한국시뮬레이션학회 논문지
Vol. 20, No. 1, pp. 79-85 (2011. 3)

도덕성을 가지는 세 종류의 보행자에 대한 긴급대피 동역학 시뮬레이션

이상희†

Simulation of Evacuation Dynamics of Three Types of Pedestrians with Morality

Sang-Hee Lee

ABSTRACT

The problem of evacuating pedestrians from a room or channel under panic conditions is of obvious importance in daily life. In recent years, several computer models have been developed to simulate pedestrian dynamics. Understanding evacuation dynamics can allow for the design of more comfortable and safe pedestrian facilities. However, these models do not take into account the type and state of mind of pedestrians. They deal with pedestrians as particles and the state of mind as a social force, which is represented by conservative and long-range interactions between individuals. In this study, I used the lattice model proposed in my previous study to explore the evacuation behavior of pedestrians with morality. In this model, three types of pedestrians are considered: adults, children, and injured people. Collisions between adults and children result in injured people. When the number of injured people continuously in contact with each other reaches a given value *k*, the injured people are removed from the lattice space. This situation is the same as that in which pedestrians start stepping over injured people. This behavior was interpreted as the morality of pedestrians. Simulations showed that the evacuation showed down and eventually became jammed owing to the injured people acting as "obstacles" in relation to the morality *k*.

Key words : Evacuation, Morality, Pedestrian, Lattice model

요 약

공항상태에서 방이나, 복도로부터 나가려고 하는 긴급대피 상황에서의 사람들 행동문제는 일상생활에서 매우 중요하다. 지난 몇 년간 보행자 동역학을 전산 모사하는 수학적 모델들이 개발되어 왔다. 긴급대피 동역학에 대한 이해는 사람들의 안전과 편안함이 고려된 설계를 하는 데 기여를 할 수 있다. 그러나 제안 되어진 대부분의 모델들은 사람들의 종류와 그들의 마음상태를 전혀 고려하지 않았다. 사람들은 입자로 묘사되어졌으며, 그들의 마음은 장거리 상호작용으로써의 개체간 상호작용으로써 기술되어 졌다. 본 연구에서, 우리는 이전에 보행자모델로 제안한 격자 모델을 이용하여 도덕성을 가진 세 종류의 사람-어른, 어린이, 부상자-의 긴급대피 동역학을 연구하였다. 대피하는 과정에서 어른과 어린이가 충돌하면 어린이가 넘어지면서 부상자가 된다. 사람들은 이러한 부상자들을 만나게 되면 지나치지 않고 기다리게 되는데, 이 정도를 사람들의 도덕성으로 해석하였다. 일정한 수의 부상자들이 발생하면 긴급한 대피상황에서 사람들을 밟고 지나가게 된다. 그리고 모델에서는 부상자들이 격자공간에서 없어진다. 시뮬레이션 결과는 도덕성과 관련하여 장애물로써 역할을 하는 부상자로 인한 교통 체증이 발생함을 보여 주었다.

주요어 : 긴급대피상황, 도덕성, 보행자, 격자모델

*This study was carried out with the support of "Cooperative Research Program for Agricultural Science & Technology Development(project No. 20100401-030-079-001-00-00)", RDA, Republic of Korea, and partly supported by National Institutes for Mathematical Sciences.
*국가수리과학연구소 융복합수리과학부
접수일(2010년 12월 18일), 심사일(1차 : 2011년 3월 14일, 2차 : 2011년 3월 18일), 게재 확정일(2011년 3월 21일)
[1] 소속누락
주 저 자 : 이상희
교신저자 : 이상희
E-mail; sunchaos@nims.re.kr

