Research Skills: Evacuation Project

Towards a safety-driven design for school halls

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Outline

Introduction

Background, Motivation, and Aims

- Stakeholder: City of Bristol
  - a hall to be built for a secondary school.
- Motivation:
  - public education spaces are getting crowded;
  - fires and terrorist attacks require emergency evacuation;
  - faster evacuation during emergencies preserves lives;
  - regulators call for evidence-based recommendations[1];
  - transfer learning between construction and safety design.
- Design goals:
  - incorporate realism in a computational model of evacuation;
  - investigate:
    1. hall shapes;
    2. location of exits;
    3. existence of poles near exits.

[1] https://cdr.leeds.ac.uk/project-evacuation/

Mathematical Modelling

Modelling Assumptions: Agents, Environment, and Threat

- Two agent species: students and teachers
- Number of students: 200
- Number of teachers: 5
- Number of exits: 2 (or 1 large)
- A general purpose hall (an auditorium)
  - 3 different geometries for its shape
- Discretized grid consisting of hexagonal cells[2]
- Threat spreading dynamics
  - fire progresses probabilistically to adjacent cells

[2] D. Yanagisawa et al., "Introduction of frictional and turning function for pedestrian outflow with an obstacle," *Phys. Rev. E*, vol. 80, no. 3, 2009.

Agent Modelling: Initialization & Foundational Behaviour

- Initialization:
  1. random spatial allocation of agents in unoccupied cells;
  2. target exit association w.r.t. closest Euclidean distance[3].
- Leader-follower model
  - teachers guide students to respective exits.
- Teachers' priority: students exhibiting elevated fear.

[3] D. Yanagisawa and K. Nishinari, "Mean-field theory for pedestrian outflow through an exit," *Phys. Rev. E*, vol. 76, no. 6, 2007.

Agent Modelling: Belief-Desire-Intention

Teachers are modelled as agents with **Belief-Desire-Intention** traits[4].

- Belief: Complete observability of the hall.
- Desire:
  1. find students with a focus towards those with elevated fear;
  2. go towards to the exits.
- Intention: Prioritize desire 1 over 2.
- Ramification: Increase in student's speed upon association with a teacher.

[4] https://gama-platform.github.io/wiki/BDIAgents

Agent Modelling: Frictional Function (1/2)

Frictional function[5]

- probability of unsolved conflict, due to psychological effects:

$$\phi_\zeta(k) = 1 - (1-\zeta)^k - k\zeta(1-\zeta)^{k-1},$$

- $k_e \geq 1$: number of conflicting agents;
- $\zeta \in [0,1]$: aggressive parameter, i.e. a measure of not yielding when multiple agents move to the same cell simultaneously.

[5] A. Kirchner, K. Nishinari, and A. Schadschneider, "Friction effects and clogging in a cellular automaton model for pedestrian dynamics," *Phys. Rev. E*, vol. 67, no. 5, 2003.

Agent Modelling: Frictional Function (2/2)

Frictional function: $\phi_\zeta(k) = 1 - (1-\zeta)^k - k\zeta(1-\zeta)^{k-1}$

- If $k = 1$, then there is no conflict.
- If $k > 1$, then unsolved conflict happens, i.e. $\phi_\zeta(k) > 0$.

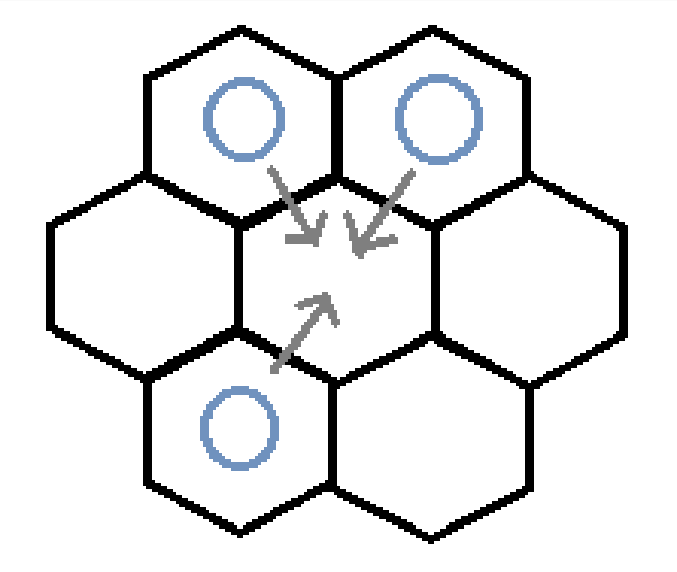


Figure 1: The number of conflicting agents is $k = 3$ in this case.

Agent Modelling: Turning Function (1/2)

Turning function[6]

- probability of whether one of the agents adjacent to the exit could successfully evacuate:

$$\alpha(\theta_m) = \beta e^{-\eta|\theta_m|}$$

- $\beta \in [0, 1]$: bottleneck parameter;
- $\eta \geq 0$: inertia coefficient in turning;
- $\theta_m \in [-\pi, \pi]$: agent's incident angle from cell m to the exit.

[6] D. Miyagawa and G. Ichinose, "Cellular automaton model with turning behavior in crowd evacuation," *Physica A*, vol. 549, 2020.

Agent Modelling: Turning Function (2/2)

Turning function: $\alpha(\theta_m) = \beta\tau$ where $\tau = e^{-\eta|\theta_m|}$

