Verification and Validation
Disclaimer

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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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1.0 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).

Simulation Modes

Each test case in this chapter is executed using three different configurations (modes) based on the **Behavior Mode** option and the **Add Basic Collisions** option (SFPE mode only) in Pathfinder's **Simulation Parameters** dialog. An SFPE simulation is run with a **Behavior Mode** selection of **SFPE**, an SFPE+ simulation is run with a **Behavior Mode** selection of **SFPE** and **Add Basic Collisions** 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 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.

Inertia

The SFPE-based modes supported by Pathfinder allow 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: 
   \[
   d_1 = 0.5 \times (v_1 - v_0) \times t_1
   \]
   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 acceleration is calculated to allow occupants to transition from being motionless to traveling at maximum velocity in 0.5 seconds, which sets \( t_1 \) at 0.5 s. \( v_0 \) is generally 0.0 m/s and \( v_1 \) is the occupant's maximum velocity.
2. Calculate \( d_2 \) as the remaining distance that needs to be traveled after \( d_1 \): 
   \[d_2 = d - d_1\]
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: 
   \[t = t_1 + t_2\]

This approach is referenced in several of the problems below with the label, "to account for inertia." In the section Movement Speed (IMO_01) the details of the approach are presented as an example.
2.0 IMO Tests
This section presents test cases described in Annex 3 of IMO 1238 (International Maritime Organization 2007).

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.

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.

Expected Results
SFPE and 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 0.5 s. From $s = 0.5 \times (v_1 - v_0) \times t$ we know
that with $v_0=0.0\text{ m/s}$, $v_1=1.0\text{ m/s}$, at $t=0.5\text{ s}$ the occupant will have covered $0.25\text{ m}$. The remaining 39.75 meters will be covered at $1.0\text{ m/s}$. Thus, steering mode should give an exit time of 40.25 seconds.

## Results

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time</th>
<th>CPU Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFPE</td>
<td>40.00</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>SFPE+</td>
<td>40.00</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>Steering</td>
<td>40.23</td>
<td>&lt; 1 s</td>
</tr>
</tbody>
</table>

## Analysis

All test cases were successful. The 0.02 s error is attributed to a time step size of 0.025. Reducing the time step size by a factor of 10 (0.0025) gives a solution that matches the predicted time exactly.

## 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.](image)
**Setup Notes**

Since Pathfinder tracks occupant location by the center point, the length of the staircase was extended behind the occupant to allow space for the back half of the occupant when standing on a step. The length between the occupant’s center starting position and the top of the staircase is 10.0 m.

**Expected Results**

The occupant is given a base maximum speed of 1.0 m/s. This speed will be reduced in all modes by a scaling factor based on the slope of the stairway. Using the velocity equations presented in the Pathfinder Technical Reference, this scale factor will be (0.918 m/s) / (1.19 m/s) = 0.77. This makes the effective stairway speed of the occupant (1.0 m/s)*0.77 = 0.77 m/s. Based on this speed, the SFPE mode and SFPE+ mode should give a result of 12.99 s and the Steering mode should give a result of 13.16 s (to account for inertia).

**Results**

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time</th>
<th>CPU Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFPE</td>
<td>12.93</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>SFPE+</td>
<td>12.93</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>Steering</td>
<td>13.10</td>
<td>&lt; 1 s</td>
</tr>
</tbody>
</table>

**Analysis**

All test results are within an acceptable margin of error (0.06 s, 0.06 s, and 0.06 s).

**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.
Setup Notes
Since Pathfinder tracks occupant location by the center point, the length of the staircase was extended behind the occupant to allow space for the back half of the occupant when standing on a step. The length between the occupant’s center starting position and the bottom of the staircase is 10.0 m.

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 \( 1.0 \text{ m/s} \times 0.77 = 0.77 \text{ m/s} \). Based on this speed, the SFPE mode and SFPE+ mode should give a result of 12.99 s and the Steering mode should give a result of 13.16 s (to account for inertia).