1. Introduction

In recent years, vehicular traffic and pedestrian flow have attracted considerable attention in the field of physical science[1-5]. Many observed self-organization phenomena in vehicular traffic and pedestrian flows have been successfully reproduced by the use of various models: cellular automaton models[6,7], lattice gas models of biased-random walkers[1,5,8], car-following models[1,3], and hydrodynamic models[1-4]. In particular, a one-dimensional cellular automata(CA) model is widely used to explore highway traffic, and a two-dimensional CA model is primarily utilized to understand city traffic[9]. In contrast, a lattice gas(or fluid) model has been extensively used to investigate pedestrian motion in evacuation situations[10,11]. It has also encouraged physicists to study evacuation processes[12-14]. These studies have revealed physical phenomena such as dynamical phase transitions and nonlinear waves[15]. However, in spite of the similarities between pedestrian and vehicular flows, the former has not been studied as extensively as the latter[16], because pedestrian movements are more complex and chaotic in several aspects. In the present study, we explored the pedestrian behavior in urgent situation.

In this study, I used the lattice type model proposed in my previous study[17] in order to understand the evacuation behavior of pedestrians with morality. What we address is the morality of pedestrians. The pedestrians consists of adults, children, and injured people. The three types of pedestrians are distinguished by their drift strengths. "Adults" move in a preferred direction, whereas "Children" move in a more random way. Injured people have no drift strength. I showed that a jamming transition occurs at a critical pedestrian density on lattice space. I further demonstrated the dependence of the jamming transition on the different densities of pedestrians entering into the system and the various moralities.

This paper is organized as follows. First, I describe my model. Then, I present results from simulations with a parallel update under periodic boundary conditions. Finally, I discuss the simulation results in order to provide insights into how the model used in this study can be applied to various situations for pedestrian flows.

2. Related Work

Pedestrians are more intelligent than vehicles, and they can choose an optimum route in a given circumstance. And pedestrians are more flexible in changing directions and not limited to "lanes," unlike vehicular flow. A slight bumping between pedestrians is acceptable and not absolutely avoided, unlike traffic flow models. The pedestrian's properties mentioned above make the understanding difficult. However, to know the behavior is important in our life. It is necessary to know the flow rate of pedestrian for rush hour and panic escape. It is also important to avoid the jammed state of pedestrians in the channel of the subway. In simulation studies, pedestrian flows have been mimicked by using interacting particles. Henderson conjectured that pedestrian crowds behave in a similar way to gases or fluids[18]. Helbing[3] has shown that human trail formation is interpreted as self-organization effect due to nonlinear interactions among persons. Muramatsu et al.[4] proposed a biased random walker model to mimic the pedestrian counter-flow in the channel of a subway. They have found that the jamming transition occurs in the pedestrian counter flow within a channel when the density is higher than the threshold. Tajima et al.[19] have shown that the clogging transition occurs in the unidirectional channel flow with a bottleneck if the density is higher than the threshold.

These studies mentioned above are helpful to understand pedestrian's behavior in evacuation. however, they had limitation in considering pedestrian's morality.

3. Model description

3.1 Model formulation

The model for pedestrian flow was established in a channel under open boundary conditions. The channel is represented by an $L \times W(W = 20\text{–}100 \text{ and } L = 200)$ site grid, where L *and* W are the length and width, respectively, of the channel. Pedestrians enter the channel from the left boundary(entrance) and leave the channel through the right boundary(exit). The density of pedestrians on the left boundary is set by the constant probabilities

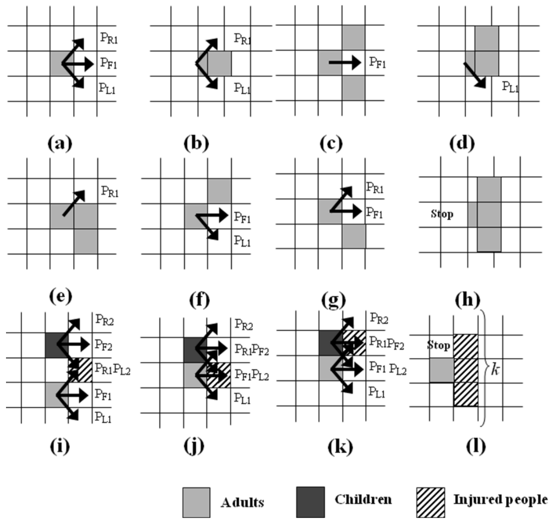


Fig. 1. All possible configurations of pedestrians in lattice space. The gray, black, and striped cells represent adults, children, and injured people, respectively. The arrows indicate the movement direction of each pedestrian

P_{adults} and $P_{children}$. When a pedestrian arrives at the right boundary, it is removed from the channel; when the pedestrian reaches the top and bottom walls, the pedestrian is reflected by the wall.

