CA Model for Bidirectional Flow in a Corridor

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Contents

Goal and Motivation

Practical Applications

- Urban planning
- Evacuation processes
- Busy crowded areas (e.g. concerts)

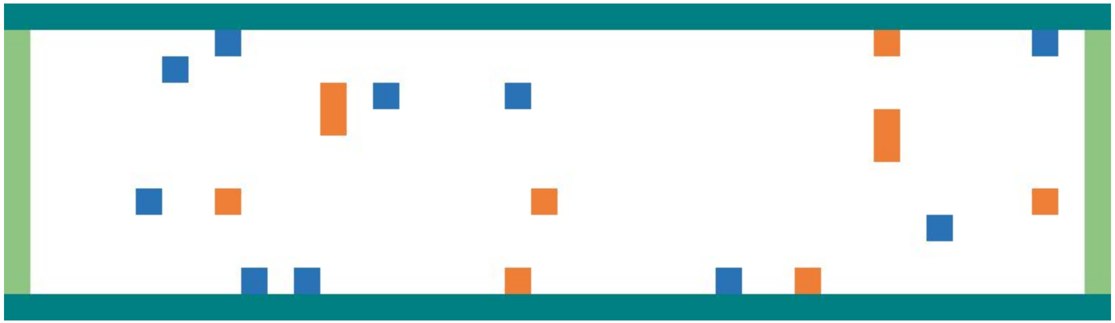
Crowd behaviour

- Lane formation
- Congestion

Research Questions

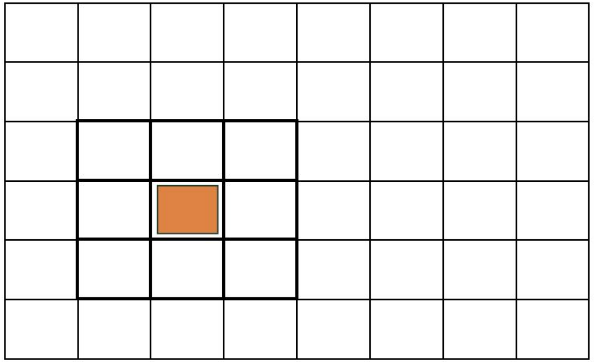
- What is the optimal pedestrian density at which lane formation emerges in the floor field automaton model?
- What is the influence of a horizontal bias on lane formation?
- What is the critical density for congestion?
- What is the influence of corridor height and width on lane formation? (In Appendix)

Model: Bidirectional Flow in an Infinite Corridor



- Agents that want to exit in the right
- Agents that want to exit in the left

Floor Field Model



- 2D cellular automata
- Moore neighbourhood
- a static and dynamic floor field for each agent type

Floor Field Cellular Automaton

$$p_{ij} = \frac{1}{Z} \exp\left(k_S S_{ij} + k_D D_{ij}\right) \xi_{ij}$$

k_S - static field coupling constant

k_D - dynamic field coupling constant

S_{ij} - static field

D_{ij} - dynamic field

ξ_{ij} - factor which is 0 for occupied cells and 1 for unoccupied ones

Z - normalization factor

Static Floor Fields

7	6	5	4	3	2	1	0
7	6	5	4	3	2	1	0
7	6	5	4	3	2	1	0
7	6	5	4	3	2	1	0
7	6	5	4	3	2	1	0
7	6	5	4	3	2	1	0

Static Floor Field 1

Agents move from the left to the right

0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7

Static Floor Field 2

Agents move from the right to the left

Dynamic Floor Fields

The dynamic floor field is a virtual layer that records movement, where particles leave temporary traces that attract others to follow the same path. The value for each cell is obtained with:

$$D_{ij}(t+1) = (1-\delta)\left[D_{ij}(t) + \frac{\alpha}{4}\Delta D_{ij}(t)\right]$$

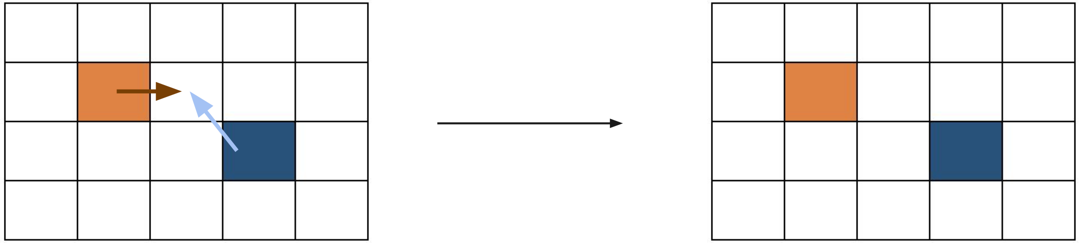
Where,

$$\Delta D_{ij}(t) = D_{i,j+1}(t) + D_{i,j-1}(t) + D_{i+1,j}(t) + D_{i-1,j}(t) - 4D_{i,j}(t)$$

