Comparison of Improved Floor Field Model and Other Models

Hyunwoo Nam, Suyeong Kwak and Chulmin Jun
Department of Geoinformatics, University of Seoul, Seoul, Korea, Republic of

Keywords: Floor Field Model, Pedestrian Dynamics, Cellular Automata, Indoor Evacuation, Microscopic Model.

Abstract: This study introduces an improved Floor Field Model (FFM) that models pedestrians using realistic physical characteristics (size, shape, and posture). Through comparison with other well-known models, the areas of improvement are elucidated. The FFM is a leading microscopic pedestrian model that uses cellular automation (CA), but it does not accurately reflect the physical characteristics of pedestrians, such as their size, shape, and posture. Therefore, it is difficult for the existing FFM to simulate certain phenomena, such as collisions and friction between pedestrians. This study proposes an improved FFM that can simulate these phenomena, and experiments were carried out to compare this model with other models, such as the existing FFM, Simulex, and Pathfinder, to confirm the improvements. Through this experiment, it was confirmed that inter-pedestrian phenomena, such as collisions, friction, and jamming, could be realistically simulated.

1 INTRODUCTION

The Floor Field Model (FFM) is a microscopic pedestrian model that utilizes cellular automata (CA). The FFM effectively models pedestrian movements with simple arithmetic calculations. However, in the FFM, the size and shape of the pedestrians in the model differ significantly from the characteristics of actual pedestrians (Burstedde et al., 2001; Kirchner et al., 2002). To realistically simulate detailed physical phenomena (collision, jamming, etc.), a shape similar to the shape of an actual pedestrian should be used; oval figures would fulfill this purpose. However, the FFM assumes a circular pedestrian, and thus it is difficult for it to reflect certain inter-pedestrian phenomena, such as collisions and jamming. Therefore, we have developed an improved pedestrian model with additional features, such as the pedestrian size, shape, posture, and turns. The improved model follows the basic rules of the FFM, and various factors, such as the lattice space and posture determination probability, were modified and added to include the abovementioned features. Through these modifications, inter-pedestrian phenomena, such as collisions and jamming, were reflected in the pedestrian modeling process.

Moreover, comparative experiments were carried out to confirm that the improved pedestrian model resolves the limitations of the existing FFM. The existing FFM and two other widely used models, Simulex and Pathfinder, were selected for comparison. The purpose of the models in use is to assess the performance of the improved model. The experiment was carried out in the first-floor space of a building on the campus of the University of Seoul, and various factors were investigated, including changes in the evacuation time depending on the evacuating population, assuming equal population distribution among the available exits, and evacuation conditions. Through this, it was confirmed that the improved model showed effects that were not previously seen in the existing FFM, such as collision and jamming, and yielded evacuation experiment results that were very similar to those of the models currently in use.

2 RELATED WORKS

2.1 Floor Field Model

Burstedde first introduced the FFM in 2001 (Burstedde et al., 2001). The FFM was designed a two-dimensional CA model and displayed various factors that impact pedestrian movement using various floor fields (Kirchner et al., 2002). The FFM utilizes cellular spaces composed of lattices, and one lattice typically encompasses a 40 cm × 40 cm square. Detailed information on the FFM can be found in

Nam, H., Kwak, S. and Jun, C.
Comparison of Improved Floor Field Model and Other Models.
DOI: 10.5220/0005658700950101
In *Proceedings of the 8th International Conference on Agents and Artificial Intelligence (ICAART 2016) - Volume 1*, pages 95-101
ISBN: 978-989-758-172-4
Copyright © 2016 by SCITEPRESS – Science and Technology Publications, Lda. All rights reserved

previous related works (Burstedde et al., 2001; Kirchner et al., 2002; Nishinari et al., 2004).

