPEED (IMO_01)
	3.2	STAIRWAY SPEED, UP (IMO_02)
	3.3	STAIRWAY SPEED, DOWN (IMO_03)
	3.4	DOOR FLOW RATES (IMO_04)
	3.5	INITIAL DELAY TIME (IMO_05)
	3.6	ROUNDING CORNERS (IMO_06)
	3.7	MULTIPLE MOVEMENT SPEEDS (IMO_07) 10
	3.8	COUNTERFLOW (IMO_08) 12
	3.9	SENSITIVITY TO AVAILABLE DOORS (IMO_09)
	3.10	EXIT ASSIGNMENTS (IMO_10)
	3.11	CONGESTION (IMO_11)
4	NIS	۲ EVACUATION TESTS1
	4.1	PRE-EVACUATION TIME DISTRIBUTIONS (VERIF.1.1)
	4.2	Speed in a corridor (Verif.2.1)
	4.3	Speed on stairs (Verif.2.2)
	4.4	MOVEMENT AROUND A CORNER (VERIF.2.3)
	4.5	Assigned demographics (Verif.2.4)
	4.6	REDUCED VISIBILITY VS WALKING SPEED (VERIF.2.5)
	4.7	OCCUPANT INCAPACITATION (VERIF.2.6)
	4.8	ELEVATOR USAGE (VERIF.2.7)
	4.9	HORIZONTAL COUNTER-FLOWS (VERIF.2.8)
	4.10	GROUP BEHAVIORS (VERIF.2.9)
	4.11	PEOPLE WITH MOVEMENT DISABILITIES (VERIF.2.10)
	4.12	EXIT ROUTE ALLOCATION (VERIF.3.1)
	4.13	SOCIAL INFLUENCE (VERIF.3.2)
	4.14	Affiliation (Verif.3.3)

	4.15	DYNAMIC AVAILABILITY OF EXITS (VERIF.4.1)	6
	4.16	CONGESTION (VERIF.5.1)	8
	4.17	MAXIMUM FLOW RATES (VERIF.5.2)	8
5	SFP	E EXAMPLE PROBLEMS	1
	5.1	EXAMPLE 1: SINGLE ROOM AND STAIRWAY (SFPE_1)	1
	5.2	EXAMPLE 2: 5-STORY BUILDING (SFPE_2)	3
6	ELE	VATORS	6
	6.1	ELEVATOR LOADING	6
7	CON	IPARISONS TO OTHER SIMULATORS	8
	7.1	ASSEMBLY SPACE	8
8	REF	ERENCES1	1

# **1** Introduction

This document presents verification and validation test data for the Pathfinder simulator. The following definitions are used throughout this document:

- Verification tests are synthetic test cases designed to ensure that the simulator is performing as specified by the Pathfinder Technical Reference. Usually these tests attempt to isolate specific simulated quantities or behaviors and may include only a small number of occupants. This type of test often has very specific pass/fail criteria. Verification tests ensure that the software implements a particular model correctly – they are not designed to measure how accurately that model reflects reality.
- Validation tests are designed to measure how well Pathfinder's implementation of simulation models captures real behavior. Usually these tests will explore the interaction between multiple simulation elements and may have less specific pass/fail criteria. Validation tests are usually based on experimental data or experience (e.g. congestion should form at a particular location).
- *Comparisons* present Pathfinder results alongside the results of other simulators. These tests are designed to give the reader a sense of where Pathfinder "fits in" relative to other simulation software.

Usage of the terms *verification* and *validation* in this document is designed to be consistent with the terminology presented in ASTM E1472 (ASTM 1998).

## **1.1 Simulation Modes**

Most test cases in this chapter are executed using three different configurations (modes) based on the **Behavior Mode** option and the **Limit Door Flow Rate** option in Pathfinder's **Simulation Parameters** dialog. An *SFPE* simulation is run with a **Behavior Mode** selection of **SFPE**, a *Steering+SFPE* simulation is run with a **Behavior Mode** selection of **Steering** and **Limit Door Flow Rate** active, and a *Steering* simulation is run with a **Behavior Mode** selection of **Steering**. In each case, all other simulator options are left at the default setting unless otherwise specified. For cases that examine speed-density behavior, only the **Steering** mode is applicable.

Simulation Parameters
Time Output Paths Behavior Misc
Behavior Mode: Steering 🗸
Steering update interval: 0.1 s
Collision Handling
☑ Limit Door Flow Rate
Boundary Layer: 15.0 cm
Specific Flow: 1.32 pers/(s·m)
OK Cancel

Figure 1: The simulation parameters dialog, showing settings for Steering+SFPE.

## 1.2 Inertia

The SFPE mode supported by Pathfinder allows occupants to instantly transition between speeds without accounting for acceleration. However, when predicting the results for simulations run using the *Steering* mode, it is necessary to account for inertia. Assuming an occupant must travel some distance *d*, this is generally done in the following way:

- 1. Calculate  $d_1$  using the following equation of motion:  $d_1 = 0.5 * (v_1 v_0) * t_1$ where  $d_1$  is the distance traveled,  $v_0$  is the initial velocity,  $v_1$  is the final velocity, and  $t_1$  is the time it takes to transition from  $v_0$  to  $v_1$ . In Pathfinder, the default acceleration is calculated to allow occupants to transition from being motionless to traveling at maximum velocity in 1.1 seconds.  $v_0$  is generally zero and  $v_1$  is the occupant's maximum velocity.
- 2. Calculate  $d_2$  as the remaining distance that needs to be traveled:  $d_2 = d d_1$ .
- 3. Calculate the time  $t_2$  needed to travel the remaining distance,  $d_2$ , using the equation:  $t_2 = d_2/v_1$
- 4. The full time t needed to accelerate from 0.0 m/s and walk distance d is then given by:  $t = t_1 + t_2$ .

Inertia also impacts the effective flow rates through the doors for the Steering+SFPE mode, since each occupant must accelerate when released to pass through the door. This effect can be reduced by increasing the acceleration, by setting the acceleration time to 0.5 s.

# **2 Fundamental Diagram and Flow Rate Tests**

Starting in Pathfinder 2015, the user can specify a Speed-Density Profile – the *fundamental diagram*. Since occupants can have different individual walking speeds, the user defines a profile that multiplies the maximum speed for that occupant (Figure 2). The default diagram corresponds to the SFPE relationship with the modification that at high densities the speed goes to a factor of 0.15 rather than zero.



Figure 2: The default SFPE Speed-Density Profile

## **2.1 Zhang and Seyfried Fundamental Diagram Experiments**

### 2.1.1 Background

Zhang and Seyfried (2012) performed a series of experiments in which they measured the fundamental diagram by controlling density in a corridor by varying the entrance and exit widths (Figure 3). The corridor width was 3 m. A summary of the results is shown in Figure 4. The correspond SFPE calculations are shown in Figure 5. Compared to the SFPE calculations, the Zhang and Seyfried experiments have a higher occupant speed (measured free velocity of  $1.55 \pm 0.18$  m/s) and a significantly higher measured specific flow (although the paper notes large specific flow variations for small changes in the experimental setup for densities greater the 2 pers/m<sup>2</sup>).



Figure 3: Setup and snapshot of unidirectional flow experiment. The gray area in the sketch shows the location of measurement area (Ref. Zhang and Seyfried, 2012).



Figure 4: Comparison of the fundamental diagrams between uni- and bidirectional pedestrian flow (Ref. Zhang and Seyfried, 2012).



Figure 5: SFPE fundamental diagrams.

### 2.1.2 Setup Notes

The corresponding Pathfinder model is shown in Figure 6. The paper does not provide the exact values of entrance and exit widths to the 3 m corridor, so the Pathfinder calculation assumed six cases where the entrance width varied from 2 to 3 m with the exit width held constant at 3 m (these are low density cases) followed by 10 cases where the entrance width was held constant at 3 m and the exit width varied from 3 to 1 m (high density cases). The sixteen cases where repeated for three walking speed assumptions: (1) a constant speed of 1.19 m/s (SFPE), (2) a uniform distribution  $1.19 \pm 0.25$  m/s (range about SFPE), and (3) the Zhang and Seyfried values of  $1.55 \pm 0.18$  m/s with a speed profile that corresponds to the speed-density data shown in Figure 4. This input curve is shown in Figure 7 and is similar to the SFPE curve in Figure 2.



