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## Verification and Validation

**Pathfinder 2014.2**

**Release 0730 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.

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# 1 Introduction

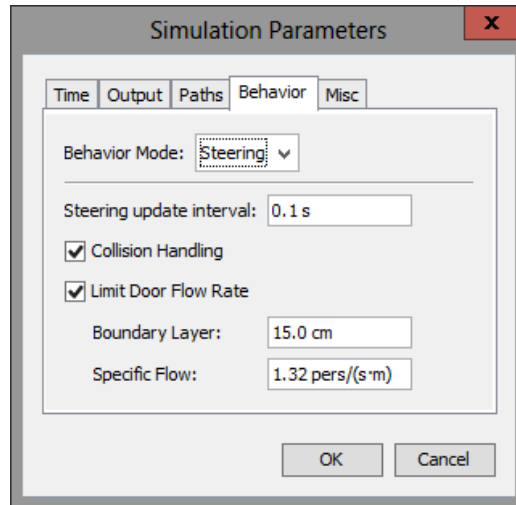
This document presents verification and validation test data for the Pathfinder simulator. The following definitions are used throughout this document:

- *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

Each test case in this chapter is 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.



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

In some cases, the results are accompanied by simulation run times. These run times represent the execution time of a problem on one of several development machines maintained by Thunderhead Engineering and should be interpreted only as a rough estimate for run time on consumer hardware.

## 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 IMO Tests

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

### 2.1 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.

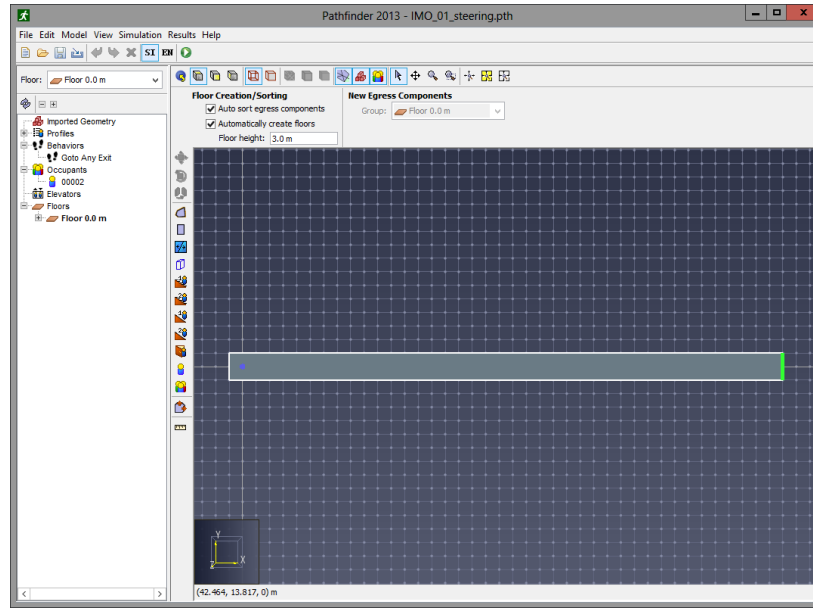


Figure 2: IMO\_01 problem setup.

#### 2.1.1 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.

#### 2.1.2 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  $v_0 = 0.0 \text{ m/s}$ ,  $v_1 = 1.0 \text{ m/s}$ , at  $t=1.1 \text{ s}$  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.

### **2.1.3 Results**

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

Mode	Time	CPU Time
SFPE	40.0	< 1 s
Steering+SFPE	40.5	< 1 s
Steering	40.5	< 1 s

### **2.1.4 Analysis**

All test cases were successful.



## 2.2 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.

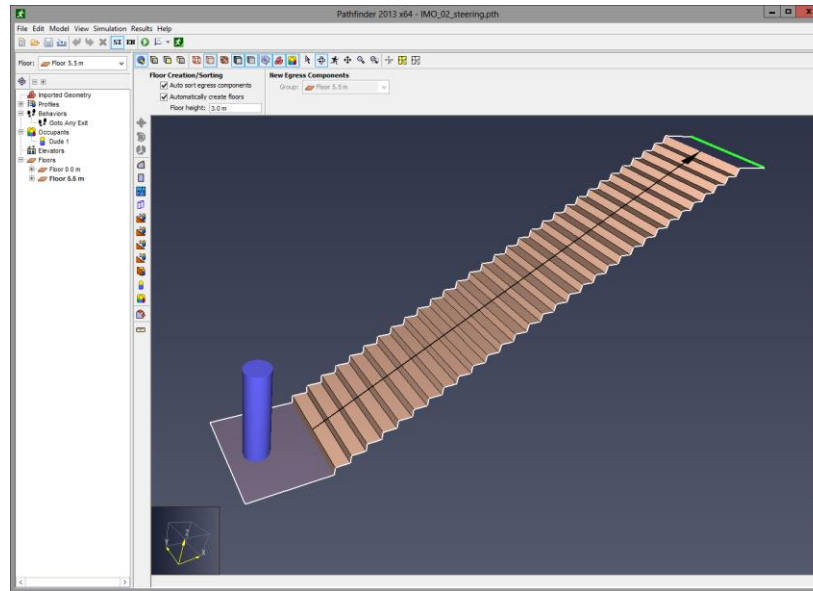


Figure 3: IMO\_02 problem setup.

### 2.2.1 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.

### 2.2.2 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  $(0.918 \text{ m/s}) / (1.19 \text{ m/s}) = 0.77$ . This makes the effective stairway speed of the occupant  $(1.0 \text{ m/s}) * 0.77 = 0.77 \text{ m/s}$ . Based on this speed, the results for all modes should be the same at 12.99 s.

### 2.2.3 Results

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

Mode	Time	CPU Time
SFPE	12.9	< 1 s
Steering+SFPE	13.1	< 1 s
Steering	12.9	< 1 s

### ***2.2.4 Analysis***

All test results are within the reported precision.

## 2.3 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.

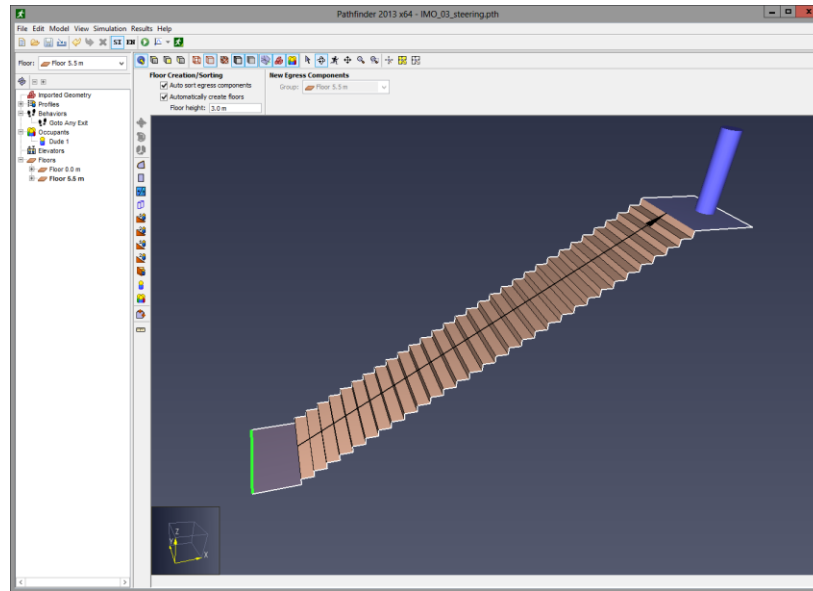


Figure 4: IMO\_03 problem setup.

### 2.3.1 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.

### 2.3.2 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  $(0.918 \text{ m/s}) / (1.19 \text{ m/s}) = 0.77$ . This makes the effective stairway speed of the occupant  $(1.0 \text{ m/s}) * 0.77 = 0.77 \text{ m/s}$ . Based on this speed, the results for all modes should be the same at 12.99 s.

### 2.3.3 Results

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

Mode	Time	CPU Time
SFPE	13.0	< 1 s
Steering+SFPE	13.0	< 1 s
Steering	13.0	< 1 s

### ***2.3.4 Analysis***

All test results are within an acceptable margin of error.

## 2.4 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.

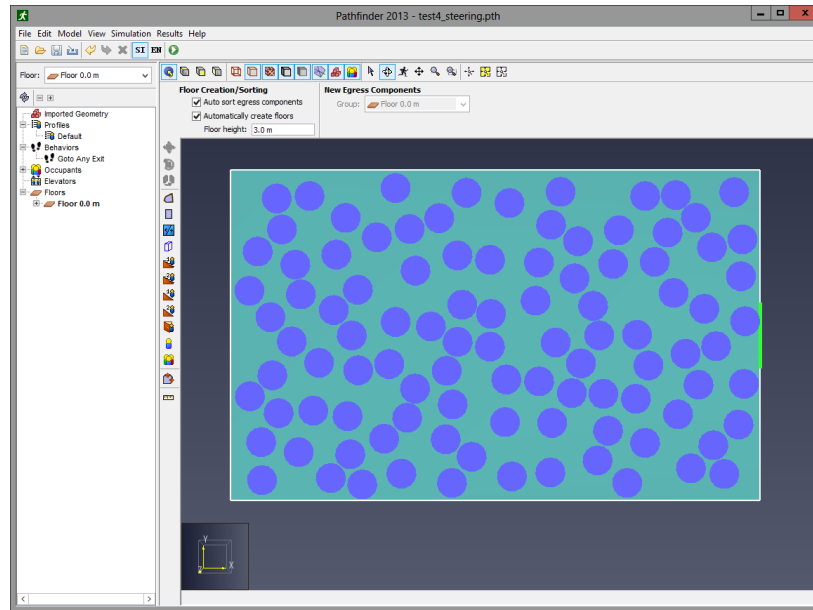


Figure 5: IMO\_04 problem setup.

### 2.4.1 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. The flow rate are shown in Figure 6, Figure 7, and Figure 8.

During the SFPE mode simulations, the boundary layer for the door was set to 0.0 m. This provides the fastest possible (least conservative) solution. 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 1.316 pers/s with zero boundary and 0.92 pers/s when a 15 cm boundary is included.

### 2.4.2 Expected Results

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

### 2.4.3 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	CPU Time
SFPE	1.33pers/s	< 1 s
Steering+SFPE	1.06pers/s	1.8 s
Steering	1.06pers/s	2.4 s

The following figures show the flow rate curves over time for each simulation mode.

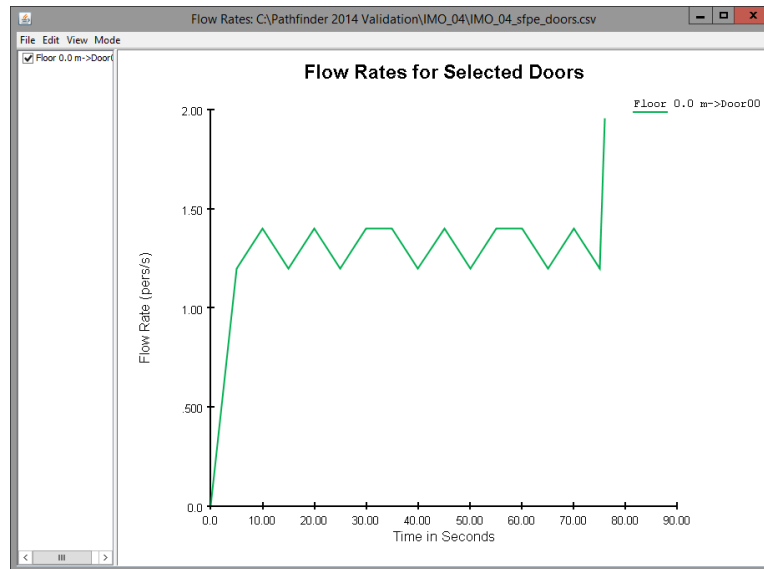


Figure 6: SFPE mode door flow rate (peak at end due to short final time interval)

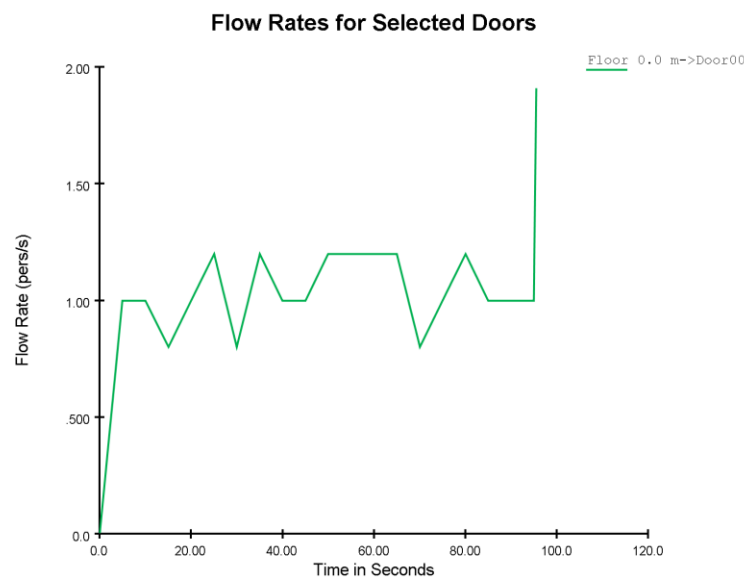
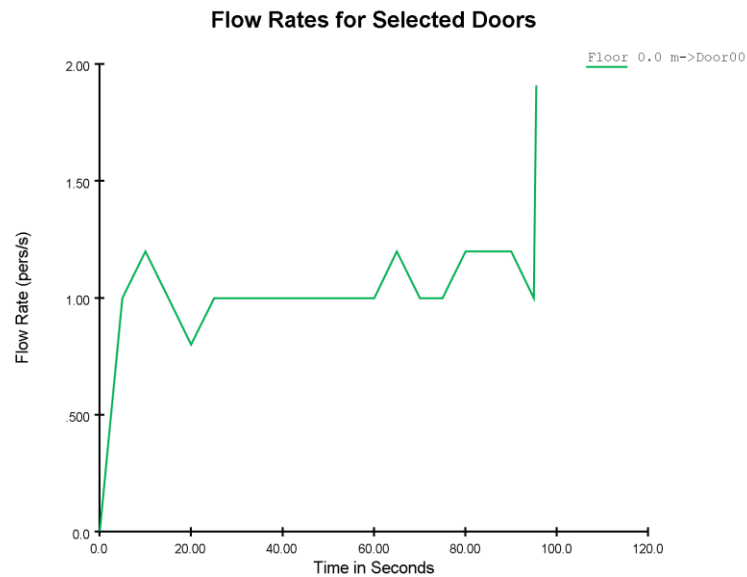


Figure 7: Steering+SFPE mode door flow rate.



**Figure 8: Steering mode door flow rate.**

## **2.4.4 Analysis**

The SFPE results exactly match the expected flow rate.

In steering mode, the flow rate is below the problem specification of 1.33 pers/s. Since flow rate is not explicitly managed by the steering mode, but emerges from underlying behavior this result is considered to be in reasonable agreement with the expectation.

## 2.5 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 9 shows the initial problem setup. 10 occupants were added to the room at random locations.

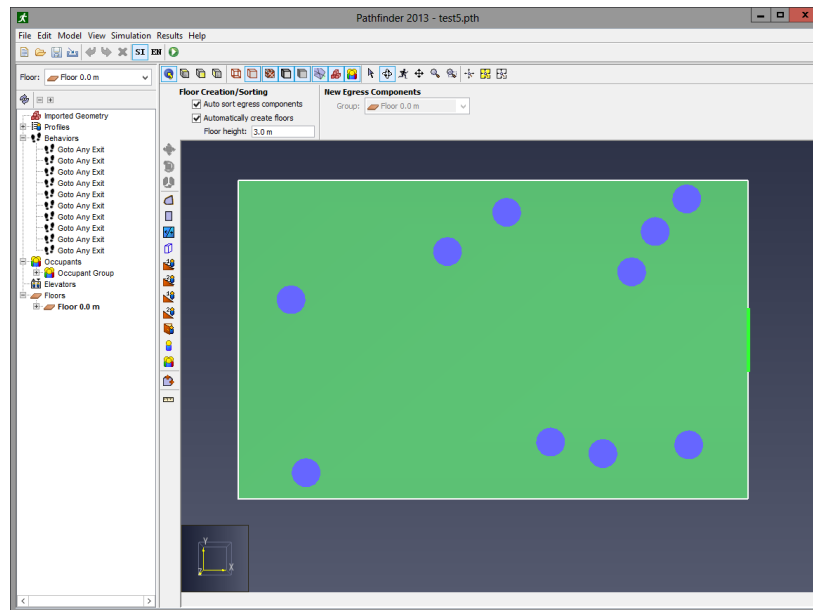


Figure 9: Problem setup for initial movement time verification.

### 2.5.1 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.

### 2.5.2 Expected Results

Initial movement times should vary between occupants. Primarily, this result will be verified by viewing the results animation; however a helpful (though not conclusive) result will be presented in the form of the occupant count for the room. This occupant count data should demonstrate that occupants exit at various times between  $t=10s$  and  $t=110s$ .

### 2.5.3 Results

Results for this problem are primarily based on animation data. In addition, Figure 10 shows the occupant counts over time for the room in this simulation.



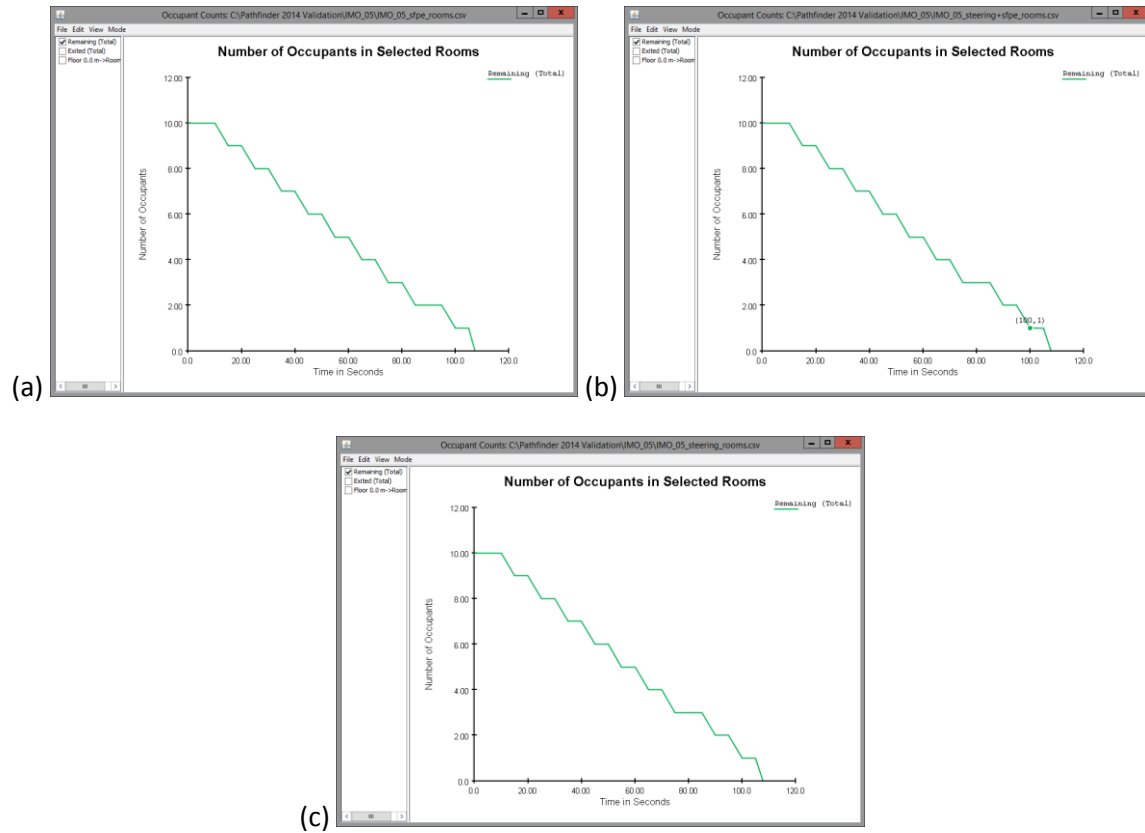


Figure 10: Number of occupants remaining in room: (a) SFPE mode, (b) Steering+SFPE mode, (c) steering mode.

