



A Modified Cellular Automaton Model for Evacuation and Resilience in Tunnel Fires

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Fire and Evacuation Modeling Technical Conference

Background







- Tunnels: connect regions, deliver goods, and solve traffic congestions
- Tunnel fire: Increase with traffic volume and accidents
- Casualties: Temperature, visibility, CO concentration, thermal radiation

Evacuation in tunnel fire

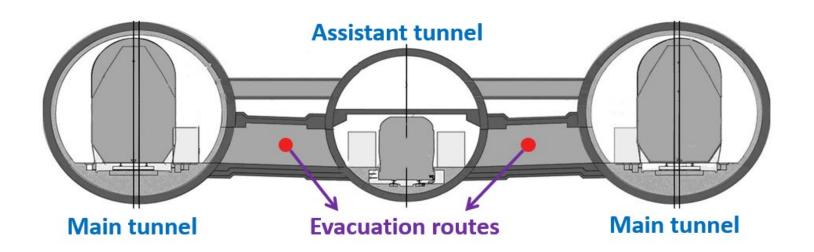






- Enclosed structure: poor ventilation and heat feedback
- Unfamiliar environment: seldom walk through, weak GPS
- Slow rescue: Fire brigades get stuck on slender roads and traffic jam

Evacuation in tunnel fire





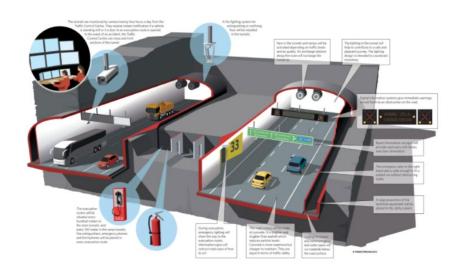
- Evacuation routes
- Guiding signages







Smart evacuation systems

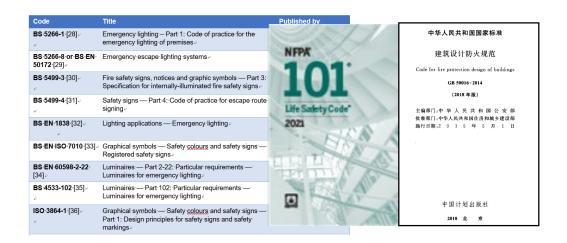


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Fire safety design for evacuation

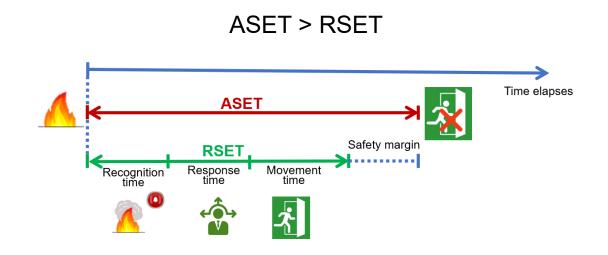
Prescriptive codes

Follow detailed rules that describe how the tunnel shall be designed (cookbook)

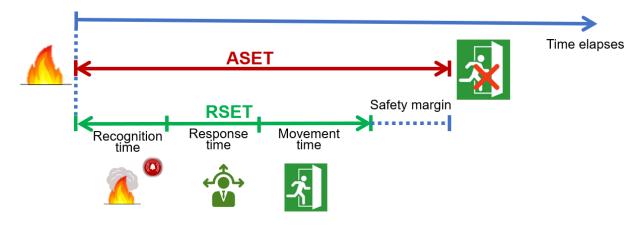


Performance-based design

Design the tunnel so that an objective is fulfilled

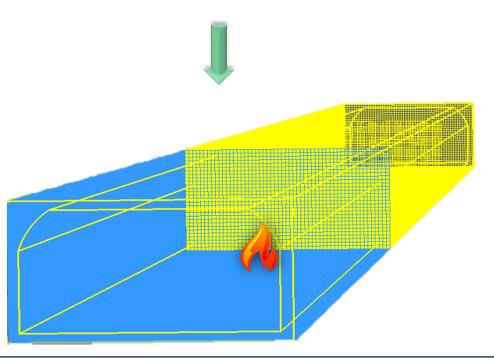


Timeline

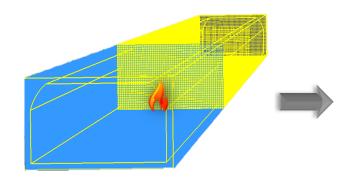




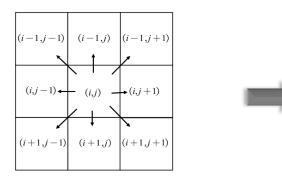
• Timeline + Space (2D or 3D)