Figure 6: Pathfinder model for Zhang and Seyfried experiments.



Figure 7: The Zhang and Seyfried Speed-Density Profile

### 2.1.3 Results

Speed-density and specific flow-density results are presented for each of the three cases. In these curves, the data is presented over time intervals when "steady-state" conditions have been reached. The gray points represent all the calculated speed-density pairs for all corridors, while the black points are the averaged values for each corridor.



Figure 8: Speed-density and specific flow results for Zhang and Seyfried experiment geometry with SFPE speed-density input and constant velocity 1.19 m/s. Time interval 110 to 250 s.



Figure 9: Speed-density and specific flow results for Zhang and Seyfried experiment geometry with SFPE speed-density input and uniform velocity distribution  $1.19 \pm 0.25$  m/s. Time interval 150 to 250 s.



Figure 10: Speed-density results for Zhang and Seyfried experiment geometry with measured speed-density input and uniform velocity distribution  $1.55 \pm 0.18$  m/s. Time interval 120 to 220 s.

### 2.1.4 Analysis

The Pathfinder calculations replicate the input speed-density curve. The calculated points are slightly below the input curves, making the results slightly conservative. The specific flow calculations also match the expected results for the rising part of the curve from a density of 0 to approximately 2 pers/m<sup>2</sup>. Above this density, the Pathfinder results lie below the theoretical SFPE curve and on the lower bounds of the Zhang and Seyfried experiments. However, it is again noted that this region of the data is sensitive to small changes in the experimental setup. The comparisons show that Pathfinder correctly uses the input speed-density curve in the calculations.

## **2.2 Door Flow Rates**

### 2.2.1 Background

This test verifies the Pathfinder door flow rate calculation. In steering mode, the door flow rates are not specified, but are emergent behavior based on the occupant movement. SFPE calculates the door flow rates based on the maximum specific flow of 1.316 pers/s-m. For doors, the specified boundary layer is 0.15 m, so a 1 m wide door is calculated to flow at 0.92 pers/s.

### 2.2.2 Setup Notes

The corresponding Pathfinder model is shown in Figure 11. The door widths range from 0.7 to 3.0 m, with the entry corridor width 5 m. Two Steering Mode cases were run, one with a constant velocity of 1.19 m/s and one with a uniform velocity distribution of  $1.19 \pm 0.25$  m/s. In addition, SFPE mode and Steering+SFPE mode cases were run for a uniform velocity distribution of  $1.19 \pm 0.25$  m/s



Figure 11: Pathfinder model used to study door flow rates. The door widths range from 0.7 to 3.0 m. Entry corridor width is 5 m.

### 2.2.3 Results

The door flow rates are shown in Figure 12 through Figure 15. This data has been averaged over the time periods where the different doors have attained "steady state" flow. For comparison, the red lines show the SFPE flow rate for the door width and a 0.15 m boundary.



Figure 12: Door flow rates for Steering mode and occupants with a max speed of 1.19 m/s.



Figure 13: Door flow rates for Steering mode and occupants with a max speed distribution of 1.19  $\pm$  0.25 m/s.



Figure 14: Door flow rates for SFPE mode and occupants with a max speed distribution of 1.19  $\pm$  0.25 m/s.



Figure 15: Door flow rates for Steering+SFPE mode and occupants with a max speed distribution of

### 2.2.4 Analysis

1.19 ± 0.25 m/s.

The Pathfinder Steering mode calculations give slightly higher door flow rates than predicted using the SFPE calculations. The Pathfinder SFPE mode results are essentially identical to the SFPE predictions. The Steering+SFPE mode results are somewhat lower than the SFPE predictions.

The predictions are satisfactory.

## **2.3 Corridor Flow Rates**

### 2.3.1 Background

This test is somewhat similar to the door flow rate verification, but examines flow rates through corridors for which SFPE species a 0.2 m boundary layer (1 m corridor has a 0.79 pers/s flow rate). It also tests the sensitivity of Pathfinder to the width of the entry shoulder on each side of the corridor.

### 2.3.2 Setup Notes

The Pathfinder models are shown in Figure 16 and Figure 17. The corridor widths are 1 and 3 m and he shoulder widths range from zero to 2 m. Steering Mode cases were run, one with a constant velocity of 1.19 m/s and one with a uniform velocity distribution of  $1.19 \pm 0.25$  m/s. In addition, SFPE mode and Steering+SFPE mode cases were run for a uniform velocity distribution of  $1.19 \pm 0.25$  m/s



Figure 16: Pathfinder model used to study corridor flow rates. The corridor with is 1 m and the entry shoulders vary from 0 to 2 m.



Figure 17: Pathfinder model used to study corridor flow rates. The corridor with is 3 m and the entry shoulders vary from 0 to 2 m.

#### 2.3.3 Results

The door flow rates are shown in Figure 12 and. This data has been averaged over the time periods where the different doors have attained "steady state" flow. For comparison, the blue lines show the SFPE corridor flow rate



Figure 18: Corridor flow rates for 1 m corridor with varying entry shoulder widths. Occupants have a constant max speed of 1.19 m/s.



Figure 19: Corridor flow rates for 1 m corridor with varying entry shoulder widths. Occupants have a max speed distribution of 1.19 ± 0.25 m/s.



Figure 20: Corridor flow rates for 3 m corridor with varying entry shoulder widths. Occupants have a constant max speed of 1.19 m/s.



Figure 21: Corridor flow rates for 3 m corridor with varying entry shoulder widths. Occupants have a max speed distribution of 1.19 ± 0.25 m/s.

### 2.3.4 Analysis

For the 1 m wide corridor, the Pathfinder calculations give slightly higher flow rates than predicted using the SFPE calculations. For the 3 m door, the flow rates are nearly identical to the SFPE calculations. The results are not sensitive to the width of the entry shoulder.

The correlation between the Pathfinder calculations and the expected flow rates is satisfactory.

## **2.4 Corridor Merging**

### 2.4.1 Background

This test expands a corridor merging problem discussed by Galea et al., 2008. The problem consists of two flow streams meeting at a junction and continuing on to the exit. We add a variation in corridor width to the original Galea problem. We also add a T-junction geometry as described by Zhang et al., 2012.

### 2.4.2 Setup Notes

Figure 1Figure 22 shows the Galea ("adjacent") geometry and typical merging behavior for a 3 m wide corridor. Figure 23 shows the T-junction ("opposite") geometry model with typical merging behavior. For both geometries we also solve for 1 m wide corridors.



Figure 22: Model for merging at a corridor junction. Called an "adjacent' geometry.



Figure 23: The geometry of a T-junction, called an "opposite" geometry.

### 2.4.3 Results

The merging ratios and exit flow rates for the adjacent geometry are shown in Figure 24. These were calculated after the door flow rates had reached "steady state" values. Figure 25 shows the same results for the "opposite" geometry.



Figure 24: Merging ratios and exit door flow rates for merging at a corridor junction with "adjacent" configuration.



Figure 25: Merging ratios and exit door flow rates for merging at a corridor junction with "opposite" configuration.

### 2.4.4 Analysis

In all cases for the "opposite" geometry, the merging flows are balanced with 50:50 ratios. This matches the Zhang et al. (2012) experimental results.

The "adjacent" geometry case is more interesting. For a 1 m corridor, the merging ratios slightly favor the south (straight) corridor flow (approximately 50:50). However, for the wider 3 m corridor, the south (straight) corridor flow strongly dominates the merging behavior (approximately 80:20). The Galea et al. (2008) paper examines the effects of different occupant "drives" on merging, but does not examine the effect of different corridor geometry.

To satisfy curiosity, we increased the width of the downstream corridor for the "adjacent" case. This resulted in more nearly equal flow from the two streams, Figure 26.

The Pathfinder results are satisfactory.



Figure 26: Flow paths for "adjacent" geometry configuration, but with a wider corridor downstream of the merge point.

## 2.5 Stairway Merging

### 2.5.1 Background

This test expands the stair merging problem discussed by Galea et al., 2008. The paper categorizes two stair merging geometries: "adjacent" and "opposite" defined by how the floor occupants merge at the landing relative to the occupants descending the stairs (Figure 27). We have added a third "open" geometry in which the floor has direct access to the exit stair.