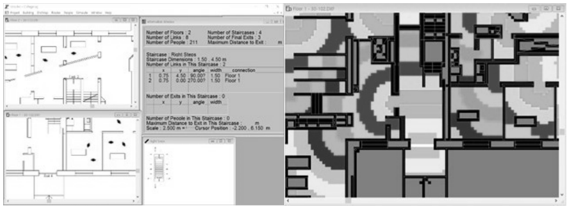
However, the FFM sets the pedestrian size and shape according to the size of the lattice. Therefore, the size and shape of the pedestrians in the FFM results differ significantly from the size and shape of actual pedestrians, meaning the model does not reflect the influence of collisions and turns between pedestrians. Although studies have been conducted to improve the existing FFM, most of these studies utilize the spatial structure, pedestrian size, and movement methods as defined by the FFM (Henein, 2008; Kirchner et al., 2003; Kirchner et al., 2004; Kirik et al., 2007; Kretz, 2006; Kwak et al., 2010; Nishinari et al., 2005; Suma et al., 2012; Varas et al., 2007; Yanagisawa and Nishinari, 2007; Yanagisawa et al., 2009). The model suggested in this study is different from the models in these previous studies, as the overall characteristics of pedestrian size and the placement methods of the FFM were approached from a different point of view. Therefore, the pedestrian posture can be defined, and the collision phenomena resulting from changes in posture can be modeled. The improved model is further explained in Section 3.

2.2 Simulex

Simulex is an evacuation simulation model introduced by Thompson (Thompson et al., 1997). The spatial data can be structured using a CAD interface, and an evacuation simulation can be performed by placing exits and pedestrians within a defined space. Moreover, Simulex was designed to make it possible to conduct simulations in a complex building setting with multiple floors.

Simulex defines data through the floors and stairs used by pedestrians, links that link the two factors, and the final exit of the building. Moreover, it uses a distance map that defines the distance of each space from the exit (Figure 1). As for the pedestrians, various factors defining their motion are set, including the placement location, the physical characteristics of the pedestrian body type, and the psychological characteristics dictating which exits should be used and how quickly they should respond to evacuation orders.

When the pedestrians are given orders to evacuate, they carry out the evacuation process based on their individual response times, and the evacuation routes are obtained using the distance maps. Throughout the moving process, the walking speed of each pedestrian is determined by the preset pedestrian characteristics, and in the case of bottlenecks, these speeds are reduced to values near 0. Moreover, the pedestrians can freely spin their bodies, and as such, collisions occur between pedestrians.



```
Number of Floors : 2          Number of Staircases : 4
Number of Links : 8           Number of Final Exits : 3
Number of People : 211        Maximum Distance to Exit :      m

Staircase : Right Steps
Staircase Dimensions : 1.50 , 4.50 m
Number of Links in This Staircase : 2
      x      y     angle   width    connection
 1   0.75   4.50   90.00?  1.50   Floor 1
 2   0.75   0.00  270.00?  1.50   Floor 1

Number of Exits in This Staircase : 0
      x      y     angle   width

Number of People in This Staircase : 0
Maximum Distance to Exit in This Staircase :        m
Scale : 2.500 m =      Cursor Position : -2.200 , 6.150  m
```

Figure 1: UI and distance map of Simulex.

2.3 Pathfinder

Pathfinder is an agent-based evacuation simulator. It contains various simulation functionalities, such as the writing and editing of spatial data, an analytics tool for three-dimensional results, in addition to the basic pedestrian simulations. Pathfinder utilizes two models, Society of Fire Protection Engineers (SFPE) and steering, to determine the pedestrian movements (Thunderhead Engineering, 2009).

The SFPE mode was developed based on the concept proposed by (Nelson and MacLennan, 2002) and represents the pedestrian movements as a flow. Moreover, pedestrians are influenced by the exit locations and pedestrian density and determine their walking speeds in a kinetic manner. At the exit, the width of the exit heavily impacts the walking speed. The unique characteristic of the SFPE mode is that there are no physical collisions between the pedestrians. Therefore, the situation created by this model is unrealistic, as numerous pedestrians are modeled as being in the same locations. However, while there are no physical collisions, i.e., when the pedestrians are modeled as occupying the same space, the density increases, which still has an impact on the actions of the pedestrians (slower speeds).

The steering mode was developed as an improvement to (Raynolds, 1999) and (Amor et al., 2006). The steering mode focuses on providing a natural depiction of pedestrian movements. The construction of the model is not based on pedestrian queues or the influence of the density but on the phenomena that occur when the pedestrians move naturally.

In both modes, the movement routes between each mesh are calculated in an area that is divided by a pedestrians in these routes, reaching critical mass, the movement routes are recalculated. Through this process, if a pedestrian bottleneck occurs, some navigation mesh, and if there are too many pedestrians choose alternative routes. The recalculation delay of the movement routes can be set in the simulator parameters. In the SFPE mode, the movements of the pedestrians are calculated in a straight line, and in the steering mode, the B-Spline algorithm is used to make their movements more smooth and realistic (Figure 2).