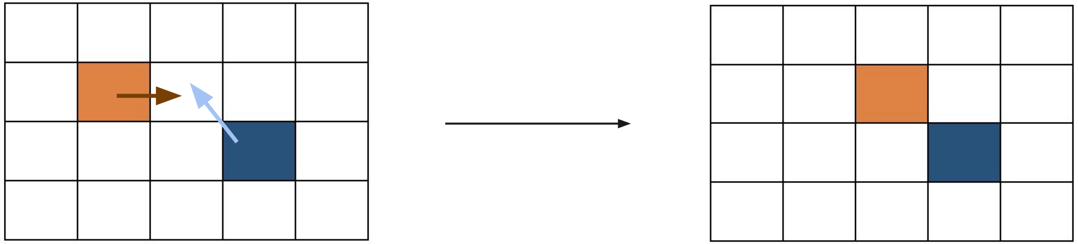
		0.07	0.08	0.08	0.06	0.01
	X	0.63	0.45	0.31	0.19	0.05
		0.07	0.08	0.08	0.06	0.01

Conflicts

If there is a conflict, there is a μ probability that it is not solved and both agents stay in the same place



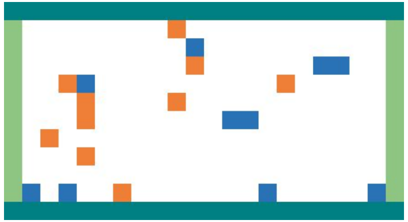
And a probability 1- μ that the conflict is solved and one agent is randomly chosen to move to the new position



Order Parameter for Lane Formation

In order to quantify the lane structure in the system, we use an order parameter given by:

$$\Phi = \frac{1}{N} \sum_{n=1}^{N} \left(\frac{N_{i_n}^{A} - N_{i_n}^{B}}{N_{i_n}^{A} + N_{i_n}^{B}} \right)^2$$

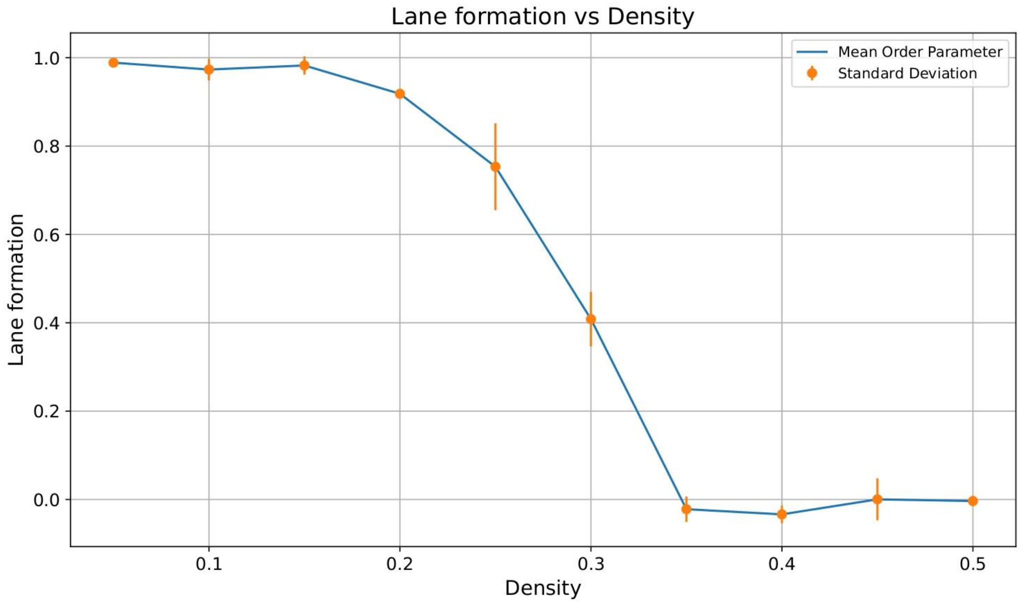


For our simulations we use the reduced order parameter:

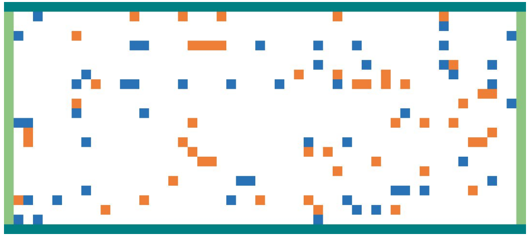
$$\tilde{\Phi} = \frac{\Phi - \Phi_0}{1 - \Phi_0}.$$

where Φ_0 is the mean value of Φ r the case where all particles are distributed at random.