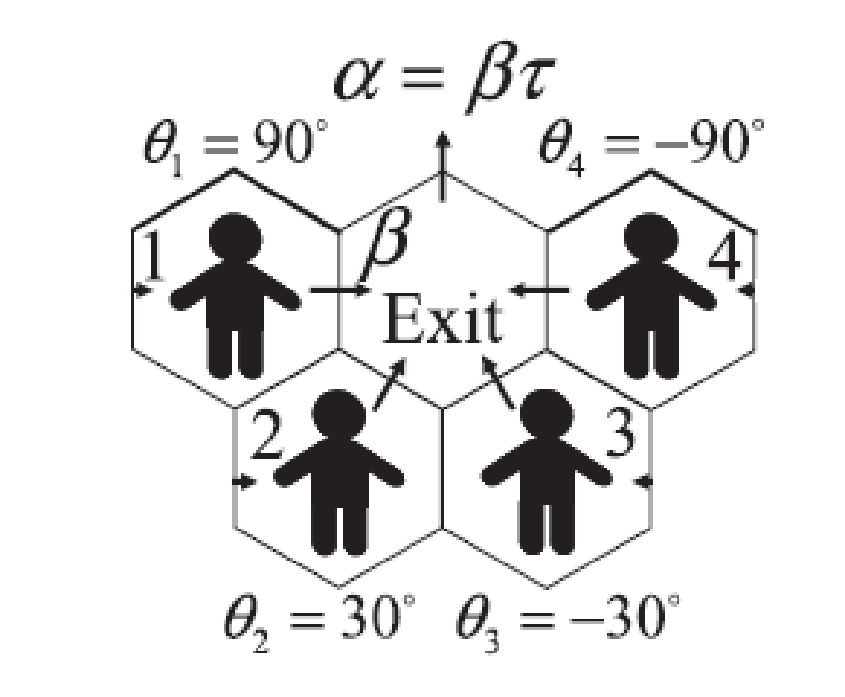


Figure 2: Four fixed incident angles[7].

[7] D. Yanagisawa et al., "Study on efficiency of evacuation with an obstacle on hexagonal cell space," *SICE J. of Cont., Meas., and Sys. Integr.*, vol. 3, no. 6, pp. 395–401, 2010.

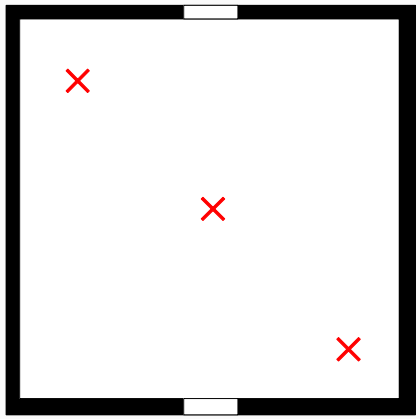
Experiment and Analysis

Simulation Environment

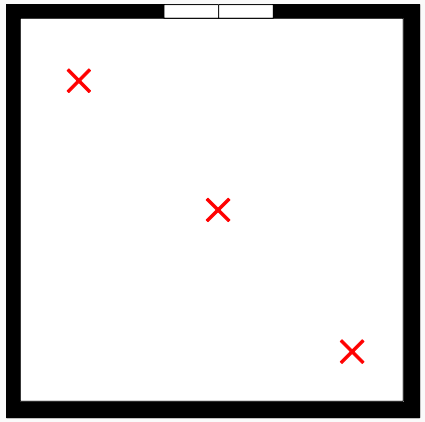
- GAMA platform[8]
  - open source;
  - Java-based;
  - spatially-explicit multi-agent simulations.
- QGIS[9]
  - open source;
  - geo-spatial data handling.
- Machine specifications
  - 2.6GHz Intel(R) Core(TM) i7-9750H;
  - 16GB of RAM;
  - NVIDIA GeForce RTX 2060.

