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Validation of a pedestrian simulation tool using the NIST stairwell evacuation data

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Abstract

Researchers at the United States National Institute of Standards and Technology (NIST) collected occupant egress data in the stairwells of several high-rise buildings for potential use in quantitative and qualitative validation of evacuation simulation tools (Kuligowski and Peacock (2010)). We found this data suitable for establishing occupant initial locations, pre-evacuation time distributions, and other parametric inputs for our simulation code (PEDFLOW). With this data set, we were able to validate several core behavioral components of PEDFLOW by directly comparing actual versus predicted values for occupant speed on stairs and building total evacuation times. This paper summarizes our work on the stairwell data sets, highlighting the methodology behind the extraction of values for the parametric inputs, and demonstrating the results obtained for one specific 10-story high-rise building data-set.

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1. Introduction

In order to properly assess the behavioral components of an evacuation simulation tool, researchers require accessible and adequate experimental data for both qualitative and quantitative model validation. One such potential data set on high-rise building evacuations was recently reported on by Peacock et al. (2012) and is available from the United States National Institute of Standards and Technology (NIST). Researchers from the Engineering Laboratory at NIST collected occupant egress data in the stairwells of several high-rise buildings during fire drill evacuations making data from five of the buildings readily available to the public (Kuligowski and Peacock (2010)). After downloading this data, we found it suitable for establishing occupant initial locations, pre-evacuation time distributions, and other parametric inputs for our simulation code (PEDFLOW). We were able to validate several core behavioral components of PEDFLOW (such as pre-evacuation time distributions and speed on stairs) by running several simulations and directly comparing the predicted values with the actual values collected by NIST. This paper summarizes our work on

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the stairwell data sets, highlighting the methodology behind the extraction of values from the data for the parametric inputs, and demonstrating the results obtained for a 10-story high-rise building.

2. Description of NIST Stairwell Data

In an attempt to develop a verification and validation standard for building fire evacuation models, Ronchi et al. (2013) highlighted several available data-sets which potentially could be used to validate core behavioral components of building evacuation models. This paper will focus specifically on the application of the stairwell evacuation data-set referenced by Ronchi et al. (2013) and provided on-line by Kuligowski and Peacock (2010). Although Peacock et al. (2012) provide a consolidated report containing potential parametric inputs, we found it valuable to process the raw data-sets provided by NIST and determine if the data-sets would allow the extraction of values for parametric input.

Although the NIST researchers collected stairwell evacuation data from a total of nine buildings ranging in height from 6 to 62 stories, the on-line NIST repository of stairwell evacuation data currently contains stairwell data from five of the buildings (only those data-sets approved for release are available). The stairwell data described in this paper comes from the two stairwells of Building 5, a 10-story office building on the West Coast of the United States. According to Peacock et al. (2012), Building 5 consists of two identical stairwells (A and B) with a full stair width of 1.27 meters, stair riser height of 0.178 meters, stair tread depth of 0.279 meters, and an exit width of 0.91 meters.

To collect the data, the NIST researchers placed cameras in each of the stairwells and recorded the evacuation drill. From the video, the NIST researchers transcribed pedestrian identification information and evacuation data into a spreadsheet. The spreadsheet contains the following identification information for each occupant:

1. gender
2. items carried (yes/no)
3. body size (relative to stair width)
4. alone or in a group
5. assisting others
6. floor on which first seen
7. occupant description

Using this identifying information, evacuation specific data was recorded for each pedestrian as he/she traveled down the stairwell and entered each of the camera views:

1. location in stairwell (relative to handrail)
2. handrail usage (yes/no)
3. time individual entered camera view
4. time individual exited camera view

Using the data from both stairwells (stairwell A and stairwell B), we extracted the total evacuation time for each pedestrian and consolidated the two sets of data into a single data-set (Figure 1). Total evacuation time was computed by subtracting the time the individual exited the first floor camera view from the camera's recorded alarm initiation time.

In addition to total evacuation time, we also extracted a starting floor for each pedestrian from the database. According to the notes in the spreadsheet, the "Floor First Seen" column is the highest floor in the stairwell where the evacuee was first seen and if the column is blank, then the occupant entered from a floor above the camera position. Since the cameras were placed on each of the odd numbered floors, we made the assumption that if the evacuee was not first seen on the odd numbered floor, then the evacuee entered from the even numbered floor immediately above the highest floor where pedestrian was recorded in the camera view. For example, evacuee number 1 from Stairwell A of Building 5 has a blank in the "Floor First Seen" column. Since the only record of evacuee number 1 on video is on the first floor camera, we assumed that evacuee number 1 started on the second floor. Similarly, evacuee number 3 from stairwell A also has a blank "First Floor Seen" value, but has a video record for the cameras on the first and third floors. Therefore, we assume that evacuee number 3 started on the fourth floor. Continuing in this manner we developed starting floor positions for each of the pedestrians (Figure 2).