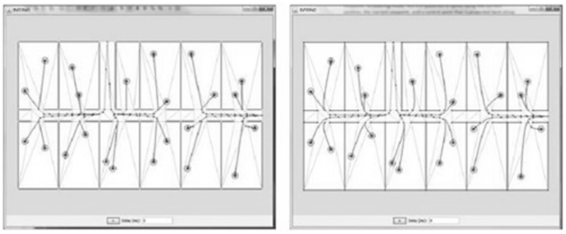


Figure 2: Movement paths in SFPE (left) and steering (right) modes (Thunderhead Engineering, 2009).

3 IMPROVED FLOOR FIELD MODEL

This paper suggests a CA-based pedestrian model that can reflect detailed physical phenomena (collision, jamming, turns, etc.) and improves upon the limitations of the existing FFM. Specifically, by adding different sizes, stride lengths, postures, and sight to the modeled pedestrians, additional factors that could not be modeled in the FFM, such as collisions and friction between pedestrians, can be considered.

3.1 Size and Shape of Pedestrians

The size and shape of each pedestrian, which are based on (Lim et al., 2006), were set at 50 cm × 30 cm: a rectangle instead of a square. As the FFM utilizes a cell of 40 cm × 40 cm in size, the pedestrian in this model was set to fit this size. This study has decreased the size of the cell to 30 cm × 30 cm, and the pedestrian no longer occupies one cell but parts of four cells. Therefore, the pedestrian, sized 50 cm × 30 cm, may occupy all four cells by itself, and depending on the situation, two pedestrians may share one cell. Moreover, to place each pedestrian in four cells, the pedestrians were placed on the inter-cell borders instead of within the cell. In Figure 3(a), the pedestrians are placed on the border points, and each cell is occupied by either one or two pedestrians. However, limiting conditions were defined to prevent situations in which physical collisions occur and is unable to place them properly, as shown in Figure 3(b).

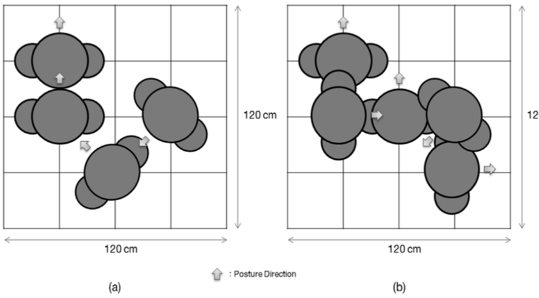


Figure 3: An example of pedestrian shapes and placement: (a) possible situations, (b) impossible situation.

3.2 Posture

In this paper, “posture” means the direction in which each pedestrian is facing. The existing FFM does not include posture information for the pedestrians. However, the posture of a pedestrian is a very important factor that influences the direction of movement, sight, and decisions of the pedestrians. Therefore, in this model, the pedestrians are given various postures and face in various directions. However, if the pedestrians can be modeled to face any direction (360 degree range), the calculations become very complex, and therefore the posture directions were limited to eight directions.

Depending on the placements of nearby obstacles and other pedestrians, each pedestrian can either turn freely or not at all. If there are no limitations nearby, they are able to change their postures freely, but if the nearby areas are filled with pedestrians, turning becomes impossible. That is, the postures of the pedestrians influence each other, and these interactions influence the overall pedestrian situation.

3.3 Posture Probability

The FFM uses transition probability to determine the movement directions of the pedestrians. This study used similar concepts to determine the postures of the pedestrians; the method used in this study is termed posture probability. The pedestrian must choose one direction out of the eight possible directions as the posture they will be facing. In a normal evacuation situation, pedestrians would face the exit and move, but if their sight is limited by factors such as power outages, their postures could be set to face different directions. Therefore, the model must be able to reflect these different scenarios through parameter control.

Posture probability is a method that determines which of the eight direction near the pedestrian will

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

be faced, given random variables. The pedestrians choose their posture every timestep, and the chosen posture influences their movement. This model only allows movement at intervals of 90° to both the left and right based on the current posture.