CFD model

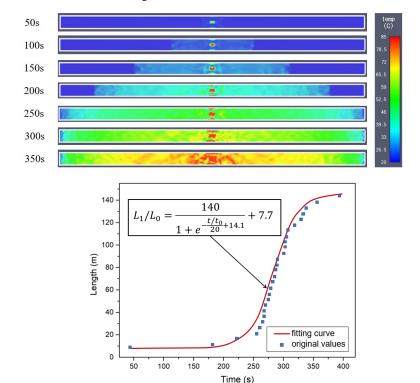


CA models

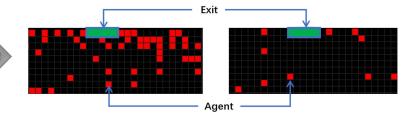


 $f: S_i^{t+1} = f(S_i^t, S_N^t)$

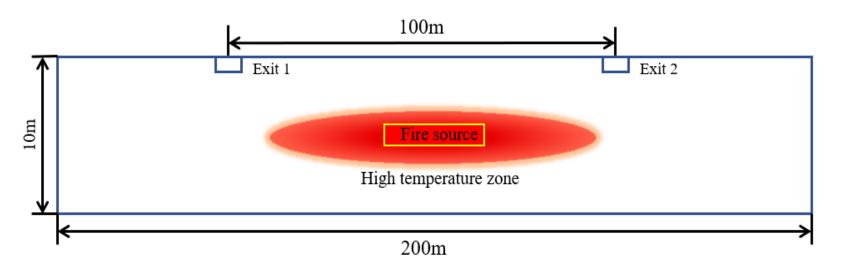
Couple to CA model

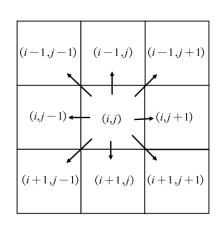


Evacuation process



Modelling assumption





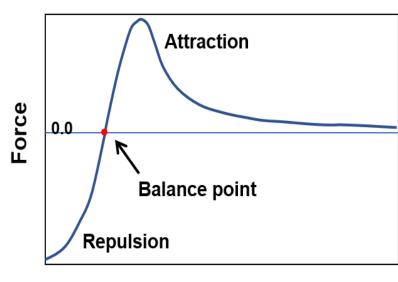
- Model choice: Cellular Automaton Moore neighbourhood
- ➤ Model size: 10m*200m 2-D model, each grid 0.4m*0.4m
- Moving speed: standard speed
- ➤ Choosing target: $L(W) = P(Y|X,W) = \prod_{i=1}^{N} P(y_i|x_i,W)$

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Moving rules

- Goal: Exits are immoveable goals.
- Obstacles: Fire are dynamic obstacles by generations.
- Attractors: social influence attracts agents to approach a goal

$$F_{ARAL} = (k_{ar}/Dis_{cheb}^{near} + 1)^{C_{AR}} + \sum_{i=1}^{n} (k_{al}/(Dis_{cheb} + 1))^{C_{AL}}$$