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time</th>
<th>CPU Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFPE</td>
<td>12.93</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>SFPE+</td>
<td>12.93</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>Steering</td>
<td>13.10</td>
<td>&lt; 1 s</td>
</tr>
</tbody>
</table>
Analysis
All test results are within an acceptable margin of error (0.06 s, 0.06 s, and 0.06 s).

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.

Setup Notes
A uniform distribution of occupants is used to achieve the high density in the room.

Flow rate will be measured using the simulation summary data. This data presents flow rate 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.

During the SFPE mode simulations, the boundary layer for the door will be set to 0.0 m. This will provide the fastest possible (least conservative) solution. Boundary layer is not used in steering mode.
simulations (the full 1.0 m door width is always used). Using the SFPE modes, this will give a maximum door flow rate of 1.33 pers/s.

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

**Results**
The following table shows the maximum exit door flow rate observed in each tested mode.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Avg. Flow Rate</th>
<th>End Time</th>
<th>CPU Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFPE</td>
<td>1.32pers/s</td>
<td>114.93 s</td>
<td>&lt; 1 s</td>
</tr>
<tr>
<td>SFPE+</td>
<td>1.08pers/s</td>
<td>139.75 s</td>
<td>1.4 s</td>
</tr>
<tr>
<td>Steering</td>
<td>1.75pers/s</td>
<td>86.13 s</td>
<td>2.5 s</td>
</tr>
</tbody>
</table>

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

**Flow Rates for Selected Doors**

![Flow Rate Graph](image)

**Figure 6: SFPE mode door flow rate.**
Figure 7: SFPE+ mode door flow rate.

Figure 8: Steering mode door flow rate.
Analysis

Results varied across the simulation modes. The overall average time for the SFPE mode and the SFPE+ mode was substantially under the maximum overall average time limit (1.33 pers/s). Based on Figure 6 and Figure 7, both SFPE-based modes took more than 30 seconds to reach maximum flow. This slow approach time can be attributed to the initial density in the room. An 8 m x 5 m room containing 100 occupants has a density of 3.75 pers/m$^2$. Based on the SFPE mode assumptions, this gives each occupant a very slow walking speed (about 0.003 m/s). The door is not able to operate at maximum flow for a long time because it simply takes longer for the occupants to reach the door. This effect is exaggerated by the SFPE+ mode because occupants are not allowed to overlap in their approach to the door.

In steering mode, the overall average time exceeded the problem specification by 0.42 s. The maximum flow rate in a 5 second moving average was 1.87 pers/sec. 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. Also, the steering mode produces a noticeably faster exit time because occupants can move freely near the front of the group and are not constrained by the overall density of the room.

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(steering mode). 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.
Setup Notes
Occupants were assigned a profile that uses a uniform distribution for the **Delay** parameter with min=10.0 s and max=100.0 s.

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

**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.

**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) SFPE+ mode, (c) steering mode.](image)
Analysis
Response times adhered to the uniform distribution specified in the user interface for all three simulation modes. In addition, the occupant count graphs confirmed that while the occupants had similar (short) travel distances and identical speeds, they exited at different times across the 70 second interval between t=20 seconds and t=90 seconds. All simulator modes are considered to pass the test.

Concave Geometry, Boundaries (IMO_06)
This case verifies Pathfinder’s support of concave geometry. 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](image)

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

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

Results
Figure 12 shows the occupant trails for all 3 simulator modes. These movement trails can be used to verify that no occupants passed through the simulation boundary.
Figure 12: Occupant trails for boundary test: (a) SFPE mode, (b) SFPE+ mode, (c) steering mode.

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.

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 13: IMO_07 problem setup

**Setup Notes**
A profile representing males 30-50 years old is distributed across 50 occupants. 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.

**Expected Results**
The occupants should display a range of walking speeds within the specified limits.

**Results**
The occupants’ speeds observed in the simulation were within the specified limits.
Figure 14: IMO_07 results animation

Analysis
All simulator modes passed.