Figure 27: Categorization of stair merging geometries. The arrows indicate the "up" direction on the stairs, not the flow direction.

### 2.5.2 Setup Notes

The width of the stairs was 1.5 m and solutions were made for corridor widths of 1.0 and 1.45 m (Figure 28). The first floor is at Z =1.6 m and the second at Z=3.2 m. The rise/run of the stairs is approximately 7/11 with a total stair length of 2.97 m. For this stair, the SFPE guidelines give a speed that is 77% of the free walking speed.



Figure 28: Stair merging geometry.

### 2.5.3 Results

Typical results for the merging behavior for the adjacent geometry with corridor widths of 1.0 and 1.45 m are shown in Figure 29. For the default occupant dimensions, the 1.0 m narrow corridor requires a "staggered" walking pattern while the wider corridor enables "side by side" walking. As a result, the floor flow is more dominant for the wider entry corridor.

The merging ratios and exit flow rates for all cases are shown in Figure 31 and Figure 32. In the "open" geometry, the floor flow dominates the merging behavior.



a. 1.0 m wide corridor entry

b. 1.45 m wide corridor entry

Figure 29: Typical merging behavior for the "adjacent" configuration with 1.19 m/s occupant speed and different corridor entry widths.



c. 1.0 m wide corridor entry



d. 1.45 m wide corridor entry

Figure 30: Typical merging behavior for the "opposite" configuration with 1.19 m/s occupant speed and different corridor entry widths.



Figure 31: Merging ratios and exit flow rates for stair merging with a constant maximum occupant speed of 1.19 m/s.



Figure 32: Merging ratios and exit flow rates for stair merging with a constant maximum occupant speed of  $1.19 \pm 0.25$  m/s.

### 2.5.4 Analysis

The calculated merging ratios fall within the range of experimental data summarized by Galea et al., 2008. The results match a general trend discussed by Galea et al. for the "opposite" geometry to favor floor merging over the "adjacent" geometry. This would appear to be related to congestion that forms at the landing. For the "adjacent" geometry both streams must merge and then proceed to the landing

leading to the exit. For the "opposite" case the two streams approach the exit stair in an approximately symmetric pattern, similar to the T-junction case for corridor merging discussed above.

However, it should be noted that Boyce et al. state: "The results indicate that, despite differences in the geometrical location of the door in relation to the stair and the relative stair/door width, the merging was approximately 50:50 across the duration of the merge period in each of the buildings studied." Their experiments noted how individual behavior could change the merge ratios.

The exit flow rates are controlled by the stair flow rate, not the exit door capacity.

The Pathfinder results are satisfactory.

# 3 IMO Tests

This section presents test cases described in Annex 3 of IMO 1238 (International Maritime Organization 2007).

## **3.1 Movement Speed (IMO\_01)**

This test case verifies movement speed in a corridor for a single occupant. The test case is based on *Test 1* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case describes a corridor 2 meters wide and 40 meters long containing a single occupant. The occupant must walk across the corridor and exit. The occupant's waking speed is 1.0 m/s.



Figure 33: IMO\_01 problem setup.

### 3.1.1 Setup Notes

Since Pathfinder tracks occupant location by the center point, the navigation mesh was extended 0.5 meters behind the occupant to allow space for the back half of the occupant when standing exactly 40 meters from the exit.

### 3.1.2 Expected Results

SFPE mode should give an exit time of 40.0 seconds.

Steering mode uses inertia and we need to account for the time it takes to accelerate to 1.0 m/s. Occupants in Pathfinder can accelerate to maximum speed in 1.1 s. From  $d_1 = 0.5 * (v_1 - v_0) * t_1$  we know that with  $v_0 = 0.0 m/s$ ,  $v_1 = 1.0 m/s$ , at t=1.1 s the occupant will have travelled 0.55 m. The remaining 39.45 meters will be covered at 1.0 m/s. Thus, steering mode should give an exit time of 40.55 seconds.

### 3.1.3 Results

The following table shows the time to exit in each tested mode.

Mode	Time
Steering	40.5
Steering+SFPE	40.5
SFPE	40.0

### 3.1.4 Analysis

All test cases were successful.

## 3.2 Stairway Speed, Up (IMO\_02)

This test verifies movement speed up a stairway for a single occupant. The test case is based on *Test 2* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case describes a stairway 2 meters wide and 10 meters long (along the incline). A single occupant with a maximum walking speed of 1.0 m/s begins at the base of the stairway and walks up to the exit. This example uses 7"x11" stairs.



Figure 34: IMO\_02 problem setup.

### 3.2.1 Setup Notes

The occupant was positioned on a lower landing at a distance 1.0 m from the staircase. For the steering mode this allows the occupant enough distance to accelerate to full speed before reaching the stairway. Pathfinder summary file reports the time of the first person entering a stairway and the time the last person leaves, so this provides an accurate measure of time on the stairs for a single occupant.

### 3.2.2 Expected Results

The occupant is given a base maximum speed of 1.0 m/s. This speed will be reduced in all modes by a scaling factor based on the slope of the stairway. Using the velocity equations presented in the Pathfinder Technical Reference, this scale factor will be (0.918 m/s) / (1.19 m/s) = 0.77. This makes the effective stairway speed of the occupant (1.0 m/s)\*0.77 = 0.77 m/s. Based on this speed, the results for all modes should be the same at 12.99 s.

### 3.2.3 Results

The following table shows the time to ascend the staircase in each tested mode.

Mode	Time
Steering	13.0
Steering+SFPE	13.1
SFPE	12.9

### 3.2.4 Analysis

All test results are within the reported precision.

## 3.3 Stairway Speed, Down (IMO\_03)

This test case verifies movement speed down a stairway for a single occupant. The test case is based on *Test 3* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case describes a stairway 2 meters wide and 10 meters long (along the incline). A single occupant with a maximum walking speed of 1.0 m/s begins at the top of the stairway and walks down to the exit. This example uses 7"x11" stairs.



Figure 35: IMO\_03 problem setup.

### 3.3.1 Setup Notes

The occupant was positioned on the upper landing at a distance 1.0 m from the staircase. For the steering mode this allows the occupant enough distance to accelerate to full speed before reaching the stairway. The length between the occupant's center starting position and the bottom of the staircase is slightly less than 10.0 m, since at the top of the stairs an occupant must allow for the door tolerance.

### 3.3.2 Expected Results

The occupant is given a base maximum speed of 1.0 m/s. This speed will be reduced in all modes by a scaling factor based on the slope of the stairway. Using the velocity equations presented in the Pathfinder Technical Reference, this scale factor will be (0.918 m/s) / (1.19 m/s) = 0.77. This makes the effective stairway speed of the occupant (1.0 m/s) \* 0.77 = 0.77 m/s. Based on this speed, the results for all modes should be the same at 12.99 s.

### 3.3.3 Results

The following table shows the time to descend the staircase in each tested mode.

Mode	Time
Steering	13.0
Steering+SFPE	13.0
SFPE	13.0

### 3.3.4 Analysis

All test results are within an acceptable margin of error.

## 3.4 Door Flow Rates (IMO\_04)

This case verifies the flow rate limits imposed by doorways in the SFPE modes. Results from the steering mode are included for comparison. The test case is based on *Test 4* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case describes a room 8 meters by 5 meters with a 1 meter exit centered on the 5 meter wall. The room is populated by 100 occupants with the expectation that the average flow rate over the entire period does not exceed 1.33 persons per second.



Figure 36: IMO\_04 problem setup.

### 3.4.1 Setup Notes

Flow rate is measured using the simulation summary data. This average flow rate is defined as the number of occupants to pass through a door divided by the amount of time the door was "active." A door is considered to be active after the first occupant has reached the door and is no longer active when the last occupant has cleared the door.

Following SFPE guidelines, the boundary layer for the SFPE mode simulations was 0.15 m. The boundary layer is not used in steering mode simulations (the full 1.0 m door width is always used). For the SFPE mode, the expected door flow rate is 0.92 pers/s when a 15 cm boundary is included.