Distance to neighbors

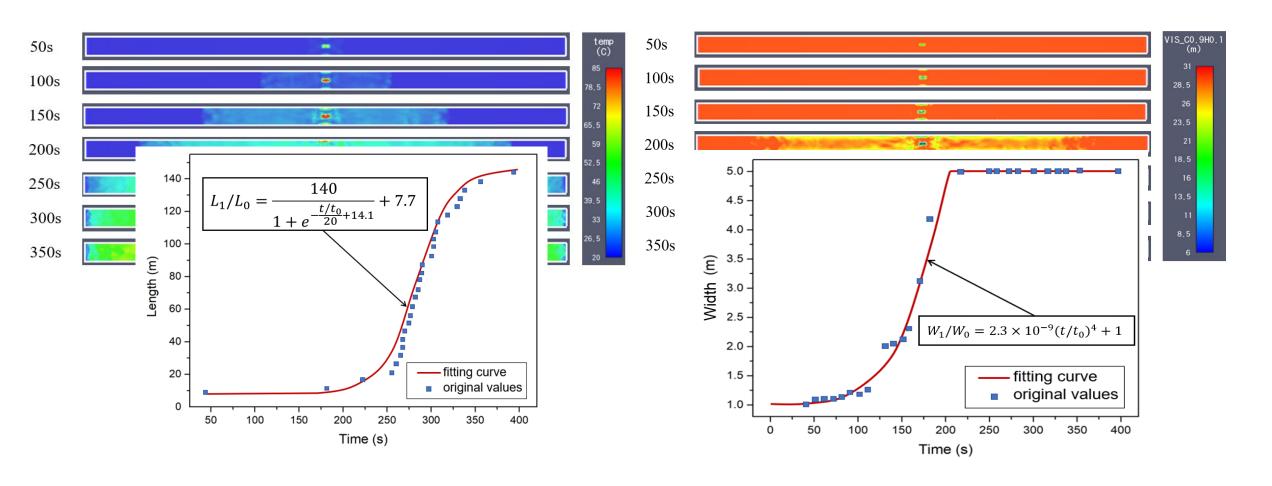
Repellors: Fire, Crowds, Nearby agents

$$F_{re} = (k_{near}/Dis_{euc}^{edge})^{CFR} + \sum_{i=1}^{n} Exit(n_{crowd} \times k_{crowd}/Dis_{chebi}^{exit})^{CCR} + \sum_{i=1}^{n} R_{neari}$$

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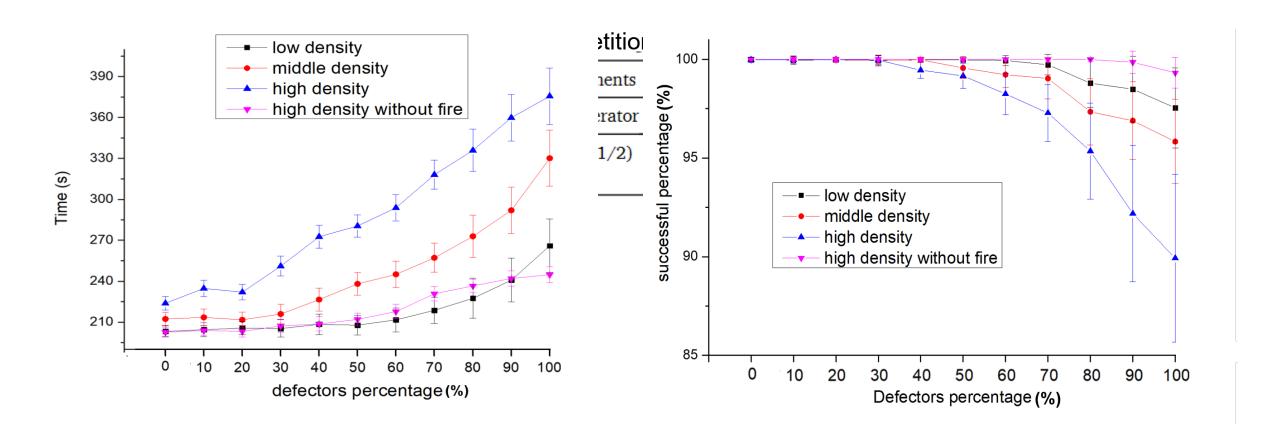
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Fire Development



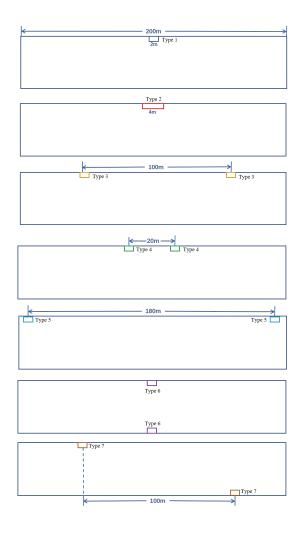
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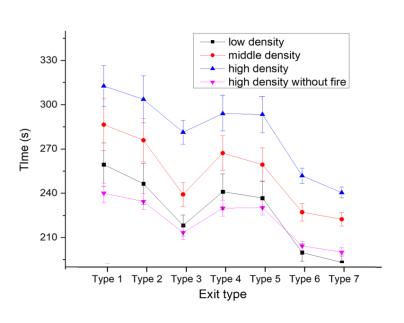
Defectors percentage