[8] https://gama-platform.github.io/
[9] https://www.qgis.org/en/site/

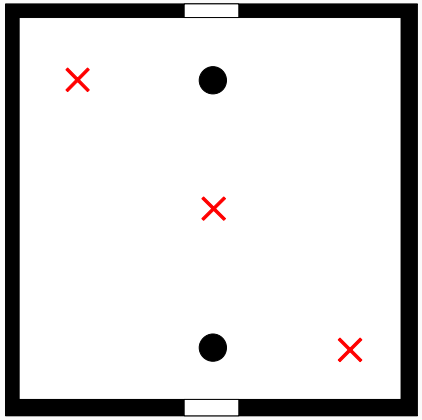
School Hall Configurations



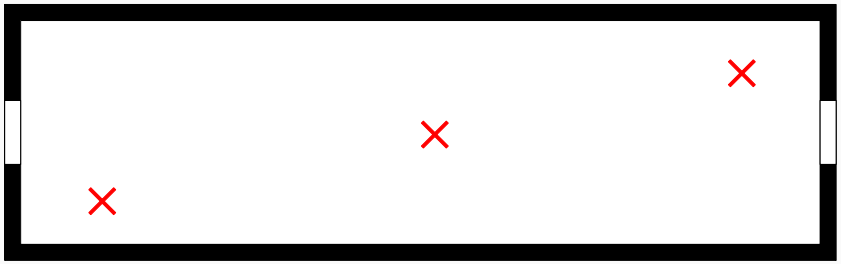
(a) square, 2 exits



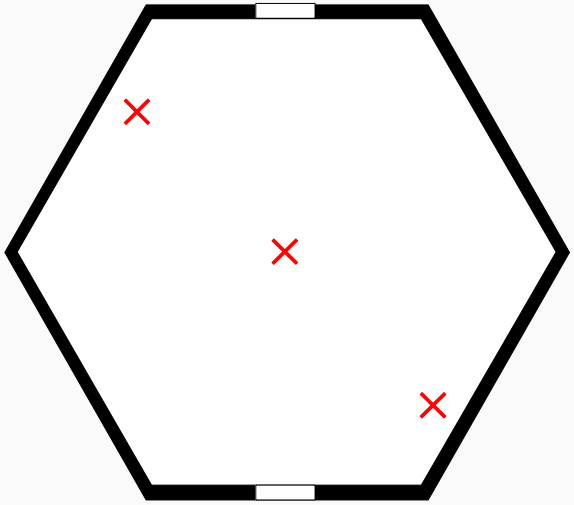
(b) square, 1 large exit



(c) square, 2 exits, poles

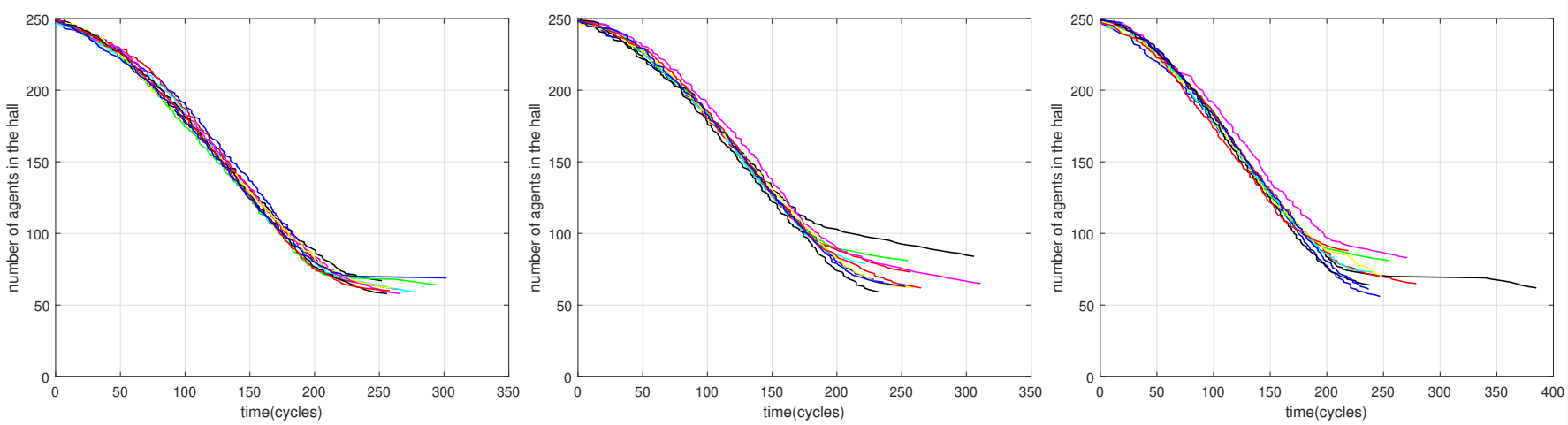


(d) rectangle, 2 exits



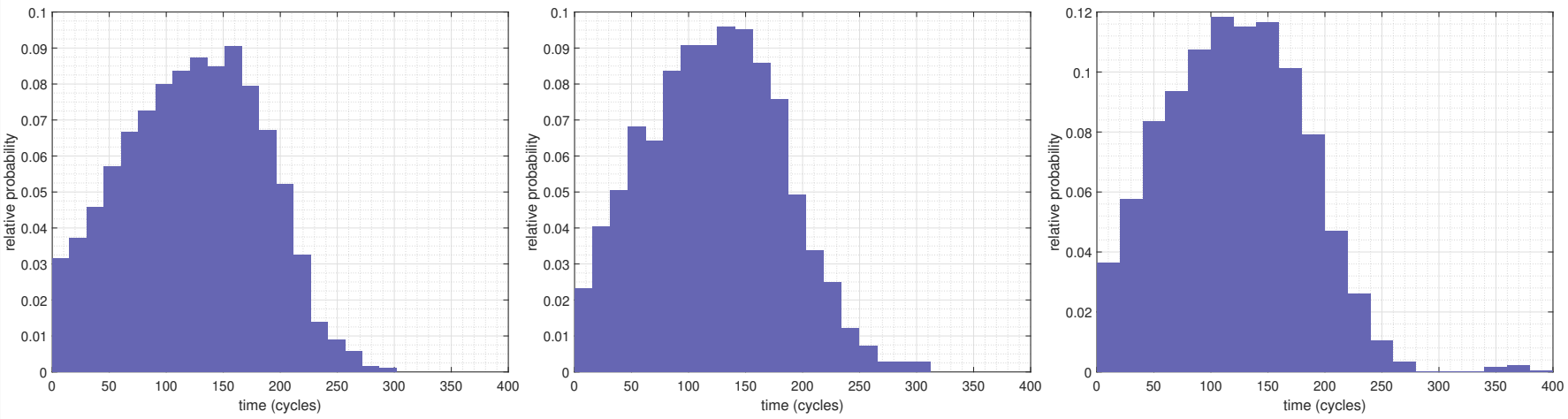
(e) hexagon, 2 exits

Simulation Results: Square hall, 2 exits



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

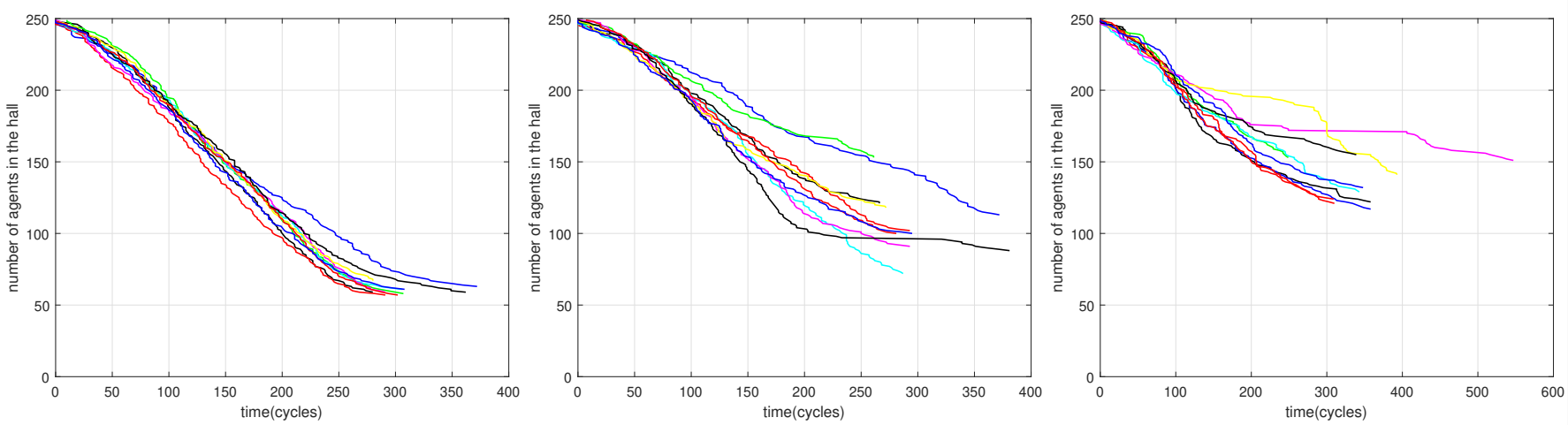
Figure 3: Number of remaining teachers and students with respect to time.



