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Towards TransiTUM: A generic framework for multiscale coupling of pedestrian simulation models based on transition zones

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Abstract

Existing pedestrian dynamics models differ in computational effort and their ability to authentically describe human movement behaviour. Hybrid approaches combine different models to speed up simulation time and to improve the results of the simulation. Current hybrid approaches can only combine a specific set of models. It is not possible to independently change the coupled models from the hybrid approach. Furthermore, transition of pedestrians between the different models is only possible at specific entry points. TransiTUM overcomes these issues and can combine any model if provided a certain set of parameters, which are common in pedestrian dynamics (e.g., pedestrians' positions, velocities). In this paper, the coupling of mesoscopic and microscopic scales is presented.

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1. Introduction

Pedestrian dynamics simulations can be divided into three different types (microscopic, mesoscopic and macroscopic) by their spatial resolution. In macroscopic models the scenario is reduced to a network of nodes and edges. The calculation itself is based on aggregated parameters of human crowds and not on the behaviour of individual pedestrians (Shiwakoti and Nakatsuji, 2005). Therefore, these kinds of pedestrian dynamics models are computationally efficient for the price of low spatial resolution. Many macroscopic models draw from the theory of fluid mechanics. For example, Henderson (1974) adopted the gas kinetic Boltzmann transport equation to describe the motion of crowds. The Lighthill-Whitham-Richards (LWR) model (Lighthill and Whitham, 1955a,b; Richards, 1956) and its variants (Hughes, 2003; Kachroo, 2009) are based on the continuity equation of fluid dynamics. These approaches are often simplified to one spatial dimension to reduce the complexity of the problem (Colombo and Rosini, 2005; Hartmann and Sivers, 2013). The second important kind of macroscopic simulations is the network flow model. These models calculate the smallest amount of time pedestrians need to exit a given network scenario (Burkard et al., 1993; Tjandra, 2003).

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Mesoscopic models, which are carried out by cellular automatons (Blue and Adler, 2001), have typically a finer spatial resolution associated with increasing computational effort. Therefore, the complete scenario needs to be split up into a regular grid. Each cell of the grid has an equal size and contains one or zero persons (Schadschneider et al., 2009). In pedestrian dynamics, unit cells have rectangular (Varas et al., 2007; Ji et al., 2013) or hexagonal (Hartmann, 2010) shapes. Both geometries have advantages and disadvantages (Birch et al., 2007). A finite set of rules routes the pedestrians locally, according to its boundary conditions, through the scenario (Schadschneider, 2001; Ji et al., 2013). Since the spatial resolution is restricted by the size of the unit cell, the pedestrians move cell-wise to their targets. This motion behaviour causes artefacts in comparison to pure euclidean movement (Köster et al., 2011).

Microscopic models simulate pedestrians, similar to cellular automatons, as discrete singular objects. However, the simulation scenario is in continuous space. For this reason, the spatial resolution is only limited by computational accuracy. Many microscopic models, like the social force (Helbing et al., 2002) or the centrifugal model (Yu et al., 2005), are based on physical principles. In these concepts, each object in the scenario has its own potential. The superposition of all forces controls the equations of the motion of crowds. Another microscopic approach is the use of utility maximisation (Hoogendoorn and Bovy, 2004). It is based on the assumption that each pedestrian locally optimises his or her walking behaviour by choosing the route with the least effort. Since an improvement in spatial resolution increases the computational effort, scenarios with large crowds can not be simulated by very detailed models in reasonable time. Usually, good simulation accuracy can be achieved even though only a small part of the total scenario is simulated in detail, while the remaining parts are calculated roughly. Furthermore, some models are more suitable to reproduce special pedestrian dynamic phenomena than others (Duives et al., 2013). In both cases, it is necessary to simulate different parts of the scenario with different pedestrian dynamic models. Since persons can exceed the borders between coupled models, transition rules have to be applied to ensure a coherent transition.

Various hybrid models exist, which carry out these tasks. Anh et al. combine a LWR-model with an agent based Leader-Follower approach to simulate evacuation behaviour on a road network. The straight parts of the streets are calculated by the macroscopic model and the cross-section, in which the pedestrians choose their next target, are simulated in the microscopic scale. Chooramun et al. (2012) designed a concept in which three scales are coupled into one hybrid model to investigate large area evacuations. The models are encapsulated in compartments (e.g., rooms) and connected by small local transition regions (e.g., doors). A coupling of two scales is presented by Xiong et al. (2010). They simulated multiple partitions of a corridor with a microscopic and a macroscopic models. Transition cells are defined on the shared borders of unequal model types.