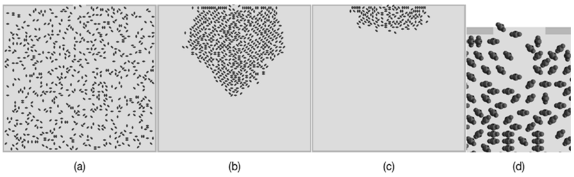


Figure 4: Simulation example of the improved model: (a) beginning stage ($t = 0$), (b) middle stage, (c) final stage. (d) Detailed pedestrian situation.

Apart from the previously mentioned factors, various factors, such as the pedestrian stride sizes and update rules, were also changed. Figure 4 shows snapshots from a sample simulation of the improved model. The pedestrians choose their posture and movement direction at each timestep, and based on these choices, they move towards a pre-determined exit. Figure 4(d) shows that the shape of the pedestrians is a rectangle, and their shape differs based on their posture.

4 SIMULATIONS WITH OTHER MODELS

This study sought to determine the characteristics of a simulated scenario calculated through the improved pedestrian model when compared with other models. Therefore, a comparative analysis was conducted for the five models described in this study: the improved model, the existing FFM, Simulex, Pathfinder (SPFE, Steering). The experimental conditions, methods, and results are discussed in this section.

4.1 Experimental Conditions

The experiment took place in the first-floor space of a university campus building. This space has six exits and is composed of spaces with diverse purposes, such as lecture rooms and libraries (Figure 5). This space was selected so that diverse pedestrian situations could be examined. The exits were assigned numbers from 1 to 6, moving clockwise from the top left corner. The dark areas in Figure 5 are close to an exit, and the light areas are far from an exit. These colors have been assigned based on the values of the Static Floor Field (SFF).

Figure 5: Experimental area.

The experiment was divided into two parts. The first part was the comparison of the trends of changes in the total evacuation time as the evacuating population increased. The purpose of this part of the experiment was to compare the influence of phenomena such as bottlenecks, collisions, and jamming, which increase with increasing evacuating population in each model.

In the second part of the experiment, when the evacuation population was set at a large enough value to cause bottlenecks (1000), the number of pedestrians using each exit and the time-series evacuation situation by exit was compared. This is to compare the evacuation situations of the different models at each exit in a detailed manner with the same evacuation population in each model.

4.2 Comparison of Total Evacuation Time based on Size of Evacuating Population

The total evacuation times of the five models were compared as the evacuation population was varied from 50 to 1200 people. The population distribution among the rooms was randomized. Basic parameters were used for Simulex and Pathfinder; for the FFM and the improved model, the degree to which the population wish to move quickly to the exit was set at k_s parameter ($k_s = 2, 1.5$) (Kirchner et al., 2002). In the improved model, the posture determination parameter k_p was set to be equal to k_s. When $k_s = 2$, the pedestrians move quickly to the exit, and when $k_s = 1.5$, they move less quickly; therefore, the evacuation time when $k_s = 2$ is slightly lower.

The results of the experiment are summarized in Figure 6. When the size of the evacuating population increased in the FFM, the evacuation time increased from approximately 40 to 70 s, showing an increase of approximately 30 s. This is because, the collision and jamming phenomena do not occur regardless of the number of pedestrians, and thus the evacuation time changed very little. Therefore, the situation identified as the limitations for FFM was confirmed through the actual experiment results.

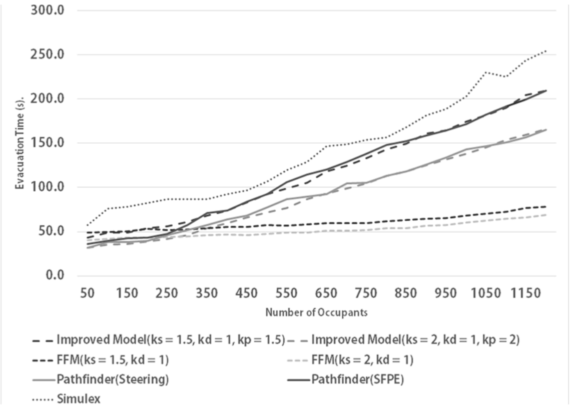


Figure 6: Comparison of evacuation times by model.