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

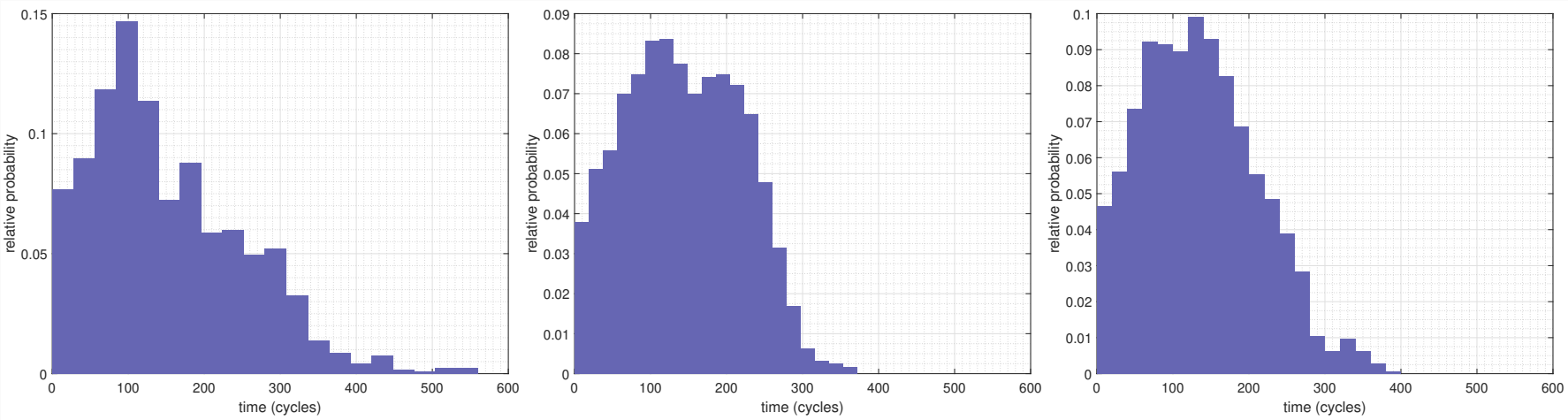
Figure 4: Relative probability of evacuation times.

Simulation Results: Rectangular hall, 2 exits



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

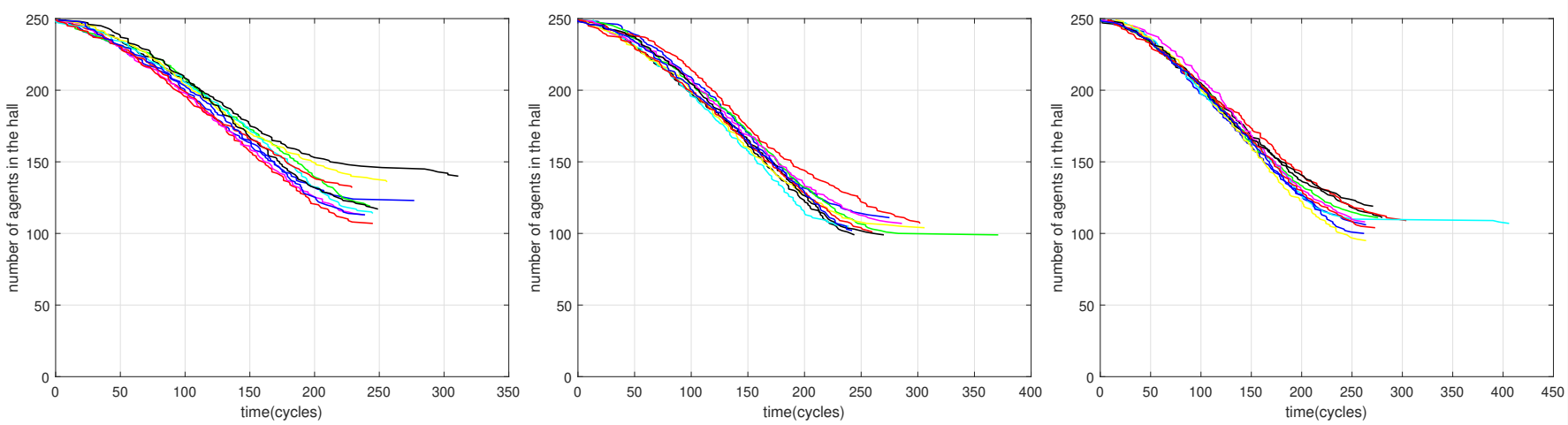
Figure 5: Number of remaining teachers and students with respect to time.



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

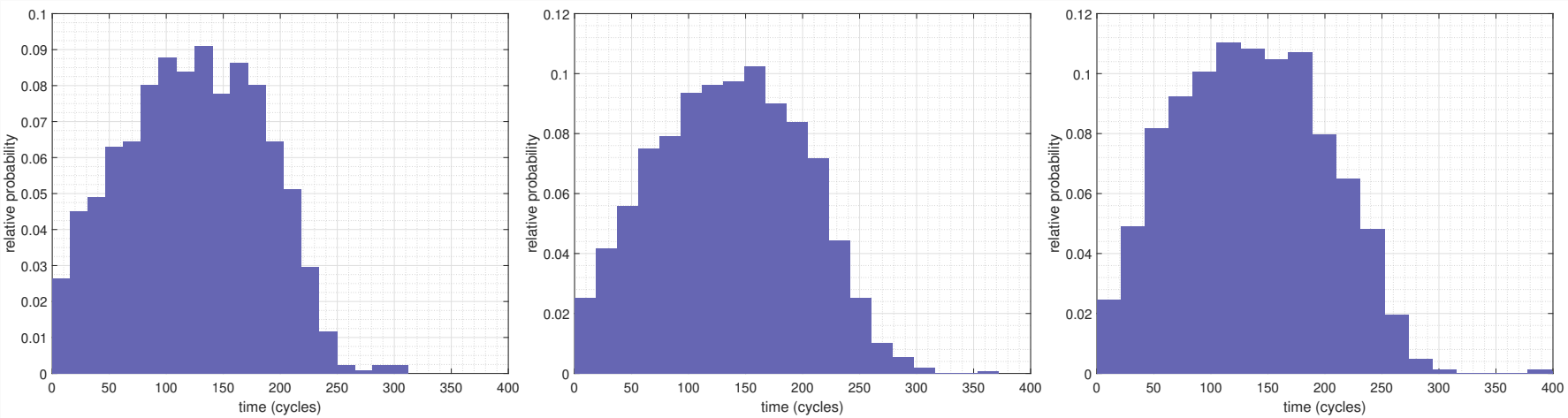
Figure 6: Relative probability of evacuation times.