Figure 1 shows all possible configurations of a pedestrian's movement. Pedestrian movement has three fundamental elements: forward stepping, cross stepping, and waiting. Forward stepping means that a person moves toward the front site in the forward direction. Cross stepping means moving in a diagonal direction between a side site and front site; this movement occurs when a person on the side and person on the front interfere with movement. Waiting means not moving owing to the presence of an injured person. In this model, pedestrians cannot pass over injured people until the latter are removed from the lattice space. This waiting behavior is interpreted as the morality of the pedestrian. The arrow sign indicates the movement direction of each pedestrian. Each pedestrian can move only one site in a time step. The update is synchronous for all pedestrians.

In this study, *Pab* denotes the probability of movement of pedestrian *b* in direction *a*, and *Db* denotes the drift strength of pedestrian b. Here, subscript *a* can be *F* (forward), *R*(right-cross), or *L*(left-cross); subscript *b* can be “1” (adult) or “2” (children). The following rules were formulated to decide how each generation is determined from the previous one:

$P_{F1}=D_1+(1-D_1)/3,\ P_{R1}=P_{L1}=(1-D_1)/3$ for configuration (a),

$P_{F1}=0, P_{R1}=P_{L1}=0.5$ for configuration (b),

$P_{F1}=1, P_{R1}=P_{L1}=0$ for configuration (c),

$P_{F1}=P_{R1}=0, P_{L1}=1$ for configuration (d),

$P_{F1}=P_{L1}=0, P_{R1}=1$ for configuration (e),

$P_{F1}=D_1+(1-D_1)/2,\ P_{R1}=0,\ P_{L1}=(1-D_1)/2$ for configuration (f),

$P_{F1}=D_1+(1-D_1)/2,\ P_{R1}=(1-D_1)/2, P_{L1}=0$ for configuration (g),

$P_{F1}=P_{R1}=P_{L1}=0$ for configuration (h),
$P_{F1}=D_1+(1-D_1)/3,\ P_{R1}=P_{L1}=(1-D_1)/3,$
$P_{F2}=D_2+(1-D_2)/3,\ P_{R2}=P_{L2}=(1-D_2)/3$
for configurations (i), (j), and (k),

$P_{F1}=P_{R1}=P_{L1}=0$ for configuration (l).

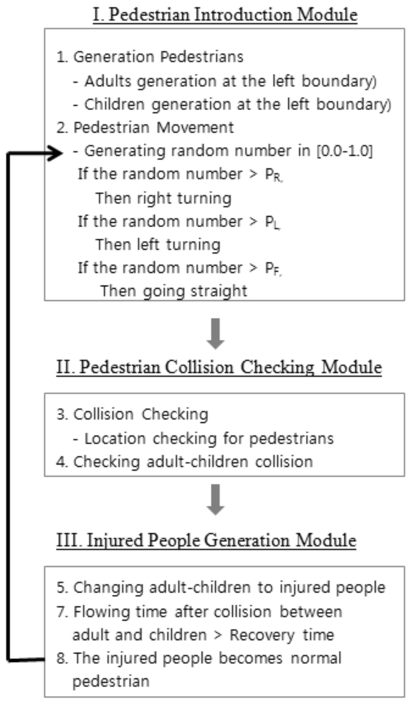
Injury can occur only when an adult and child collide. As soon as they collide, they become injured. When a child collides with another child or an adult collides with another adult, no injury occurs. This explains what will happen just after the injury events of (i), (j), or (k). Pedestrians behind injured people cannot move until the number of injured people continuously connected with each other reaches a given threshold value *k*. This value can be interpreted as a kind of morality of the pedestrians, which is important in areas with high pedestrian density. When more than one pedestrian competes for one cell, only one will be chosen randomly, with equal probability.