Considering the two scenarios of the improved model, when $k_s = 2$, the results are very similar to the results of the Pathfinder (Steering) model. Moreover, when $k_s = 1.5$, the results are very similar to the results of the Pathfinder (SFPE) model. The two Pathfinder models reflect the phenomena of collisions and jamming between pedestrians, and as the bottlenecks become more intense, the evacuation time increases. It can thus be concluded that the interactions between pedestrians influence the results of the improved model, similar to Pathfinder. Therefore, when effects that were excluded in the existing FFM were considered, the calculations yielded evacuation times that are very similar to those obtained by the currently widely used models.

Lastly, Simulex yielded longer evacuation times than all other models. This is thought to be because there is a stronger emphasis on the interaction between pedestrians than in the other models, and the walking speed was influenced by other factors.

4.3 Comparison of Evacuation Situation by Exit

The experimental area in Figure 5 includes six exits, and the width of each exit is approximately 2–3 m. In this experiment, the evacuating population is set to be large enough to cause bottlenecks (1000), and the evacuation situations of the six exits are compared. In both the FFM and the improved model, only the $k_s = 2$ scenarios were tested. Figure 7 shows the evacuating population by exit. In all models, exit 3 had the most people, followed by exit 2 and exits 1, 4, and 6, which had approximately the same number of people, and exit 5 had the fewest people.

When regarded on an exit-by-exit basis, in the two Pathfinder models, approximately 120 and in the other three models, approximately 90 people left through exit 1. The other three models utilize the distance map and SFF to move the pedestrians to the exits (Thompson et al., 1997; Burstedde et al., 2001). Each pedestrian selects an exit based on their distance from the exit, and the spaces near each exit are calculated in advance. The possibility of the pedestrian located in each area moving to their assigned exits becomes very high. Therefore, the allocated population of these three models show overall similarities in their movements. However, in the Pathfinder simulation, if there are many pedestrians along the route a pedestrian wishes to take, an alternative route is calculated in real time (Thunderhead Engineering, 2009). Therefore, there were pedestrians that were initially assigned to exit 1 as well as other pedestrians who detoured from their initial routes to different exits, resulting in a larger outflow of pedestrians through this exit.

The Pathfinder models show fewer people leaving through exit 2 compared with other models. According to Figure 7, exit 2 had the second-largest evacuating population and experienced severe bottlenecks. Therefore, based on the alternative route calculations, the bottlenecks occurring at exit 2 led to pedestrians taking a detour to exit 1, and because the other three models do not have the ability to calculate alternative routes, the number of people using this exit is similar in these models.

In all five models, approximately 400 pedestrians were assigned to exit 3. Exits 4 and 5 are next to each other in a hallway (shown in Figure 5). However, because the hallway is closer to exit 4, the pedestrians who passed along the hallway tended to decide to use exit 4. However, in the Pathfinder simulations, when there were bottlenecks at exit 4, the pedestrians detoured to exit 5. Therefore, unlike the other models, approximately 40 evacuating pedestrians used exit 5. All five models treated exit 6 similarly.

Figure 8 compares the states of evacuation through exit 1 in the five models. The time-series data of the cumulative evacuation population are shown for each model. The slope of the straight line is the speed of evacuation; for larger slopes, the bottlenecks have less influence, and for smaller slopes, the bottlenecks have more influential. Figure 9 shows snapshots of the evacuation simulation at similar points in time for all four models except the SPFE model.

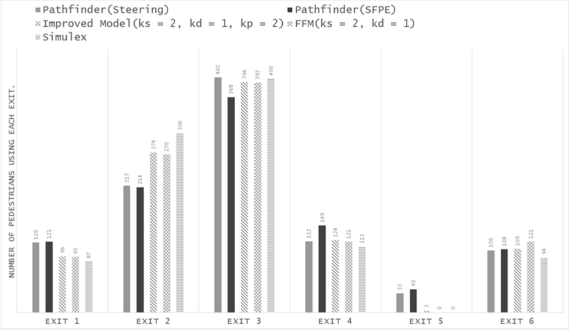


Figure 7: Number of evacuating pedestrians by exit.

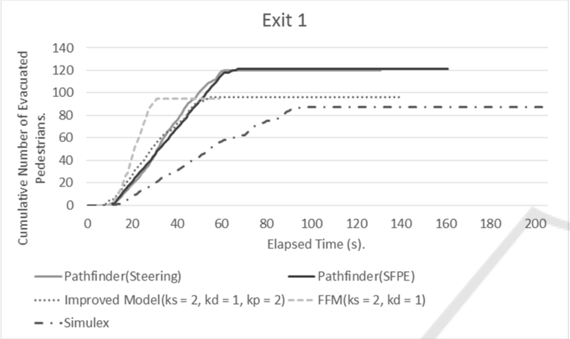


Figure 8: Comparison of evacuation situations of exit 1 in the five models.