Simulation Results: Hexagonal hall, 2 exits



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

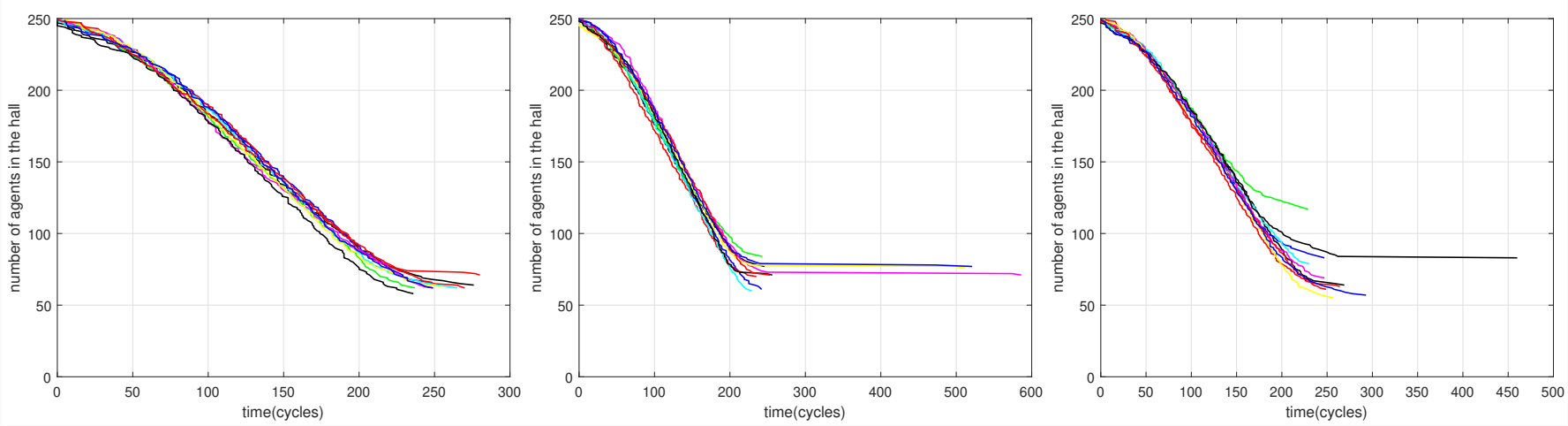
Figure 7: Number of remaining teachers and students with respect to time.



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

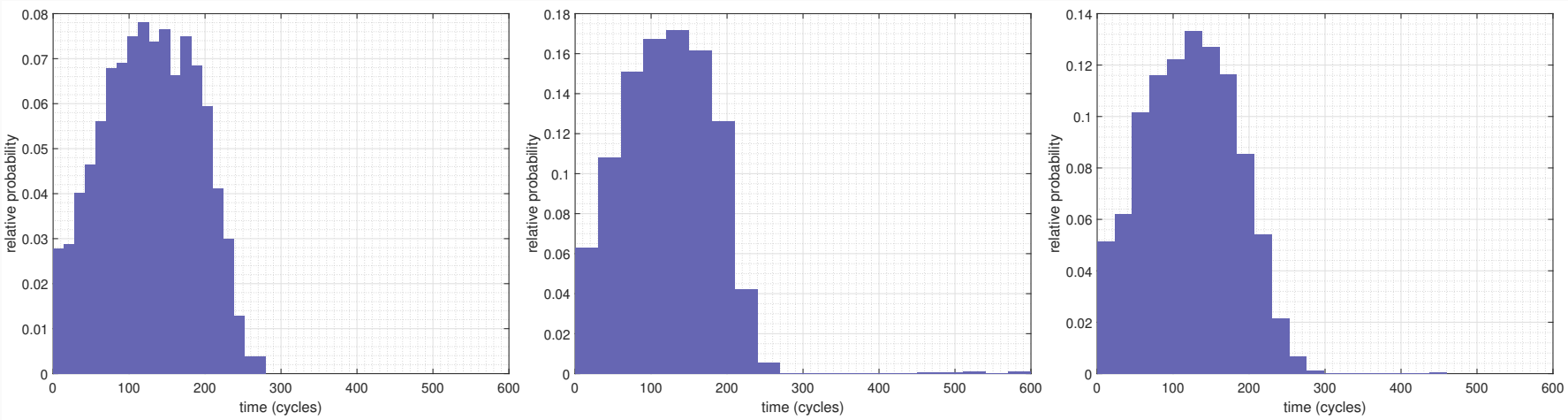
Figure 8: Relative probability of evacuation times.

Simulation Results: Square hall, 2 exits, with poles near the exits



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

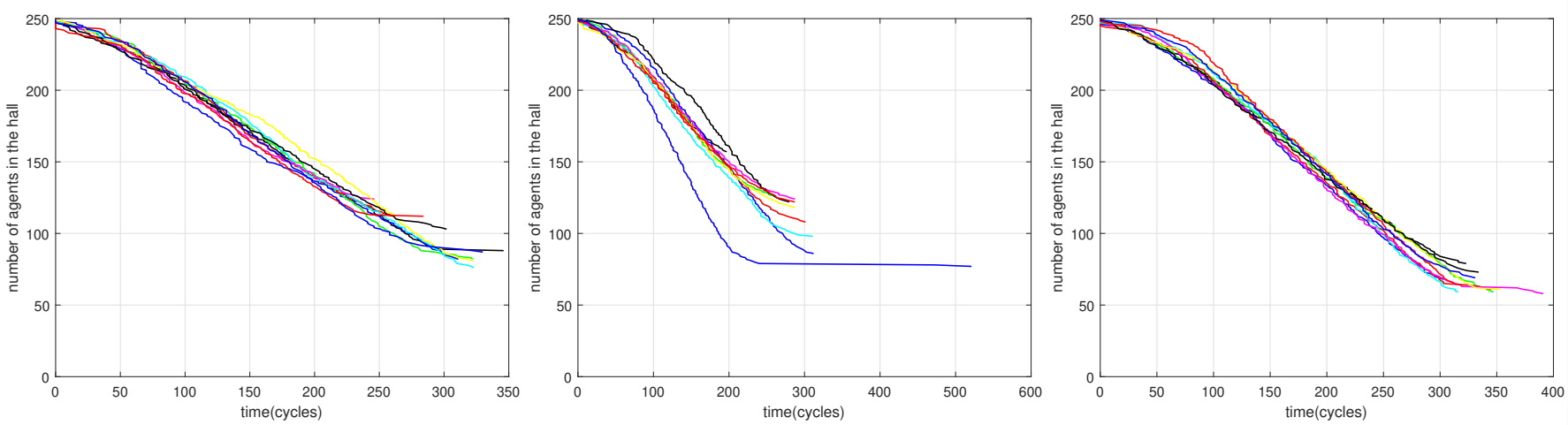
Figure 9: Number of remaining teachers and students with respect to time.