Similarly, the pedestrian transition probability *Pab* can be defined for the possible configurations when children may encounter children, adults, or injured people. In this simulation, I used the drift strengths of

D_1 = 0.9(adults) and D_2 = 0.5(children). I assumed that adults know where they are going, how to get there, and have a very low probability of being distracted on the way(purposeful and familiar), whereas children are relatively unsure of how to get there and as a result may get distracted(purposeful and unfamiliar).

3.2. Flow-Chart of the present model

To facilitate understanding for the relationship among moduls of the present model, flow-chart is presented as follows;



4. Simulation results

Figure 2 shows the time evolution of pedestrian distribution in the lattice space for children, injured people, and adults at t =1,000((a)-(c)), t= 5,000((d)-(f)), and t =15,000((g)-(i)), where $P_{children}$ = 0.5, P_{adults} = 0.8, k = 5, L = 200, and W = 60. Each solid dot represents a single pedestrian. While the patterns at snapshots of t = 1,000 and 5,000 showed typical well-moving flows, the snapshots at t = 15,000 represent the typical pattern of jamming. In this case, adults and children become injured

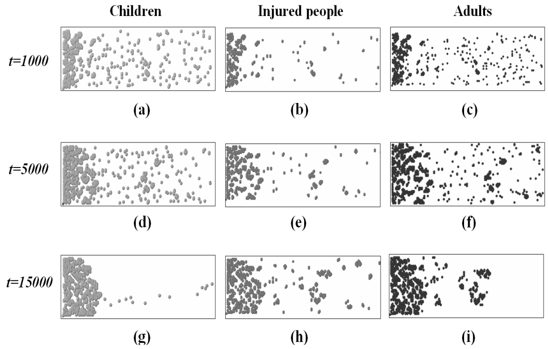


Fig. 2. Time evolution of patterns of pedestrians at (a)-(c) t=1,000;(d)-(f)t=5,000;and(g)-(i)t=15,000,where k=5,P_{adults}= 0.8, $P_{children}$= 0.5, L=200,and$W$=60.

people mostly near the entrance. This eventually causes pedestrian jamming.

I investigated the pedestrian flow rate J, where $\langle J_{adults} \rangle$ is for adults and $\langle J_{children} \rangle$ is for children, against different values of the entrance densities of P_{adults} and $P_{children}$. The flow rate is defined as the mean number of pedestrians moving through the exit per unit time for a sufficiently long time when the pedestrian flow reaches a steady state. The flow rate is measured by averaging 10 samples over 50 time steps. Figure 3 shows the plots of pedestrian flow versus P_{adults} for different $P_{children}$ at k = 2 and 6. As the values of $P_{children}$ became higher at morality k = 2, $\langle J_{children} \rangle$ decreases with P_{adults}(Fig. 3(a)), while $\langle J_{adults} \rangle$ increases with P_{adults}(Fig. 3(b)). With an increase in the number of adults entering the channel, the collision frequency between children and adults also increased. As mentioned above, whenever a collision occurred between a child and an adult, they became injured. Therefore, the number of children entering the channel decreased with the increase in collision frequency (Fig. 3(a)). Otherwise, even though the number of adults also decreased with increasing collision frequency, the higher P_{adults} value compensated sufficiently for the loss of adults. This is why $\langle J_{adults} \rangle$ increased with P_{adults} (Fig. 3(b)).

At higher values of k(k = 6), it was difficult for pedestrian flow to move owing to the higher morality, which acted as a major obstacle and eventually caused a lower flow rate of pedestrians(Figs. 3(c) and (d)).