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 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.
Setup Notes
The problem geometry is set up as described above, with the addition of two doors across the far walls. The occupants in each room are assigned the exit in the other 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.

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

Results
The following table shows the time it takes to exit the simulation based on the number of occupants in counterflow.

<table>
<thead>
<tr>
<th>Mode</th>
<th>0</th>
<th>10</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFPE</td>
<td>71.83 s</td>
<td>76.50 s</td>
<td>92.33 s</td>
<td>107.00 s</td>
</tr>
<tr>
<td>SFPE+</td>
<td>71.60 s</td>
<td>76.20 s</td>
<td>89.00 s</td>
<td>155.00 s</td>
</tr>
<tr>
<td>Steering</td>
<td>53.95 s</td>
<td>70.20 s</td>
<td>108.58 s</td>
<td>152.70 s</td>
</tr>
</tbody>
</table>

Analysis
In each mode, more counterflow increases simulation time. All modes passed test criteria, though the ratio of times for numbers of occupants in counterflow was considerably different across different simulator modes.
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. 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 16: IMO_09 problem setup containing both configurations

**Setup Notes**

Interior walls are added at the midpoints of the exterior walls before adding occupants to ensure that the same number of occupants go through each door.

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.

**Expected Results**

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

**Results**

The following table shows the time it takes to exit the simulation for both cases. In addition, the Ratio column shows the ratio of the 2 door case to the 4 door case, and the Percent Error column shows how far the simulation differs from a perfect ratio of 2.
## Analysis

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

## 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 17: IMO_10 problem setup](image_url)

### 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.

### Expected Results

Each occupant should leave the model using the specified exit.
Results

Figure 18 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 18: Trace of occupant paths](image)

(a) SFPE mode, (b) SFPE+ mode, (c) steering mode

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.

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 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 19 shows the problem setup in Pathfinder.
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: density is (initially) at least 3.5 pers/m², 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/m². Based on the congestion criteria, this condition is sufficient to qualify the initial room as congested.

Measuring congestion at the base of the stairway is challenging because we must use the accumulation rate, which is an integrated quantity not supported by Pathfinder. In the standard SFPE mode, it is possible to measure queue sizes at doors. However, since SFPE+ and steering mode do not support the queue size measurement, we must instead look at the flow into and out of the corridor. For all three modes, we can identify the time when occupants begin to flow out of the corridor. From that moment to the end of the simulation, 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 rooms.csv output file and will be processed using a spreadsheet tool.

**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 similar decrease in speed in Pathfinder, we will use a stairway with a slope of 1.05.

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 0.50 m/s to 0.84 m/s. These speeds are slightly higher than those given in IMO 1238 (0.47 m/s to 0.79 m/s). The higher stairway speeds will make congestions less likely and provide a conservative result.

**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.

**Results**
Time history data describing the change in occupant count in the corridor is shown in Figure 20. Values are shown for each second after the first occupant has cleared the corridor end entered the stairs and before the last occupant has exited the initial room.

![Change in Occupant Count in Corridor Leading to Stairs (Using 5 second Moving Average)](image)

**Figure 20**: Change in occupant counts over time for IMO 11. Data begins when the first occupant enters the stairs and ends when the last occupant leaves the initial room. Values above 1.5 indicate congestion.
Analysis

In all simulation modes, the initial room had a density of 3.75 pers/m². 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.
3.0 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).

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 stairways 50 ft (measured along the diagonal). 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 21. The small room is 6 ft x 30 ft with an exit spanning the wall opposite the stairs.

![Figure 21: Initial configuration for SFPE_1.](image)

Setup Notes

To help ensure that the stairway load remains balanced (i.e. ensure that each stairway is used by the same number of occupants), the room was divided into 2 sections. Each section contains 150 people.

The two occupants nearest the stairway entrance are positioned exactly 2 ft from the stairway entrance door to make it possible to exactly calculate movement time to the controlling component.