### 2.5.4 Analysis

Response times adhered to the uniform distribution specified in the user interface for all three simulation modes. All simulator modes passed the test.

## 2.6 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.

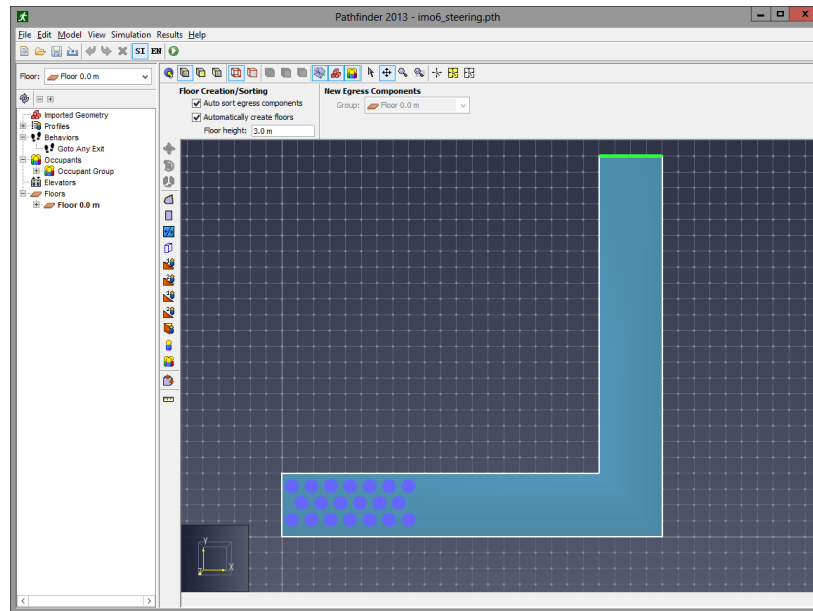


Figure 11: IMO\_06 problem setup

### 2.6.1 Setup Notes

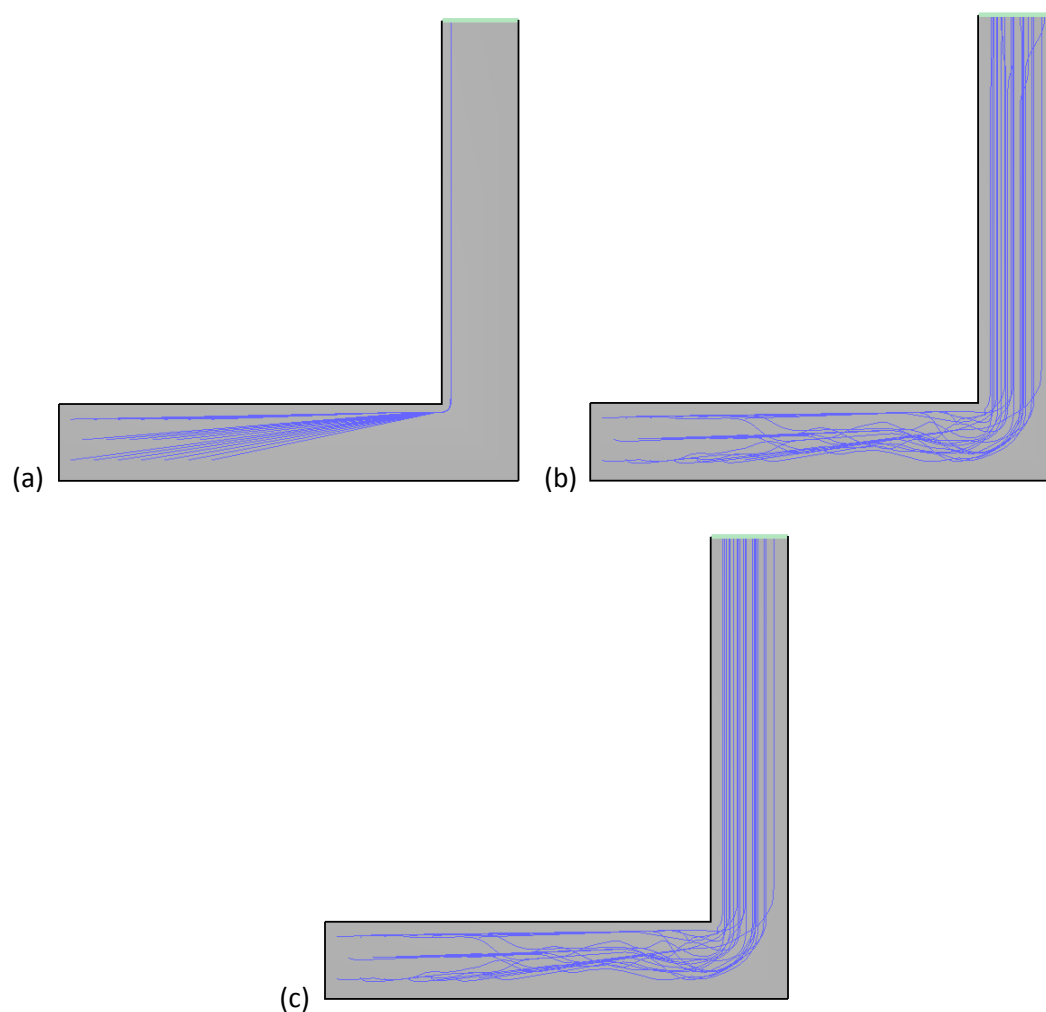
20 persons are uniformly distributed in the first 4 meters of the corridor.

### 2.6.2 Expected Results

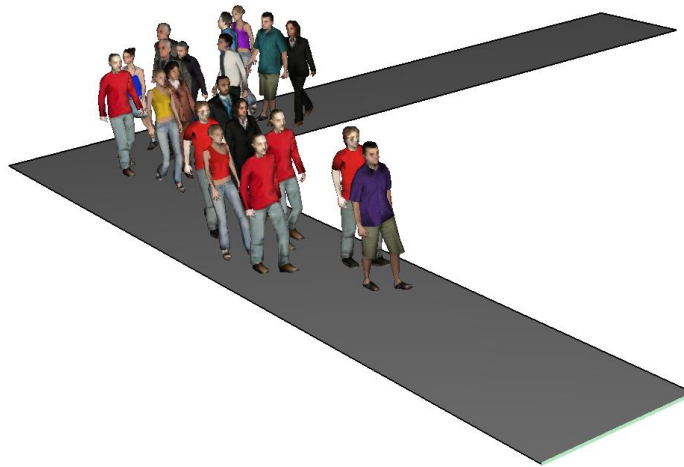
Each occupant should navigate the model while staying inside the model boundaries.

### 2.6.3 Results

Figure 12 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 12: Occupant trails for boundary test: (a) SFPE mode, (b) Steering+SFPE mode, (c) steering mode.**



**Figure 13: More realistic view of occupants for the steering mode analysis**

### ***2.6.4 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.

## 2.7 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.

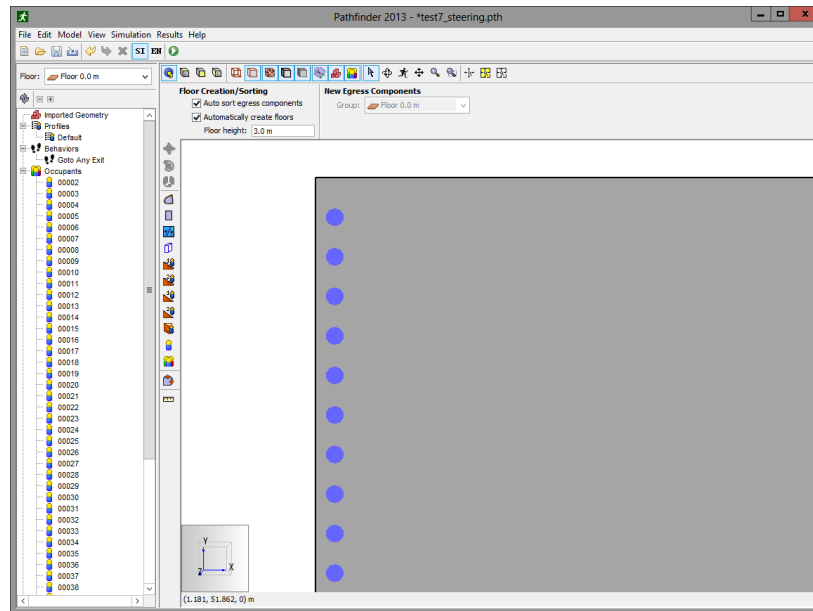


Figure 14: IMO\_07 problem setup

### 2.7.1 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.

### 2.7.2 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).

### 2.7.3 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 15 shows the occupant paths at 20 s.

Mode	First Arrival	Last Arrival	CPU Time
SFPE	24.8 s	40.9 s	< 1 s
Steering+SFPE	25.3 s	41.5 s	< 1 s
Steering	25.3 s	41.5 s	< 1 s

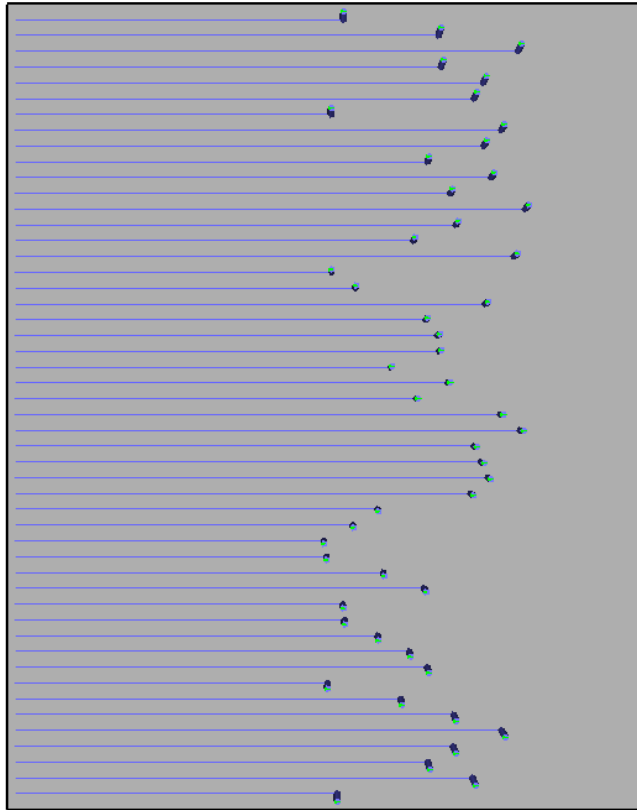


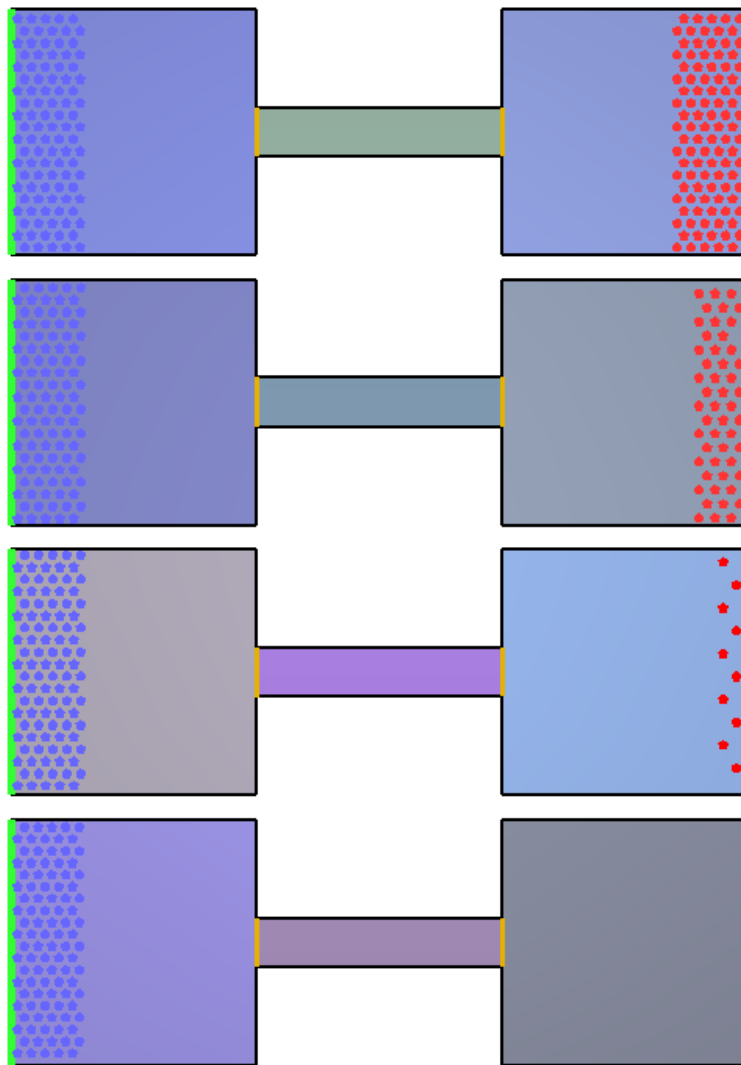
Figure 15: IMO\_07 results showing occupant paths at 20 s

#### **2.7.4 Analysis**

All simulator modes passed.

## 2.8 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 16: IMO\_08 problem setup containing all four configurations and doors in the corridor entrances**

Two models were used, one with doors at the entrances to the corridor and one in which both rooms and the corridor are one large room. The reason for providing two models is that counterflow is not addressed in the SFPE Engineering Guide. Since SFPE allows more than one person to occupy the same

space, counterflow does not slow movement. However, SFPE walking speeds do depend on room density. Adding doors to the entrances of the corridor result in the corridor being defined as a separate room. As occupants move into the corridor, their speeds will slow due to increased density. Arguably, this is closer to the intent of the IMO specification, than just using one big room in which density does not change as occupants enter the corridor.

### **2.8.1 Setup Notes**

The problem geometry is set up as described above, with exits at the far walls. One model included doors at the corridor entrances and one did not. 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.

### **2.8.2 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  $(27 \text{ m})/(1.62 \text{ m/s}) = 16.7 \text{ s}$  and the slowest arrival time could be  $(30 \text{ m})/(0.97 \text{ m/s}) = 30.9 \text{ s}$ . 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.

For the SFPE case with corridor doors, the max flow rate through a 2 m door is 2.632 pers/s. For the 0 person counterflow case, a total of 100 people require 40 s to pass through the door. For the 100 person counterflow case the time is 80 s. To this we add the walking times discussed above, so that the 0 counterflow case give exit times between 16.7 s and 70.9 s. For the 100 person counterflow case the exit times should be between 18.7 s and 114.7 s.



### 2.8.3 Results

Figure 17 shows the occupant positions for the steering mode, 100 person counterflow, no corridor doors case at 50 s. Figure 18 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.

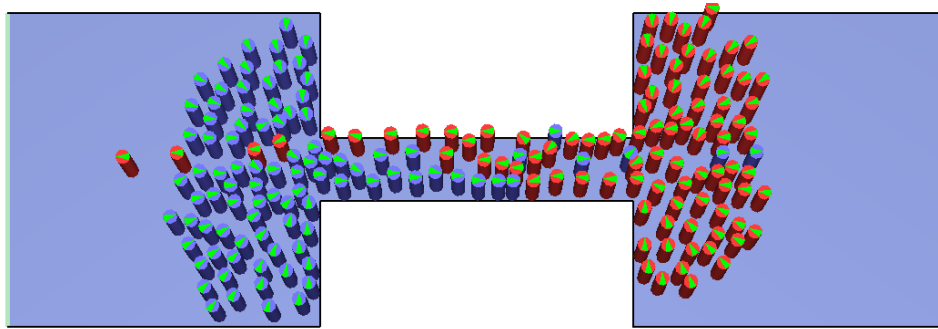


Figure 17: Occupant positions for the steering mode, 100 person counterflow case at 50 s

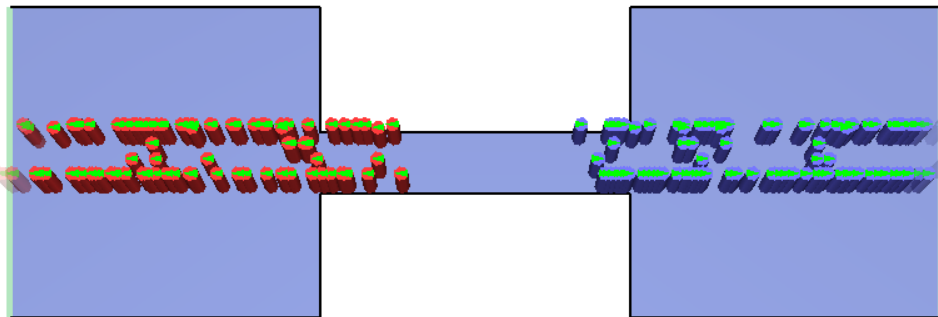


Figure 18: Occupant positions for the SFPE mode, 100 person counterflow case at 20 s

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.

Mode	0		10		50		100	
	First	Last	First	Last	First	Last	First	Last
SFPE	17.2 s	29.9 s	17.7 s	30.7 s	18.0 s	31.2 s	19.1 s	31.7 s
Steering+SFPE	17.9 s	62.7 s	20.1 s	81.5 s	22.5 s	175.1 s	26.4 s	253.4 s
Steering	17.9 s	62.7 s	20.1 s	81.5 s	22.5 s	175.1 s	26.4 s	253.4 s

The following table shows the time it takes to exit the simulation as a function of the number of occupants in counterflow with corridor doors. 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.

Mode	0		10		50		100	
	First	Last	First	Last	First	Last	First	Last
SFPE	18.1 s	65.9 s	20.2 s	69.9s	19.9 s	85.3 s	19.5 s	98.4 s
Steering+SFPE	19.1 s	73.1 s	19.1 s	92.3 s	26.7 s	171.5 s	36.1 s	255.4 s
Steering	17.9 s	60.2 s	19.8 s	84.1 s	25.9 s	163.0 s	27.6 s	238.2 s

### **2.8.4 Analysis**

In each mode, more counterflow increases simulation time. All modes passed test criteria. Using doors at the entrance to the corridor more closely represents the intent of this IMO problem and results in times that more closely match the expected results.