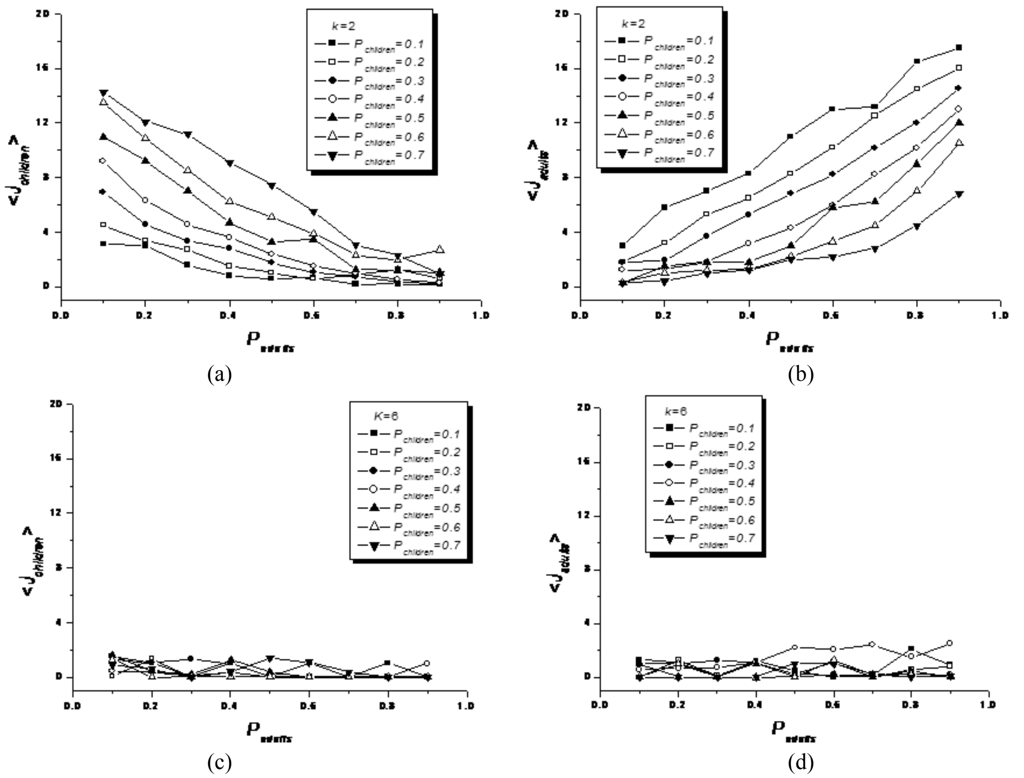


Fig. 3. (a) Saturation flow rate of children $<J_{children}>$ versus density of adults P_{adults} for various $P_{children}$ at morality k=2. (b) Saturation flow rate of adults $<J_{adults}>$ versus density of adults P_{adults} for various $P_{children}$ at k=2. (c) Saturation flow rate of children $<J_{children}>$ versus density of adults P_{adults} for various $P_{children}$ at morality k=6. (d) Saturation flow rate of adults $<J_{adults}>$ versus density of adults P_{adults} for various $P_{children}$ at k=6.

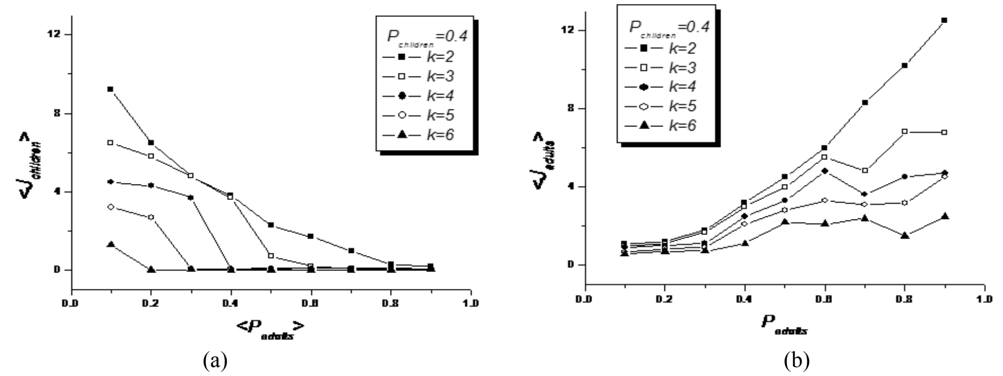


Fig. 4. Saturation flow rate of (a) children $J_{children}$ and (b) J_{adults} versus density of adults P_{adults} for morality k=2,3,4,5, and 6 when $P_{children}$=0.4.