### 3.4.2 Expected Results

The maximum observed flow rate should be less than 1.33 persons per second.

### 3.4.3 Results

The following table shows the exit door flow rate observed in each tested mode (zero boundary in SFPE mode). The average was calculated by dividing 100 people by the time interval between the first and last person's exit.

Mode	Avg Flow Rate (pers/s)
Steering	0.98
Steering+SFPE	0.99
SFPE	0.93

### 3.4.4 Analysis

All test results are within an acceptable margin of error.

## 3.5 Initial Delay Time (IMO\_05)

This case verifies initial delay (pre-movement) times. The test case is based on *Test 5* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case describes a room 8 meters by 5 meters with a 1 meter exit centered on the 5 meter wall. The room is populated by 10 occupants with uniformly distributed response times ranging from 10 to 100 seconds. Figure 37 shows the initial problem setup. 10 occupants were added to the room at random locations.





### 3.5.1 Setup Notes

Occupants were assigned initial delays between a min=10.0 s and max=100.0 s.

Occupant parameters were not randomized between simulations. This should lead to similar occupant count graphs.

### 3.5.2 Expected Results

Initial movement times should vary between occupants. This was verified by viewing the results animation. Pathfinder also has the option to output detailed comma-separated files for each occupant.

### 3.5.3 Results

Results for this problem were first verified using the animation. Figure 38 shows the detailed output data for occupant 1, who had an initial delay time of 60 s. Movement then begins after 60 s.

t(s)	id	name	active	x(m)	y(m)	z(m)	v(m/s)	distance(	location		
0	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	00"
5	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
10	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	00"
15	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
20	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
25	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
30	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
35	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
40	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
45	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
50	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
55	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	100"
60	0	"00001"	1	4.901	0.895	0	0	0	"Floor 0.0	m->Room	00"
65	0	"00001"	0	8.013	2.348	0	0.398	3.444			
70	0	"00001"	0	8.013	2.348	0	0.398	3.444			
75	0	"00001"	0	8.013	2.348	0	0.398	3.444			
80	0	"00001"	0	8.013	2.348	0	0.398	3.444			
85	0	"00001"	0	8.013	2.348	0	0.398	3.444			
90	0	"00001"	0	8.013	2.348	0	0.398	3.444			
95	0	"00001"	0	8.013	2.348	0	0.398	3.444			
100	0	"00001"	0	8.013	2.348	0	0.398	3.444			
105	0	"00001"	0	8.013	2.348	0	0.398	3.444			
108.025	0	"00001"	0	8.013	2.348	0	0.398	3.444			
(L											1

Figure 38: Output file for occupant 1. This occupant had a delay time of 60 s, so movement is recorded after 60 s.

### 3.5.4 Analysis

All simulator modes passed the test.

## 3.6 Rounding Corners (IMO\_06)

The test case is based on *Test 6* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case describes 20 occupants navigating a corner in a 2 meter wide corridor. The expected result is that the occupants round the corner without penetrating any model geometry.



Figure 39: IMO\_06 problem setup

### 3.6.1 Setup Notes

20 persons are uniformly distributed in the first 4 meters of the corridor.

## 3.6.2 Expected Results

Each occupant should navigate the model while staying inside the model boundaries. For the steering modes the occupants will retain a separation distance, but the SFPE mode allows multiple occupants to be located at the same space.

### 3.6.3 Results

Figure 40 shows the occupant trails for all 3 simulator modes. These movement trails can be used to verify that all occupants successfully navigated the corner.



Figure 40: Occupant trails for boundary test: (a) Steering mode, (b) Steering+SFPE mode, (c) SFPE mode.



Figure 41: More realistic view of occupants for the steering mode analysis

### 3.6.4 Analysis

Occupant trails indicate that no occupants passed outside the simulation boundary in any of the three simulation modes. All simulation modes successfully pass the verification test. The SFPE mode is basically a flow calculation, so occupants may be superimposed in the same space. The steering mode provides the most realistic movement.

All simulator modes passed the test.

## 3.7 Multiple Movement Speeds (IMO\_07)

This test verifies multiple walking speeds in Pathfinder. The test case is based on *Test 7* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case involves the assignment of population demographics to a group of occupants.



Figure 42: IMO\_07 problem setup

### 3.7.1 Setup Notes

A walking speed profile representing males 30-50 years old is distributed across 50 occupants. The walking speeds are a uniform random distribution with a minimum of 0.97 m/s and a maximum of 1.62 m/s. The information for this profile comes from Table 3.4 in the appendix to the Interim Guidelines for the advanced evacuation analysis of new and existing ships.

The occupants were lined 0.5 m from the left side of a 40.5 x 51.0 m room with a door across the entire right side of the room. Each occupant then moved with their assigned speed in a straight line to the right.

### 3.7.2 Expected Results

The occupants should display a range of walking speeds within the specified limits, so that the arrival times at the right edge of the room should be between 24.7 s and 41.2 s (neglecting the inertia in the steering mode).

### 3.7.3 Results

The occupants' speeds observed in the simulation were within the specified limits. The first arrival and last arrival times are given in the table below. Figure 43 shows the occupant paths at 20 s.

Mode	First Arrival (s)	Last Arrival (s)
Steering	25.3	42.0
Steering+SFPE	25.3	42.0
SFPE	24.8	40.9



Figure 43: IMO\_07 results showing occupant paths at 20 s

#### 3.7.4 Analysis

All simulator modes passed.

## **3.8 Counterflow (IMO\_08)**

This test verifies Pathfinder's counterflow capability. The test case is based on *Test 8* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case involves the interaction of occupants in counterflow. Two 10 meter square rooms are connected in the center by a 10 meter long, 2 meter wide hallway. 100 persons are distributed on the far side of one room as densely as possible, and move through the corridor to the other room. Occupants in the other room move in the opposite direction. The test is run with 0, 10, 50, and 100 occupants moving in counterflow with the original group.



Figure 44: IMO\_08 problem setup containing all four configurations and doors in the corridor entrances

### 3.8.1 Setup Notes

The problem geometry is set up as described above, with exits at the far walls. The occupants in each room are assigned the exit in the opposite room.

To simplify collection of results, all four simulation scenarios are created in the same model. This can be accomplished by duplicating the initial geometry 3 times, then using different numbers of occupants in the room at the right.

A walking speed profile representing males 30-50 years old is distributed across all occupants. The walking speeds are a uniform random distribution with a minimum of 0.97 m/s and a maximum of 1.62 m/s. The information for this profile comes from Table 3.4 in the appendix to the Interim Guidelines for the advanced evacuation analysis of new and existing ships.

### 3.8.2 Expected Results

As the number of occupants in counterflow increases, the occupants should slow down and increase the simulation time.

Since in the SFPE mode, there is no restriction on occupants being superimposed in the same space, counterflow does not slow the movement. However, room occupation density does reduce walking speed.

For the SFPE case with no corridor doors, there is one room with an area of 220 m<sup>2</sup> and we can assume a constant density during the simulation. For 100 people the density is 0.455 pers/ m<sup>2</sup>, and for 200 people the density is 0.9091 pers/ m<sup>2</sup>. The corresponding nominal SFPE walking speeds are 1.19 m/s and 1.06 m/s, respectively. The minimum distance a person must walk to reach the opposite exit is 27 m. For the 0 person counterflow case the walking speed is not reduced, so the first arrival is expected to be at (27 m)/(1.62m/s) = 16.7 s and the slowest arrival time could be (30 m)/(0.97 m/s) = 30.9 s. For the 100 person counterflow case the speed reduction factor due to density is 1.06/1.19 = 0.891, so the first arrival is expected to be at 18.7 s and the slowest arrival time 34.7 s. Pathfinder actually evaluates density each time step, so as occupants exit, the walking speed will increase.

### 3.8.3 Results

Figure 45 shows the occupant positions for the steering mode, 100 person counterflow, no corridor doors case at 75 s. Figure 46 shows the occupant positions for SFPE mode, 100 person counterflow, no corridor doors case at 20 s. Each group has already passed through the corridor.



Figure 45: Occupant positions for the steering mode, 100 person counterflow case at 75 s. No corridor doors.



Figure 46: Occupant positions for the SFPE mode, 100 person counterflow case at 20 s. No corridor doors.