Current hybrid models have two common weaknesses. The transition of pedestrians between coupled models is limited on elected regions of the boundary (e.g., doors, cross-sections). Therefore, a transition is not possible on the whole border of a model. This approach is sufficient for restricted scenarios (e.g., road networks, buildings) in which the transition can simply happen on local nodes (e.g., cross-sections, doors), but it is inadequate for settings on open areas (e.g., public events). In these scenarios, persons can enter a region from any direction. Therefore, the whole border of a coupled model has to be able to transmit pedestrians to adjacent models. Another weak point of state-of-the-art hybrid modelling is the inflexibility of exchanging the combined models. There is no broad framework which supplies a method to connect arbitrary pedestrian dynamic models. Therefore, we develop TransiTUM, a generic transition framework based on transition zones. In the following we propose a first approach to solve the mentioned problems (see Figure 1a) for the coupling of a cellular automaton and a microscopic model.

2. Composition of the transition framework

The proposed transition framework couples a more detailed model with a more coarse model. The scenario is separated by these models into two independent parts. Each model has knowledge solely about components of the setting which are inside its own layer. The transition framework itself knows about all layers of the scenario. If pedestrians approach the border of their current scale they get transmitted by TransiTUM to the adjacent scale. Therefore, a shared set of parameter has to be assigned to the pedestrians. The minimum set contains the current velocity $\vec{v}_i$, the next target $\vec{z}_i$, the diameter $d_{ped,i}$ and the current position $\vec{o}_i$ for each pedestrian P_i. The index i flags pedestrians in the microscopic model, while the index j flags pedestrians of the mesoscopic model. Additionally, a global peak speed v_{max} and the duration of time steps for each scale (Δt_{ds}, Δt_{cs} respectively) is necessary. These parameters are sufficient for successful transformations. The coupled models export parameters after each simulation time step. TransiTUM reads and modifies this data to enforce the transition of pedestrians. Before the next simulation step, the models import

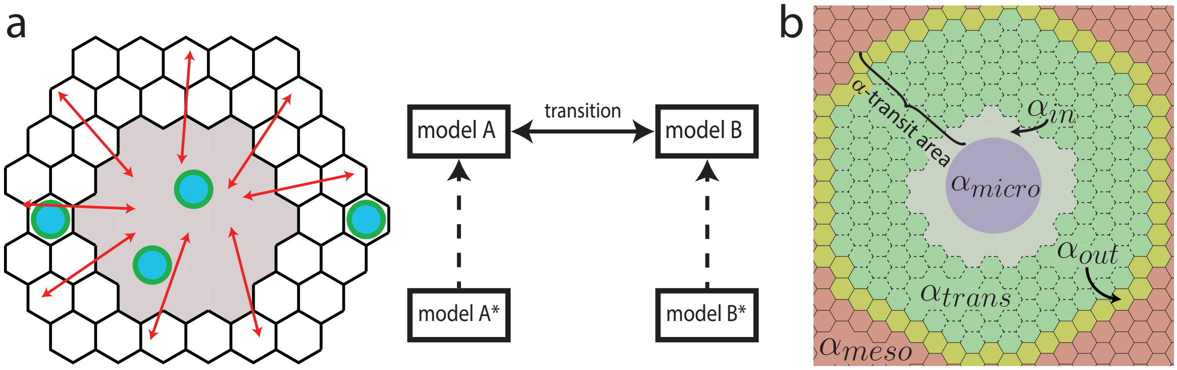

Fig. 1. (a) Direction independent transition and flexible exchange of models. (b) Components of the transit area.