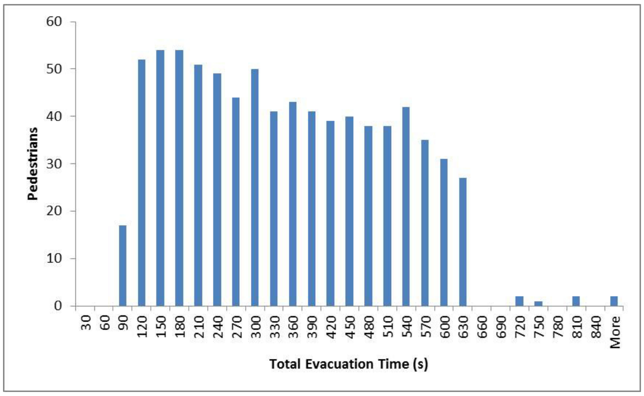

Fig. 1. Evacuee total evacuation times from a 10-story building (extracted from Kuligowski and Peacock (2010)).

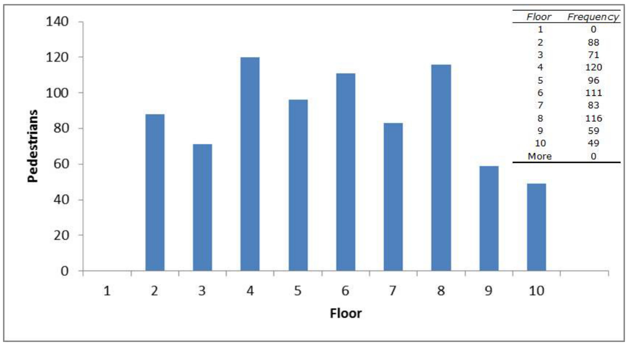

Fig. 2. Evacuee initial floor locations in a 10-story building (extracted from Kuligowski and Peacock (2010)).

According to the description in Peacock et al. (2012) the ”Floor First Seen” column was also used to compute a ”pre-observation” delay value for a subset of the evacuees. Those evacuees who entered the stairwell from even numbered floors (between camera locations) were not included in the computation of these values. The authors called this value a ”pre-observation” delay rather than the typical pre-evacuation delay to distinguish the fact that this value not only includes all activities prior to starting evacuation, but also includes the time it took to walk to the stairwell while evacuating. To compute the distribution of pre-observation delay times from the data-set, we took the value in the ”Floor First Seen” column and simply subtracted the alarm initiation time (for that particular camera) from the time the individual initially entered the camera view (Figure 3).

3. Description of the Pedestrian Simulation Tool

The pedestrian flow simulation tool (PEDFLOW) used in this analysis is a discrete model where each pedestrian is treated individually and motion is influenced by Newtonian dynamics, namely the interaction of forces, similar to the widely-known Helbing-Molnár-Farkas-Viczek social force model, introduced by Helbing et al. (2002) and improved upon by Lakoba et al. (2005). Within PEDFLOW, global movement is controlled by the individual's desired destination, modeled as an internal will force. Local movement is controlled by additional internal forces such as intermediate collision avoidance, near-range (contact) collision avoidance, and wall/obstacle avoidance forces, as well as external pedestrian-pedestrian and pedestrian-object contact forces. For a complete description of the forces, their interactions, data structures, and example simulation capabilities of PEDFLOW see Löhner (2010).

Coded in Fortran-77 and scalable using Open-MP, PEDFLOW contains a complete suite of pre- and post-processing tools. The computer aided design tool included in PEDFLOW allows the user to input all information required to set up the test case including the geometric definitions; boundary conditions; pedestrian types, characteristics and desired

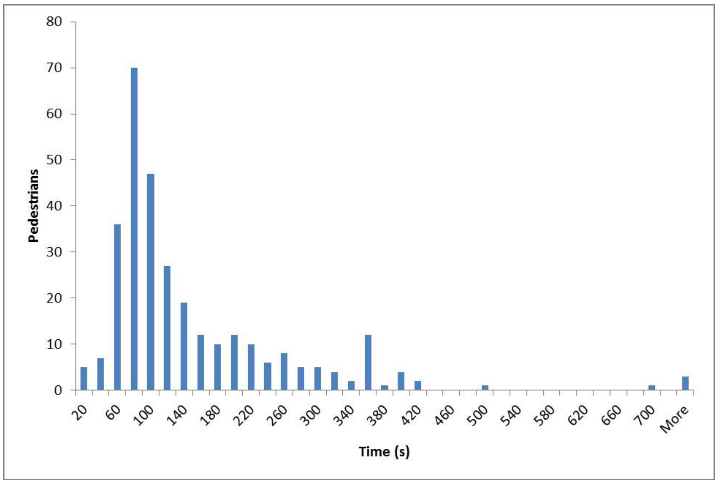

Fig. 3. Evacuee pre-observation delay times in a 10-story building (extracted from Kuligowski and Peacock (2010)).