The following table shows the time it takes occupants to exit the simulation (on the right) as a function of the number of occupants in counterflow for the no corridor door case. First indicates the first time that an occupant starting on the left exited and last indicates the last time an occupant from the left side exited.

	Number of Occupants Starting on Right Side								
Mada	0		10		50		100		
wode	First	Last	First	Last	First	Last	First	Last	
	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)	
Steering	18.8	68.6	21.0	98.8	38.6	251.5	53.3	403.5	
Steering+SFPE	18.8	68.6	21.0	98.8	38.6	251.5	53.3	403.5	
SFPE	17.2	29.9	17.7	30.7	18.1	31.3	19.2	31.8	

### 3.8.4 Analysis

In each mode, more counterflow increases simulation time. The SFPE mode does not account for counterflow interference, so there is little effect on exit times.

All modes passed test criteria.

## **3.9 Sensitivity to Available Doors (IMO\_09)**

This test verifies Pathfinder's exit time sensitivity to a changing number of available doors. The test case is based on *Test 9* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). The test case involves the evacuation of 1000 occupants from a large room, 30 meters by 20 meters, with doors of 1.0 m width. The 1000 occupants are distributed uniformly in the center of the room, 2 meters from each wall. The test is run with 4 exits and 2 exits, with the expectation that the evacuation time will double in the 2 exit case.



#### Figure 47: IMO\_09 problem setup containing both configurations

### 3.9.1 Setup Notes

Occupants are given a profile corresponding to males 30-50 years old from Table 3.4 in the appendix to IMO 1238. The walking speeds are a uniform random distribution with a minimum of 0.97 m/s and a maximum of 1.62 m/s.

To simplify data collection, both model configurations are added to a single simulation model.

#### 3.9.2 Expected Results

Simulation time should approximately double when using half as many doors. A tolerance of 5% will be used to determine success.

For the SFPE mode, the single door flow rate is 0.924 pers/s (15 cm boundary included), giving an evacuation time of 541 s for two doors and 271 s for four doors.

### 3.9.3 Results

The following table shows the time it takes to exit the simulation for both cases. Since the initial locations of the occupants were randomly assigned, the number of persons that exit each door are not exactly equal.

Madal	4 D	oors	2 Doors		
Iviodei	Min (s)	Max (s)	Min (s)	Max (s)	
Steering	196.7	199.0	393.5	394.2	
Steering+SFPE	273.2	283.2	554.5	563.7	
SFPE	264.7	275.6	540.7	549.3	

### 3.9.4 Analysis

For all modes, the simulation times, while not exactly double, are well within the acceptable margin for validity.

All modes passed test criteria.

## **3.10 Exit Assignments (IMO\_10)**

This test verifies exit assignments in Pathfinder. The test case is based on *Test 10* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). 23 occupants are placed in a series of rooms representing ship cabins and assigned specific exits.



#### Figure 48: IMO\_10 problem setup

### 3.10.1 Setup Notes

The occupants in the left 8 rooms are assigned to the main (top) exit. The occupants in the remaining 4 rooms are assigned to the secondary (right) exit. Occupants are given a profile corresponding to males

30-50 years old from Table 3.4 in the appendix to IMO 1238. The walking speeds are a uniform random distribution with a minimum of 0.97 m/s and a maximum of 1.62 m/s

### 3.10.2 Expected Results

Each occupant should leave the model using the specified exit.

### 3.10.3 Results

Figure 49 shows the paths taken by occupants in each simulation mode. The trails of the four occupants intended to use the secondary exit are shown in red, all other occupant trails are shown in blue.





### 3.10.4 Analysis

The results for all simulator modes indicate that the four occupants directed to exit via the secondary exit, did so.

All modes passed test criteria.

## 3.11 Congestion (IMO\_11)

This test examines the formation of congestion in Pathfinder. The test case is based on *Test 11* given in Annex 3 of IMO 1238 (International Maritime Organization 2007). 150 occupants must move from a 5 m x 8 m room, to a 2 m x 12 m corridor, up a stairway, and out of the simulation via a 2 m wide platform. Congestion is expected to form initially at the entrance to the corridor, then later at the base of the stairs.

Figure 50 shows the problem setup in Pathfinder.

x	Pathfinder 2013 x64 - test11_steering.pth
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Floor: 🟉 Floor 4.6 m 🗸 🗸	
🏟 🗄 🖻	Floor Creation/Sorting New Egress Components
- A Imported Geometry	Automatically create floors
E Behaviors	Floor height: 3.0 m
Goto Any Exit	
E Gocupants	
Elevators	
E Ploor 0.0 m	
- Ploor 4.6 m	
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#### Figure 50: IMO\_11 problem setup.

A specific definition for congestion is given in Section 3.7 of the document (International Maritime Organization 2007). Congestion is present when either of the following conditions is achieved: initial density is at least 3.5 pers/m<sup>2</sup>, or queues grow (occupants accumulate) at a rate of more than 1.5 pers/s at a joint between two egress components.

The initial density in the 5m x 8m room containing 150 occupants is  $3.75 \text{ pers/m}^2$ . Based on the congestion criteria, this condition is sufficient to qualify the initial room as congested.

Congestion is measured using the queue at the base of the stairway. Congestion is identified by either of the following criteria: (1) initial density equal to, or greater than, 3.5 persons/m2; or (2) significant queues (accumulation of more than 1.5 persons per second between ingress and exit from a point). Data to measure this occupant count over time is available in the doors.csv output file and is processed using a spreadsheet.

### 3.11.1 Setup Notes

The 150 occupants are added to the initial room using a uniform distribution.

The problem description in IMO 1238 requires that occupants be assigned velocities corresponding to 30-50 year old males. This velocity data is provided in ranges for level travel, for stairs up, and for stairs down. Because Pathfinder calculates the stairway velocity based on the level travel speed and the slope of the stairs, we are forced to approximate the stairway velocities using the (unspecified) slope of the stairway. If we compare the minimum and maximum values of the level travel speeds to the minimum and maximum values of the stairs up speed, we find that the IMO assumption is that occupants walk up stairs about half as fast as they walk on level ground (min: 48%, max: 49%). To produce a 50% decrease

in speed in Pathfinder, we will use a stairway with a slope of 1.0715. Note that although the geometry represents a slope of 1.0, it is the definition of the rise and run that is used to calculate the slope for the speed calculation.

All occupants were assigned a profile corresponding to level walking speed for 30-50 year old males (as specified in (International Maritime Organization 2007). This gives a uniform speed distribution ranging from 0.97 m/s to 1.62 m/s. Based on the slope of the stairway, this should also give stairway speeds (up and down) from 0.49 m/s to 0.81 m/s. These speeds are slightly higher than those given in IMO 1238 (0.47 m/s to 0.79 m/s).

## 3.11.2 Expected Results

Congestion should form in the corridor leading to the stairs. This would be represented by a net occupant count increase (at least 1.5 pers/s) in the corridor after the first occupant has passed through the corridor and entered the stairs.

We can estimate the fastest exit time for the SFPE case. For a walking speed of 1.62 m/s, the time to cross the 12 m corridor is 7.4 s (neglecting inertia). The length of the stairs is 5.7 m, so for a 50% speed decrease on stairs, the time required is 7.0 s. Crossing the landing requires another 1.2 s, for a total of time of 15.6 s.

### 3.11.3 Results

The total evacuation times for the three cases are given below:

Mode	First Out (s)	Last Out (s)	
Steering	16.8	166.4	
Steering+SFPE	17.2	168.2	
SFPE	18.0	140.1	

Time history data describing the occupant count in the corridor and the rate of change of count are shown in Figure 51 and Figure 52. As defined above, values greater than 1.5 in the rate indicate the formation of congestion.

Figure 53 visually shows congestion forming at the base of the stairs. The density contour plot in Figure 54 shows densities greater than 3.0 pers/m<sup>2</sup> at the base of the stairs.



Figure 51: Occupant counts in the corridor



Figure 52: Rate of change in occupant count over time for IMO 11. Values above 1.5 indicate congestion.



Figure 53: Visual demonstration of congestion at base of stairs.



Figure 54: Density contours showing congestion at base of stairs.