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

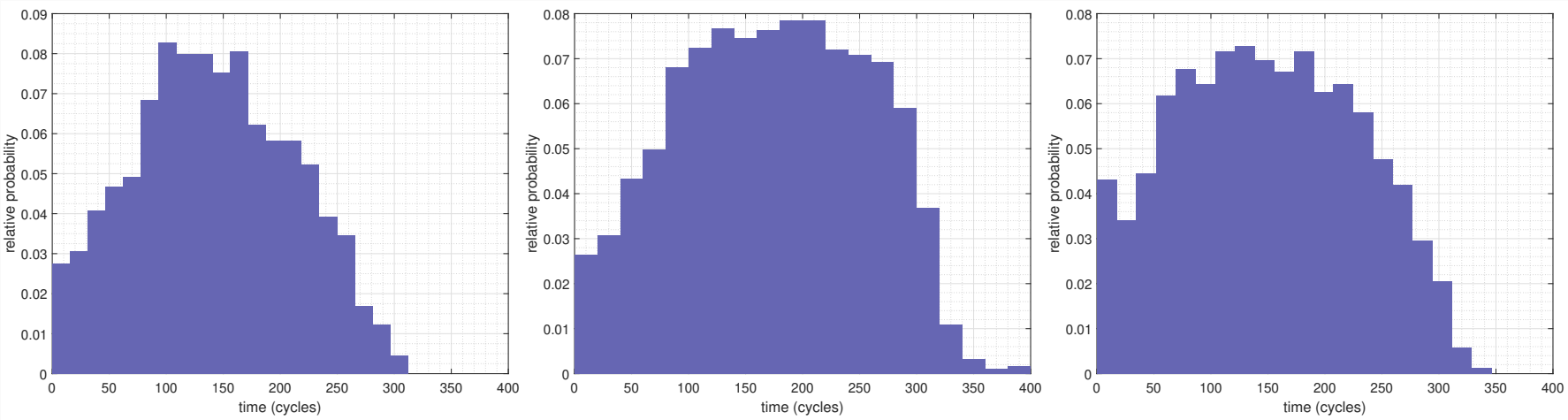
Figure 10: Relative probability of evacuation times.

Simulation Results: Square hall, 1 large exit



(a) fire at the center (b) fire in the upper side (c) fire in the lower side

Figure 11: Number of remaining teachers and students with respect to time.

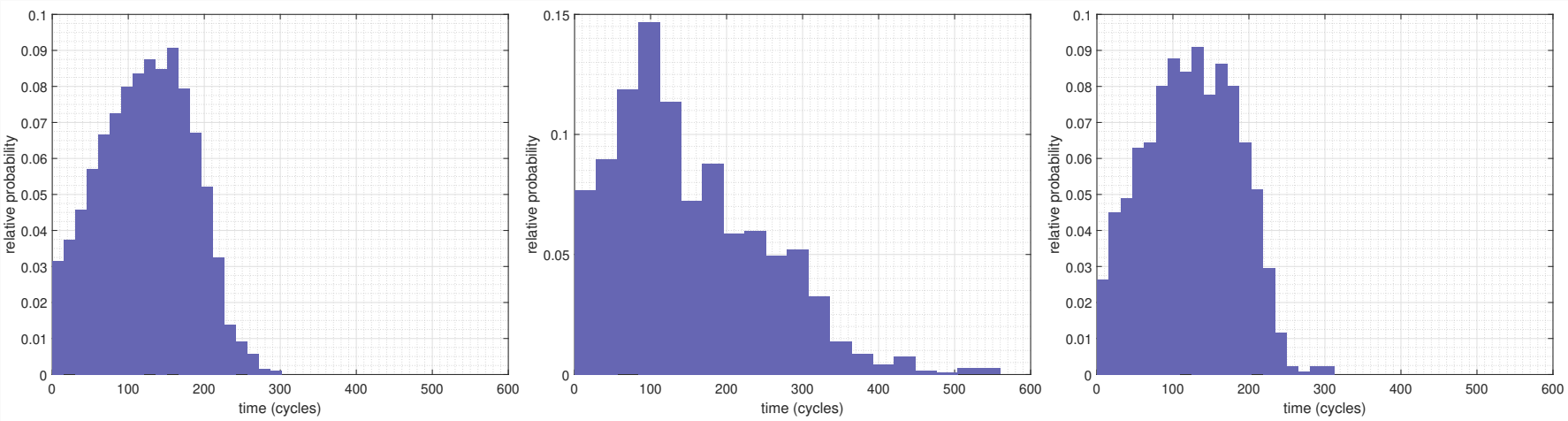


(a) fire at the center (b) fire in the upper side (c) fire in the lower side

Figure 12: Relative probability of evacuation times.

Comparison: Square, Rectangular, and Hexagonal (1/2)

- Rectangular hall exhibits higher portion of agents evacuating in more than 250 cycles.
- Hexagonal hall registers larger amount of agents, on average, failing to evacuate (i.e., they either die or faint).