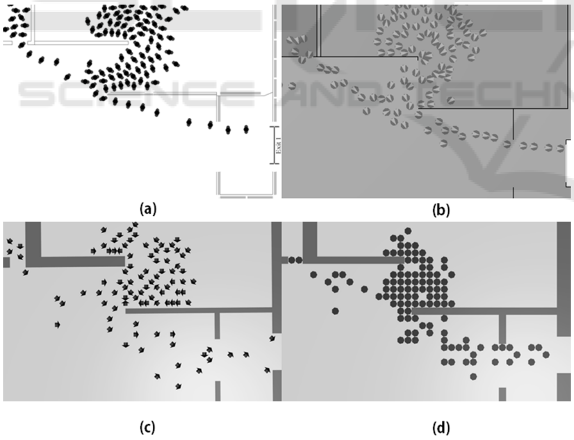


Figure 9: Evacuation from exit 1: (a) Simulex, (b) Pathfinder (Steering), (c) improved model, (d) FFM.

The simulation results in Figure 8 show that the number of people accumulate most rapidly in the FFM (broken line); after approximately 30 s, 95 pedestrians were evacuated. For the improved model and the two Pathfinder models, the evacuation began at approximately 15 s, after which the evacuation speed was very similar. As shown in Figure 9(b) and (c), there are differences in the situation of the evacuation in the improved and steering models, but as shown in Figure 8, they are very similar in terms of evacuation speed.

However, in the Simulex model, the evacuation process was much slower than in the other models. Although the number of pedestrians in the Simulex model was similar to those in the improved model, the improved model completed evacuation at approximately 50 s, whereas Simulex ended at approximately 90 s. The reasons for this are the structure of this building and the placement of pedestrians. Figure 9(a) shows the Simulex evacuation. Exit 1 is located in the bottom right hand corner, and there is a large group of pedestrians in the large room. To reach exit 1, the pedestrians must take a detour. In this process, the collisions and jamming were more influential than the improved model. As shown in Figure 9(a), many bottlenecks were created in the process of moving around the wall, so the speed of evacuation was slow. However, in the other models, despite the same structure and situation (Figure 9(b), (c), (d)), bottlenecks occurred less than Simulex. For the remaining five exits, the evacuation situation was calculated differently based on the structure of the building and the placement of pedestrians. The existing FFM showed a very high evacuation speed, the two Pathfinder models and the improved model showed similar evacuation speeds, and Simulex showed the slowest evacuation speeds.

5 CONCLUSION

This paper proposed an improved FFM model to solve the limitations of the existing FFM and identified the characteristics of the improved model by comparing it with other models. Because the FFM models pedestrian with a shape that differs from the shape of actual pedestrians, certain phenomena, such as collisions and jamming, cannot be simulated in this model. Therefore, to improve this model, various factors were added, including rectangular (rather than square) pedestrians, pedestrian placement rules, and postures, and these additions resulted in an improved model. The improved model was compared with models currently in use, such as Simulex and Pathfinder (Steering, SFPE) to confirm that the improved effects yielded accurate results.

A comparison experiment was carried out in two parts using a specific space in a campus building. First, changes in evacuation times resulting from increasing evacuating population size were studied. The FFM yielded a very low evacuation time even when the evacuating population was large. However, the improved model yielded results very similar to the

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

Pathfinder results, and these results were demonstrated to have overcome the limitations of the previous model. Moreover, in the second part of the experiment, in which the evacuation situations were considered by exit, differences between the models were observed with respect to the pedestrians allocated to each exit, depending on the spatial structure and the situation at the exits.

Overall, the improved model proposed in this study seems to have overcome the limitations of the FFM. In the future, it would be beneficial to conduct further research to incorporate further physical factors, such as inertia and pace, as well as psychological factors common in evacuation situations.