In addition, the path of one person was monitored for the steering mode case. This person, with a maximum walking speed of 1.58 m/s, entered the corridor at 0.8 s, entered the stairway at 8.4 s, entered the landing at 15.2 s, and exited at 16.7 s. Using the procedure described above in *Expected Results*, these times match the expected times.

### 3.11.4 Analysis

Congestion forms at the base of the stairs, but using the Pathfinder default occupant sizes and comfort distances results in only marginally meeting the congestion criteria specified in IMO 1238. As the occupants enter the corridor the rate of change of occupants in the corridor initially increases by more than 1.5 pers/s. It then levels off to a value of about 1.25 pers/s and, once the corridor has been filled, the occupant count remains constant. The density contour shows values of about 3 pers/ m<sup>2</sup>, but not reaching 3.5 pers/ m<sup>2</sup>.

There are two reasons for this. In the SFPE mode, the user defines the maximum occupant density in a room. The default value is 1.88 pers/m<sup>2</sup>, so the number of occupants in the corridor is limited to 45. Once the corridor reaches this occupancy, people are only allowed into the corridor as people exit up the stairs. This is clearly seen in Figure 51.

A similar effect occurs in steering mode, where the occupant size and Comfort Distance defines the packing density of the agents. The default occupant size (diameter) is 45.58 cm and the default comfort distance is 8 cm. Assuming a perfect square tiling, the expected packing density is 3.5 pers/m<sup>2</sup> (84 packed occupants in the corridor). For a perfect hexagonal tiling, the expected packing density is 4.0 pers/m<sup>2</sup> (96 packed occupants in the corridor). Figure 51 shows maximum occupancy values of about 68 persons for the steering modes. Thus, a queue density of 3.5 pers/m<sup>2</sup> is not quite reached.

The user could adjust the occupant sizes and comfort distance to increase packing density, but that would affect the door flow rates in steering mode, so is not recommended.

The conclusion is that Pathfinder does show congestion, but only marginally meets the congestion definition of IMO 1238.

# **4 NIST Evacuation Tests**

This section presents test cases described in NIST Technical Note 1822 (NIST Technical Note 1822, 2013). Section 3 (Suggested Verification and Validation Tests) presents a new set of recommended verification tests and discusses possible examples of validation tests. Tests have been presented in relation to the five main core elements available in evacuation models, namely 1) pre-evacuation time, 2) movement and navigation, 3) exit usage, 4) route availability and 5) flow conditions/constraints.

## 4.1 Pre-evacuation time distributions (Verif.1.1)

A modification of IMO Test 5, which has already been presented.

## 4.2 Speed in a corridor (Verif.2.1)

IMO Test 1, which has already been presented.

## 4.3 Speed on stairs (Verif.2.2)

IMO Tests 2 and 3, which have already been presented.

## 4.4 Movement around a corner (Verif.2.3)

IMO Test 6, which has already been presented.

## 4.5 Assigned demographics (Verif.2.4)

A modification of IMO Test 7, which has already been presented.

## 4.6 Reduced visibility vs walking speed (Verif.2.5)

The current version of Pathfinder does not use visibility to change walking speeds, so this verification test is not applicable.

Pathfinder does however, allow the user to specify a Speed Modifier by room that can be defined as values as a function of time. This can be used to approximate the effect of smoke in a room.

## 4.7 Occupant incapacitation (Verif.2.6)

The current version of Pathfinder does not use the Fractional Effective Dose to simulate incapacitation, so this verification test is not applicable.

Pathfinder does however, allow the user to specify a Speed Modifier by room that can be defined as values as a function of time. This can be used to provide a very rough approximation of incapacitation.

## 4.8 Elevator usage (Verif.2.7)

This test verifies the capability of evacuation models to simulate evacuation using elevators. A schematic of the geometry is shown in Figure 55. The corresponding Pathfinder model is shown in Figure 56.



Figure 55: Geometry of elevator verification (Verif.2.7). Figure from NIST Technical Note 1822, 2013.



#### Figure 56: Pathfinder model of elevator verification

#### 4.8.1 Setup Notes

Room 1 is located at Z=0.0 and Room 2 at Z=3.5 m. An elevator connects the two rooms in accordance with Figure 55. The Floor 1 exit door is 1 m wide. The elevator is called from Room 1, reaches Room 2 and carries the occupant and back to Room 1.

The occupant has an unimpeded walking speed of 1 m/s in Room 2 with an instant response time. To minimize inertia effects, the Acceleration Time was set to zero. To simplify distance calculations, the occupant size was set to 50 cm. The initial distance between the center of the occupant and the elevator door is 17.5 m. However, since the occupant radius is 0.25 m and the distance from the elevator to activate a call is 0.5 m, the occupant walks 16.75 m to activate the call.

The elevator parameters include: door open and close times of 3.5 s, pickup and discharge travel times of 2.5 s between the two floors, and door open and close delays of 5.0 s. The open delay is the minimum time an elevator's door will stay open on a floor (does not impact this test case) and the close delay is the time the elevator door will remain open after the last person enters.

### 4.8.2 Expected Results

The occupant starts walking at time zero and the elevator is called from the discharge floor after the occupant has walked 16.75 m in 16.73 s. Once called, the door must close on the discharge floor and then the elevator must move to the second floor (time when finished is 26.25 s). The door then opens, the occupant walks in (occupant radius), there is a door close delay, and finally the door closes (time is 35.0 s). The elevator then moves to the discharge floor, the door opens, and the occupant leaves the building. The total expected evacuation time is 60.75 s, Figure 57.

Evacuation Time				
Task	Calc	Time	Pathfinder	
Start =	0.0	0.0	0	
Walk to activate elevator call =	16.75	16.75	16.8	
Door closes on discharge floor =	3.50	20.25	20.3	
Elevator pickup time =	2.50	22.75	22.8	
Door open on call floor =	3.50	26.25	26.3	
Load Time =	0.25	26.50	26.5	
Door close delay time =	5.00	31.50	31.6	
Door close on call floor =	3.50	35.00	35.1	
Elevator discharge travel time =	2.50	37.50	37.7	
Door open on discharge floor =	3.50	41.00	41.1	
Building exit time =	19.75	60.75	61	

#### Figure 57: Calculation of expected evacuation time

### 4.8.3 Results

As shown in Figure 57, the observed exit time is 61.0 s for steering mode. This matches the expected result, since the expected result calculation did not take into account the slightly slower speed of passing through the elevator door to ensure the correct door flow rate. Identical results (within tolerance) were obtained for the Steering+SFPE and SFPE modes.

## 4.9 Horizontal counter-flows (Verif.2.8)

A modification of IMO Test 8, which has already been presented.

## 4.10 Group behaviors (Verif.2.9)

The current version of Pathfinder does not use group behaviors, so this verification test is not applicable.

## 4.11 People with movement disabilities (Verif.2.10)

This test is designed for the verification of emerging behaviors of people with disabilities. It tests the possibility of simulating an occupant with reduced mobility (e.g. decreased travel speeds and increased space occupied by the occupants) as well as representing the interactions between impaired individuals and the rest of the population and the environment.

Construct two rooms at different heights, namely room 1 (1 m above the ground level) and room 2 (at ground level), connected by a ramp (or a corridor/stair if the model does not represent ramps). Insert one exit (1 m wide) at the end of room 2.

Scenario 1: Room 1 is populated with a sub-population consisting of 24 occupants in zone 1 (with an unimpeded walking speed of 1.25 m/s and the default body size assumed by the model) and 1 disabled occupant in zone 2 (the occupant is assumed to have an unimpeded walking speed equal to 0.8 m/s on horizontal surfaces and 0.4 on the ramp. The disabled occupant is also assumed to occupy an area bigger than half the width of the ramp (>0.75 m). All occupants have to reach the exit in room 2.

Scenario 2: Re-run the test and populate zone 2 with an occupant having the same characteristics of the other 24 occupants in zone 1 (i.e. no disabled occupants are simulated). All occupants have to reach the exit in room 2.

A schematic of the geometry is shown in Figure 58. The corresponding Pathfinder model is shown in Figure 59.



Figure 58: Geometry of movement disabilities verification (Verif.2.10). Figure from NIST Technical Note 1822, 2013.