Door boundary layer is specified as 6 in (the default boundary layer is 5.91 in or 15 cm).
Remember to specify the door width for the doors at the top and bottom of each stairway. By default, these doors will be the same width as the stairway (i.e. 44 inches).

**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 $T_{\text{TOTAL}} = T_1 + T_2 + T_3$ where: ($T_1$) the time it takes the first occupant to reach the controlling component, ($T_2$) the time it takes 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.

Since the nearest occupant is initially 2 ft from the controlling component, $T_1$ is:

$$T_1 = \frac{d}{v} = \frac{2 \text{ ft} \left(\frac{0.3048 \text{ m}}{\text{ft}}\right)}{0.85 \times 1.40 \text{ m/s}} = 0.51 \text{ s}$$

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

$$T_2 = \frac{P}{F_{\text{max}} W_e} = \frac{298 \text{ pers}}{1.32 \frac{\text{pers}}{\text{m/s}}} \times 2 \left[\frac{32 \text{ in} - 2(6 \text{ in})}{\text{ft}}\right] \times \frac{\text{ft}}{12 \text{ in}} \times \frac{3048 \text{ m}}{\text{ft}} = 222.20 \text{ s}$$

Notice that in the previous calculation, we used $P=298$ occupants. In Pathfinder, queue delay times only apply after an occupant has passed through a door. The first occupant gets to pass through immediately. If we were to use 300 occupants in the equation, the results would be the difference between the time the first occupant passed through the door and the time when the door queues were able to pass an additional occupant after the last occupant had left. More details of this approach are presented in the Pathfinder Technical Reference. This approach does yield slightly faster times (e.g. with 300 occupants, $T_2$ would be 223.7 s).

The time needed for the last occupant to move from the controlling component to the exit, $T_3$ is:

$$T_3 = \frac{d}{v} = \frac{50 \text{ ft} \left(\frac{3048 \text{ m}}{\text{ft}}\right)}{0.85 \times 1.08 \text{ m/s}} = 16.60 \text{ s}$$

The total evacuation time, $T_{\text{TOTAL}}$ is:

$$T_{\text{TOTAL}} = T_1 + T_2 + T_3 = 0.51 \text{ s} + 222.20 \text{ s} + 16.60 \text{ s} = 239.31 \text{ s}$$

Results for the Steering mode will also be presented. However, the steering mode does not explicitly control door flow rate -- the controlling factor in this test case. Thus, this test does not verify a particular function of the simulator when Steering mode is in use. These results will still be presented as a comparison between Steering mode and the SFPE techniques.
Results
For each simulation mode, the following table lists the results within the context of the SFPE hand calculations. $T$ indicates the total movement time, $T_1$ indicates the time for the first occupant to reach the door at the top of the stairway, $T_2$ indicates the time for all occupants to clear the door at the top of the stairway, and $T_3$ indicates the time for the last occupant to move from the door at the top of the stairway to the door at the bottom of the stairway.

<table>
<thead>
<tr>
<th>Mode</th>
<th>$T_{\text{TOTAL}}$ (s)</th>
<th>$T_1$ (s)</th>
<th>$T_2$ (s)</th>
<th>$T_3$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated</td>
<td>239.31</td>
<td>0.51</td>
<td>222.00</td>
<td>16.60</td>
</tr>
<tr>
<td>SFPE</td>
<td>242.23</td>
<td>0.78</td>
<td>222.10</td>
<td>19.30</td>
</tr>
<tr>
<td>SFPE+</td>
<td>242.23</td>
<td>0.78</td>
<td>222.10</td>
<td>19.30</td>
</tr>
<tr>
<td>Steering</td>
<td>173.48</td>
<td>0.98</td>
<td>153.35</td>
<td>20.13</td>
</tr>
</tbody>
</table>

Analysis
The SFPE and SFPE+ simulation mode were 2.92 seconds slower than the calculated time, respectively. Because this difference is only 1.2% more than the expected time, the SFPE mode simulations are considered to have passed this test.