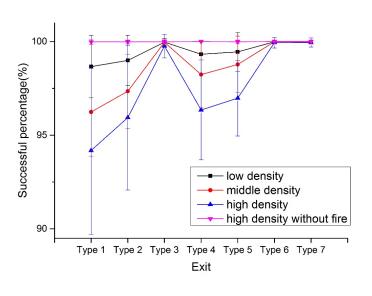


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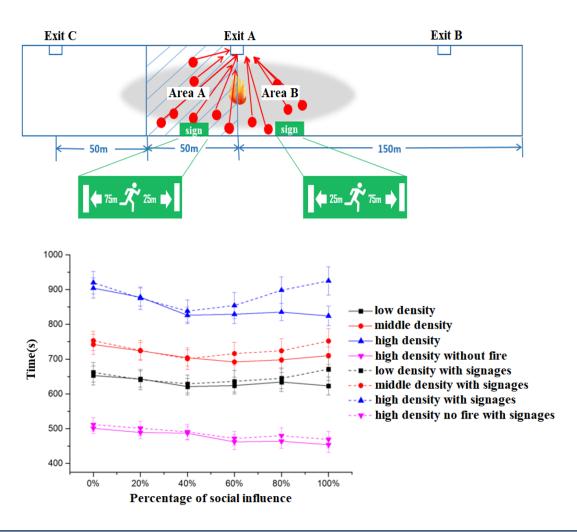
Exit location