## 2.9 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.

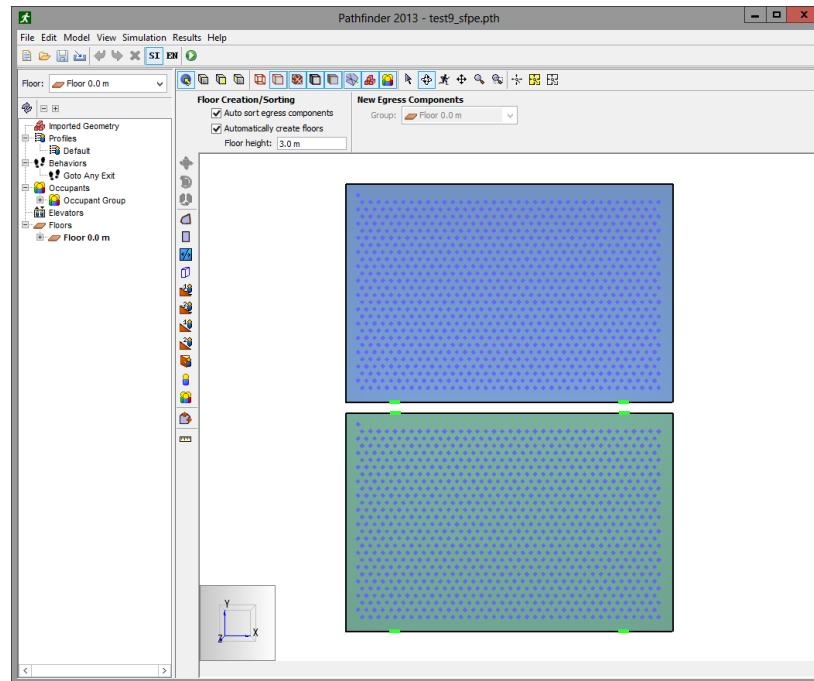


Figure 19: IMO\_09 problem setup containing both configurations

### 2.9.1 Setup Notes

Occupants are given a profile corresponding to males 30-50 years old from Table 3.4 in the appendix to IMO 1238.

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

### 2.9.2 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 persons/s (15 cm boundary included), giving an evacuation time of 541 s for two doors and 271 s for four doors.

### 2.9.3 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. For the Steering two door case 485 and 515 persons exited each door. For the Steering four door case the distribution was 247, 250, 252, 251 persons.

Mode	4 Doors		2 Doors	
	Min	Max	Min	Max
SFPE	263.4 s	274.5 s	538.2 s	547.0 s
Steering+SFPE	272.1 s	282.9 s	551.9 s	564.9 s
Steering	221.5 s	227.4 s	451.9 s	457.8 s

### 2.9.4 Analysis

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

## 2.10 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.

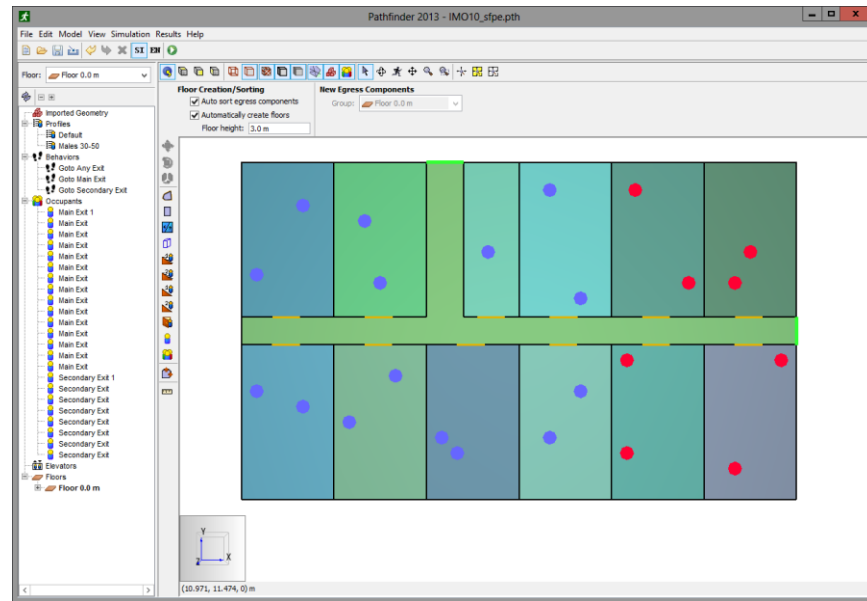


Figure 20: IMO\_10 problem setup

### 2.10.1 Setup Notes

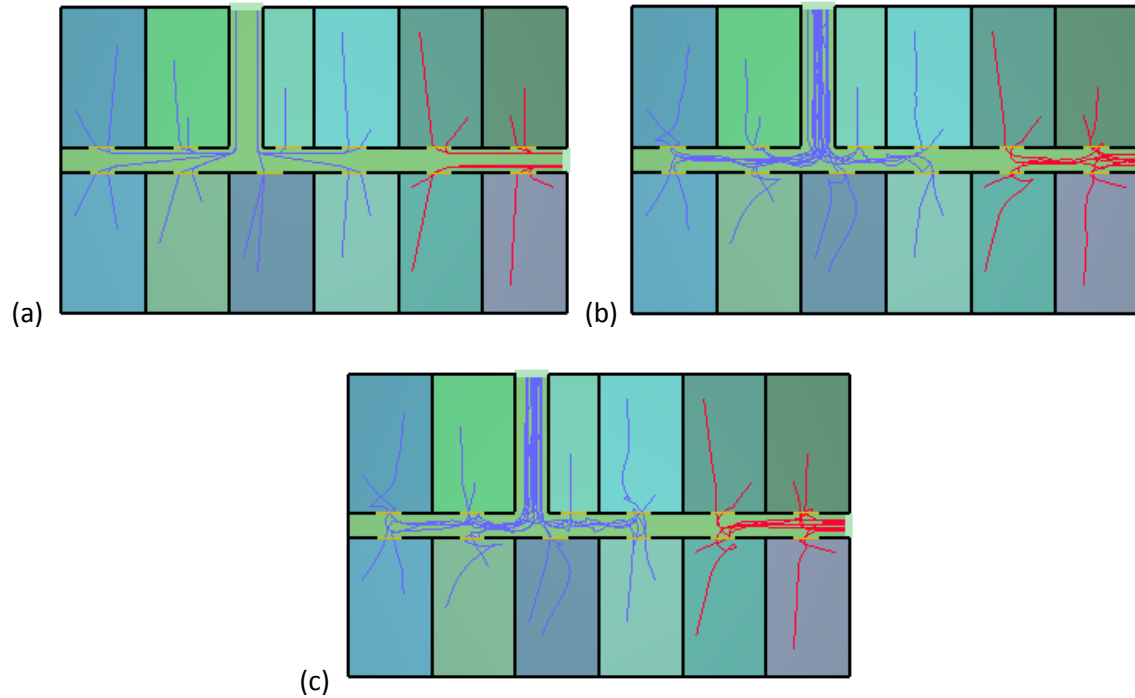
The occupants in the left 8 rooms are assigned to the main (top) exit. The occupants in the remaining 4 rooms are assigned to the secondary (right) exit. Occupants are given a profile corresponding to males 30-50 years old from table 3.4 in the appendix to IMO 1238.

### 2.10.2 Expected Results

Each occupant should leave the model using the specified exit.

### 2.10.3 Results

Figure 21 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.



**Figure 21: Trace of occupant paths: (a) SFPE mode, (b) Steering+SFPE mode, (c) steering mode**

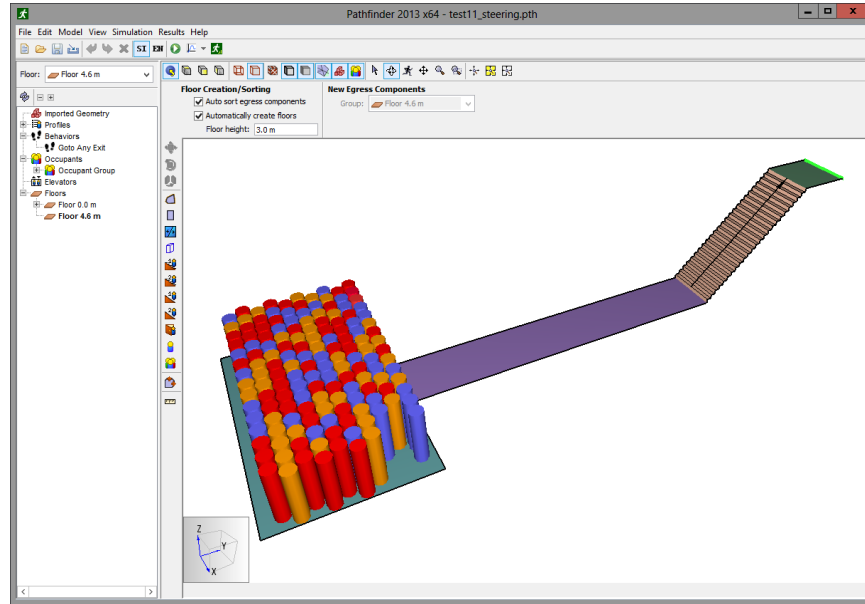
#### **2.10.4 Analysis**

The results for all simulator modes indicate that the four occupants directed to exit via the secondary exit, did so. However, this test is a weak indicator because these occupants may have made the same choice based on the "nearest exit" parameter selection. The test does not differentiate between the two parameter choices. Additional verification is needed to ensure exit choice is working properly. This test has been preserved in its current form to match the criteria set by the International Maritime Association.

## 2.11 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 22 shows the problem setup in Pathfinder.



**Figure 22: 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 pers/m<sup>2</sup>. 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. Any time the change in the occupant count exceeds 1.5 pers/s, the corridor will be assumed to be congested. Data to measure this occupant count over time is available in the doors.csv output file and is processed using a spreadsheet.

### 2.11.1 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).

### **2.11.2 Expected Results**

The initial room is already congested, so this element of the test passes by default. In addition, 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.

### **2.11.3 Results**

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

Mode	Time	CPU Time
SFPE	126.5	1.1 s
<i>Steering+SFPE</i>	121.4	1.8 s
Steering	113.7	1.5 s

Time history data describing the occupant count in the corridor and the rate of change of count are shown in Figure 23 and Figure 24. As defined above, values greater than 1.5 in the rate indicate the formation of congestion.



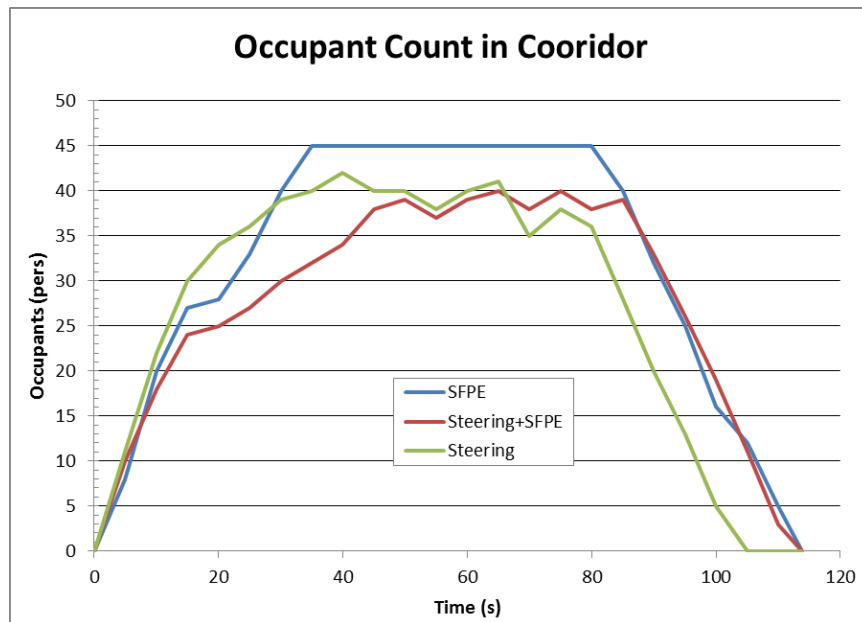


Figure 23: Occupant counts in the corridor

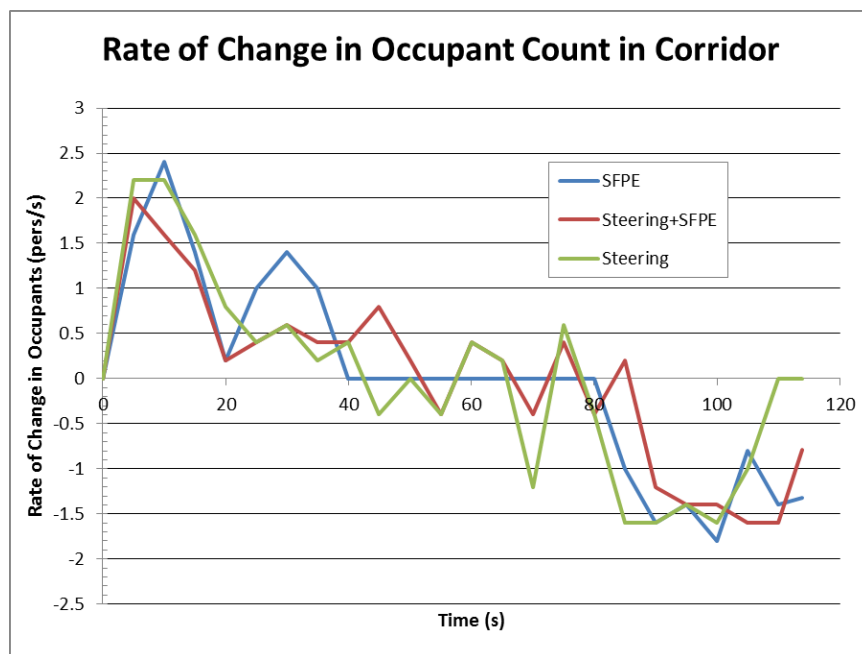


Figure 24: Rate of change in occupant count over time for IMO 11. Values above 1.5 indicate congestion.

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.

#### **2.11.4      *Analysis***

In all simulation modes, the initial room had a density of 3.75 pers/m<sup>2</sup>. This satisfied the congestion criteria for the initial room according to the given definition.

Pathfinder did not produce the expected corridor congestion in any of the three simulator modes. While all three modes consistently showed increasing occupant counts in the corridor (indicating that occupants were entering the corridor more quickly than they could leave), this increase fell short of the 1.5 pers/s criteria defined by IMO 1238.

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 23.

A similar effect occurs in steering mode, where the Comfort Distance defines the packing density of the agents. Assuming a square tiling, the expected packing density is 1.7 pers/m<sup>2</sup>, which results in 40 occupants in the corridor. This is seen in Figure 23.

## **3 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.

### **3.1 Pre-evacuation time distributions (Verif.1.1)**

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

### **3.2 Speed in a corridor (Verif.2.1)**

IMO Test 1, which has already been presented.

### **3.3 Speed on stairs (Verif.2.2)**

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

### **3.4 Movement around a corner (Verif.2.3)**

IMO Test 6, which has already been presented.

### **3.5 Assigned demographics (Verif.2.4)**

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

### **3.6 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.

### **3.7 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.

### **3.8 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 25. The corresponding Pathfinder model is shown in Figure 26.

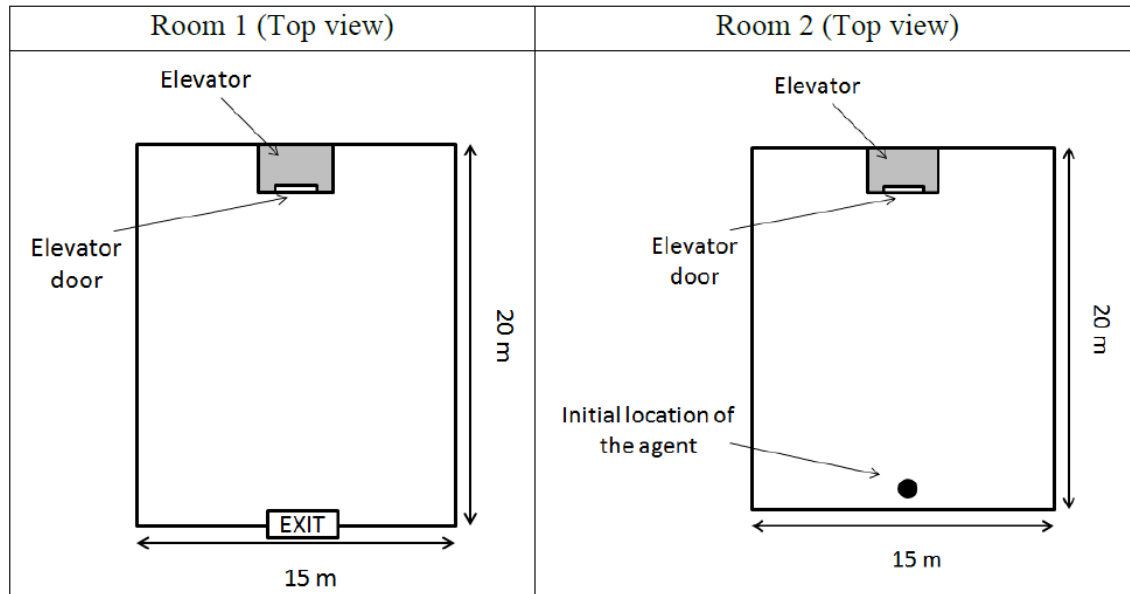


Figure 25: Geometry of elevator verification (Verif.2.7). Figure from NIST Technical Note 1822, 2013.

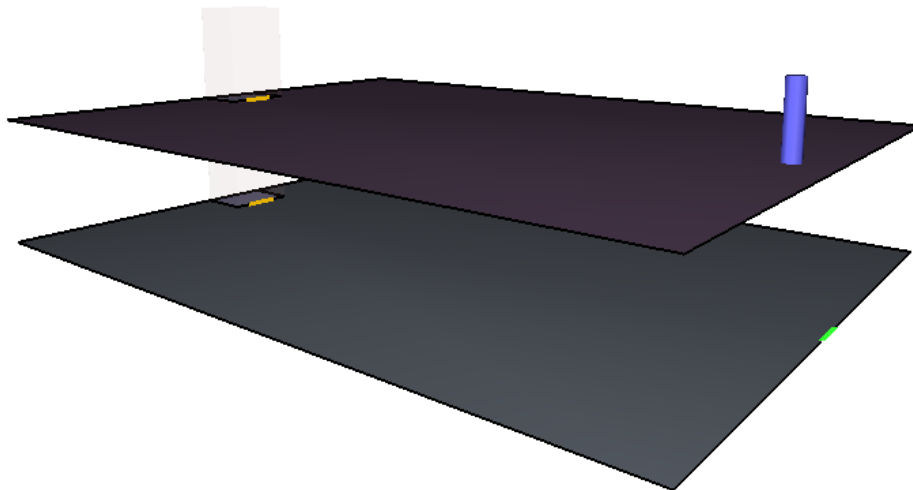


Figure 26: Pathfinder model of elevator verification

### 3.8.1 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 25. 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.