paths; as well as any scenario-specific information (such as evacuation). In addition, the user may use the computer aided design tool to specify required diagnostics as a means of collecting all necessary quantitative and qualitative information during the simulation run for analysis during post-processing. Once pre-processing is complete, the PEDFLOW tool runs the simulation and outputs all requested diagnostic information to data files for post-processing.

Using the geometric description of the stairwells provided by Peacock et al. (2012), we created a simple 10-story building with two stairwells, each with an exit at the base of the stairs (Figure 4). The pedestrians were distributed

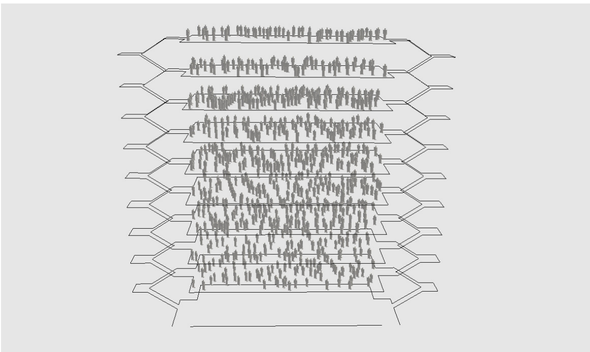

Fig. 4. Evacuee initial positions and geometric description of a 10-story building with two stairwells.

throughout the building in accordance with the distribution given in Figure 2. In order to represent a wide set of pedestrian demographics within the building, we initialized the pedestrians with a velocity distribution of 1.00 +/- 0.5 meters per second, a relaxation time of 0.50 meters per second, a radius of 0.25 +/- 0.02 meters, an ellipticity value in the range of 0.0 to 1.0, a pushiness value in the range of 0.0 to 0.80, and a desired comfort zone of 0.25 meters. To set up the evacuation run, we decided to use the pre-observation delay time as the pre-evacuation delay since the travel-to-stairwell time difference between the two values is well within the statistical uncertainty. Two pre-observation delay time distributions were used. First, we used a Gaussian distribution with parametric values as reported by Peacock et al. (2012) in Table 3 which provided an average pre-observation delay time of 171 +/- 124 seconds for the 10-story building. Second, we used the distribution extracted from Kuligowski and Peacock (2010) and shown in Figure 3.

4. Comparison of Actual and Simulated Values

Prior to running the full simulation, we wanted to confirm that, when unimpeded, our pedestrians' average stair descent speeds were somewhat near to the value reported in Table 3 from Peacock et al. (2012). Therefore, we initiated a single pedestrian on the tenth floor and recorded his velocity throughout the descent. Figure 5 clearly shows that this pedestrian's velocity when descending the stairs is within the 0.44 +/- 0.19 meters per second range provided by Peacock et al. (2012).

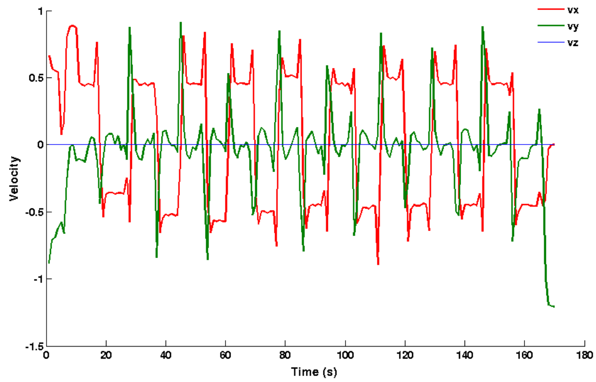

Fig. 5. Average velocity during descent from tenth floor.

When using a Gaussian distribution with a mean of 171 seconds and standard deviation of 124 seconds for the pre-evacuation delay, the PEDFLOW simulation evacuated the 10-story building in 742 seconds, 4 minutes and 40 seconds faster than the actual total evacuation time of 1022 seconds recorded by Peacock et al. (2012). As can be seen from Figure 6, this type of distribution does not seem to properly fit the pre-observation data (left), nor does it provide a fit for the observed building exit times (right).