ACKNOWLEDGEMENTS

This research was supported by the Disaster Safety Technology Development & Infrastructure Construction Program funded by the Ministry of Public Safety and Security("NEMA-Infrastructure-2014-116")

REFERENCES

Amor, H. B., Murray, J. and Obst, O. (2006). Fast, Neat, and Under Control: Arbitrating Between Steering Behaviors. In S. Rabin(Ed.), *AI Game Programming Wisdom 3*, pages 221-232.

Burstedde, C., Klauck, K., Schadschneider, A. and Zittartz, J. (2001). Simulation of pedestrian dynamics using a two-dimensional cellular automaton. In *Physica A:Statistical Mechanics and its Applications*, 295(3):507–525.

Henein, C. (2008). Crowds Are Made of People: Human Factors in Microscopic Crowd Models. In Ph.D. thesis, Carleton University, Canada.

Kirchner, A., Klupfel, H., Nishinari, K., Schadschneider, A. and Schreckenberg, M. (2004). Discretisation Effects and The Influence of Walking Speed in Cellular Automata Models for Pedestrian Dynamics. In *J Stat Mech* 10:P10011.

Kirchner, A., Nishinari, K. and Schadschneider, A. (2003). Friction effect and clogging in a cellular automatation model for pedestrian dynamics. In *Phys. Rev. E*, 67, 056122.

Kirchner, A., and Schadschneider, A. (2002). Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics. In *Physica A:Statistical Mechanics and its Applications*, 312:260-276.

Kirik, E., Yurgel'yan, T. and Krouglov, D. (2007). An intelligent floor field cellular automation model for pedestrian dynamics. In *Proceedings of The Summer Computer Simulation Conference*, pages 1031-1036.

Kretz, T. (2006). Pedestrian Traffic - Simulation and Experiments. In PhD thesis, University Duisburg-Essen.

Kwak, S., Nam, H. and Jun, C. (2010). An Indoor Pedestrian Simulation Model Incorporating the Visibility. In *Journal of Korea Spatial Information Society*, 18(5):133-142.

Lim, W., Ryu T., Choi, H., Choi, H. and Chung, M. (2006). A Comparision of Gait Characteristics between Korean and Western Young People. In *Journal of the Ergonomics Society of Korea*, 25(2):33-41.

Nelson, H. E. and MacLennan. H. A. (2002). Emergency movement. In P. DiNenno(Ed.), *The SFPE Handbook of fire Protection Engineering,* 3rd Edition, National Fire Protection Association, Quincy, pages 3-367-3-380.

Nishinari, K., Kirchner, A., Namazi, A. and Schadschneider, A. (2004). Extended floor CA model for evacuation dynamics. In *IEICETrans. Inf. Syst*, E87-D:726-732.

Nishinari, K., Kirchner, A., Namazi, A, and Schadschneider, A. (2005). Simulations of evacuation by an extended floor field CA model. In *Traffic and Granular Flow '03*, pages 405-410.

Raynolds, C. W. (1999). Steering Behaviors For Autonomous Characters. In *Proceedings of the Game Developers Conference 1999, Miller Freeman Game Group*, pages 763-782.

Suma, Y., Yanagisawa, D. and Nishinari, K. (2012). Anticipation effect in pedestrian dynamics:Modeling and experiments. In *Physica A:Statistical Mechanics and its Applications*, 391:248-263.

Thunderhead Engineering. (2009). Pathfinder Technical Reference. In *Thunderhead Engineering Consultants, Inc., Manhattan.*

Thompson, P., Wu, J. and Marchant, E. (1997). Simulex 3.0: Modelling Evacuation in Multi-Storey Buildings. In *Fire Safety Science-Proceedings of the Fifth International Symposium*, pages 725–736.

Varas, A., Cornejo, M. D., Mainemer, D., Toledo, B., Rogan, J., Munoz, V. and Valdivia, J. A. (2007). Cellular automaton model for evacuation process with obstacles. In *Physica A:Statistical Mechanics and its Applications*, 382:631-642.

Yanagisawa, D. and Nishinari, K. (2007). Mean-field theory for pedestrian outflow through an exit. In *Phys. Rev. E*, 76, 061117.

Yanagisawa, D., Kimura, A., Tomoeda, A., Ryosuke, N., Suma, Y., Ohtsuka, K. and Nishinari, K. (2009). Introduction of frictional and turning function for pedestrian outflow with an obstacle. In *Phys. Rev. E*, 80, 036110.