Figure 4(a) shows the plots of saturated flow rates of children $<J_{children}>$ versus the entrance density of adults Padults for five different moralities(k = *2, 3, 4, 5,* and 6). The saturated flow rate $<J_{children}>$ decreased with increasing Padults. For k = 2, slow jamming occurred because the lower value of k played an important role in preventing the accumulation of injured people. The critical entrance density of pedestrians, P_c, indicated by

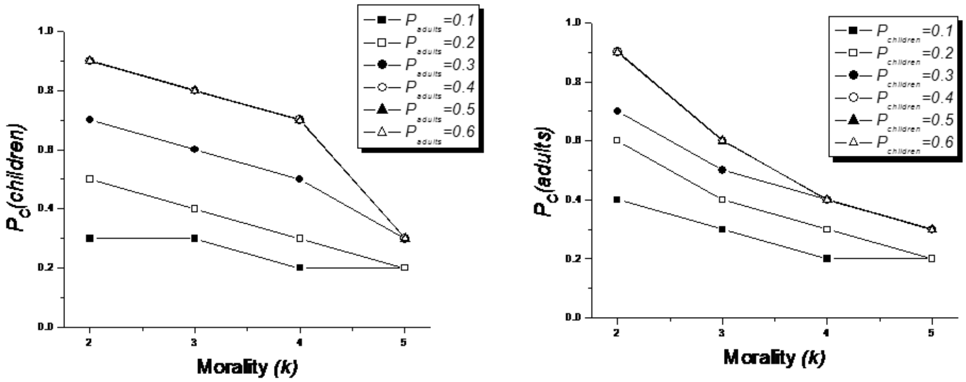


Fig. 5. (a) Plots of critical density P_c(children) for children entrance density $P_{children}$versus morality$k$.
(b) Plots of critical density P_c(adults) for adult entrance density P_{adults}versus morality$k$.

arrows was defined as the density when the saturated flow rate became almost zero. With increasing morality k, the critical entrance density P_c for children decreased. This is owing to the increase in injured people acting as “obstacles” in the vicinity of the entrance. Figure 4(b) shows the plots of the saturated flow rate of adults <J_{adults}> versus the entrance density of adults, P_{adults}. The saturated flow rate <J_{adults}> increased with increasing P_{adults}. The fluctuation in Jadults was attributed to the nonlinearity caused by the injured people. The trend of decrease($J_{children}$) or increase(J_{adults}) as shown in Fig. 4 can be explained in a manner similar to those for trends shown in Figs. 3(a) and (b).

Figure 5 shows the plot of the critical density P_c versus the morality k for (a) P_{adults} = 0.1–0.6, $P_{children}$ = 0.1–0.9 and (b) $P_{children}$ = 0.1–0.6, P_{adults} = 0.1–0.9. As morality increased, the critical density Pc for children or adults decreased. With larger morality, a pedestrian is confronted with a large obstacle posed by injured people. These obstacles impede the movement of the other competing pedestrians.

5. Discussions and conclusions

The simulation of traffic and pedestrian motion has attracted much attention in recent years. It is necessary to study the motion of pedestrians in various emergencies such as a fire in a room, because the obtained results can aid the development of space-efficient designs for the interiors of buildings, bridges, or heavily congested metropolitan areas. For example, it is useful to know how to lead persons through a shopping mall or how to increase the efficiency of an evacuation process onboard a cruise ship. The latter point is of interest to ship designers when they are designing corridors and stairs that can allow for fast evacuation while providing as many cabins as possible. It is also interesting for insurance companies to evaluate the risk to passengers on such a ship. In this study, I used a lattice model to understand the evacuation behavior of three types of competing pedestrians with morality in a pedestrian channel flow. A jamming transition occurred when the moving phase transformed to the jammed phase, at the critical entrance density of pedestrians, P_c. As morality increased, P_c decreased. I numerically proved that injured people and morality have a significant effect on pedestrian flow. To the best of my knowledge, this study is the first to show dynamical jamming transition occurring in pedestrian flow with three types of pedestrians with morality under open boundary conditions. The model I used in this study was considerably simplified in terms of pedestrian behavior in order to decrease the number of variables involved in mimicking real pedestrians. For this reason, the simulation results may deviate from real pedestrian behavior. However, this model has high potential for use by clients, practitioners, and developers in the decision-making process for the planning and design of pedestrian-frequented areas.