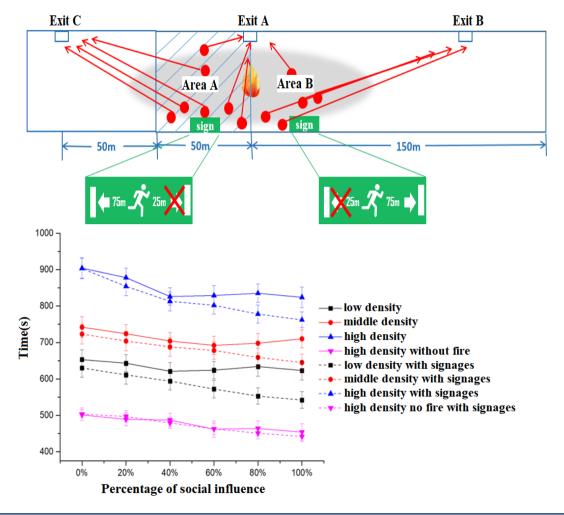




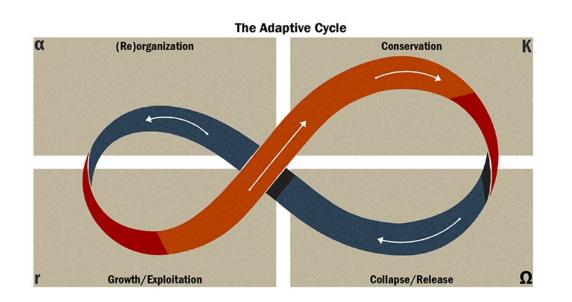


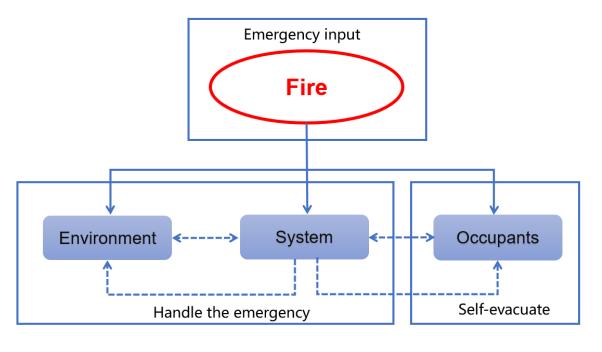
Signages





Evacuation resilience



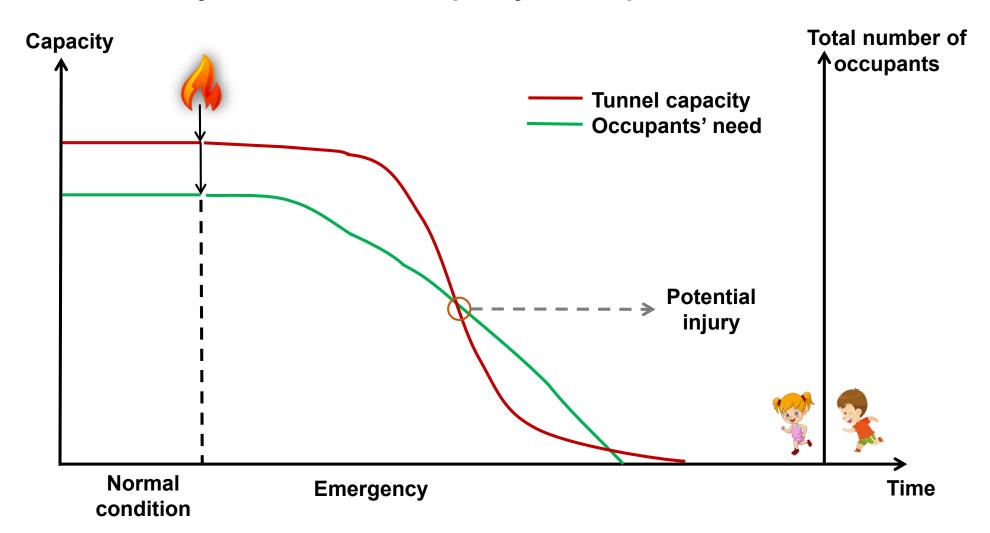


- The state change from normal operation to emergency operation.
- The capability to ensure occupants' safety in a tunnel fire.
- Moreover, reduce the damage to the tunnel.

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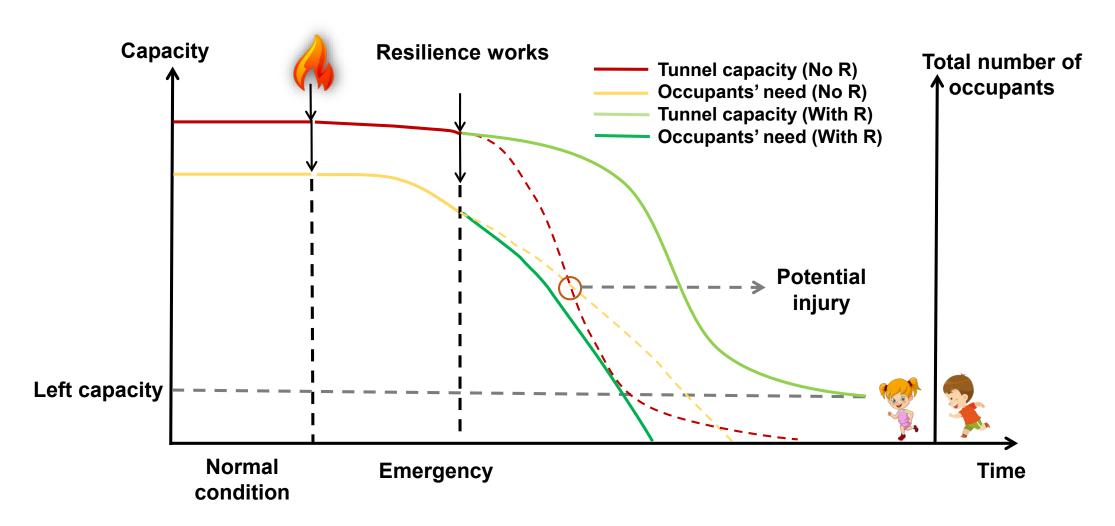
Without evacuation resilience

Safety Criteria: Tunnel capacity > Occupants' need



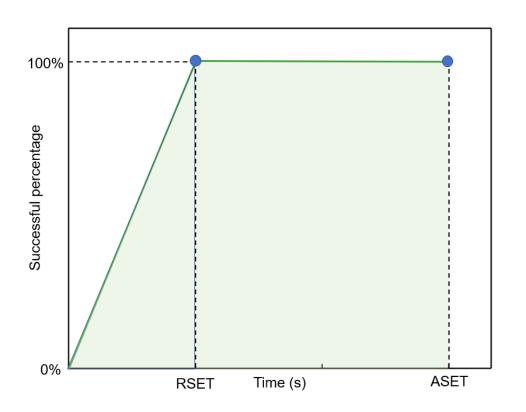
With evacuation resilience

Safety Criteria: Tunnel capacity (With R) > Occupants' need (With R)

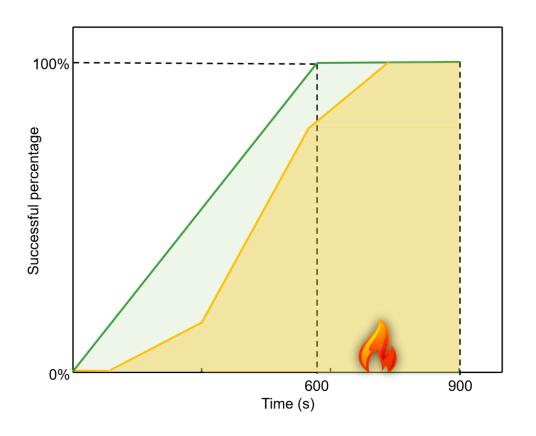


Evacuation resilience expression

Without fire (Ideal evacuation scenarios)