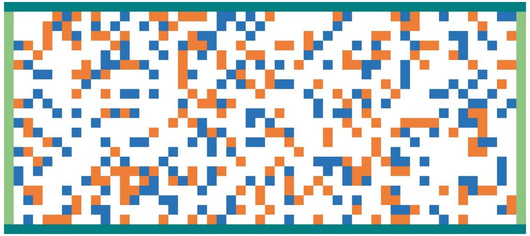
Influence of Density on Lane Formation



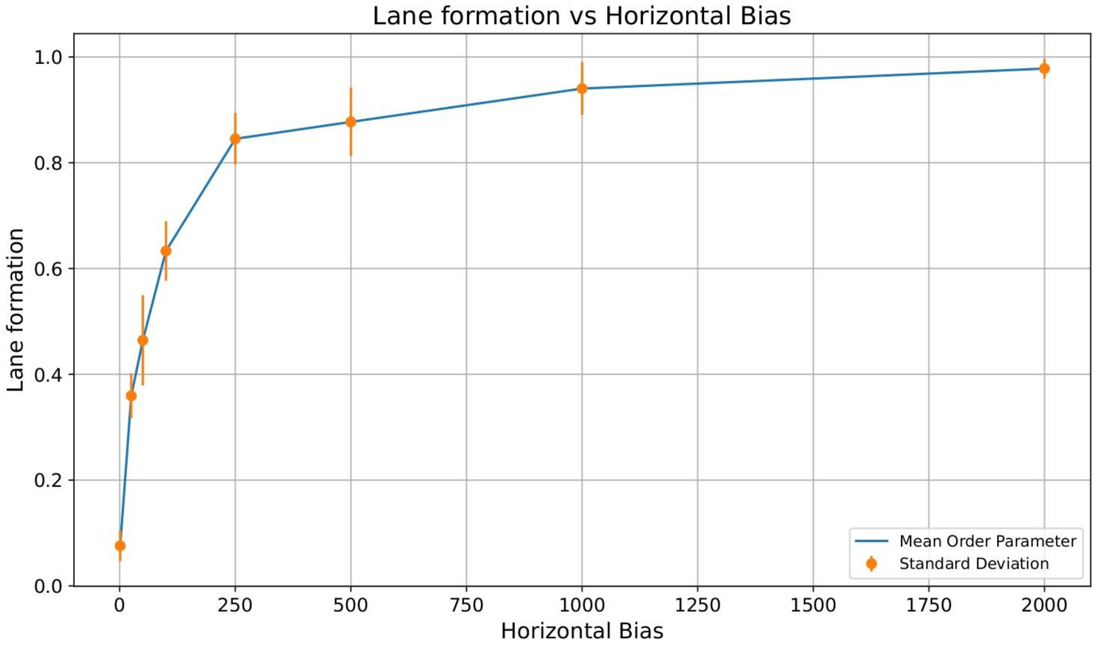
Density of 0.1:



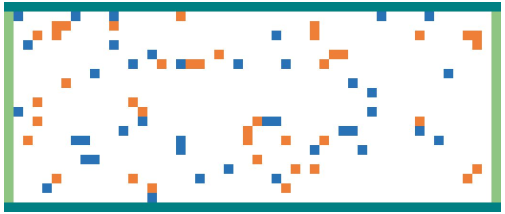
Density of 0.4:



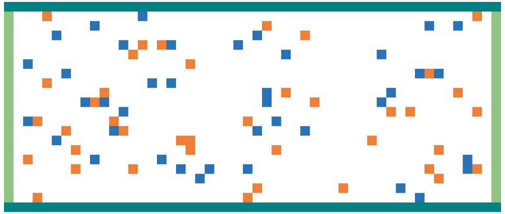
Horizontal Bias Parameter



horizontal bias=1



horizontal bias=2000



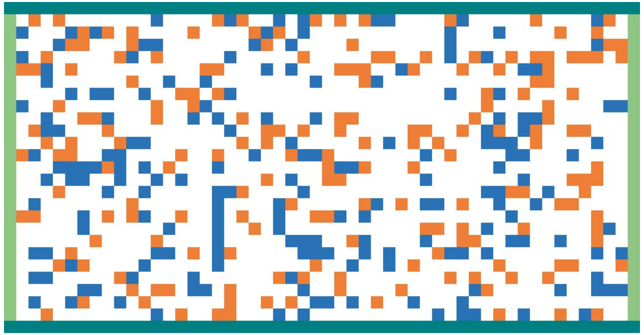
Metric for Congestion

Congestion Ratio:

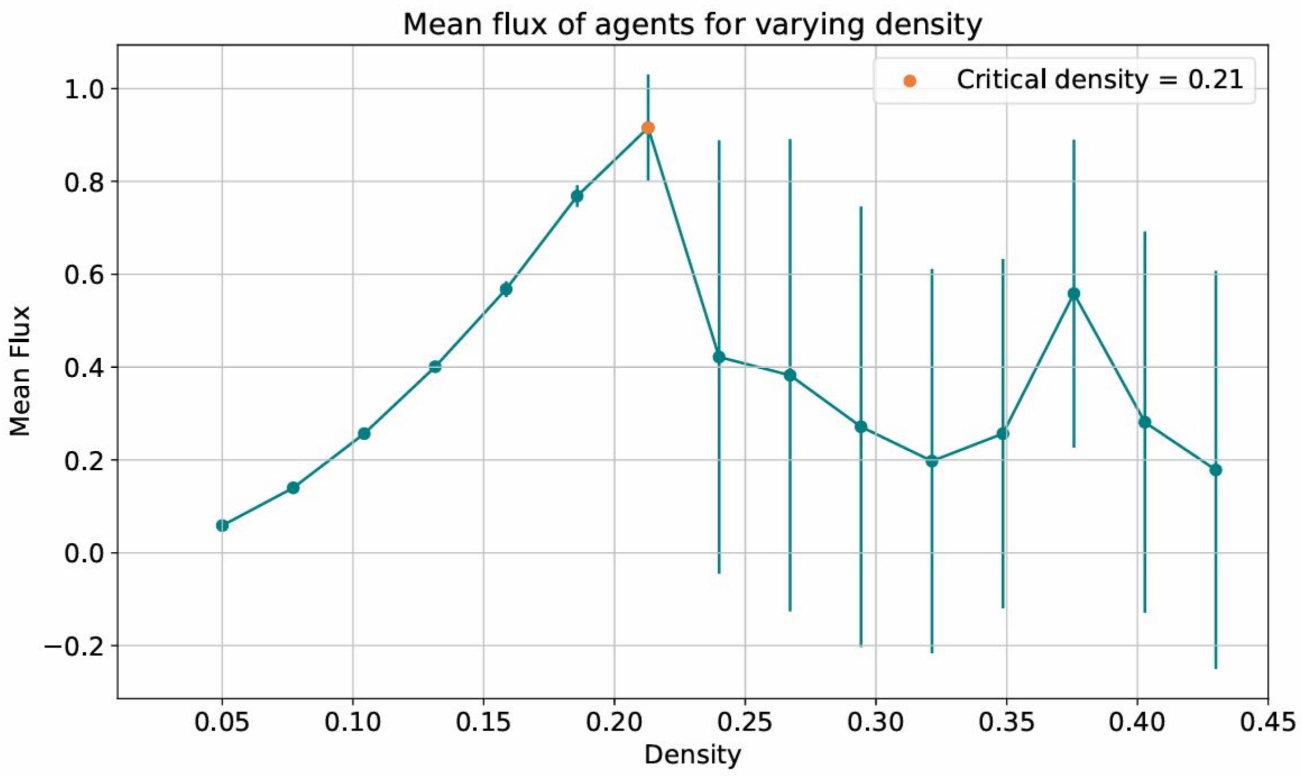
$$\mathrm{CR} = \frac{N_{\mathrm{congested}}}{N_{\mathrm{total}}}$$

Agent Flux:

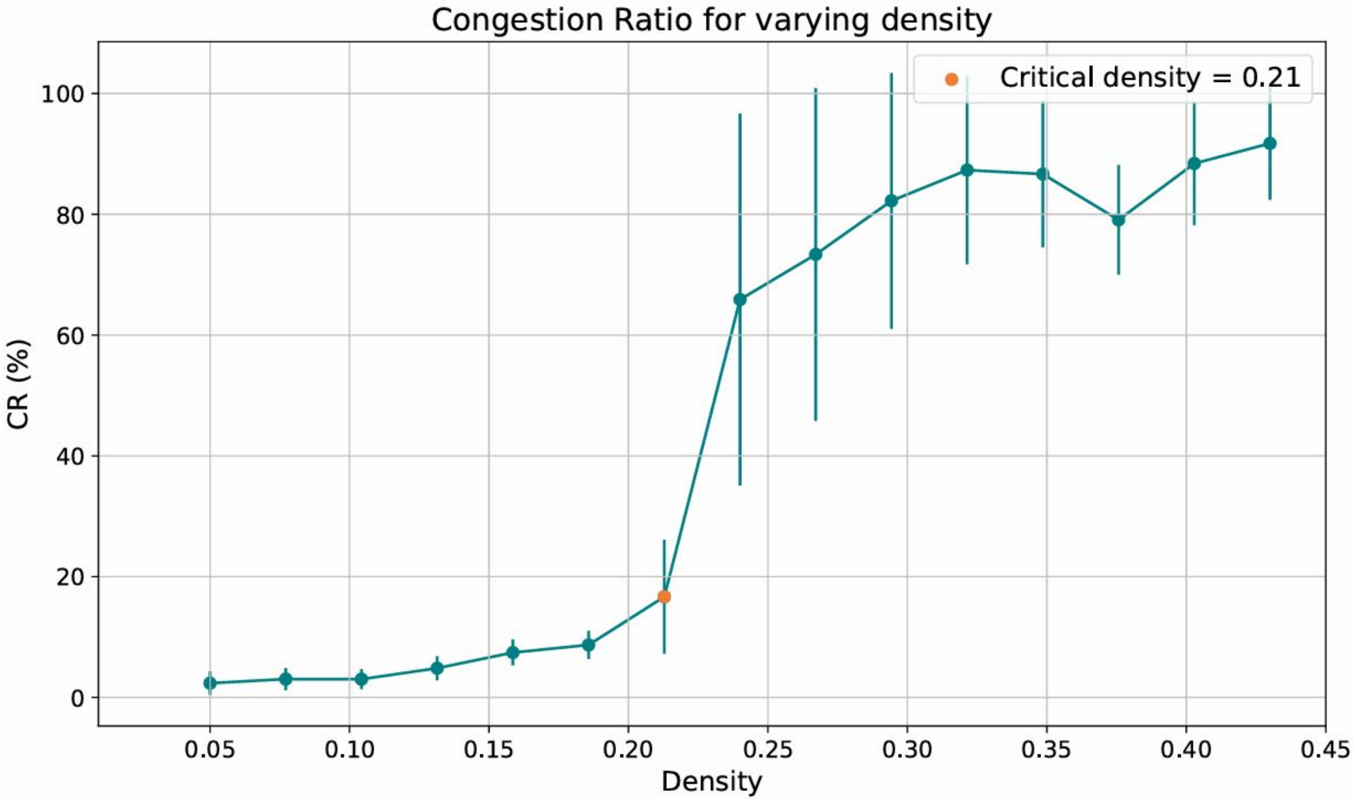
$$F = \rho \cdot v$$



Critical density for Congestion



Congestion Ratio



Conclusions

Observed Emergence: Each pedestrian responds to immediate surroundings, leading to global patterns:

- **Lane Formation** (**Self-Organization**): pedestrians naturally align their movement with others, minimizing interference and optimizing flow.
- **Congestion** (**Phase Transition**): as pedestrian density increases, movement transitions from a free-flowing state to congestion.

Conclusions:

- Lane formation was observed (for lower densities)
- Congestion was observed (for higher densities)
- A horizontal bias factor increases lane formation

Future Work

- Implement swapping
- Looking into how swapping can affect the percolation rate of the congestion
- Adding objects
- Changing structure (e.g. T-shape)