### 3.8.2 Expected Results

The occupant starts walking at time zero and the elevator is called from the discharge floor after they have 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 27.

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
Unload time =	19.75	60.75	60.9

Figure 27: Calculation of expected evacuation time

### 3.8.3 Results

As shown in Figure 27, the observed exit time is 60.9 s. 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.

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

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

## 3.10 Group behaviors (Verif.2.9)

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

### 3.11 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 28. The corresponding Pathfinder model is shown in Figure 29.

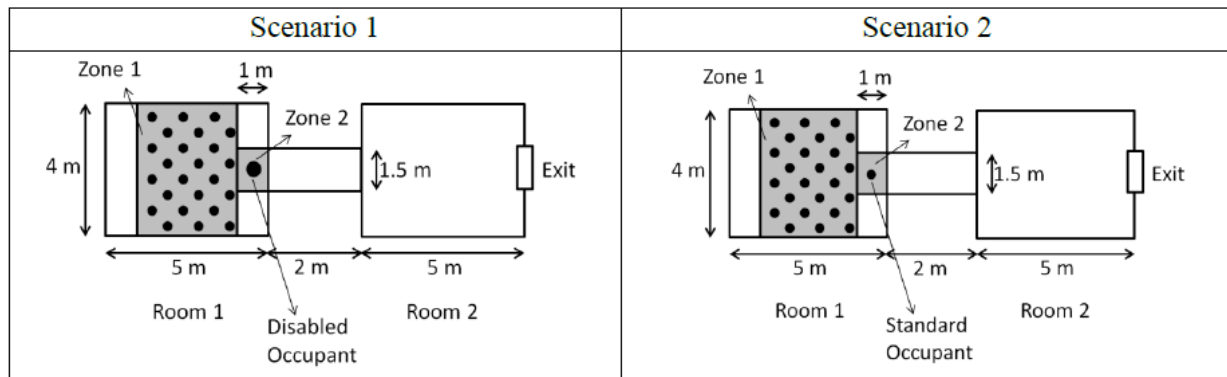
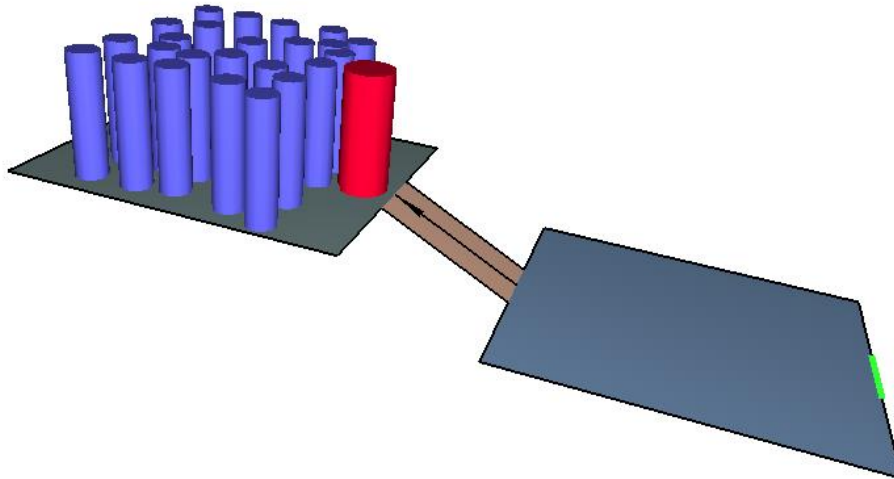


Figure 28: Geometry of elevator verification (Verif.2.7). Figure from NIST Technical Note 1822, 2013.



**Figure 29: Pathfinder model of movement with disabilities. Red occupant has disabilities.**

### **3.11.1 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.

### **3.11.2 Expected Results**

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

### **3.11.3 Results**

The following table shows the time to evacuate all occupants. Including the disabled occupant did slow the evacuation slightly. The faster occupants moved around the disabled occupant, so the effect of the disabled occupant was reduced, Figure 30.

Mode	Scenario 1	Scenario 2
Steering	38.0 s	32.0 s
Steering+SFPE	42.9 s	39.4 s
SFPE	35.9 s	32.6 s

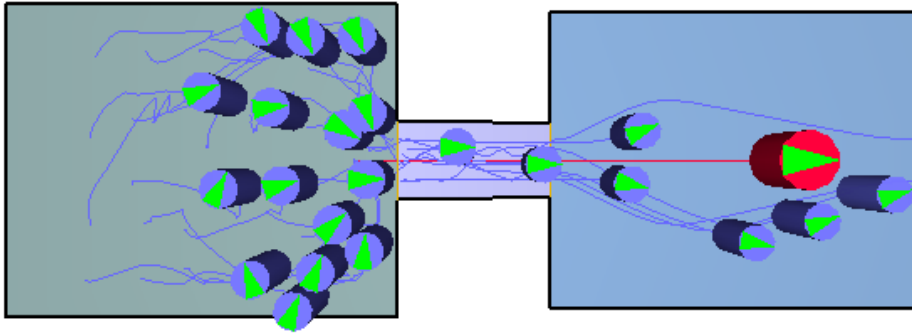


Figure 30: Faster occupants move around disabled occupant. Lines show paths.

### 3.12 Exit route allocation (Verif.3.1)

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

### 3.13 Social influence (Verif.3.2)

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

### 3.14 Affiliation (Verif.3.3)

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

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

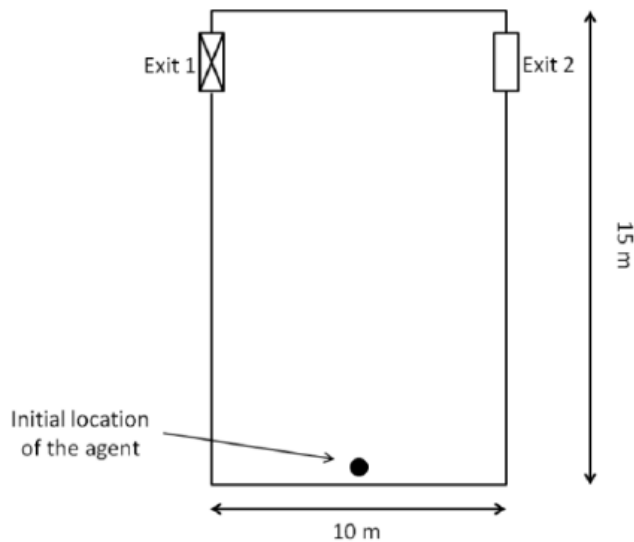
This test is aimed at qualitatively evaluating the capabilities of the model to represent the dynamic availability of exits.

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 31.





**Figure 31: Geometry for dynamic availability of exits (Verif.4.1). Figure from NIST Technical Note 1822, 2013.**

### **3.15.1 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.

### **3.15.2 Expected Results**

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

### **3.15.3 Results**

Figure 32 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.

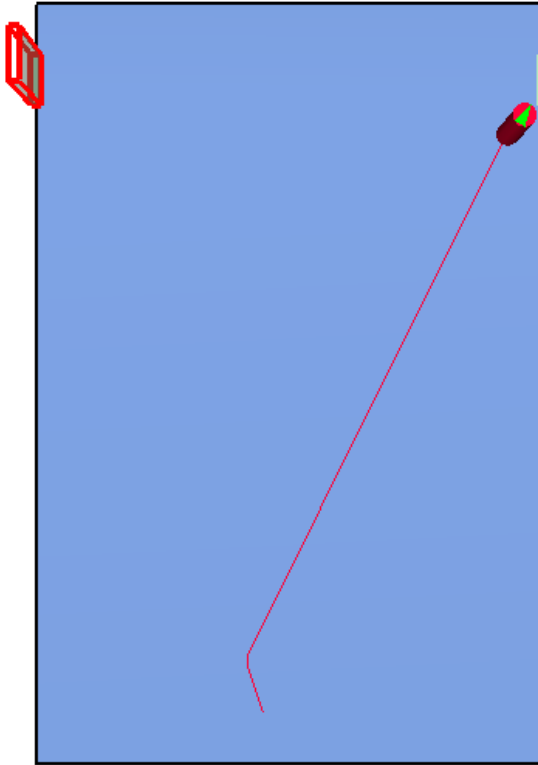


Figure 32: Change in exit selection at 1.0 s. Line shows path. Steering mode.

### **3.16 Congestion (Verif.5.1)**

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

### **3.17 Maximum flow rates (Verif.5.2)**

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

## 4 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).

### 4.1 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 33. The small room is 6 ft x 30 ft with an exit spanning the wall opposite the stairs.

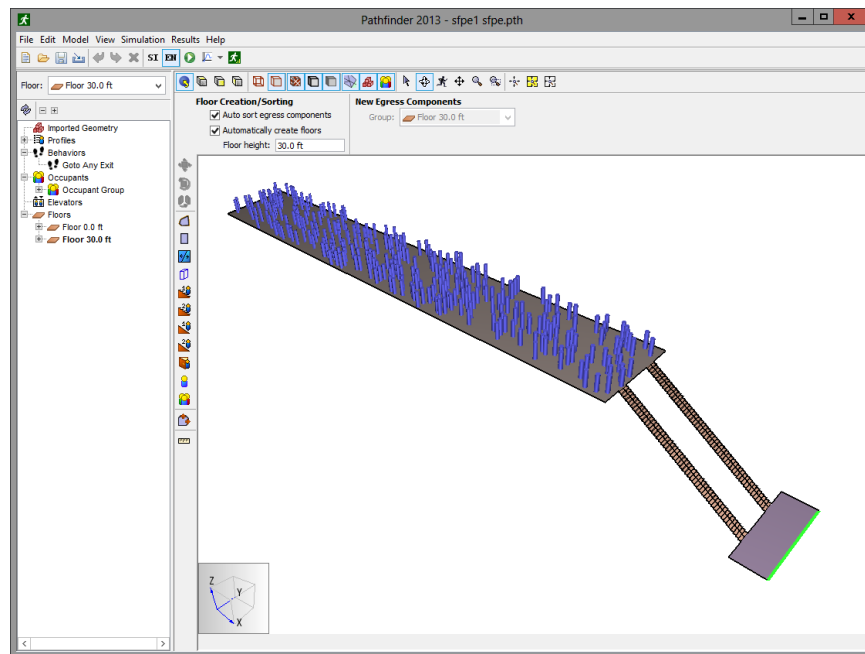


Figure 33: Initial configuration for SFPE 1.

#### 4.1.1 Setup Notes

The door boundary layer is specified as 6 in.

#### 4.1.2 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: ( $T_1$ ) is the

time it takes the first occupant to reach the controlling component, ( $T_2$ ) the time it takes 300 occupants to flow through two 32-inch doors, and ( $T_3$ ) 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:

$$T_1 = 0.7 \text{ s}$$

The time needed for 300 occupants to pass through the two 32 inch doors,  $T_2$  is:

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

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

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

The total evacuation time,  $T_{total}$  is:

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

### 4.1.3 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	PersRIGHT	TLEFT (s)	TRIGHT (s)
SFPE	145	155	234.0	248.0
Steering+SFPE	148	152	262.3	264.0
Steering	150	150	213.8	216.7

### 4.1.4 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 slightly faster, since door flow rates are not limited.

## 4.2 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 34 shows the problem setup.

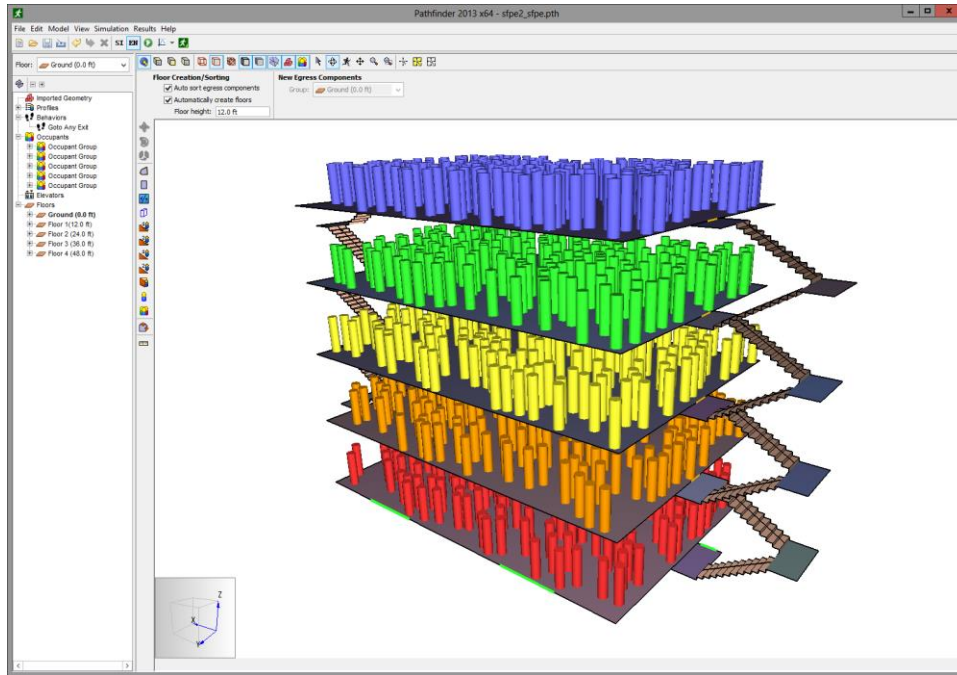


Figure 34: SFPE Example 2 Problem Setup

### 4.2.1 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%.

### 4.2.2 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: ( $T_1$ ) the time it takes the first occupant to reach the controlling component, ( $T_2$ ) the time it takes 400 occupants to flow through the controlling component (a 32 in door), and ( $T_3$ ) the time it takes for the last occupant to move from the controlling component to the exit.

The calculation for  $T_1$  has four parts:

- ( $T_A$ ) the time it takes the occupant nearest the door on the second floor to travel from their initial location to the stairway entrance,
- ( $T_B$ ) the time to move down the stairs to the platform,
- ( $T_C$ ) the time to walk across the platform, and
- ( $T_D$ ) 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:

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

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

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

$$T_B + T_D = 2 \left( \frac{d}{v_{stair}} \right) = 2 \left( \frac{11.17 \text{ ft}}{0.92 \frac{m}{s}} \right) \left( \frac{0.3048 \text{ m}}{\text{ft}} \right) = \mathbf{7.4 \text{ s}}$$

$$T_C = \frac{d}{v_{level}} = \frac{8 \text{ ft} \left( \frac{0.3048 \text{ m}}{\text{ft}} \right)}{1.19 \frac{m}{s}} = \mathbf{2.0 \text{ s}}$$

$$T_1 = T_A + T_B + T_C + T_D = 1.5 \text{ s} + 7.4 \text{ s} + 2.0 \text{ s} = \mathbf{10.9 \text{ s}}$$

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

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

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

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

The total evacuation time,  $T_{total}$  is:

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

### 4.2.3 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)
SFPE	405	395	616.4	602.8
Steering+SFPE	402	398	613.1	608.7
Steering	392	408	397.7	411.3
Steering (queue)	407	393	414.8	398.1

### 4.2.4 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.

## 5 Elevators

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

### 5.1 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 35.

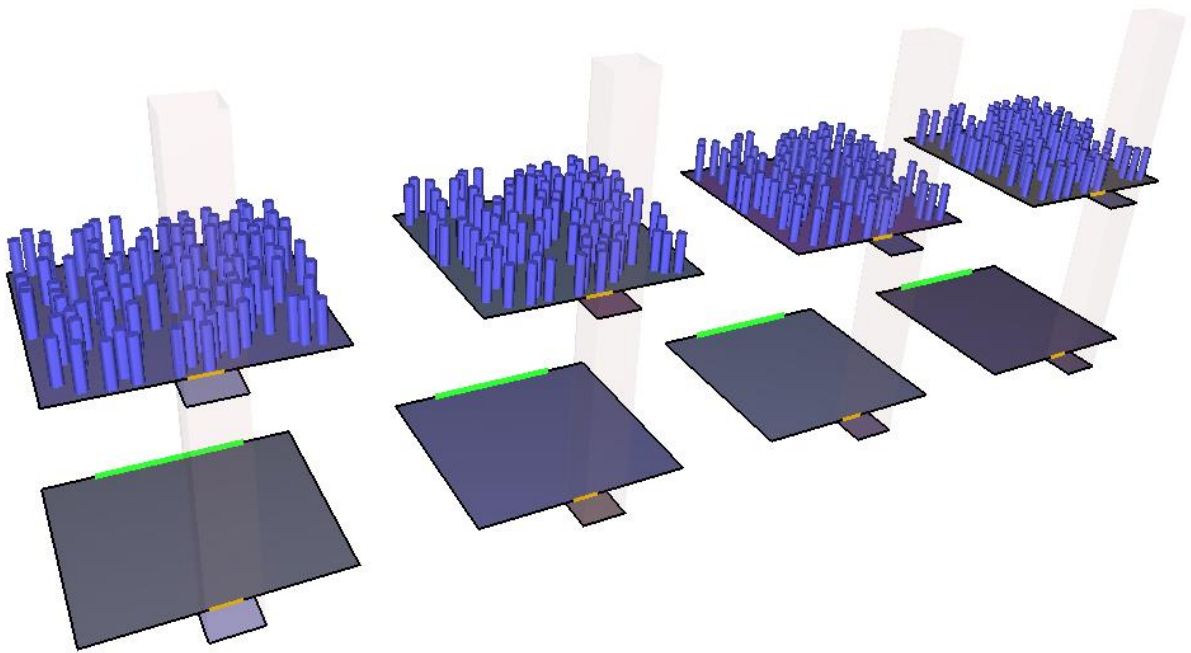


Figure 35: Elevator loading test

#### 5.1.1 Setup Notes

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

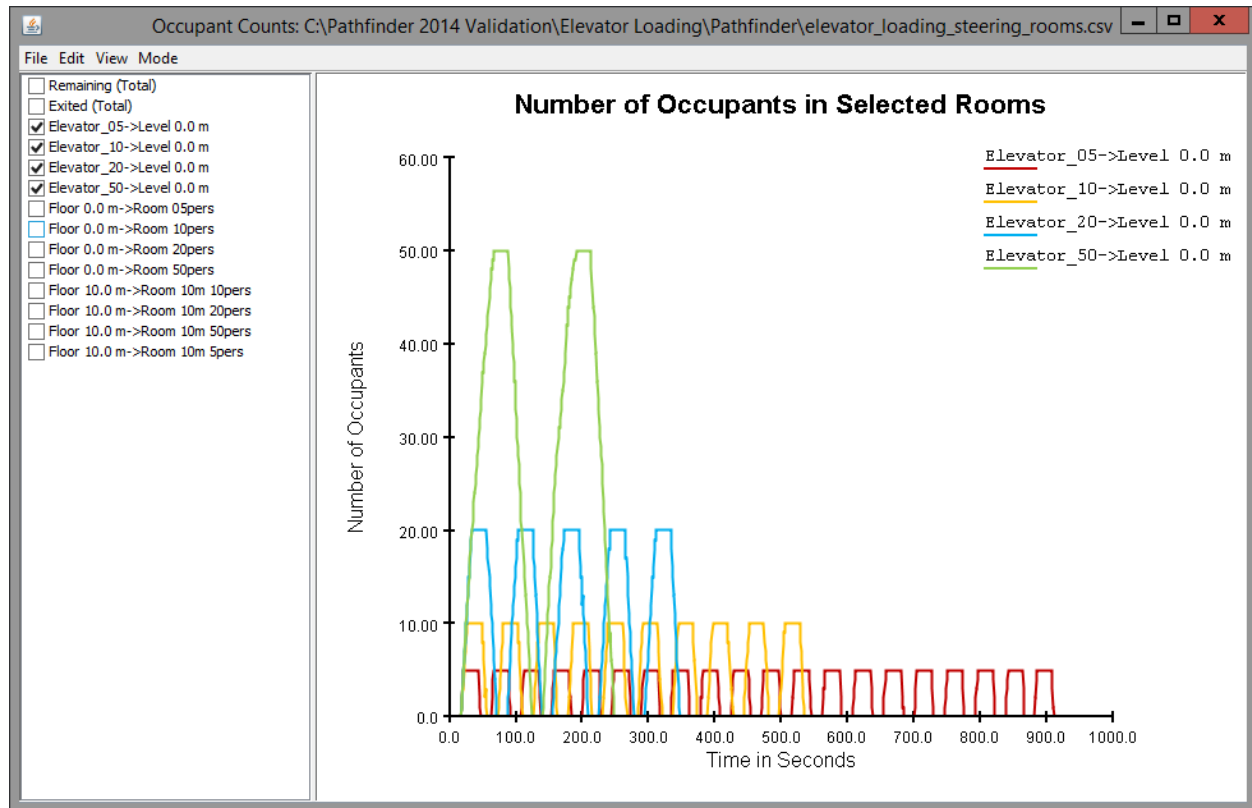
#### 5.1.2 Expected Results

The elevators should load to the expected nominal loads.