the modified parameters and execute the simulation based on that information. The transformation of persons from one scale to another is based on the position of the pedestrians $\vec{o}_i$. If a pedestrian entity is put into another model, it is deleted from its current scale and added in the new scale at the nearest possible position (see Section 3). If a pedestrian is placed in one cell of the mesoscopic grid, no further pedestrians can access this cell, since a cell has a maximum capacity of one person. The composition of the transit system is shown in Figure 1b. The microscopic and mesoscopic models plus the α-transit area specify the scenario. The mesoscopic model simulates on the α_{meso}- , α_{out}- and α_{trans}-areas, while the microscopic model simulates the α_{micro}-, α_{in}- and α_{trans}-areas. So the α_{trans}-area of the scenario is calculated by both coupled models. In this area, the transformation between the different models takes place. Only pedestrians inside α_{trans} can be transmitted to another scale. Since no pedestrian should reach the borders of his current model during one mesoscopic time step Δt_{cs}, the width r_{trans} of the α_{trans}-area has to be large enough:

$$r_{trans} = v_{max} \cdot \Delta t_{cs} \tag{1}$$

This distance is sufficient, since a transition is executed after each time step Δt_{cs} and since no pedestrian can be faster than v_{max}. We define the areas α_{in} and α_{out} as relaxation zones. If pedestrians are converted to another scale, they mostly have to be shifted to a slightly different position in the scenario. The artefacts caused by the conversion event can decay in the relaxation zones. Therefore, simulation results taken from α_{in} respectively α_{out} have to be considered carefully. Due to the relaxation zones, the outcome of α_{meso} and α_{micro} should be free of any transition artefacts.

Another problem arises, if the next destination of a person is located outside of his current layer. Then the vector $\vec{z}_i$ has to be truncated to the borders of the actual scale (see Figure 2a) until this person gets transformed.

Different pedestrian dynamic models can have different duration of time steps. Therefore, a generic framework has to support the coupling of models with unequal time steps. Since a finer spatial resolution requires a smaller time resolution, it is assumed that $\Delta t_{ds} \leq \Delta t_{cs}$. For each coarse time step, $\frac{\Delta t_{cs}}{\Delta t_{ds}} \geq 1$ detailed time steps are necessary to reach the same amount of simulation time. This proportion is usually no natural number, so the detailed steps do not match exactly the duration of the coarse time step. The surplus fractions $\Delta t_{frac} < \Delta t_{ds}$ gets add up in the following k simulation steps till $\sum_k \Delta t_{frac} \geq \Delta t_{ds}$. At that time, an additional time step Δt_{ds} is executed. The necessary number d_n of detailed time steps Δt_{ds} to match the nth time step Δt_{cs} can be calculated by:

$$d_n = \left\lfloor n \frac{\Delta t_{cs}}{\Delta t_{ds}} \right\rfloor - \left\lfloor (n-1) \frac{\Delta t_{cs}}{\Delta t_{ds}} \right\rfloor \tag{2}$$

After the execution of the nth mesoscopic time step Δt_{cs}, an amount of $d_n + 1$ microscopic time steps Δt_{ds} are executed(see Figure 2b). Subsequently, the interpolation and transition phase is carried out (see Figure 2c). The interpolation of pedestrian positions is necessary to bring the mesoscopic and microscopic time steps in line for the transformation. We have information about the microscopic positions at the time steps d_n and $d_n + 1$, but the positions at the simulation time step n are required. So we need to interpolate the microscopic positions from $\vec{o}_i$ to $\vec{o}_i^*$:

$$\vec{o}_i^* = \vec{o}_i + \vec{v}_\alpha \cdot \Delta t_\alpha \tag{3}$$

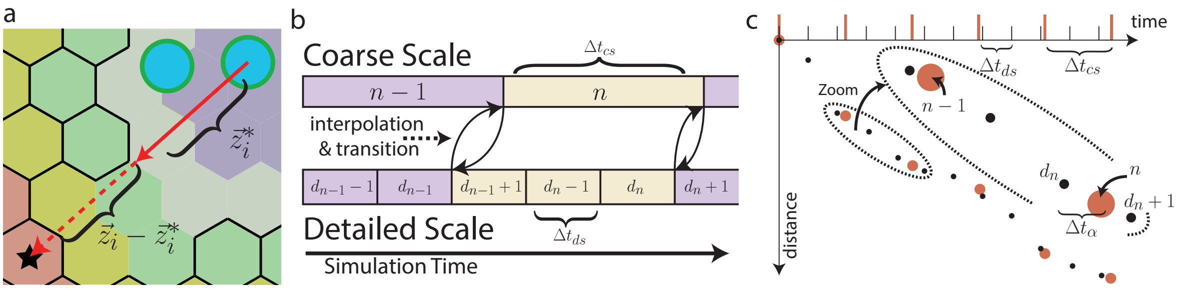

Fig. 2. (a) Reduced target vector $\vec{z}_i$. (b) Time flow of the detailed and the coarse scale. (c) Interpolation of a pedestrian's positions from the d_nth microscopic to the nth mesoscopic step. Small black dots are microscopic and the large red dots mesoscopic positions.