Figure 59: Pathfinder model of movement with disabilities. Red occupant has disabilities.

### 4.11.1 Setup Notes

The room geometry is setup as defined. While Pathfinder includes ramps, the current implementation applies the same speed reduction to all occupants, so no speed reduction was defined for the ramp. The shoulder width of the 24 occupants is 45.58 cm and of the disabled person 75 cm. The walking speed of the 24 occupants is Room 1 is 1.25 m/s and the walking speed of the disabled person was defined as 0.4 m/s. Since, as noted above, Pathfinder applies ramp speed reductions uniformly to all occupants, it was decided to apply the ramp speed (0.4 m/s) to the disabled occupant for the entire simulation.

The SFPE and Steering+SFPE calculations included a 15 cm boundary layer.

### 4.11.2 Expected Results

All occupants will reach the exit. Scenario 1 will have a longer evacuation time than scenario 2.

### 4.11.3 Results

The following table shows the time to evacuate all occupants. The disabled occupant did slow the evacuation slightly by blocking flow on the ramp, but after leaving the ramp the faster occupants moved around the disabled occupant, so the slowing effect was reduced, Figure 60.

Mode	Scenario 1 (s)	Scenario 2 (s)	
Steering	37.9	33.6	
Steering+SFPE	41.7	38.8	
SFPE	36.1	32.7	



a. Steering mode showing occupant with disabilities blocking flow on ramp. Lines show paths.



b. Steering mode showing how faster occupants move around disabled occupant past ramp. Lines show paths.

Figure 60: Faster occupants move around disabled occupant. Lines show paths.

## 4.12 Exit route allocation (Verif.3.1)

A modification of IMO Test 10, which has already been presented.

## 4.13 Social influence (Verif.3.2)

The current version of Pathfinder does not use social influence, so this verification test is not applicable.

## 4.14 Affiliation (Verif.3.3)

The current version of Pathfinder does not use social affiliation, so this verification test is not applicable.

## 4.15 Dynamic availability of exits (Verif.4.1)

This test is aimed at qualitatively evaluating the capabilities of the model to represent the dynamic availability of exits.

Construct a room of size 10 m by 15 m. Two exits (1 m wide) are available on the 15 m walls of the room and they are equally distant from the 10 m long wall at the end of the room (see Figure 11).

Insert an occupant in the room with a response time equal to 0 and a constant walking speed equal to 1 m/s as shown in Figure 11. Exit 1 becomes unavailable after 1 s of simulation time. Check the exit usage for both Exit 1 and Exit 2.

A schematic of the geometry is shown in Figure 61.





### 4.15.1 Setup Notes

The room geometry is setup as defined. Pathfinder uses a "locally quickest" algorithm to select the exit door from a room. To ensure that the occupant selects Exit 1, the occupant was located at X=4.5 m or 0.5 m closer in the X direction to Exit 1.

### 4.15.2 Expected Results

The occupant will initially select Exit 1, then at 1.0 s will change to Exit 2.

### 4.15.3 Results

Figure 62 shows path used by the occupant. At 1.0 s, the occupant changes from Exit 1 to Exit 2. The same result was obtained for Steering+SFPE and SFPE modes.



Figure 62: Change in exit selection at 1.0 s. Line shows path. Steering mode.

## 4.16 Congestion (Verif.5.1)

A modification of IMO Test 11, which has already been presented.

## 4.17 Maximum flow rates (Verif.5.2)

A modification of IMO Test 4, which has already been presented.

# **5 SFPE Example Problems**

This section presents Pathfinder results for models based on example problems given for the hand calculations presented in the SFPE Handbook (Nelson and Mowrer 2002) and Engineering Guide for Human Behavior in Fire (Society of Fire Protection Engineers 2003).

## 5.1 Example 1: Single Room and Stairway (SFPE\_1)

This is a verification test for SFPE-based simulation results. This example reproduces Example 1 given in the SFPE Engineering Guide (Society of Fire Protection Engineers 2003). In this example, 300 occupants are initially positioned in a room of unspecified geometry. The room is connected (directly) to two 44 in wide stairways via two 32 in doors, which are then connected to a 30 ft x 6 ft room. The occupants must move through the doors and down the 7 inch height x 11 inch depth, 50 ft long stairs. After reaching the base of the stairway, the occupants exit the model. The problem specifies that the maximum travel distance between an occupant's initial position and the nearest door leading to a stairway is 200 ft. This test will assume the initial room is a 200 ft x 30 ft room with both stairways positioned on one of the 30 ft walls Figure 63. The small room is 6 ft x 30 ft with an exit spanning the wall opposite the stairs.



Figure 63: Initial configuration for SFPE 1.

### 5.1.1 Setup Notes

The door boundary layer is specified as 6 in.

### 5.1.2 Expected Results

In this example, the door entering each stairway is the controlling component. The problem is symmetrical so, for the hand calculation, the divided flow can be modeled as a single wide door and

stairway. To calculate the total movement time, we must calculate  $T_{TOTAL} = T_1 + T_2 + T_3$  where: (T<sub>1</sub>) is the time it takes the first occupant to reach the controlling component, (T<sub>2</sub>) the time it takes 300 occupants to flow through two 32-inch doors, and (T<sub>3</sub>) the time it takes the last occupant to move from the controlling component to the exit.

The value of  $T_1$  depends on the location of the occupants. For this model, the value ranges from 0.2 to 1.2 s. The average is:

$$T_1 = 0.7 s$$

The time needed for 300 occupants to pass through the two 32 inch doors, T<sub>2</sub> is:

$$T_2 = \frac{P}{F_{s_{max}}W_e} = \frac{300 \text{ pers}}{24 \frac{pers}{min \cdot ft} \times 2[32 \text{ in} - 2(6 \text{ in})] \times \frac{1 \text{ ft}}{12 \text{ in}}} = 3.75 \text{ min} = 225.0 \text{ s}$$

The time needed for the last occupant to move down the stairs,  $T_3$  is:

$$T_3 = \frac{d}{v} = \frac{50 ft}{0.85 \times 212 \frac{ft}{min}} = 0.277 \min = 16.6 s$$

The total evacuation time, T<sub>total</sub> is:

$$T_{total} = T_1 + T_2 + T_3 = 242.3 s$$

### 5.1.3 Results

For each simulation mode, the following table lists the results for the left and right stairs, including the number of people that used each stair.

Mode	PersLEFT	Pers <sub>RIGHT</sub>	T <sub>LEFT</sub> (s)	T <sub>RIGHT</sub> (s)
Steering	148	152	253.1	258.1
Steering+SFPE	150	150	263.6	263.0
SFPE	145	155	235.0	249.0

### 5.1.4 Analysis

The average exit time for the SFPE case matches the expected value. The Steering and Steering+SFPE modes are slightly slower.

## 5.2 Example 2: 5-Story Building (SFPE\_2)

This is a verification test for SFPE-based simulation results. This example reproduces Example 2 given in the SFPE Engineering Guide (Society of Fire Protection Engineers 2003). In this example, we have a 5-story building. Each floor is served by two 44 inch stairways. The stairs have a 7 inch rise and an 11 inch run. The stairways have hand-rails on both sides 2.5 inches from the wall. Each stairway connects to a 4 ft x 8 ft platform located between the level of the floors. The distance between the floors is 12 ft. The stairways connect to the floors with 32 inch doors. There are 200 people on each floor. Figure 64 shows the problem setup.



#### Figure 64: SFPE Example 2 Problem Setup

#### 5.2.1 Setup Notes

Detailed setup notes are presented in the Pathfinder example guide.

Following the intention of the problem, all occupants of the ground floor exit from four large side doors and all occupants on higher floors exits from doors at the base of the stairs.

A second steering mode case was run where occupants had an increased preference to remain in their current door queue (**Current Door Preference** parameter of the **Profile**). This parameter was changed from the default 35% to 80%.

### 5.2.2 Expected Results

In this example, the controlling component is the exit door at the base of the stairway. We will assume the occupants use the stairways evenly, in which case we only need to model the time it takes for half the occupants on the second through fifth floors to pass through the controlling 32 inch door.