#### 5.1.3 Results

The resulting elevator loads for the steering simulation are shown in Figure 36. They match the expected results. The results for Steering+SFPE and SFPE modes also matched the expected results.





**Figure 36: Observed elevator loading for steering mode**

## 5.1.4 Analysis

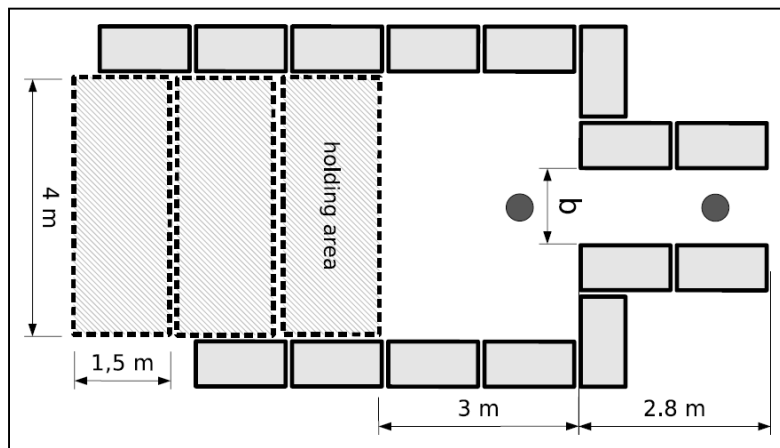
The elevator loadings matched the expected values.

## 6 Comparisons to Experiments

This section presents Pathfinder models designed to reproduce experimental results.

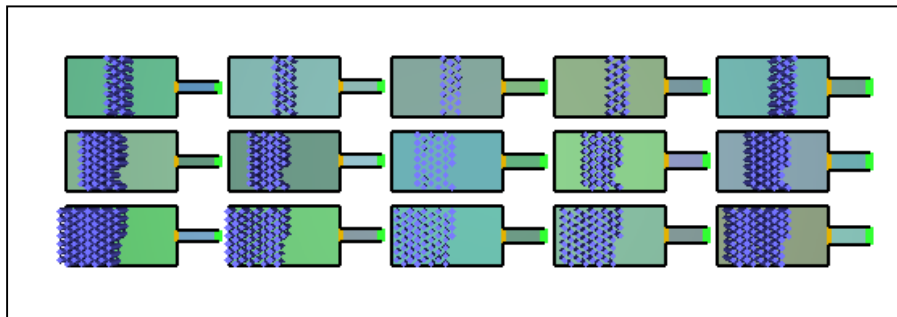
### 6.1 Seyfried et al.

This validation test compares Pathfinder to a series of small-scale experiments (Seyfried, Passon, et al., Capacity Estimation for Emergency Exits and Bottlenecks 2007). The experiments were conducted in a room constructed with dividers and an adjustable-width corridor. Once occupants had exited the corridor they were clear of the experimental environment. Figure 37 illustrates the experimental setup.



**Figure 37: Experimental setup (Seyfried, Passon, et al., Capacity Estimation for Emergency Exits and Bottlenecks 2007).**

Each holding area can accommodate 20 occupants, allowing for experiments to be run with 20, 40, and 60 occupants. The corridor width was adjusted in the range from 0.8 m to 1.2 m at 0.1 m intervals. These two variables provide for 15 test cases. Figure 38 shows the Pathfinder model used to simulate all 15 cases. Currently, only the bottom row of test cases can be compared because the experimental data available for direct comparison is limited to the N=60 cases.



**Figure 38: A Pathfinder model designed to replicate all 15 cases of the experiments.**

### **6.1.1 Setup Notes**

All occupant count and door width variants are handled with a single Pathfinder model.

The occupant walking speed distributions were not given in the paper, but are assumed to be young males and females based on overhead camera data. Based on this assumption, a uniform distribution of walking speeds was chosen with a lower bound of 0.93 m/s and an upper bound of 1.85 m/s. These bounds represent the union of two population groups presented in IMO 1238 (International Maritime Organization 2007): "Males younger than 30 years" and "Females younger than 30 years."

Each test case was run 3 times. Prior to each run, all occupant data was randomized (select all occupants, right-click, on the context menu, click **Randomize**).

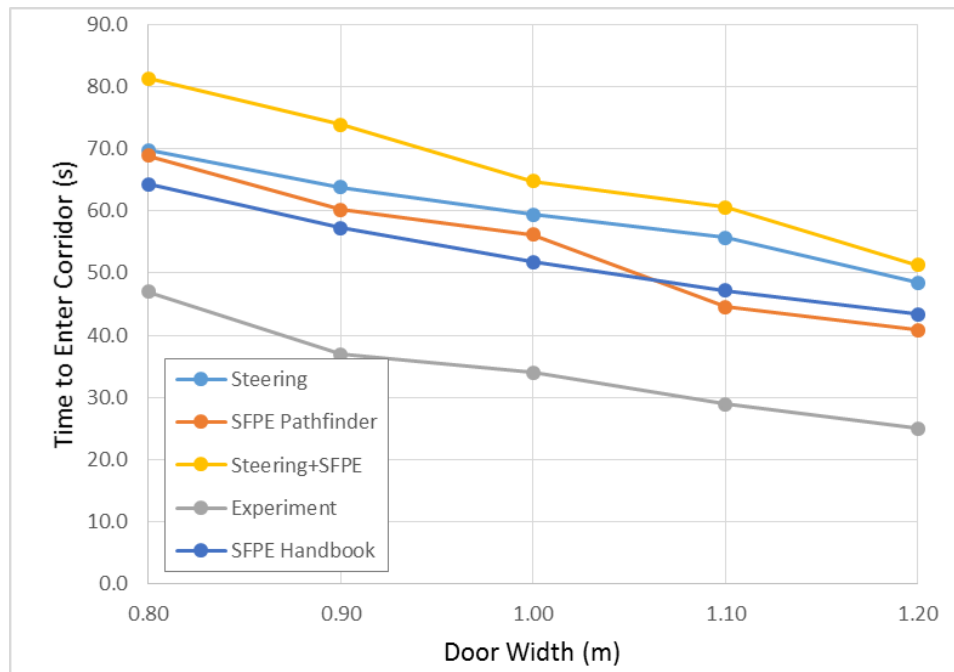
The SFPE and Steering+SFPE simulations were run without a boundary layer. Including a boundary layer would increase the exit times.

### **6.1.2 Results**

Sufficient comparison data is only available for the N=60 experimental scenarios.

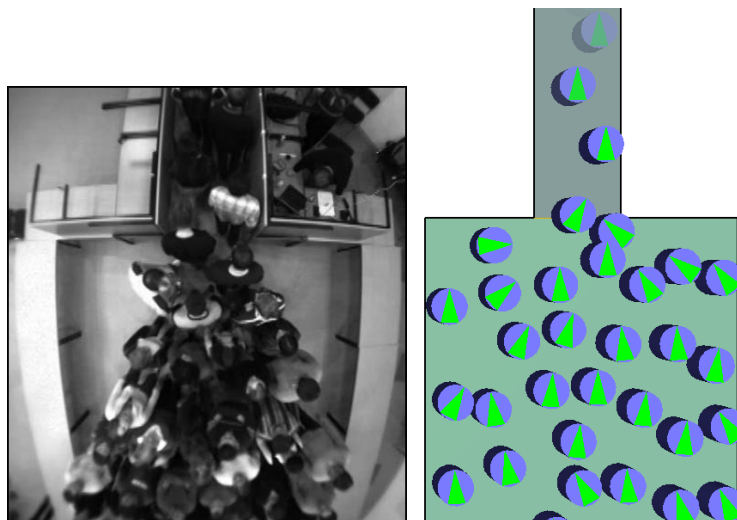
The first result we will examine is the time it took for occupants to pass through the entrance to the corridor. This data can be extracted from Figure 3 in the original paper by identifying the time at which density equals 0.0 (i.e. crossed the y-intercept). The data is plotted in Figure 39.

Width (m)	Experiment (s)	Steering <sub>AVG</sub> (s)	SFPE <sub>AVG</sub> (s)	Steering+SFPE <sub>AVG</sub> (s)
0.8	47.0	69.8	68.9	81.3
0.9	36.9	63.9	60.2	73.9
1.0	34.0	59.4	56.2	64.8
1.1	28.9	55.7	44.6	60.6
1.2	25.0	48.5	40.8	51.3



**Figure 39: Comparison of times to exit room**

In addition, we are able to compare the overhead camera footage in the experiment to the results visualization in Pathfinder. The exact scenario shown in the video at the left of Figure 40 is unknown, but based on the apparent door width and ability of occupants to form two distinct columns, the results video for a steering simulation using door width of 1.1 meters was selected for comparison (at right). The figure was created using the cylinder visualization that illustrates occupant orientation with an inset triangle.



**Figure 40: Experimental video (Seyfried, Passon, et al., Pedestrian and Evacuation Dynamics NETWORK 2009) compared to Pathfinder visualization.**

### **6.1.3 Analysis**

All three Pathfinder simulator modes produce exit times slower than the experimental data. This can be partially explained by the "micro" nature of the experiment combined with a young, able-bodied occupant population. However, there were noteworthy differences in the queue formation (shape) in Steering and Steering+SFPE modes and the exit times for the SFPE mode.

The discrepancy between the experimental data and in the SFPE and Steering+SFPE modes is due to the strict door flow rate imposed by the SFPE technique. It is likely that the fundamental diagram on which the SFPE mode is based (Nelson and Mowrer 2002) did not adequately capture this particular scenario. Commentary on this subject is available in the experimental documentation.

The graphical comparison suggests that the individuals in the experiment were organized in a relatively tight wedge compared to the simulated (steering-mode) occupants. This preemptive "zipper" action was not reflected in the simulation and probably accounted for some of the time difference between the steering mode and the experiment.

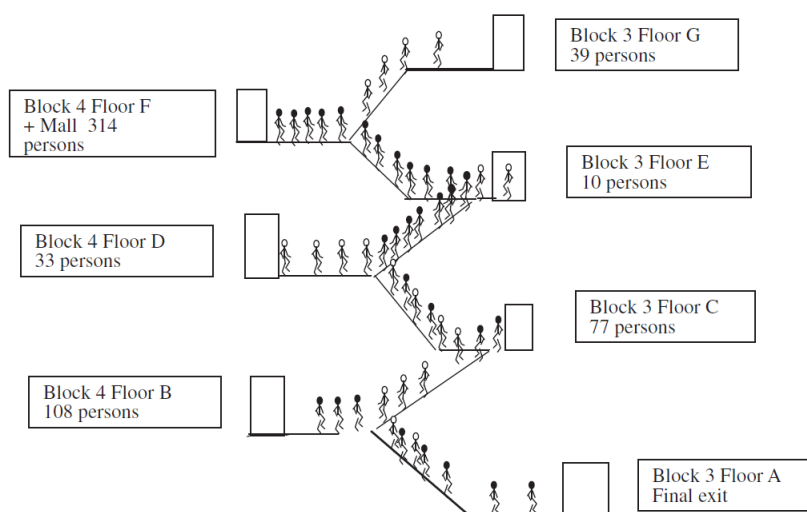
## 6.2 Merging Behavior in a Staircase

This validation test compares Pathfinder to a staircase merging experiment by Karen E. Boyce, David A. Purser and T. Jim Shields, 2011, <http://onlinelibrary.wiley.com/doi/10.1002/fam.1091/abstract>. The referenced paper describes three evacuation studies that focused on merging behavior in staircases. We will use study 1, an evacuation of the University of Ulster's Jordanstown Campus, for validation of Pathfinder. During the evacuation, video recordings were used to count the number of persons passing merge points at staircase landings over 20 s time periods. The primary focus of the study was to evaluate the merging ratio (people on stairs:people on floor). The paper reports that “In evacuation study 1 the merging ratio over the whole period was almost 50:50, but varied somewhat throughout the merge period.”

As described in the paper:

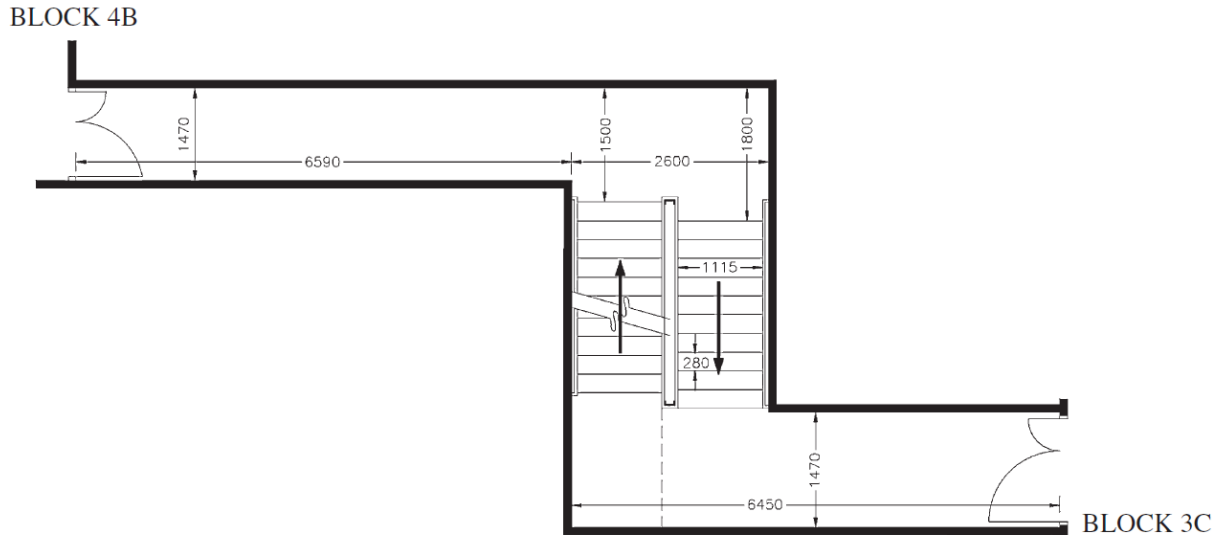
*The University Campus comprises 17 teaching and administration blocks connected by a central mall area. Each teaching block comprises 3 or 4 storeys and has two designated evacuation routes via protected stairways located at the each end of the block. The focus of this study was the stairs, which are common to Blocks 3 and 4. ... The stairs common to Block 3 and 4 were considered to have the greatest potential usage during evacuation, and hence the greatest potential for sustained merging on stairs. In order to increase the likely usage of this stair, permission was sought and granted to direct persons evacuating along the mall into Block 4 at level F, and to direct all occupants of Blocks 4 and 3 at all levels to exit via this stair. This redirection was achieved by positioning members of staff, dressed as security personnel, at the entrances to the alternative stairs at each level preventing them from being used, and by additional directional signs.*

A schematic of the evacuation stair layout and numbers of occupants using each exit is shown in Figure 41.



**Figure 41: Schematic of basic stair layout and numbers of occupants using each exit (Boyce et al., 2011)**

A detailed plan of the stair is shown below. The stair width dimension shown, i.e. 1115 mm, is the width between handrails. The actual width of the step itself is 1160 mm. The tread is 280 mm and riser is 160 mm. There are 10 steps in each flight.