Parameter Δt_α is the time interval from the d_nth microscopic to the nth mesoscopic step. The velocity $\vec{v}_\alpha$ can be calculated by the weighted average value of the velocities $\vec{v}_{d_n}$ and $\vec{v}_{d_n+1}$:

$$\vec{v}_\alpha = \vec{v}_{d_n}\left(1 - \frac{\Delta t_\alpha}{\Delta t_{ds}}\right) + \vec{v}_{d_{n+1}}\frac{\Delta t_\alpha}{\Delta t_{ds}} \quad (4)$$

The procedure for the estimation from the nth mesoscopic to the d_nth microscopic step is similar. However, given the fact that the $(n+1)$th mesoscopic time step is not calculated yet (see Figure 2b), an extrapolation from the nth mesoscopic step has to be executed to find $\vec{\sigma}^*_j$:

$$\vec{\sigma}^*_j = \vec{\sigma}_j + \vec{v}_n\left(\Delta t_{ds} - \Delta t_\alpha\right) \quad (5)$$

After the positions were inter- and extrapolated, the transformation of the pedestrians can be carried out.

3. Transition of the pedestrians

The propagated movement vector $\vec{\sigma}_i$ is calculated for all microscopic pedestrians P_i in the area of α_{trans}.

$$\vec{\sigma}_i = \frac{\vec{v}_i}{v_i} \cdot v_{max} \cdot \Delta t_{cs} \quad (6)$$

A pedestrian can be transformed if his vector $\vec{\sigma}_i$ approaches the area of α_{out}. So only persons, who approach the borders of the microscopic model, can be converted to the mesoscopic scale (see Figure3a). A microscopic person P_i can intersect multiple unoccupied cells. Next all pedestrians P_i are considered, who intersect at least one ”singular-manned” cells. A cell $c_{m,n}$ is ”singular-manned” if exactly one person intersects this cell $c_{m,n}$. The pedestrians are placed in their ”singular-manned” cell with the lowest d_{CoM} value:

$$d_{CoM} = \left|\vec{\sigma}_i - \vec{S}_{c_{m,n}}\right| \quad (7)$$

Equation 7 calculates the distance between the center-of-mass of the pedestrian P_i and of the cell $c_{m,n}$ (see Figure 3b). The remaining P_i are staying on cells, which are manned by multiple persons. These cells get occupied by the pedestrian with the lowest d^*_{CoM} value (see Figure 3c). Individuals, who are still not transformed, intersect solely with cells which are not accessible. So the nearest free cell $c^*_{m,n}$ inside of α_{trans} has to be found for these persons (see Figure 3d). Therefore, all cells with $d_{CoM} \leq r_{place}$ are examined to find the cell with the lowest d_{CoM} value for each remaining P_i. If $d_{CoM} > r_{place}$ the mistake of translating the pedestrian to his nearest cell is larger than refusing the transition of P_i for one time step. The assumption $r_{place} = v_{max} \cdot \Delta t_{cs}$ seems reasonable since a pedestrian can have a maximum speed of v_{max} and the time between two transition phases is Δt_{cs} long. After the cells $c^*_{m,n}$ are determined for all remaining P_i, the pedestrian with the lowest d_{CoM} value is transmitted to his preferred cell $c^*_{m,n}$. If other pedestrians have the same $c^*_{m,n}$, they have to calculate a new nearest cell. If a person can not find an accessible cell, he does not get transformed during the current transition phase. The process is repeated until all P_i are transmitted to the mesoscopic scale.