To calculate the total movement time, we must calculate  $T_{TOTAL} = T_1 + T_2 + T_3$  where: (T<sub>1</sub>) the time it takes the first occupant to reach the controlling component, (T<sub>2</sub>) the time it takes 400 occupants to flow through the controlling component (a 32 in door), and (T<sub>3</sub>) the time it takes for the last occupant to move from the controlling component to the exit.

The calculation for T1 has four parts:

- (T<sub>A</sub>) the time it takes the occupant nearest the door on the second floor to travel from their initial location to the stairway entrance,
- (T<sub>B</sub>) the time to move down the stairs to the platform,
- (T<sub>c</sub>) the time to walk across the platform, and
- (T<sub>D</sub>) the time to move down the stairs to the door.

We assume a low-density velocity calculation for the first occupant to reach the stairs and the landing. For  $T_A$  we assume the person must walk 6 ft to reach the center of the stairs. For  $T_B$  we will assume the occupant must walk 8 ft, an average length of travel, to traverse the platform. This leads to the following calculations:

$$v_{level} = 0.85 \times 1.40 \, \frac{m}{s} = 1.19 \, \frac{m}{s}$$

$$v_{stair} = 0.85 \times 1.08 \frac{m}{s} = 0.92 \frac{m}{s}$$

$$T_A = \frac{d}{v_{level}} = \frac{6 ft \left(\frac{0.3048 m}{ft}\right)}{1.19 \frac{m}{s}} = 1.5 s$$

$$T_B + T_D = 2\left(\frac{d}{v_{stair}}\right) = 2\left(\frac{11.17 \ ft}{0.92 \ \frac{m}{s}}\right) \left(\frac{0.3048 \ m}{ft}\right) = 7.4 \ s$$
$$T_C = \frac{d}{v_{level}} = \frac{8 \ ft \ \left(\frac{0.3048 \ m}{ft}\right)}{1.19 \ \frac{m}{s}} = 2.0 \ s$$

$$T_1 = T_A + T_B + T_C + T_D = 1.5 \ s + 7.4 \ s + 2.0 \ s = 10.9 \ s$$

The time for 400 people to move through a 32 inch door,  $T_2$  is:

$$T_2 = \frac{P}{F_{s_{max}}W_e} = \frac{400 \text{ pers}}{1.32 \frac{\text{pers}}{\text{m} \cdot \text{s}} \times [32 \text{ in} - 2(6 \text{ in})] \times \frac{ft}{12 \text{ in}} \times \frac{0.3048 \text{ m}}{ft}} = 596.5 \text{ s}$$

The time for the last person to move from the stairs to the exit is:

$$T_3 = \frac{d}{v_{level}} = \frac{4 ft \left(\frac{0.3048 m}{ft}\right)}{1.19 \frac{m}{s}} = 1.0 s$$

The total evacuation time, T<sub>total</sub> is:

$$T_{total} = T_1 + T_2 + T_3 = 10.9 s + 596.5 s + 1.0 s = 608.4 s$$

### 5.2.3 Results

For each simulation mode, the following table lists the results for both exits, including the number of people that used each exit. This is symmetric problem with door flow rates on the upper floors that stall due to emptying of the lower floors. In such a situation, people waiting in queues can decide to leave their door queue when another door begins to flow, even if the flow is intermittent. The resulting back and forth behavior, while it does not affect the total exit time, can appear somewhat unexpected. Pathfinder allows the user to increase the commitment of occupants to remain in the queues they are currently in. These are the results reported for the **Steering (queue)** case.

Mode	Pers <sub>1</sub>	Pers <sub>2</sub>	Total <sub>1</sub> (s)	Total <sub>2</sub> (s)
Steering	400	400	560.0	560.5
Steering+SFPE	399	401	610.8	614.7
SFPE	407	393	624.0	604.2
Steering (queue)	414	386	579.1	540.7

### 5.2.4 Analysis

The average exit time for the SFPE case matches the expected value. The Steering+SFPE case is slightly slower, since the steering behavior reduces the flow into the doors. The Steering mode is faster, since door flow rates are not limited. Adding the increased commitment to remain in the current queue had the effect of stopping the back and forth movement to alternate queues.

# **6 Elevators**

This section presents Pathfinder results for models that use elevators. The NIST Verif problem set also includes an elevator problem.

## 6.1 Elevator loading

This problem tests elevator loading. 100 occupants are located in a 10x10 m room at an elevation of 10 m. The occupants exit using an elevator with dimensions 2 m wide and 1.7 m deep, for a typical elevator loading of about 16 people (Klote and Alvord, 1992). The elevator door width is 1.2 m. The elevators have an Open+Close Time of 7.0 s, Pickup and Discharge times of 10.0 s, and Open and Close delays of 5.0 s (see Pathfinder manual for definitions). There are four elevators, with specified Nominal Loads of 5, 10, 20, and 50 persons, Figure 65.



Figure 65: Elevator loading test

#### 6.1.1 Setup Notes

The four problems are independent, so allow a quick verification.

### 6.1.2 Expected Results

The elevators should load to the expected nominal loads.

### 6.1.3 Results

The resulting elevator loads for the steering simulation are shown in Figure 66. They match the expected results. The results for Steering+SFPE and SFPE modes also matched the expected results.



#### Figure 66: Observed elevator loading for steering mode

### 6.1.4 Analysis

The elevator loadings matched the expected values.

# 7 Comparisons to Other Simulators

This section presents the results of Pathfinder simulations alongside previously published results for other simulation software. These comparisons can be used to better understand how Pathfinder "fits in" relative to other simulation software.

## 7.1 Assembly Space

This comparison adds data from Pathfinder to a simulator comparison presented in the FDS+Evac v5 Technical Reference and User's Guide (Korhonen and Hostikka 2009). The problem describes an assembly space filled with 1000 occupants. The initial room measures 50 m x 60 m. At the right, there is a 7.2 m doorway leading to a 7.2 m corridor. The corridor contains a sharp turn to the left before continuing on to the exit. Additional setup notes can be found on page 45 of the original document.



#### Figure 67: Initial configuration of the assembly space.

The feature of interest in this problem is the corner in the corridor. Based on how different simulators handle the flow of large groups around a corner, different simulators can produce substantially different answers. Notably, the current body of movement research presents us with little guidance toward a "correct" solution to this problem.

### 7.1.1 Setup Notes

SFPE and Steering+SFPE modes had identical results, so only SFPE and Steering modes are presented for comparison.

An alternate version of this simulation was run without the corridor. Results associated with this simulation run are referred to as *door*. Results associated with simulation runs including the corridor are referred to as *corr*. To simplify results gathering, the *corr* simulation and the *door* simulation can be run simultaneously by duplicating the *corr* geometry (creating two separate geometric regions with a total of 2000 occupants), then removing the corridor portion.

### 7.1.2 Results and Analysis

Figure 68 shows a time history plot of the remaining population. Solid graph markers refer to the *corr* data and hollow graph markers refer to the *door* data. The data source for FDS+Evac, Simulex, and Exodus was the original document (Korhonen and Hostikka 2009).

The SFPE flow rate for a 7.2 m door with no boundary is 9.47 pers/s, so the SFPE calculation should give 106 s for the door evacuation. Pathfinder calculates 108 s. Since it takes some time for enough occupants to reach the door and form a queue, the 2 s difference is acceptable. The room density is 0.333 pers/m<sup>2</sup>, giving a walking speed of 1.19 m/s. The corridor adds approximately 42 m distance (assuming the occupants "cut the corner"), which requires an additional 35 s to walk, for a predicted exit time of 143 s. Pathfinder in SFPE mode calculates 145 s, which is an acceptable difference since, again, time is required to form a queue.



#### Figure 68: Simulator comparison for assembly space.

All simulators present similar results for the *door* case. For the *corr* test, Pathfinder in steering mode predicts an exit time (234.7 s) that lies between the FDS+Evac calculation and Simulex or Exodus. In the *corr* example, faster times correspond to the group of occupants more fully utilizing the width of the corridor, Figure 69. In the Pathfinder simulation, there is some grouping that occurs in the vertical

section of the corridor. This is a result of increased density which leads to slower movement. There is no experimental data to document the expected result, so the Pathfinder results are certainly reasonable.



Figure 69: Steering mode showing use of the corridor at 50 sec.

# 8 References

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