REFERENCES

1. Nagatani, T., "The physics of traffic jams," Reports on Progress in Physics 65, pp. 1331-1386, 2002.
2. Helbing, D., "Traffic and related self-driven many-particle systems," Reviews of Modern Physics 73, pp. 1067-1141, 2001.
3. Helbing, D. and Mulnar, P., "Social force model for pedestrian dynamics," Physical Review E 51, pp. 4282-4286, 1995.
4. Muramatsu, M., Irie, T., and Nagatani, T., "Jamming transition in pedestrian counter flow," Physica A 267, pp. 487-498, 1999.
5. Nagatani, T., "Dynamical transition and scaling in a mean-field model of pedestrian flow at a bottleneck," Physica A 300, pp. 558-566, 2001.
6. Burstedde, C., Klauck, K., Schadschneider, A., and Zittartz, J., "Simulation of pedestrian dynamics using a two-dimensional cellular automaton," Physica A 295, pp. 507-525, 2001.
7. Klupfel, H., Meyer-Konig, M., Wahle, J., Schreckenberg, M. in: S. Babdini, T. Worsch(Eds.), "Proceedings of the Fourth International Conference," CA, Springer, London, p.63, 2000.
8. Tajima, Y. and Nagatani, T., "Scaling behavior of crowd flow outside a hall," Physica A 292, pp. 545-554, 2001.
9. Nagel, K. and Schreckenberg, M., "A cellular automaton model for freeway trafic," Journal de Physic I France 2, pp. 2221-2229, 1992.
10. Muramatsu, M. and Nagatani, T., "Jamming transition in two-dimensional pedestrian traffic," Physica A 275, pp. 281-291, 2000.
11. Nagatani, T., "Jamming transition in the traffic-flow model with two level crossing," Physical Review E 48, pp. 3290-3294, 1993.
12. Helbing, D., Farkas, I., and Vicsek, T., "Simulating dynamical features of escape panic," Nature 407, pp. 487-490, 2000.
13. Helbing, D., Farkas, I., and Vicsek, T., "Freezing by heating in a driven mesoscopic system," Physical Review Letter 84, pp. 1240-1243, 2000.
14. Helbing, D., Isobe, M., Nagatani, T., Takimoto, K., "Lattice gas simulation of experimentally studied evacuation dynamics," Physical Review E 67, p.067101, 2003.
15. Nagatani, T., "Thermodynamic theory for the jamming transition in traffic flow," Phys. Rev. E 58, pp. 4271-4276, 1998.
16. Blue, V. J. and Adler, J. L., "Cellular automata microsimulation for modeling bi-directional pedestrian walkways," Transportation Research Part B 35, pp. 293-312, 2001.
17. Lee, S.-H., Park, J. H., and Pak, H. K., "Jamming transition in three types of competing pedestrians(adults, children and injured people) with morality, using a cellular automaton model," Journal of Korean Physical Society 44, pp. 660-663, 2004.
18. Henderson, L. F., "The Statistics of Crowd Fluids," Nature 229, pp. 381-383, 1971.
19. Tajima, Y., Takimoto, K., Nagatani, T., "Pattern formation and jamming transition in pedestrian counter flow," Physica A 294, pp. 257.

이 상 희 (sunchaos@nims.re.kr)

2005 부산대학교 물리학과 박사
2008 국가수리과학연구소 가상생태계 모델 개발 팀장
2009～현재 한국수리생물학회 운영위원
2010～현재 국가수리과학연구소 융복합수리과학연구부 부장

관심분야 : 생물행동 모델링, 생태계 모델링, 최적화 이론