**Figure 42: Dimensions of stair (Boyce et al., 2011)**

As reported in Boyce et al., 2011:

*In this study, sustained merging of the floor occupants with those descending the stairs occurred at levels 3C and 4B only. In total at 3C 473 persons descended the stair and 77 exited the floor, while at 4B the numbers were 550 and 108, respectively. The first person from Floor 4B emerged 21 s after the alarm. Six more followed closely, with another person emerging 64 s from alarm. At this time there was no sustained flow on the stairs leading to 4B. The main group of evacuees emerged from 4B at 1 min and 41 s after the alarm. These 97 people took 2 min and 46 s to leave the floor, i.e. a flow of 35 people/min, specific flow of 23.9 people/min/m or 30 people/min/m effective width. In the same time period, 82 stair occupants passed, i.e. a flow of 29.6 people/m, specific flow 25.5 people/s/m full width or 34.5 people/min/m effective width. ... The flow past the line of merge during the merge period was 64.2 people/min, specific flow 42.8 people/min/m full width or 53.5 people/min/m effective width. The merging ratio, i.e. ratio of those on stairs compared with those from the floor during the main merge period at level 4B was 46:54. In this case there was a slight bias towards the floor occupants over the entire merge period.*

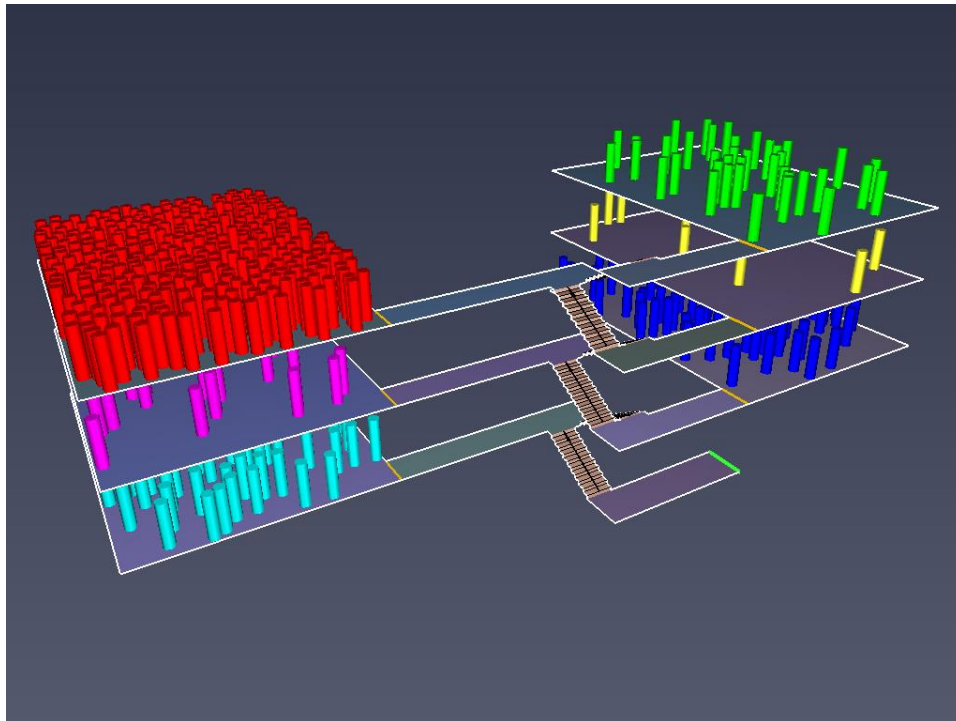
*On 3C the main group of 67 people started to leave the floor 1 min 56 s after the alarm and merged with those coming down the stairs from floors 3G, 4F and 3E above. Merging of occupants from Floor 4B below had already started. The time for these 67 people to leave the floor was 3 min 44 s, i.e. a flow of 18 people/min, specific flow of 12 people/min/m clear width or 15.3 people/min/m effective width. In the same time period, 69 people from the stairs passed the merge point, i.e. flow of 18.5 people/min, 15.9 people/min/m clear width or 21.4 people/min/m effective width. The flow past this line during the*

*merge period was 36.6 people/min. The merging ratio at level 3C, i.e. ratio of those from the stair compared with those on the floor during the main merge period was 51:49, i.e. almost 50:50.*

The total time for the evacuation was 13 min 12 s (792 s). The paper reports “The reason for this extended evacuation time was mainly due to the large numbers of evacuees from the mall who, for the purposes of this study, were directed along Block 4F to the stair of focus.”

### **6.2.1 Pathfinder Simulations**

The Pathfinder model is shown below. In addition to the stairs and landings shown in Figure 42, rooms have been added in which to initially position the people. The number of people in each room matches the numbers indicated in Figure 43.

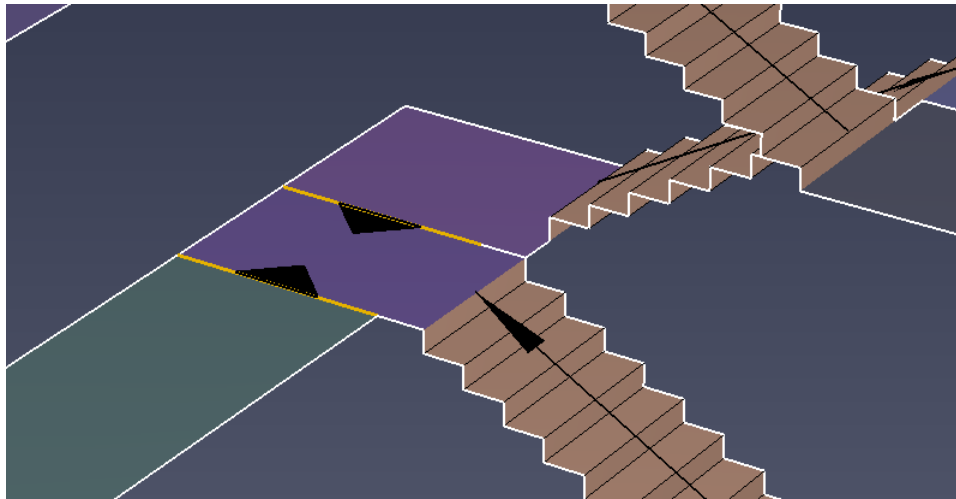


**Figure 43: Pathfinder model**

In the Pathfinder model, the merge points are defined as the tops of the stairs leading from the landing down to the lower floor. So the merge point for Level 4B is the top of the stairway between floors A and B; the merge point for Level 3C is the top of the stairway between floor B and C.

A variation of the Pathfinder model has doors on each landing, as shown in Figure 44. When occupants pass through a door, their path is perpendicular to the door. This tends to equalize the merging flows from the stairs and floor.





**Figure 44: Detail showing doors on landing**

In the evacuation experiment, there were significant delays before people arrived at the floor landings. At Floor B the main group of people arrived at 101 s after the alarm and cleared the floor at 267 s. At Floor C the main group arrived at 116 s and cleared the floor at 340 s. To approximate these arrival times, the Pathfinder model included initial delays. People on floors B and C were assigned delays that gave arrival times similar to the experiment. On floors D, E, and G there is no experimental information provided in the paper. Since there is no specific information on the flow rate of arrivals at each floor, a uniform distribution of initial delays over a 60 s period was assumed. As noted in the report, evacuees from Floor F were redirected from the mall, so people on Floor F were assigned initial delays between 100 and 750 s.

**Table 1: Initial delay times used in simulation (times in seconds)**

Floor	Min Delay	Max Delay	Experimental Observations
B	85	200	Main group arrives at 101 s and clears at 267 s
C	100	200	Main group arrives at 116 s and clears at 340 s
D	100	200	Paper does not discuss
E	100	200	Paper does not discuss
F	100	750	Mall evacuees delayed due to redirection to Floor F
G	100	200	Paper does not discuss

A uniform distribution of walking speeds was chosen with a lower bound of 0.93 m/s and an upper bound of 1.85 m/s. These bounds represent the union of two population groups presented in IMO 1238 (International Maritime Organization 2007): "Males younger than 30 years" and "Females younger than 30 years."

### **6.2.2 Expected SFPE Results**

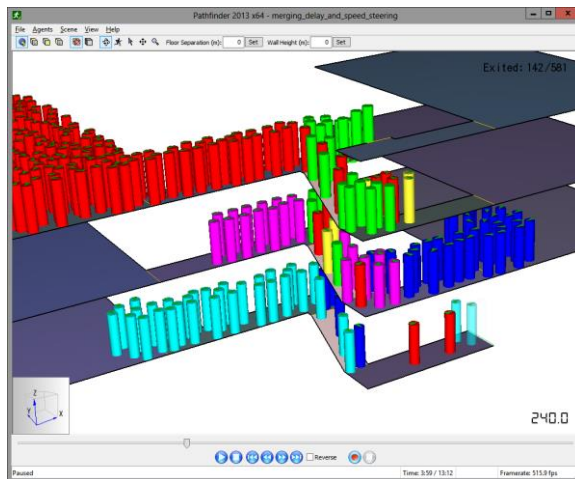
The stairway from floor B to floor A controls the flow of the occupants. For a 1.16 m wide 165/305 stairway, the flow rate is 0.938 pers/s. The total evacuation time using the SFPE calculation consists of:

1. The initial delay (100 s)
2. The time to walk 14 m from the Floor B door to the top of the Stairway A-B (12 s).
3. The time for 581 persons to pass through Stairway A-B (664 s).
4. The time for the last person to walk down the 3 m long stairs (2 s)
5. The time for the last person to walk 6 m from the bottom of the stairs to the exit door (5 s).

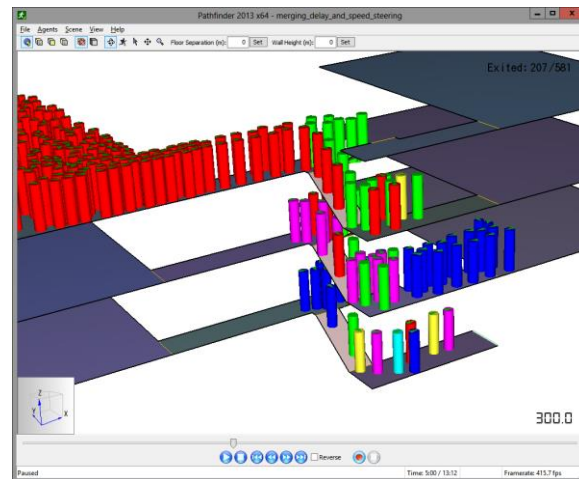
This assumes the first and last person walk at 1.19 m/s. The total predicted SFPE evacuation time is then 783 s. It should be emphasized that SFPE does not control merging behavior, only speeds and flow rates. As a result, the merging ratios and, as a result the landing clearing times, should not be expected to match experimental results.

### 6.2.3 Results

A snapshot of the merging behavior is shown in Figure 45 at two times, one before Floor B clears and one after. As will be noted, when Floor B clears, the stair flow rate for Floor C increases, since there is no longer any merging that must occur at Floor B.



a. Merging at time 240 s



b. Merging at time 300 s

**Figure 45: Snapshots of merging behavior**

The total evacuation times are compared in Table 2. Because the experimental evacuation time was controlled not by flow capacity, but by the delayed arrival of people to Floor F, this is not a sensitive measure of simulator performance. The Pathfinder results for the agent calculations all strongly depend on the assumed delay times. The SFPE calculation provides a reference point with the time controlled primarily by flow rate on the lower stair.

**Table 2: Total evacuation times (times in seconds)**

Case	Time	Comment
SFPE Hand Calculation	783	Idealized, uniform speeds
Experiment	792	Experimentally observed delayed arrival at Floor F slowed evacuation.
Pathfinder - Steering	792	Includes initial delays and speed distribution.
Pathfinder - Steering+Doors	795	Includes initial delays and speed distribution.
Pathfinder - SFPE+Steering	795	Includes initial delays and speed distribution. Door flow rates limited to SFPE standards.
Pathfinder - SFPE	788	Includes initial delays and speed distribution. SFPE Mode.

The paper provides information on the arrival and clearing times for Floors B, C, and (indirectly) F. Comparisons with the experimentally observed results are provided in Table 3. In general, the Pathfinder steering simulations compare favorably with the data. The SFPE clearing times are significantly longer than observed. This is because the SFPE mode does not attempt to control merging at stairs. Instead, the order of merging changes if it is recognized that the stairway occupation density has exceeded the specified value. The clearing times for Floors B and C are significant occupants queued at the Floor B stairway during the time interval between the time arrival at Floor B and the clearing of Floor C. So the clearing times are controlled by flow capacity, not the initial delay times.

**Table 3: Floor arrival and clearing times (times in seconds)**

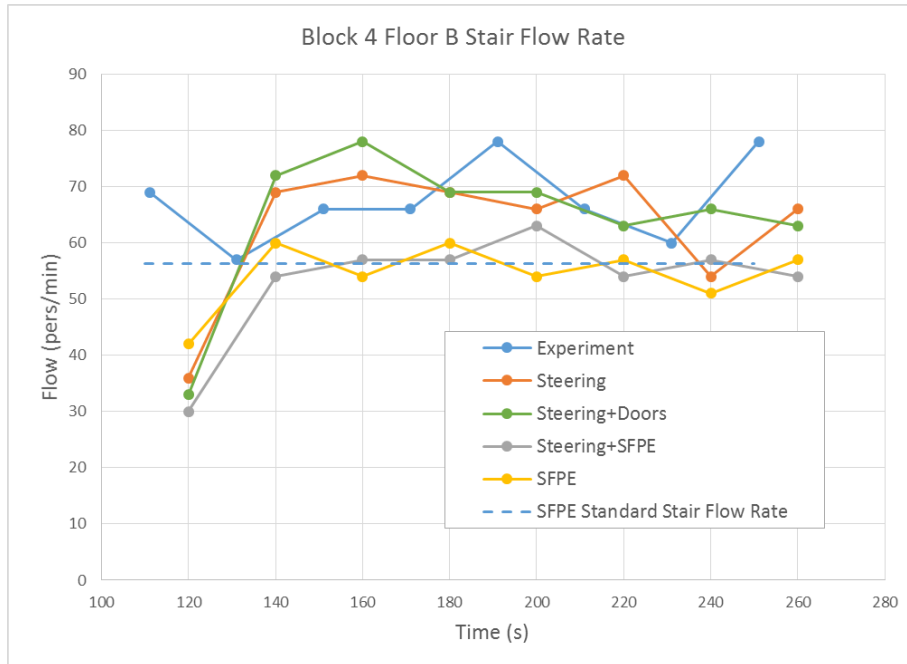
Floor	Experiment		Pathfinder							
			Steering		Steering+doors		Steering+SFPE		SFPE	
	Arrival	Clear	Arrival	Clear	Arrival	Clear	Arrival	Clear	Arrival	Clear
B	101	267	102	318	102	269	102	342	102	619
C	116	340	106	343	106	311	106	379	111	567
D	n/a	n/a	109	274	109	314	109	353	109	524
E	n/a	n/a	109	266	109	268	109	213	109	407
F	n/a	792*	113	761	113	761	111	762	111	760
G	n/a	n/a	107	215	107	288	107	245	107	208

\* This is total evacuation time

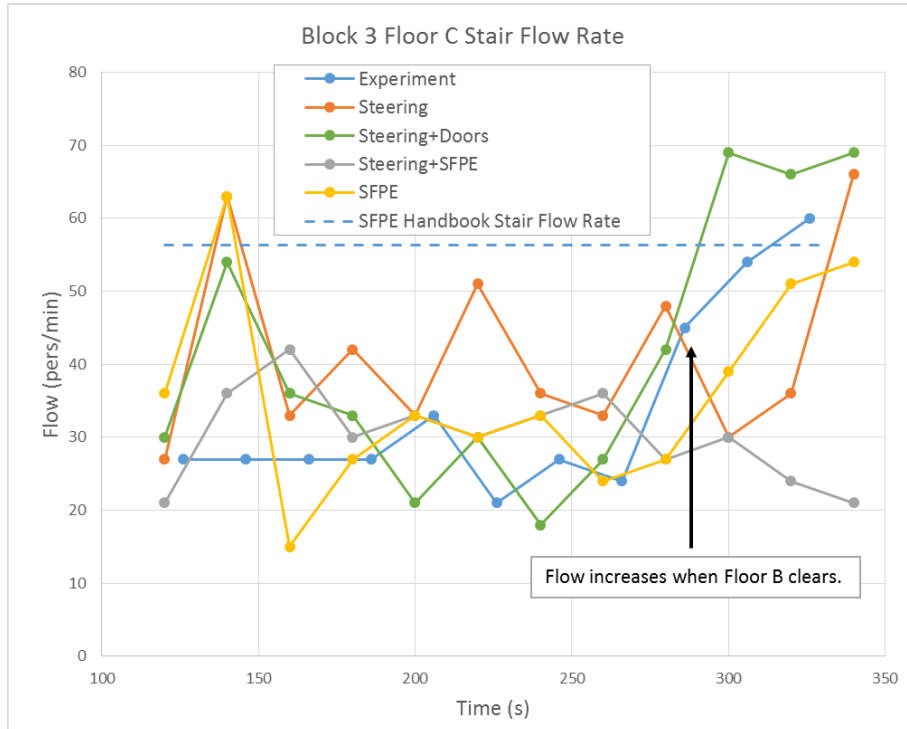
The paper also reports flow rates at 20 s intervals at the stairs leading from Floors B and C. Comparisons with Pathfinder calculations are shown in Figure 46 and Figure 47.

Figure 46 is important because it is an indication of the maximum experimentally observed flow rate on stairs. In the experiment, an average of 67.5 pers/min used the lower stair. This is somewhat greater than the calculated SFPE handbook value of 56 pers/min. The Steering mode simulation predicted an average flow rate of 64.5 pers/min. Figure 47 shows that, as expected, the flow rate in the stair leading

from Floor C is reduced until Floor B clears, at which the flow rate rises to the higher unimpeded stair flow rate.



**Figure 46: Flow rates in stairs below Floor B merge point**



**Figure 47: Flow rates in stairs below Floor C merge point**

Experimental merging ratios are reported for landing 4B and landing 3C. The merging ratio is calculated over the times during which queues had formed on the landings. The paper presents the Floor B data in Table II and the average stair/floor merge ratio was observed to be 0.85. Over a corresponding time interval, Pathfinder without the landing doors predicts an average stair/floor merge ratio of 1.5 while with the landing doors the merge ratio is 0.76. At Floor C Pathfinder predicted a merge ratio of 1.5 without landing doors and a value of 0.75 with doors, compared to the experimental value of 1.0.

Results are only presented for Steering mode, since SFPE mode does not specify merging. It should be noted that merging behavior impacts the calculation of relative clearing of floors, but does not impact the total evacuation time.

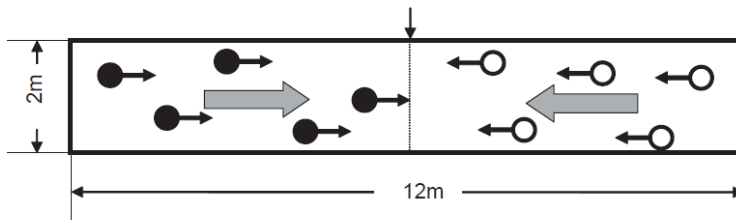
### **6.2.4 Analysis**

The Pathfinder and experimental results compare quite well. The long arrival delays (based on experimental data) specified for the people who emerged from Floor F control the final evacuation times, so this is not a sensitive measure of simulator accuracy. Without landing doors, Pathfinder predicts a larger stair/flow merging ratio than experimentally observed and with landing doors Pathfinder predicts a somewhat lower ratio. Pathfinder does perform satisfactorily in capturing stair flow rates.

### 6.3 Pedestrian Counter Flow

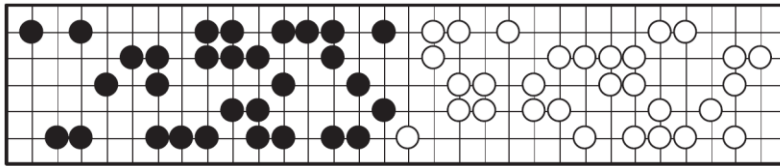
This validation test compares Pathfinder to a counterflow experiment by Motoshige Isobe, Taku Adachi, and Takashi Nagatani, 2004, *Experiment and simulation of pedestrian counter flow*, [Physica A 336 \(2004\) 638-650](#).

The experimental setup consisted of a 2m by 12m corridor, with open exits on the left and right boundaries. Equal numbers of people were initially positioned randomly in the left and right halves of the corridor. Those in the left half exited to the right; those in the right half exited to the left. At  $t > 0$ , all people began to move. Eight different densities were investigated, with 10 repeated experiments at each density.



**Figure 48: Schematic of experimental setup (Isobe et al., 2004)**

The density defined in the paper (*lattice density*) is reported as persons/site. The number of sites is a reference to the number of total locations that can be occupied in the lattice representation developed in the paper. In the lattice model, each pedestrian occupies  $0.4 \text{ m} \times 0.4 \text{ m}$  ( $0.16 \text{ m}^2$ ) and the corridor area is  $24 \text{ m}^2$ , so this corresponds to 150 sites, as shown below.