The Steering mode results were presented for comparison. The primary difference was the flow rate through the door ($300 / T_2$), which was 1.96 pers/s compared to 1.35 pers/s in the SFPE mode simulators. The total movement time for the Steering mode simulation was 28% faster than the time given for the SFPE mode simulations.

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 2 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 22 shows the problem setup. The occupants marked in red are the occupants used to calculate $T_1$ in the Expected Results section.
Figure 22: SFPE Example 2 Problem Setup

Figure 23: SFPE Example 2 Exit Door
Setup Notes
Detailed setup notes are presented in the Pathfinder example guide.

This test model is a variant of the model discussed in the example guide. The example write-up in the SFPE Engineering Guide assumes that occupants are able to exit immediately after the controlling doorway. However, the Pathfinder example guide assumes occupants will walk briefly through the ground floor before exiting. To allow occupants to exit directly after the controlling doorway and more closely match the example write-up, we’ve added a small room with an exit at the base of both sets of stairs and cut out a section of floor on the ground floor (to prevent first floor occupants from using the door). Figure 23: SFPE Example 2 Exit Door shows this setup. The room and cutout both measure 1 ft x 44 in (stair width), and the exit door spans the width of the room.

To allow for symmetric calculations, the two occupants nearest the stairway door on the second floor will be positioned 2 ft from that door. In addition, each floor was split down the middle and 100 occupants were added to each side.

Expected Results
In this example, the controlling component is the door at the base of the stairway (also the exit door). 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 $T_{\text{TOTAL}} = T_1 + T_2 + T_3$ 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 ($T_3$) will be zero since the controlling component is an exit door.

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 his 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. For $T_A$, we will assume the occupant is 2 ft from the stairway door. Because this occupant will be the first one to enter the stair, we will assume a low-density velocity calculation in the initial room, the stairs and the platform. For $T_B$ we will assume the occupant must walk 4 ft to traverse the platform.

This leads to the following calculations:

\[ v_{\text{level}} = 0.85 \times 1.40 \frac{m}{s} = 1.19 \frac{m}{s} \]

\[ T_A = \frac{d}{v_{\text{level}}} = \frac{2 \text{ ft} \left( \frac{0.3048 \text{ m}}{\text{ft}} \right)}{1.19 \frac{m}{s}} = 0.51 \text{ s} \]

\[ v_{\text{stair}} = 0.85 \times 1.08 \frac{m}{s} = 0.92 \frac{m}{s} \]
\[ T_B + T_D = 2 \left( \frac{d}{v_{stair}} \right) = 2 \left( \frac{11.24 \, ft}{0.92 \, m/s} \right) \left( \frac{0.3048 \, m}{ft} \right) = 7.45 \, s \]

\[ T_C = \frac{d}{v_{level}} = \frac{4 \, ft \left( \frac{0.3048 \, m}{ft} \right)}{1.19 \, m/s} = 1.02 \, s \]

\[ T_1 = T_A + T_B + T_C + T_D = 0.51 \, s + 7.45 \, s + 1.02 \, s = 8.98 \, s \]

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

\[ T_2 = \frac{P}{F_{s_{max}} \cdot W_e} = \frac{399 \, pers}{1.32 \, m/s \times [32 \, in - 2(6 \, in)] \times \frac{ft}{12 \, in} \times \frac{0.3048 \, m}{ft}} = 595.03 \, s \]

For the above calculation, \( P=399 \) because of the way Pathfinder handles door queues. The first occupant is not queued (passing through immediately). More details of this approach are presented in the Pathfinder Technical Reference. This approach does yield slightly faster times (e.g. with 400 occupants, \( T_2 \) would be 223.7 s).