References

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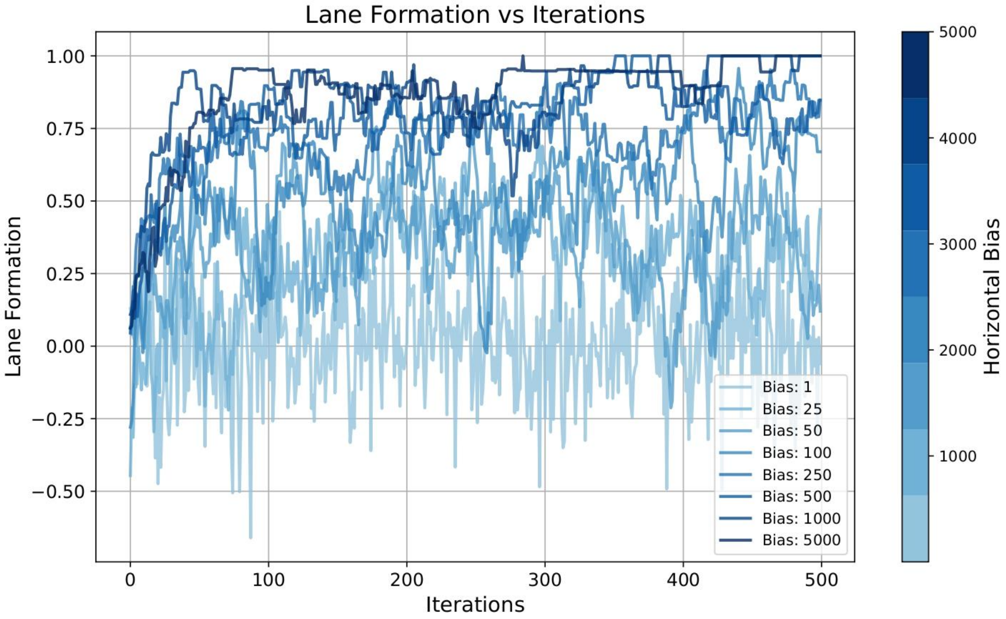
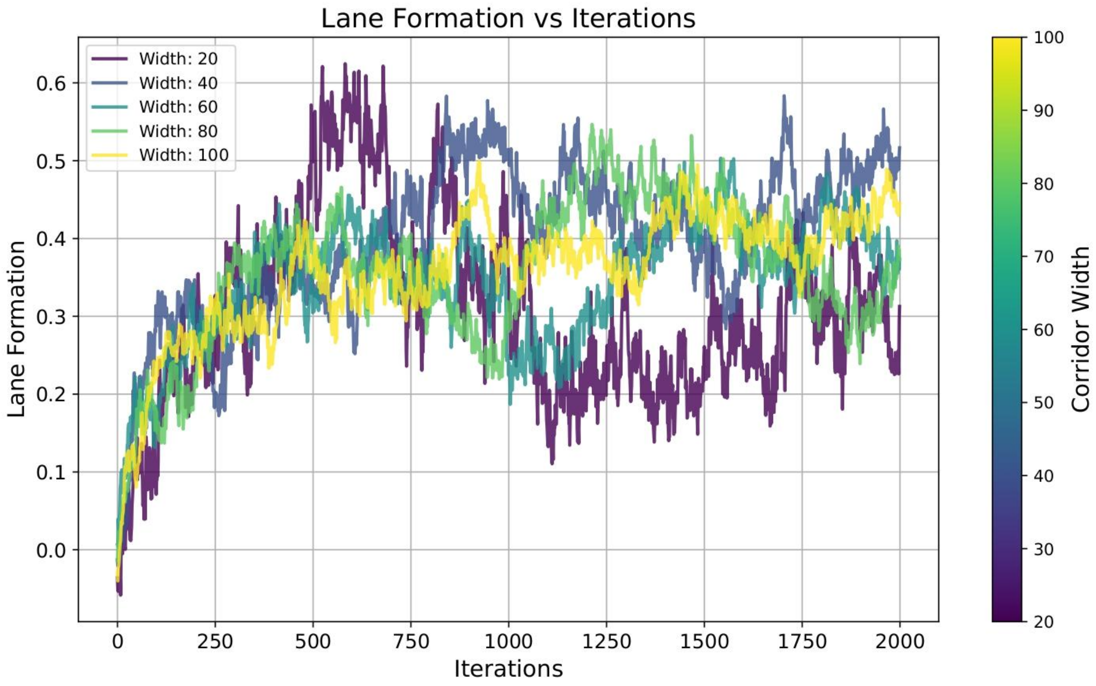
- Wang, Z., Chen, T., Wang, Y., Li, H.(2024). A cellular automaton model for mixed traffic flow considering the size of CAV platoon. Physica A: Statistical Mechanics and its Applications, 643

Extra Slides



Dependence of Lane Formation on Corridor Width



Dependence of Lane Formation on Corridor Length