**Figure 49: Lattice model that defines the number of sites used to define density (Isobe et al., 2004)**

The table below gives density as a function of people. For 60 pedestrians, the density measured in persons/site is  $60/150 = 0.4$  persons/site. For density measured in persons/ $\text{m}^2$  the density is  $60/24 = 2.5$  persons/ $\text{m}^2$ .

Number of People	Lattice Density (pers/site)	Density (pers/m <sup>2</sup> )
2	0.013	0.083
10	0.067	0.417
20	0.133	0.833
30	0.200	1.250
40	0.267	1.667
50	0.333	2.083
60	0.400	2.500
70	0.467	2.917
90	0.600	3.750
120	0.800	5.000
150	1.000	6.250

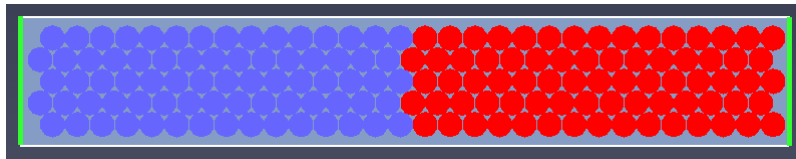
**Figure 50: Density calculations**

The results are reported in a plot of mean arrival time as a function of initial occupant lattice density. The reference paper notes that the maximum occupancy of the corridor was 150 persons. However, the experiment became dangerous for more than 70 pedestrians, since the corridor jammed and some pedestrians fell due to pushing.

### **6.3.1 Setup Notes**

Two Pathfinder variables were changed from their default values in order to correspond to the experimental setup. The first parameter was the size of the occupants. For 150 pedestrians to occupy the corridor, it was necessary to reduce the shoulder width of the pedestrians to 40 cm, from the default Pathfinder value of 45.58 cm. In addition, the experiment shows that two pedestrians have an average arrival time of 8.0 s. This corresponds to an unobstructed walking speed of  $(\text{mean travel distance})/(\text{mean arrival time}) = (9 \text{ m})/(8 \text{ s}) = 1.125 \text{ m/s}$ . This constant walking speed was used in the Pathfinder simulations. The default Pathfinder value is 1.19 m/s.

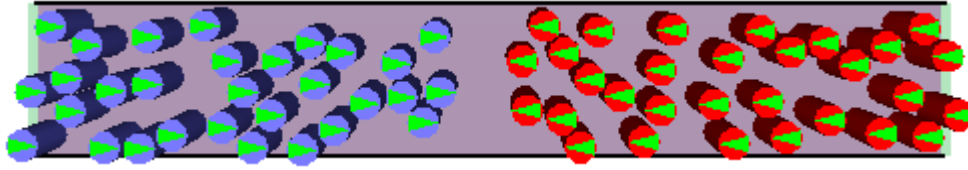
The image below shows the packing of 150 people into the corridor using a shoulder width of 40 cm.



**Figure 51: Dense packing of 150 people**

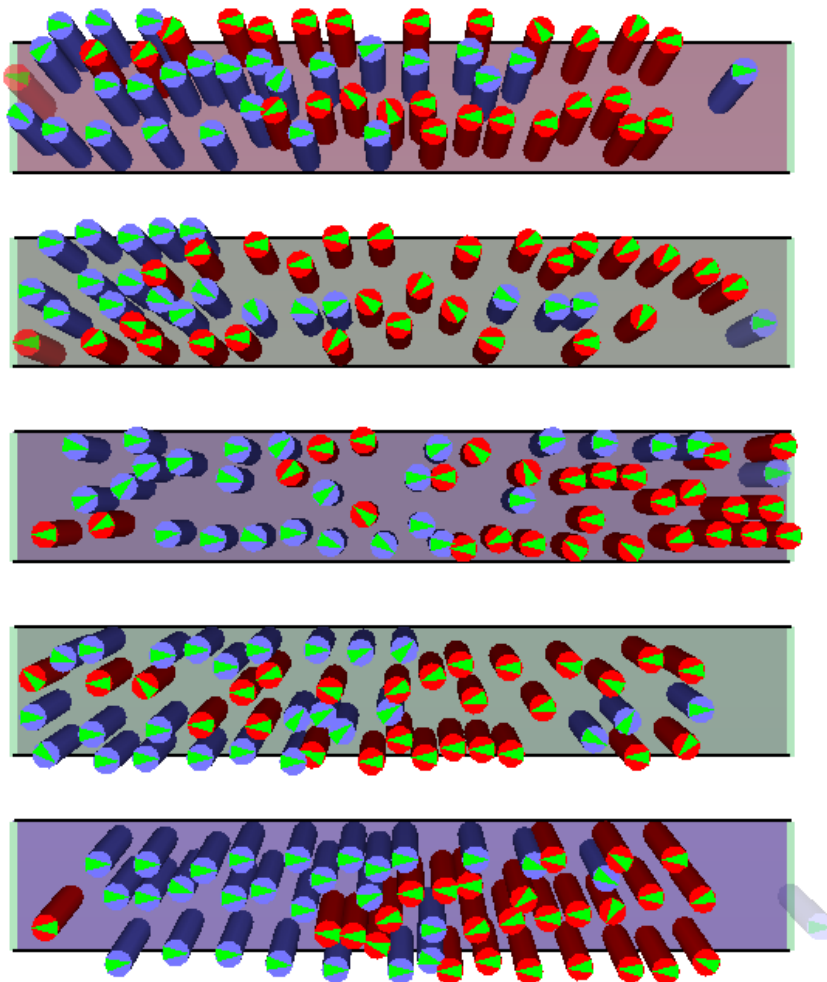
### **6.3.2 Results**

The Pathfinder model is shown below for a case with 60 pedestrians. The corridor is divided into two rooms by a full-width door. This was done to make it easy to assign pedestrians to the left and right halves of the model. The door does not change the result.



**Figure 52: Typical Pathfinder model showing initial positions for 60 people**

Five simulations were run for each model and the results averaged. Results for the 5 cases with 60 occupants are shown in Figure 53 at a time of 20 seconds. Some lane-forming arises, but the average evacuation times are longer than observed experimentally.



**Figure 53: Results for the five cases with 60 occupants**

A comparison of Pathfinder with experimental results is shown below. The error bars show one standard deviation. This figure also includes an SFPE calculation using constant walking speeds calculated based on the initial room occupation density (persons/area).



speed = velocity factor -  $(0.266 \text{ m}^2/\text{person}) * (\text{velocity factor}) * (\text{density persons}/\text{m}^2)$

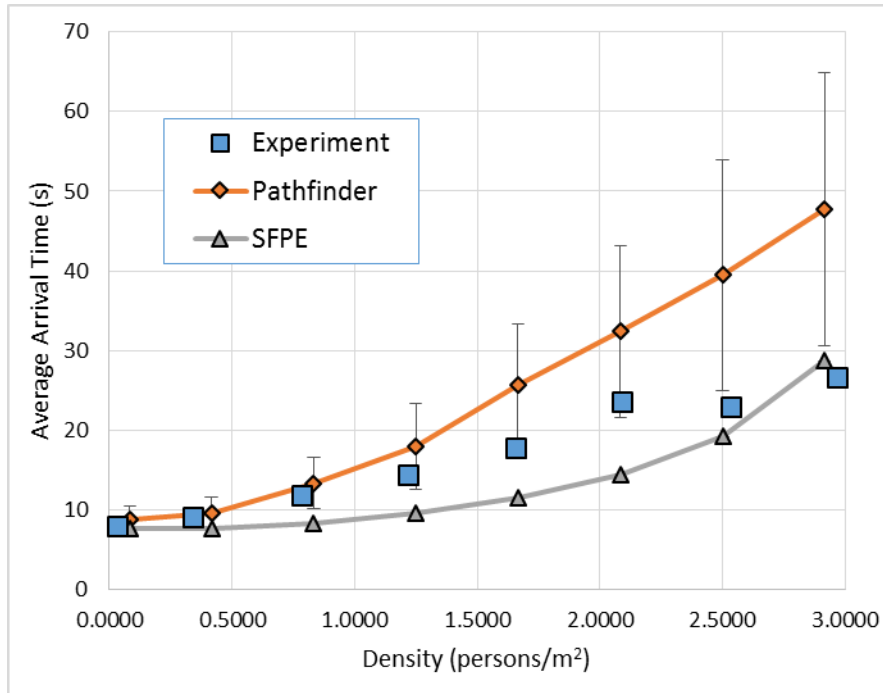


Figure 54: Comparison of Pathfinder results with experimental data

### 6.3.3 Analysis

The steering mode calculations match the experimentally observed values more closely than the SFPE calculations. However, users should be aware that Pathfinder does not capture the jamming of the corridor for more than 70 persons. Instead, the calculation always allows even tightly-packed occupants to eventually leave the corridor, although at a much slower rate.

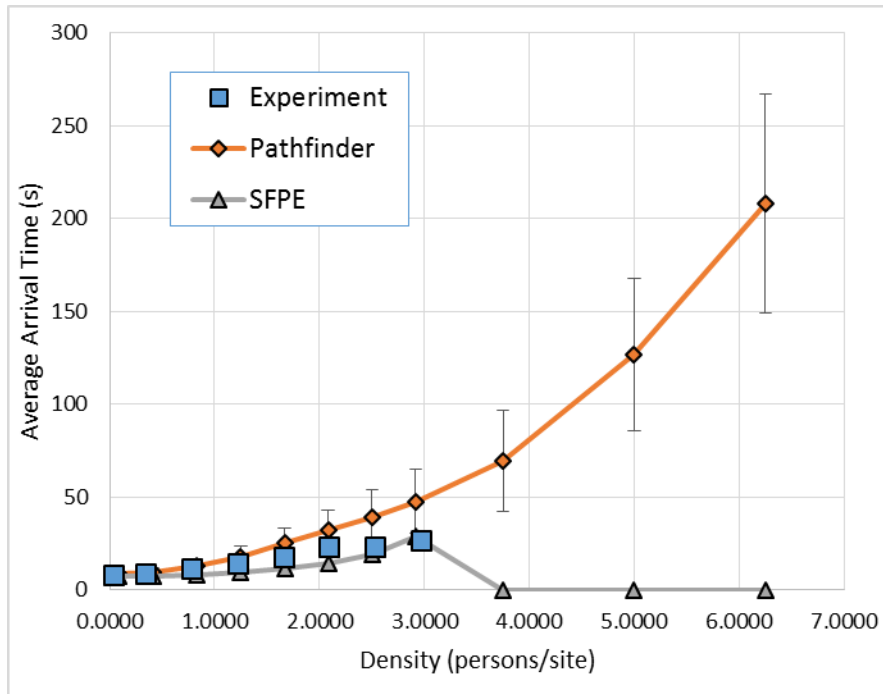


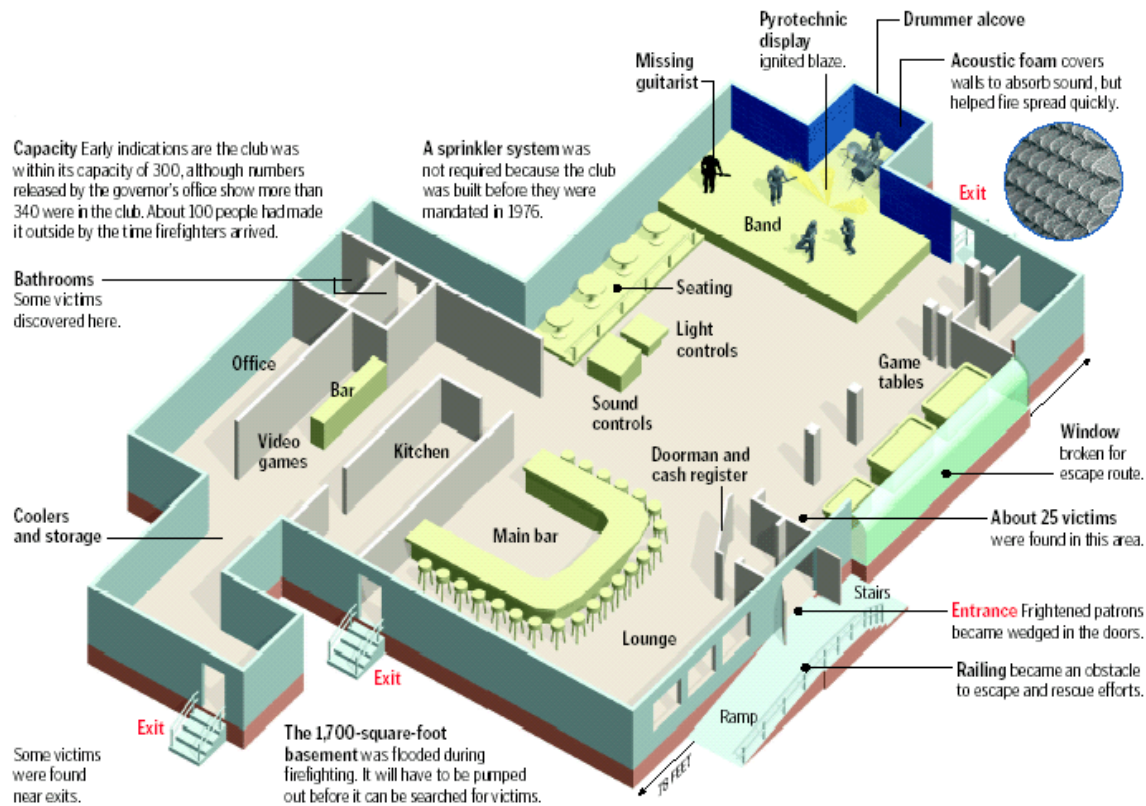
Figure 55: Pathfinder results for densities greater than tested experimentally

## 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 The Station nightclub

This comparison involves reproducing an alternate evacuation simulation for The Station nightclub as presented in Section 6.6 of the NIST Report of the Technical Investigation of The Station Nightclub Fire (Grosshandler, Bryner and Madrzykowski 2005). A schematic of the nightclub is shown in Figure 56.



**Figure 56: Schematic of Station nightclub (image from <http://frogstorm.com/?p=3609>, no attribution on the web site)**

The evacuation simulations described in the NIST report used two commercially available egress simulation models, buildingEXODUS and Simulex. Three scenarios were evaluated to investigate the following questions regarding the evacuation from the nightclub:

1. How long would it take to evacuate a building similar to The Station with no fire present assuming exit numbers, exit widths, and occupancy limits were consistent with current national model building codes?

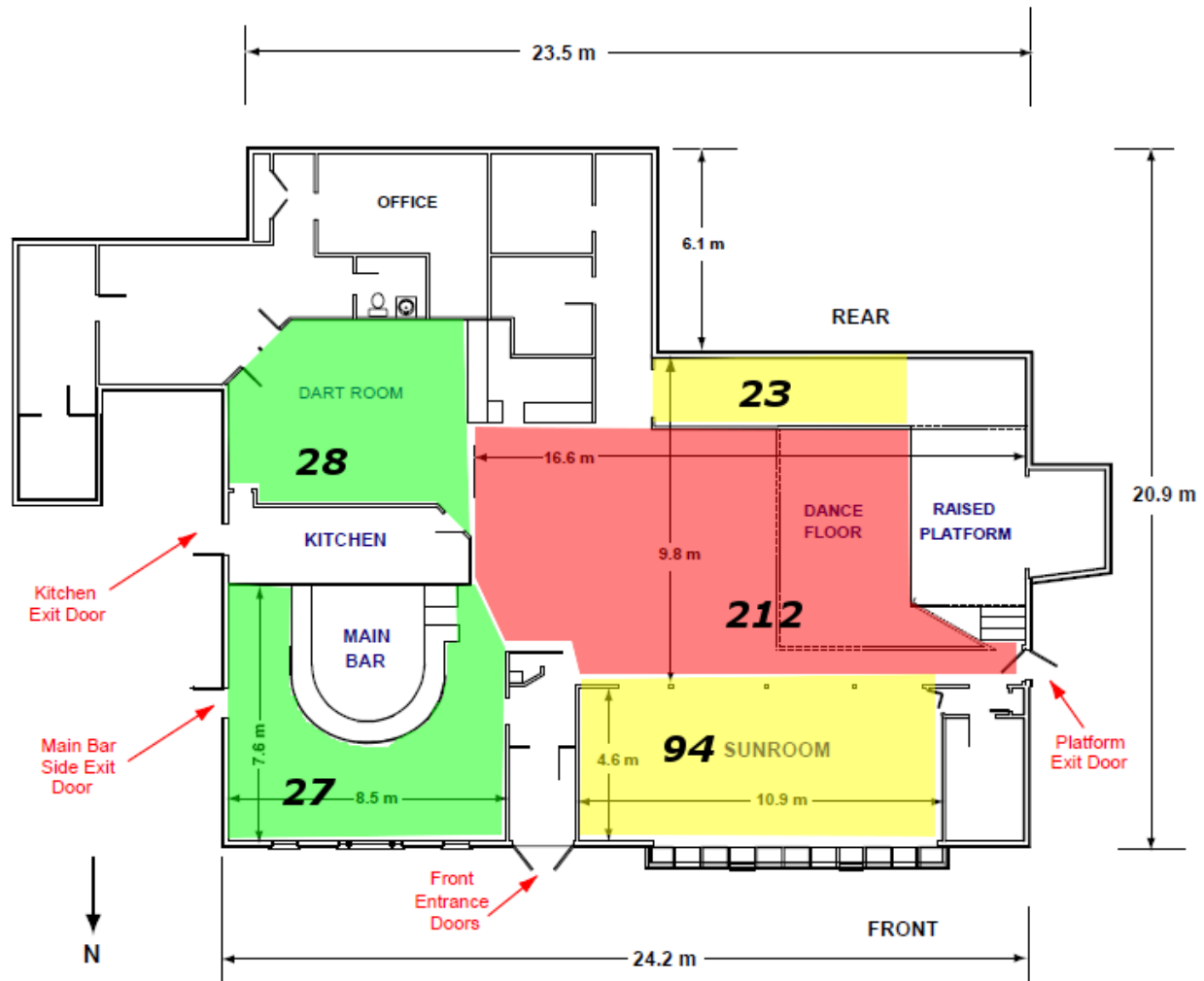
2. How long would it have taken to evacuate The Station assuming the platform door became impassable in 30 seconds and the main entrance in front became blocked in 90 seconds?
3. How long would it take to evacuate a building similar to The Station assuming that the doorway near the ticket-taker was the same width as the double doors leading to the outside and that it did not become blocked, but that the platform door became impassable in 30 seconds?

The first question is important to answer since it yields the minimum time that could be expected. The second question is a challenge to our ability to predict reality when it comes to an emergency evacuation. The third question provides insight into the effectiveness of a possible change in model code requirements.

The problem involves input of the floor plan of the single story nightclub filled with 420 occupants, the placement of the occupants was described in the NIST Report in the following way:

*To run these models it was necessary to distribute the 420 occupants throughout the building. It was assumed that the dance floor and area around the platform were at the maximum density permitted by the current national model codes described in chapter 7, 2.17 persons/m<sup>2</sup>(5 ft<sup>2</sup>/person), that the sunroom and raised area around the dance floor had a density of 1.56 persons/m<sup>2</sup>(7 ft<sup>2</sup>/person), that the main barroom and back room were populated at 0.72 persons/m<sup>2</sup> (15 ft<sup>2</sup>/person), and that the 36 remaining occupants were scattered about the kitchen, behind the bar, restrooms, storage area, dressing room, and corridor.*

The density-based occupant counts (not including the 36 additional occupants) and occupancy areas are shown in Figure 57.