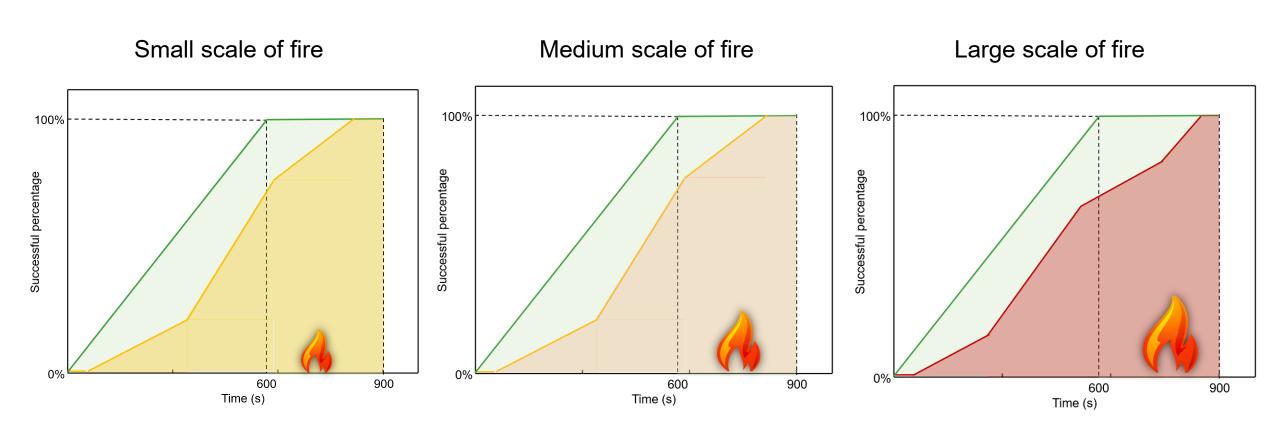


With fire (Specific evacuation scenarios)

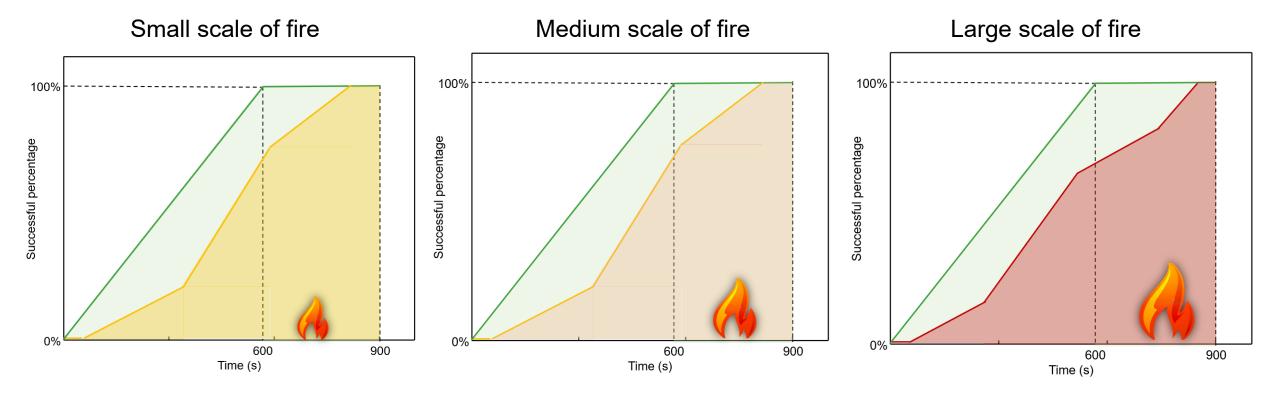


Score = Area(yellow)/Area(green) \times 100

A case study



Discussion



Different score of resilience on different fire scenarios

Other factors will affect evacuation progress as well such as firefighting systems, technical installations, occupants' densities

Then, how to choose or combine different cases for the overall resilience?

Conclusions



A Modified Cellular Automaton Model for Evacuation and Resilience in Tunnel Fires

- A modified cellular automation model is built to study evacuation in a tunnel fire.
- It considers the influence of fire on evacuation intensively.
- Many scenarios and evacuation performance could be calculated accordingly.
- Evacuation resilience is proposed and discussed.





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