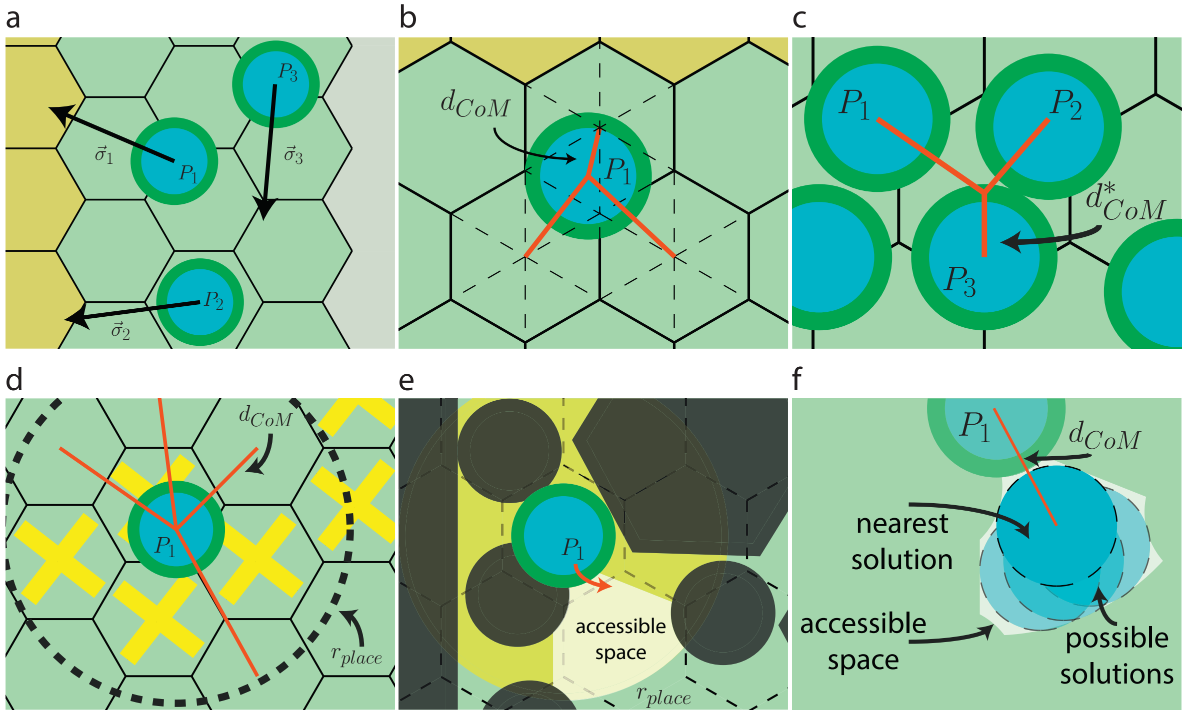

Fig. 3. (a) P_1 and P_2 will be transformed since their propagation vectors $\vec{\sigma}_1$ and $\vec{\sigma}_2$ reach the mesoscopic scale. (b) P_1 is transformed to the cell with the lowest distance d_{CoM}. (c) P_3 is put into the cell due to the lowest d^*_{CoM} compared to P_2 and P_3. (d) Search for the nearest free cell, yellow-crossed cells are not accessible. (e) Collision detection to find accessible space. (f) Selection of the nearest solution.

By the transition from mesoscopic to the microscopic scale, sufficiently large areas have to be found in the continuous space. Since a pedestrian is assumed as having a circular shape, the minimum needed space is $\frac{1}{4}\pi d^2_{ped,i}$ with $d_{ped,i}$ as the pedestrian's diameter. At first, the propagation vector $\vec{\sigma}_j$ is calculated for each mesoscopic pedestrian P_j in α_{trans}:

$$\vec{\sigma}_j = \frac{\vec{v}_j}{v_j} \cdot v_{max} \cdot \Delta t_{cs} \tag{8}$$

If $\vec{\sigma}_j$ intersects α_{in}, the person can be transformed to the microscopic scale. Based on the centre-of-mass of the pedestrian's current cell $S_{c_{m,n}}$, 2D-collision detection tests (Lin, 1993) are executed to find accessible space to place P_i in the microscopic scale (see Figure 3e). Thereby, only pedestrians with $d_{CoM} \leq r_{place}$ are considered. If multiple solutions are possible, the spot with the lowest d_{CoM} value is chosen (see Figure 3f). In the case, that no solution could be found, the pedestrian does not get transformed in the current transition phase.

4. Conclusion

In this paper, the first part of the transition framework TransiTUM was introduced. Doing so, the coupling of microscopic models with cellular automatons was presented. TransiTUM overcomes two main issues of current hybrid modelling. Firstly, it is independent of the connected models and can be applied to any pair of microscopic and mesoscopic models. The coupled models export their current position at the end of each time step Δt_{cs} to an external data file. TransiTUM executes the transition by modifying this data file. At the beginning of each time step Δt_{cs}, the coupled models import the new positions to start the next simulation steps. Therefore, the simulation is executed independently from the transition of pedestrians. Secondly, pedestrians can enter the transit area from any direction. Furthermore, a coupling of different time scales is possible, since TransiTUM matches unequal time steps by interand extrapolation routines during the transition phase. If pedestrians get transmitted to another model, they are placed in the nearest possible position or into the closest cell to reduce conversion artefacts. Relaxation zones between the coupled models help to minimise left over disruptions. In further research, the coupling of mesoscopic models with the macroscopic scale will be developed. In addition, we plan to develop a zoom-aproach which allows to dynamically switch the applied simulation model for a given region of interest.