(a) square hall (b) rectangular hall (c) hexagonal hall

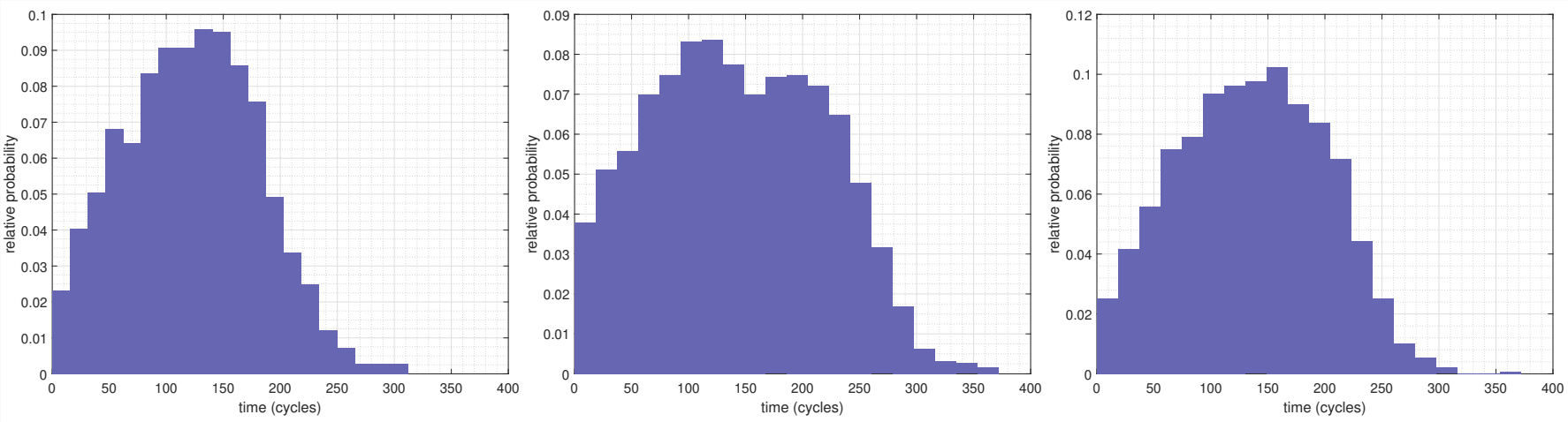
Figure 13: Relative probability of evacuation times when fire starts at the center.

shape	mean(t)	std(t)	min(t)	max(t)	mean(fail)	std(fail)	min(fail)	max(fail)
square	123.3	59.7	1	302	62.4	3.9	58	69
rectangular	150.8	100.1	1	547	60.1	3.1	57	67
hexagonal	123.8	60.2	1	311	121.4	11.1	107	140

Table 1: Summary values for evacuation time in cycles and number of agents failed to evacuate.

Comparison: Square, Rectangular, and Hexagonal (2/2)

- Rectangular hall still exhibits higher portion of agents requiring more than 250 cycles.
- Both rectangular and hexagonal register higher number of agents failing to evacuate.



(a) square hall (b) rectangular hall (c) hexagonal hall

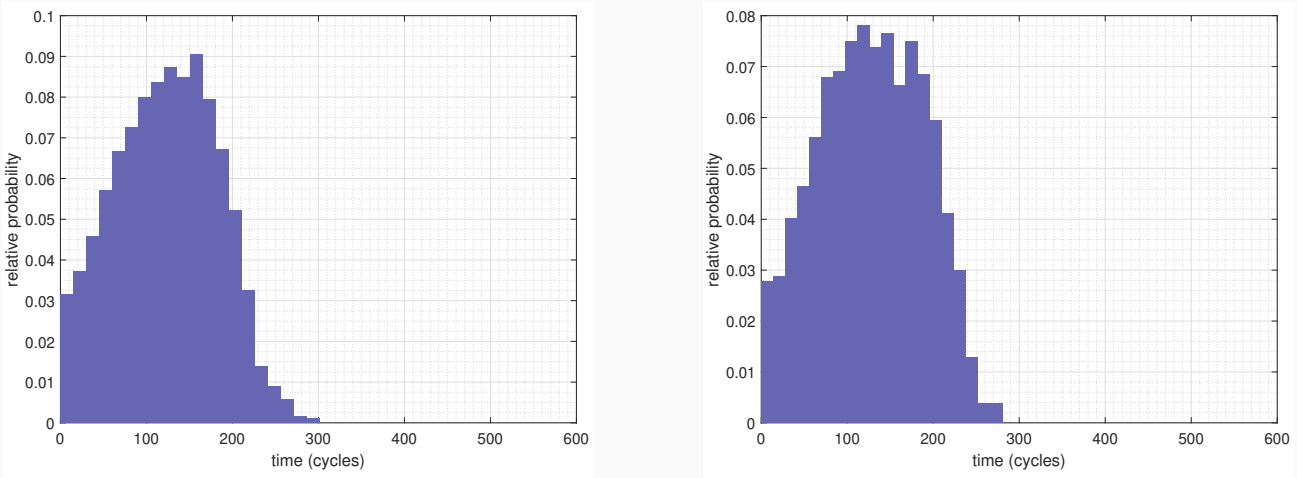
Figure 14: Relative probability of evacuation times when fire starts in the upper side.

shape	mean(t)	std(t)	min(t)	max(t)	mean(fail)	std(fail)	min(fail)	max(fail)
square	122.1	59.0	1	311	69.4	9.1	59	84
rectangular	143.5	76.2	1	372	105.8	22.2	72	153
hexagonal	135.7	64.6	1	371	103.4	4.1	99	111

Table 2: Summary values for evacuation time in cycles and number of agents failed to evacuate.

Comparison: Square with and without obstacles

- No significant difference between square hall with and without poles near the exits.
- BDI behaviour: students walking around the pole while following the teacher, degrading any beneficial effect from the pole itself.



(a) without obstacles (b) with obstacles

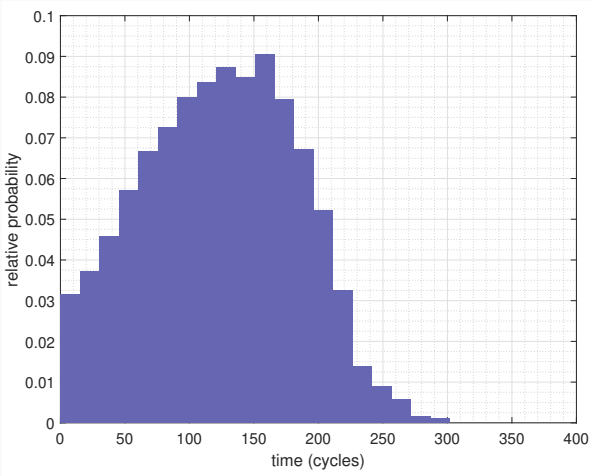
Figure 15: Relative probability of evacuation times when fire starts at the center.

square shape	mean(t)	std(t)	min(t)	max(t)	mean(fail)	std(fail)	min(fail)	max(fail)
without obstacles	123.3	59.7	1	302	62.4	3.9	58	69
with obstacles	121.1	61.8	1	586	63.1	3.3	58	71

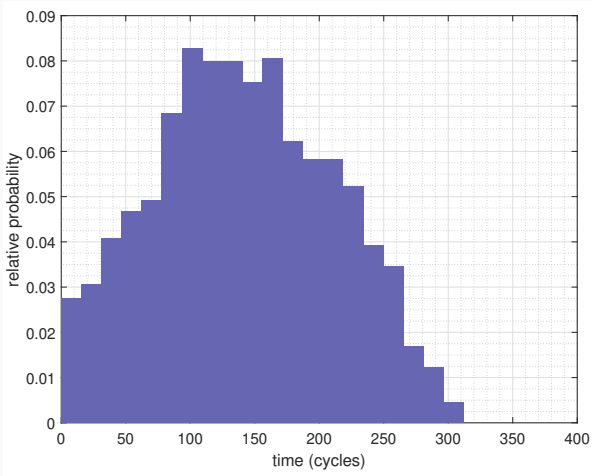
Table 3: Summary values for evacuation time in cycles and number of agents failed to evacuate.