**Figure 57: Computed occupancy loads for the station nightclub model. The underlying figure is from the NIST Report (Grosshandler, Bryner and Madrzykowski 2005). Shading and occupancies were added.**

Based on the information provided in Appendix L of the NIST report, the Pathfinder simulations attempt to use the same parameters as used in the Simulex and EXODUS models. The Pathfinder model did include stairs at the side exits and included the ramp and stairs at the front door. The stairs had a 7.5/10 inch rise/run. Based on the SFPE manual, a 36" door with no boundary layer has a flow rate of 1.2 pers/s and a 36" stair (7.5/10) with no boundary layer has a flow rate of 0.86 pers/s.

The three scenarios are described below.

#### **Scenario 1 (all doors, kitchen limited):**

- Doors leading to stairs were placed at all doorways leading to the outside (kitchen door, platform door, bar door – all 36", and main door (72")).
- A 36" door was placed in front vestibule.

- No boundary layers included in doors or stairs.
- Kitchen door only accessible by the three persons initially in kitchen.
- Two sets of steps were placed inside the nightclub area, one to the raised dining area (7.5" in height) and one to the stage/platform (3 steps 7.5" high with 45.5" diagonal length of steps).
- 420 people were placed throughout the nightclub using the loads shown in Figure 57 and distributed as shown in Figure 58.
- Pre-evacuation time/delay time = 0 seconds.
- Shortest route chosen to exits.
- Occupant walking speeds uniformly distributed between 0.93 and 1.85 m/s, based on data in IMO, 2007 for females and males younger than 30 years in age.

### **Scenario 1a (queues included in time estimate):**

- Queue times included in selection of exit.
- All other parameters identical to Scenario 1

### **Scenario 2 (trapped scenario):**

- Event times were specified:
  - Platform exit closed after 30 seconds.
  - Front door (two 36" doors) closed after 90 seconds
- All other parameters identical to Scenario 1

### **Scenario 3 (double width vestibule door):**

- Interior vestibule door at front entrance width changed from 36" to 72".
- Event times were specified:
  - Platform exit closed after 30 seconds. Front door stays open.
- All other parameters identical to Scenario 1

### **Scenario 3.a (double width vestibule door):**

- Queue times included in selection of exit.
- All other parameters identical to Scenario 3

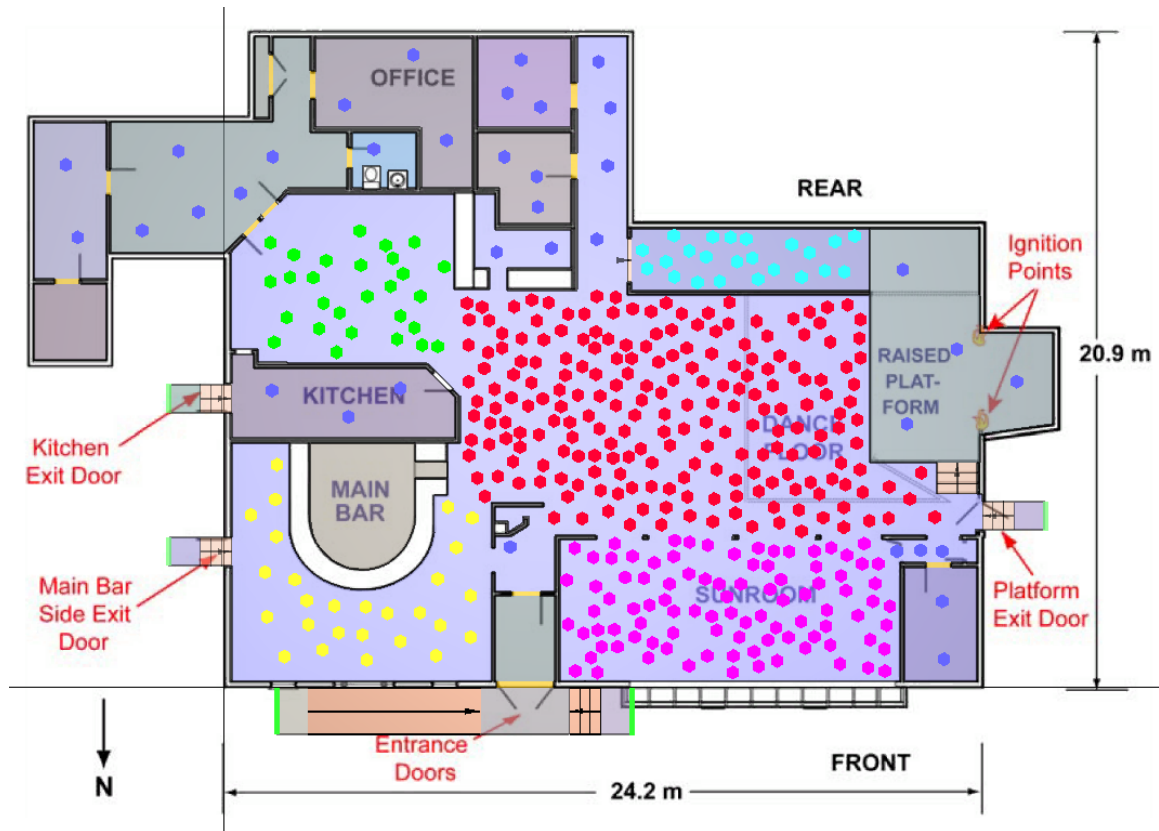


Figure 58: Initial configuration of The Station nightclub simulation in Pathfinder. The Pathfinder model is shown semi-transparent over the background floor plan image.

### 7.1.1 Results and Analysis

Table 4 shows the results of the Pathfinder simulation for the Scenario 1 evacuation simulations. The table is a reproduction of Table 6-2 in the NIST report which summarizes the results of the building EXODUS and Simulex results for evacuation scenario.

In general, Pathfinder gives similar results to buildingEXODUS and Simulex. When occupants include the estimate of queue times in selection of exits, they redistribute themselves with the result that exits are used more equally than when selecting the exit based purely on distance. This is demonstrated by the Scenario 1.a results, where the use of the main bar exit increased from about 20 occupants to about 120, with a corresponding reduction of total exit time. The same was noted for the Scenario 3.a results.

The SFPE flow rate through a 36" door with no boundary is 1.2 pers/s, while the flow rate through a 7.5/10 stairs with no boundary is 0.855 pers/s. For the Pathfinder SFPE case, this gives a time of 173 s for 207 people to exit the front door and 218 s for 188 people to exit the platform door that leads to a stair. Pathfinder reports an exit time of 173 s for the front door and 210 s for the platform stair (recall that the occupants had distributed walking speeds with the average higher than the standard SFPE value, so the time on the stair was somewhat reduced).

**Table 4: Pathfinder results comparison with other egress simulators**

Scenario	Total Evacuation Time (s)	Occupants to Front Door	Occupants to Platform Door	Occupants to Kitchen Door	Occupants to Main Bar Door	Total Remaining at 90 sec
1 (Simulex)	188	213	184	3	20	166
1 EXODUS	202	214	180	4	22	208
1 Pathfinder (SFPE)	214	207	188	3	22	220
1 Pathfinder (Steering+SFPE)	288	185	210	3	22	265
1 Pathfinder (Steering)	248	184	211	3	22	242
1.a Pathfinder (SFPE)	152	153	134	3	130	169
1.a Pathfinder (Steering+SFPE)	191	146	139	3	132	229
1.a Pathfinder (Steering)	164	151	140	3	126	190
2 EXODUS	330	91	32	3	273	271
2 Pathfinder (SFPE)	552*	104	22	3	291	274
2 Pathfinder (Steering+SFPE)	544	68	20	3	329	310
2 Pathfinder (Steering)	453	85	22	3	310	294
3 (Simulex)	198	358	39	3	20	173
3 EXODUS	202	363	33	4	20	201
3 Pathfinder (SFPE)	165	373	25	3	19	178
3 Pathfinder (Steering+SFPE)	270	375	23	3	19	240
3 Pathfinder (Steering)	257	372	26	3	19	232
3.a Pathfinder (Steering)	184	280	25	3	112	178



\* The long time for SFPE is due to a known bug in Pathfinder 2013.1.1004 that occurs only in SFPE mode when a door closes and occupants must re-route to another exit. The release rate from the queue is slower than it should be.

Exited: 242/420

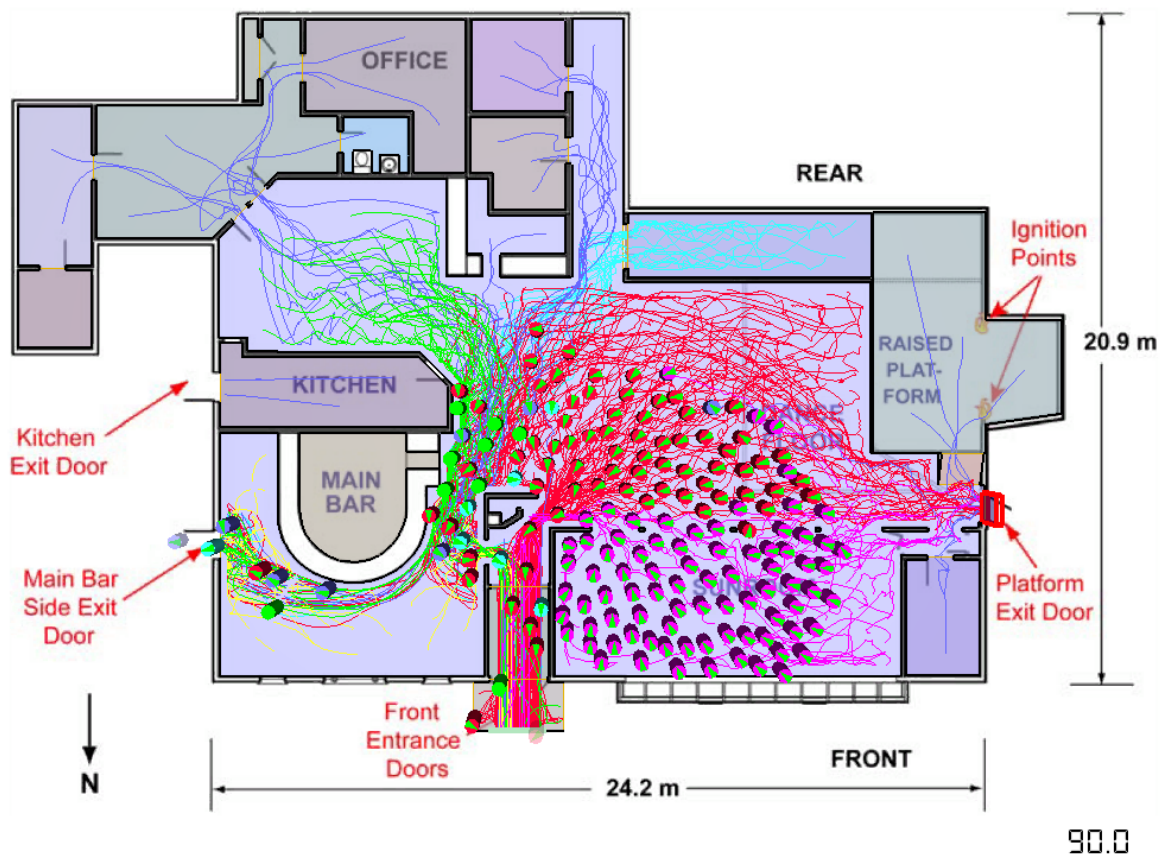
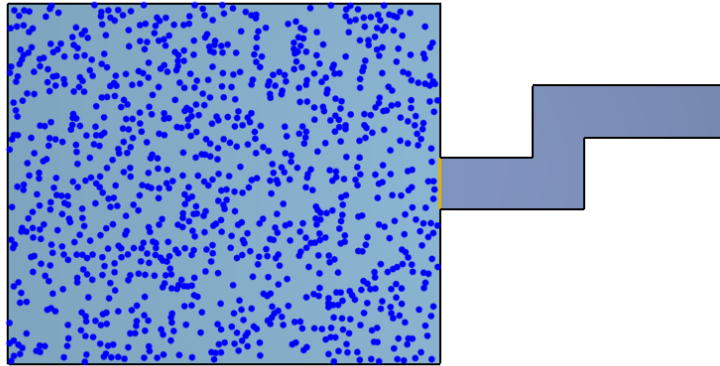


Figure 59: Pathfinder steering mode Scenario 3.a results at 90 seconds.

## 7.2 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 60: 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.

### 7.2.1 Setup Notes

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

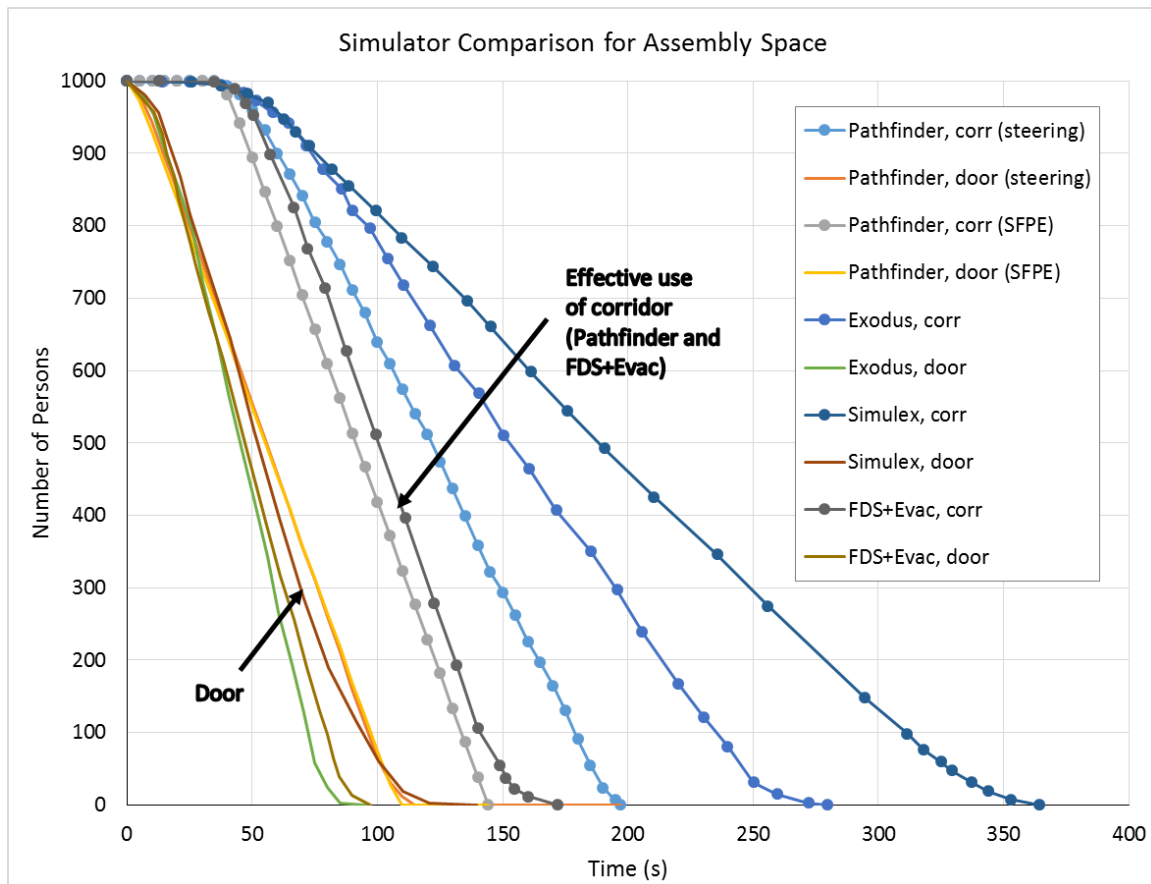
An alternate version of this simulation was run without the corridor. Results associated with this simulation run are referred to as *door*. Results associated with simulation runs including the corridor are referred to as *corr*. To simplify results gathering, the *corr* simulation and the *door* simulation 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.

### 7.2.2 Results and Analysis

Figure 61 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).

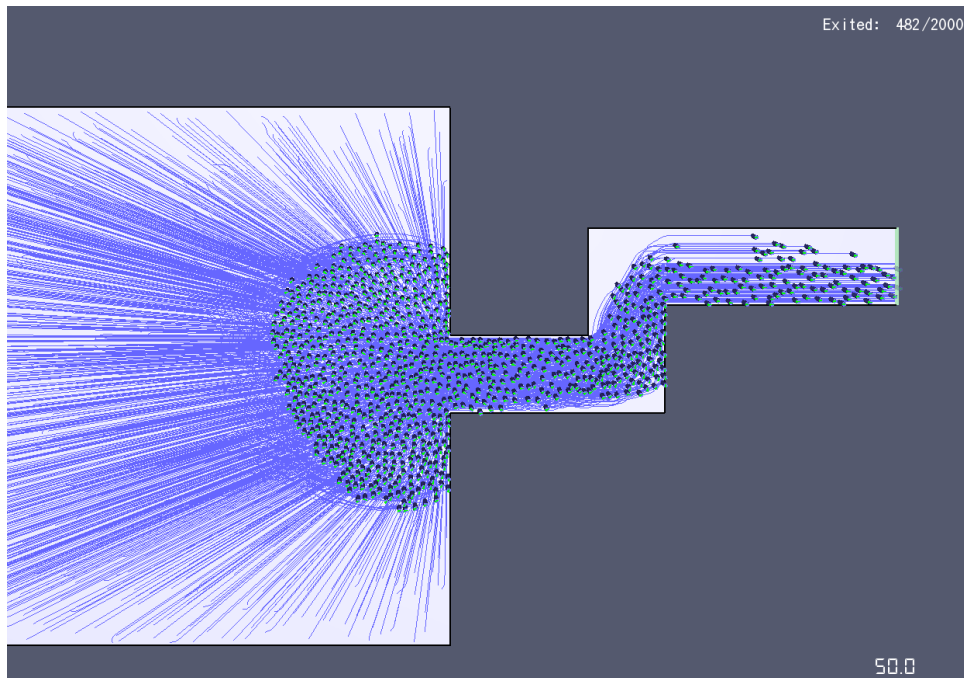
The SFPE flow rate for a 7.2 m door with no boundary is 9.47 pers/s, so the SFPE calculation should give 106 s for the door evacuation. Pathfinder calculates 108 s. Since it takes some time for enough

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 calculates 144 s, which is an acceptable difference since, again, time is required to form a queue.



**Figure 61: Simulator comparison for assembly space.**

All simulators present similar results for the *door* case. For the *corr* test, Pathfinder and FDS+Evac present noticeably faster evacuation times than Simulex or Exodus. In the *corr* example, faster times correspond to the group of occupants more fully utilizing the width of the corridor, Figure 62.



**Figure 62: Steering mode showing use of the corridor at 50 sec.**

## 8 References

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