The total evacuation time, \( T_{total} \) is:

\[ T_{total} = T_1 + T_2 + T_3 = 8.98 \, s + 595.03 \, s + 0.0 \, s = 604.01 \, s \]

**Results**

For each simulation mode, the following table lists the results within the context of the SFPE hand calculations. \( T_{TOTAL} \) indicates the total movement time, \( T_1 \) indicates the time for the first occupant to reach the exit door at the bottom of the stairway, and \( T_2 \) indicates the time for all occupants to pass through the same door.

<table>
<thead>
<tr>
<th>Mode</th>
<th>( T_{TOTAL} ) (s)</th>
<th>( T_1 ) (s)</th>
<th>( T_2 ) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated</td>
<td>604.01</td>
<td>8.98</td>
<td>595.03</td>
</tr>
<tr>
<td>SFPE</td>
<td>600.98</td>
<td>10.73</td>
<td>590.25</td>
</tr>
<tr>
<td>SFPE+</td>
<td>601.33</td>
<td>10.93</td>
<td>590.4</td>
</tr>
<tr>
<td>Steering</td>
<td>385.58</td>
<td>11.03</td>
<td>374.55</td>
</tr>
</tbody>
</table>

**Analysis**

The SFPE and SFPE+ simulation mode gave nearly identical results. The SFPE and SFPE+ mode simulations were 3.03 seconds and 2.68 seconds faster, respectively, than the expected time. This difference is less than 1% of the calculated time. The SFPE mode simulations are considered to have passed this test.
The primary difference was in the time for the first occupant to exit, specifically the $T_c$ part of the $T_1$ calculation. The SFPE guide assumes a 4 ft travel distance across the landing, while the simulation’s travel distance averages 5 ft. This accounts for a 0.26 second difference in $T_1$.

The Steering mode results were presented for comparison. The primary difference was the flow rate through the door ($400 / T_2$), which was 1.07 pers/s compared to 0.68 pers/s in the SFPE mode simulators. The total movement time for the Steering mode simulation was 35% faster than the time given for the SFPE mode simulations.
4.0 Comparisons to Experiments

This section presents Pathfinder models designed to reproduce experimental results.

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 24 illustrates the experimental setup.

![Experimental setup](image)

**Figure 24:** 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 25 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.

![Pathfinder model](image)

**Figure 25:** A Pathfinder model designed to replicate all 15 cases of the experiments.
**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 SFPE+ simulations were run using a 15 cm boundary layer.

**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).

<table>
<thead>
<tr>
<th>Width (m)</th>
<th>Experiment (s)</th>
<th>Steering(\text{AVG}) (s)</th>
<th>SFPE(\text{AVG}) (s)</th>
<th>SFPE+(\text{AVG}) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>47.0</td>
<td>45.9</td>
<td>94.6</td>
<td>94.6</td>
</tr>
<tr>
<td>0.9</td>
<td>36.9</td>
<td>43.7</td>
<td>79.7</td>
<td>79.7</td>
</tr>
<tr>
<td>1.0</td>
<td>34.0</td>
<td>38.8</td>
<td>69.1</td>
<td>69.1</td>
</tr>
<tr>
<td>1.1</td>
<td>28.9</td>
<td>35.9</td>
<td>61.1</td>
<td>61.1</td>
</tr>
<tr>
<td>1.2</td>
<td>25.0</td>
<td>32.5</td>
<td>54.9</td>
<td>54.9</td>
</tr>
</tbody>
</table>

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 26 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 26: Experimental video (Seyfried, Passon, et al., Pedestrian and Evacuation Dynamics NETwork 2009) compared to Pathfinder visualization.

Analysis

All three Pathfinder simulator modes produce exit times that were considerably 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 mode and the ratio of exit times for the SFPE and SFPE+ modes.

The following table shows the ratio between the average simulated times and the experimental data.