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References

Anh, N., Daniel, Z., Du, N., . A hybrid macro-micro pedestrians evacuation model to speed up simulation in road networks. Advanced Agent Technology , 371–383.

Birch, C.P., Oom, S.P., Beecham, J.A., 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. Ecological Modelling 206, 347–359.

Blue, V.J., Adler, J.L., 2001. Cellular automata microsimulation for modeling bi-directional pedestrian walkways. Transportation Research Part B: Methodological 35, 293–312.

Burkard, R., Dlaska, K., Klinz, B., 1993. The quickest flow problem. Zeitschrift für Operations Research 37, 31–58.

Chooramun, N., Lawrence, P.J., Galea, E.R., 2012. An agent based evacuation model utilising hybrid space discretisation. Safety Science 50, 1685–1694.

Colombo, R., Rosini, M., 2005. Pedestrian flows and non classical shocks. Mathematical Methods in the Applied Sciences , 1–17.

Duives, D., Daamen, W., Hoogendoorn, S., 2013. State-of-the-art crowd motion simulation models. Transportation Research Part C .

Hartmann, D., 2010. Adaptive pedestrian dynamics based on geodesics. New Journal of Physics 12, 043032.

Hartmann, D., Sivers, I.V., 2013. Structured first order conservation models for pedestrian dynamics. Networks and Heterogeneous Media 8, 985–1007.

Helbing, D., Farkas, I.J., Molnar, P., Vicsek, T., 2002. Simulation of pedestrian crowds in normal and evacuation situations. Pedestrian and evacuation dynamics 21, 21–58.

Henderson, L., 1974. On the fluid mechanics of human crowd motion. Transportation research .

Hoogendoorn, S.P., Bovy, P.H.L., 2004. Pedestrian route-choice and activity scheduling theory and models. Transportation Research Part B: Methodological 38, 169–190.

Hughes, R., 2003. The flow of human crowds. Annual review of fluid mechanics 35, 169–182.

Ji, X., Zhou, X., Ran, B., 2013. A cell-based study on pedestrian acceleration and overtaking in a transfer station corridor. Physica A: Statistical Mechanics and its Applications 392, 1828–1839.

Kachroo, P., 2009. Pedestrian dynamics: Mathematical theory and evacuation control. CRC Press.

Köster, G., Hartmann, D., Klein, W., 2011. Microscopic pedestrian simulations: From passenger exchange times to regional evacuation , 571–576.

Lighthill, M.J., Whitham, G.B., 1955a. On Kinematic Waves. I. Flood Movement in Long Rivers. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 229, 281–316.

Lighthill, M.J., Whitham, G.B., 1955b. On Kinematic Waves. II. A Theory of Traffic Flow on Long Crowded Roads. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 229, 317–345.

Lin, M., 1993. Efficient Collision Detection for Animation and Robotics. Ph.D. thesis.

Richards, P., 1956. Shock waves on the highway. Operations research 4, 42–51.

Schadschneider, A., 2001. Cellular automaton approach to pedestrian dynamics-theory. arXiv preprint cond-mat/0112117 .

Schadschneider, A., Klingsch, W., Klüpfel, H., Kretz, T., Rogsch, C., Seyfried, A., 2009. Evacuation dynamics: Empirical results, modeling and applications. Springer. pp. 3142–3176.

Shiwakoti, N., Nakatsuji, T., 2005. Pedestrian simulations using microscopic and macroscopic model. Infrastructure Planning , 1–4.

Tjandra, S., 2003. Dynamic network optimization with application to the evacuation problem. Ph.D. thesis.

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

Xiong, M., Lees, M., Cai, W., Zhou, S., Low, M.Y.H., 2010. Hybrid modelling of crowd simulation. Procedia Computer Science 1, 57–65.

Yu, W.J., Chen, R., Dong, L.Y., Dai, S.Q., 2005. Centrifugal force model for pedestrian dynamics. Physics Review E 72, 26112–26117.