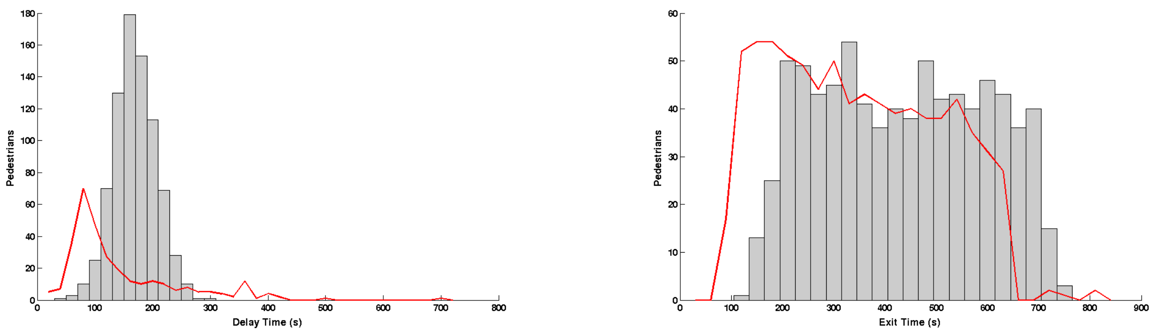

Fig. 6. Comparison of experimental (red line) versus simulation-obtained values for pre-evacuation delay (left) and building exit times (right) for Gaussian distribution of pre-evacuation delay.

However, when using the distribution of pre-observation times shown in Figure 3, we get much more satisfactory results. The 10-story building is now evacuated in 872 seconds, only 2 minutes and 30 seconds faster than the actual evacuation time. As shown in Figure 7, the user-defined table of pre-evacuation times (left) seems to match the pre-observation times obtained during the evacuation drill. Similarly, notice in Figure 7 that the simulated building exit times (right) also better match the evacuation exit times recorded by Peacock et al. (2012).

It is important to note that during the actual evacuation drill, six firefighters entered one of the stairwells and traveled against the floor of traffic up to the seventh floor. The simulation results described in this section do not

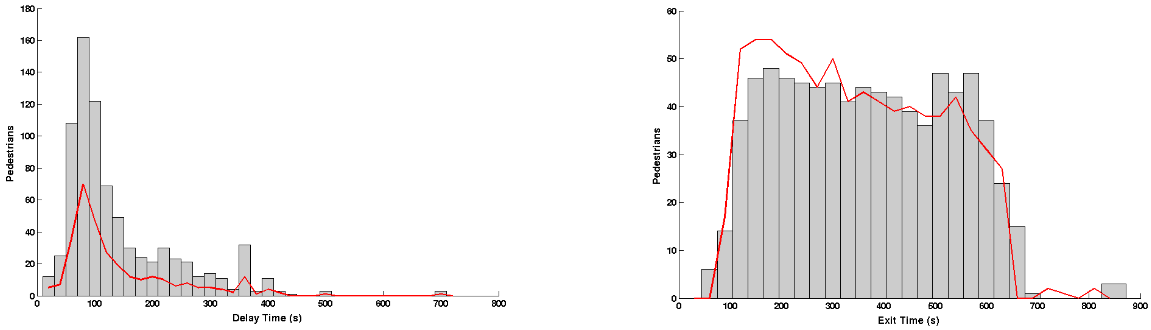

Fig. 7. Comparison of experimental (red line) versus simulation-obtained values for pre-evacuation delay (left) and building exit times (right) with video-extracted pre-evacuation delay.

account for the effects from this type of counterflow. We have initiated methods to implement the movement of emergency responders into evacuation scenarios, but further research is necessary. In addition, some of the individuals with lengthy pre-observation delay values (identifiable outliers in Figure 3) were individuals with responsibilities to sweep the floor and ensure all occupants evacuate prior to evacuating themselves. Typically, these individuals wore yellow safety vests during the evacuation and although they are treated in this analysis as regular evacuees, a better solution currently under development is to assign them pedestrian characteristics consistent with their responsibilities within the simulation.

5. Conclusions

With the NIST stairwell data readily available, we have shown that it is suitable for use in validation of a pedestrian simulation tool. With a relatively small amount of pre-processing, the data can be used to establish parametric inputs such as occupant initial locations and pre-evacuation time distributions. In addition, the data can be used to validate several core behavioral components of the simulation tool such as the assignment of the pre-evacuation time distributions and speed on stairs. Although this paper focuses specifically on the evacuation drill of the 10-story building, further research and attempted validation tests are on-going for the other four buildings available from NIST.

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