<table>
<thead>
<tr>
<th>Width (m)</th>
<th>Experiment (s)</th>
<th>Steering ( \text{AVG} )</th>
<th>SFPE ( \text{AVG} )</th>
<th>SFPE+ ( \text{AVG} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>47.0</td>
<td>1.0x</td>
<td>2.0x</td>
<td>2.0x</td>
</tr>
<tr>
<td>0.9</td>
<td>36.9</td>
<td>1.2x</td>
<td>2.2x</td>
<td>2.2x</td>
</tr>
<tr>
<td>1.0</td>
<td>34.0</td>
<td>1.1x</td>
<td>2.1x</td>
<td>2.1x</td>
</tr>
<tr>
<td>1.1</td>
<td>28.9</td>
<td>1.2x</td>
<td>2.1x</td>
<td>2.1x</td>
</tr>
<tr>
<td>1.2</td>
<td>25.0</td>
<td>1.3x</td>
<td>2.2x</td>
<td>2.2x</td>
</tr>
</tbody>
</table>

The steering calculation produced results that were a consistent factor slower than the experimental data. The discrepancy between the experimental data and in the SFPE and 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.
5.0 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.

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). The evacuation simulation described in the NIST report involves utilizing two commercially available computer egress simulation models, buildingEXODUS and Simulex, to predict the evacuation time from the nightclub considering a non-fire condition and assuming exit numbers, widths, and occupancy limits were in compliance with current national model building codes. The purpose of reproducing this simulation is to compare the movement time results in Pathfinder with the movement times predicted by buildingEXODUS and Simulex as presented in the NIST Report.

The problem (Scenario 1) 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$^2$(5 ft$^2$/person), that the sunroom and raised area around the dance floor had a density of 1.56 persons/m$^2$(7 ft$^2$/person), that the main barroom and back room were populated at 0.72 persons/m$^2$ (15 ft$^2$/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 27.
Figure 27: 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 nightclub simulation considers four available exterior exit doors: a 36-inch door in the kitchen that is only available to the 3 occupants in the kitchen, a 36-inch door near the Main bar, a 36-inch door near the platform/stage, and a 72-inch main entrance door. In addition, the Pathfinder simulation makes the Main Bar Side Exit available only to persons standing in the Main Bar and surrounding area at the start of the simulation.
Figure 28: Floor plan of the station nightclub (Grosshandler, Bryner and Madrzykowski 2005)

Figure 29: Initial configuration of The Station nightclub simulation in Pathfinder
Results and Analysis

Figure 30 shows the results of the Pathfinder simulation for the alternative 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.

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Total Evacuation Time</th>
<th>Occupants to Front Door</th>
<th>Occupants to Platform Door</th>
<th>Occupants to Kitchen Door</th>
<th>Occupants to Main Bar Door</th>
<th>Total Remaining at 90 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulex</td>
<td>188 s</td>
<td>213</td>
<td>184</td>
<td>3</td>
<td>20</td>
<td>166</td>
</tr>
<tr>
<td>Building EXODUS</td>
<td>202 s</td>
<td>214</td>
<td>180</td>
<td>4</td>
<td>22</td>
<td>208</td>
</tr>
<tr>
<td>PathFinder (SFPE)</td>
<td>145 sec</td>
<td>280</td>
<td>115</td>
<td>3</td>
<td>22</td>
<td>154</td>
</tr>
<tr>
<td>PathFinder (SFPE+)</td>
<td>154 sec</td>
<td>275</td>
<td>120</td>
<td>3</td>
<td>22</td>
<td>156</td>
</tr>
<tr>
<td>PathFinder (Steering)</td>
<td>151 sec</td>
<td>205</td>
<td>190</td>
<td>3</td>
<td>22</td>
<td>152</td>
</tr>
</tbody>
</table>

Figure 30: Results comparison with other egress simulators

Figure 31: Pathfinder steering mode results at 90 seconds.
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 32: 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.

Setup Notes

This simulation was not run in SFPE+ mode, only SFPE mode and Steering mode 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.

Results and Analysis

Figure 33 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).
Figure 33: 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, slower times correspond to a greater flow loss across the corner in the corridor. Faster times correspond to the group of occupants more fully utilizing the corridor.
6.0 References