Comparison: Square with 2 exits versus 1 large exit

- Non-negligible difference in amount of agents evacuating successfully in more than 250 cycles.
- Utilization of 1 large exits increases, on average, the amount of students failing to evacuate.



(a) 2 exits



(b) 1 large exit

Figure 16: Relative probability of evacuation times when fire starts at the center.

square shape	mean(t)	std(t)	min(t)	max(t)	mean(fail)	std(fail)	min(fail)	max(fail)
2 exits	123.3	59.7	1	302	62.4	3.9	58	69
1 large exit	141.5	69.6	1	312	94.8	16.8	76	124

Table 4: Summary values for evacuation time in cycles and number of agents failed to evacuate.

Parameters

- The parameters in friction and turning functions were adopted from the literature (an experiment in Japan[10]):

$$\begin{cases} \beta = 0.97; \\ \zeta = 0.22; \\ \eta = 0.09. \end{cases}$$

- Validation of parameter selection in the case of school hall evacuation is done by means of sensitivity analysis.

[10] D. Yanagisawa et al., "Study on efficiency of evacuation with an obstacle on hexagonal cell space," *SICE J. of Cont., Meas., and Sys. Integr.*, vol. 3, no. 6, pp. 395–401, 2010.

Sensitivity Analysis

- Frictional function depends on parameter ζ.
- Curve related to total evacuation time for $\zeta = 0.19, 0.20, 0.21, \ldots, 0.25$:

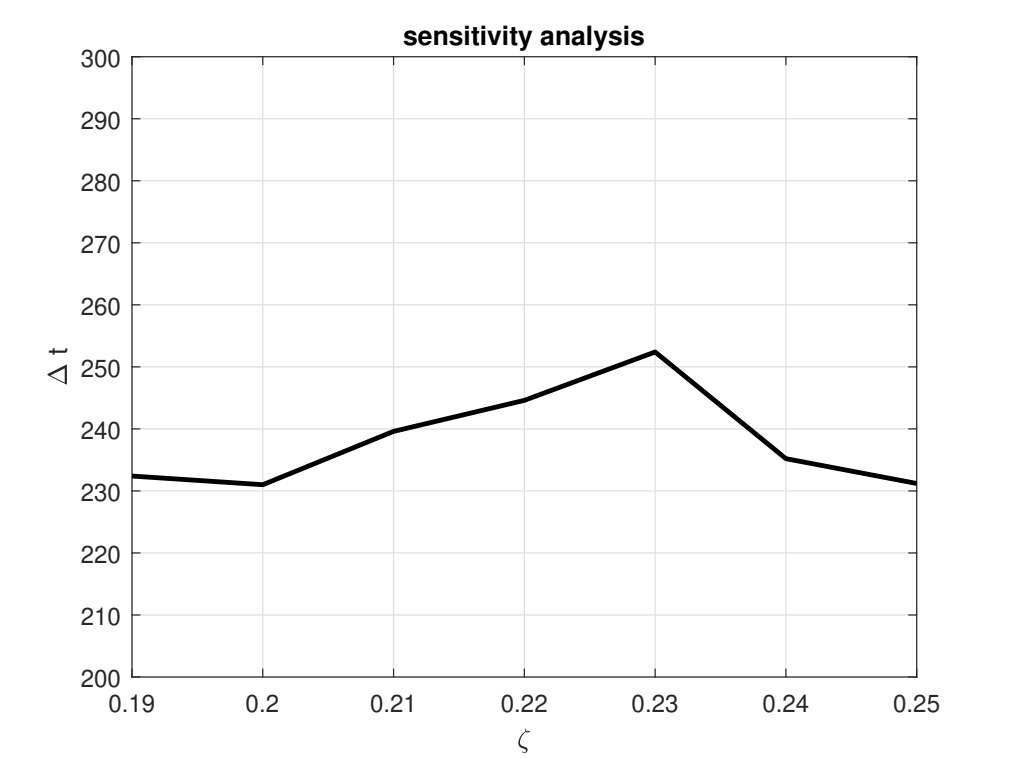


Figure 17: Sensitivity analysis of parameter ζ.

Conclusion and Future Work

Concluding Remarks & Path Forward

- Evidence-based suggestion:
  - square hall, over rectangular or hexagonal;
  - 2 emergency exits, instead of 1 large exit;
  - no significant ramification from poles near exits.

[11] C. Wang and J. Wang, "A modified floor field model combined with risk field for pedestrian simulation," *Mathematical Problems in Engineering*, vol. 2016.

Concluding Remarks & Path Forward

- Evidence-based suggestion:
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  - no significant ramification from poles near exits.
- Future work:
  - refine the underlying assumptions to increase the level of realism;
    1. variations in physiological traits among agent population;
    2. slow response to evacuation alarms;
    3. familiar way out instead of nearest exit;
    4. relaxation of global perception assumption;
    5. adaptive behaviour among agents;
    6. intricate fire dynamics;
    7. fusion of a BDI-based scheme with a dynamic floor field model[11].

[11] C. Wang and J. Wang, "A modified floor field model combined with risk field for pedestrian simulation," *Mathematical Problems in Engineering*, vol. 2016.

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  - different communication strategies among students;

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    7. fusion of a BDI-based scheme with a dynamic floor field model[11].
  - different communication strategies among students;
  - asynchronous versus synchronous updates.

[11] C. Wang and J. Wang, "A modified floor field model combined with risk field for pedestrian simulation," *Mathematical Problems in Engineering*, vol. 2016.

Thank you for your attention!

Questions?