URBAN SOLUTIONS AND SUSTAINABILITY
R&D CONGRESS 2023
BUILDING SUSTAINABLE, RESILIENT, AND LIVEABLE CITIES OF TOMORROW
4TH – 5TH OCTOBER 2023

Systemic Analysis of Singaporean Traffic Resilience through Epidemic Model

Wu Dake
Department of Physics
National University of Singapore
dake.wu@u.nus.edu

with Andrew J. Schauf, Feng Ling, Chen Kan and Lai Choy Heng

NUS National University of Singapore

Institute of High Performance Computing
IHPC

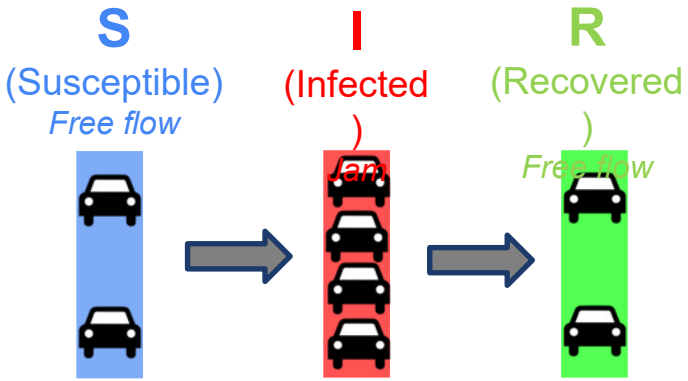
Background

- Traffic congestion used to be studied as a localized problem.
- Systemic level study of congestions in the **network spreading approach** provides new perspectives
  - Predictable
  - Explainable
  - Extrapolate
  - Dynamical model

Li, Daqing, et al. "Percolation transition in dynamical traffic network with evolving critical bottlenecks." Proceedings of the National Academy of Sciences 112.3 (2015): 669-672.
Saberi, Meead, et al. "A simple contagion process describes spreading of traffic jams in urban networks." Nature communications 11.1 (2020): 1616.

SIR model (fully mixed)

Predict the time evolution of spreading epidemic with a set of PDEs of S, I and R



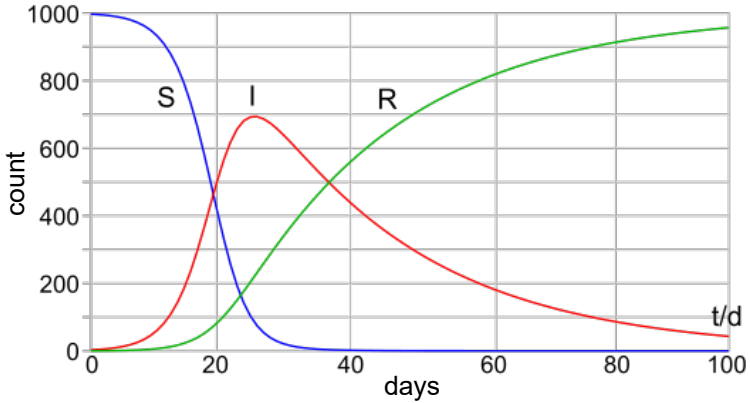
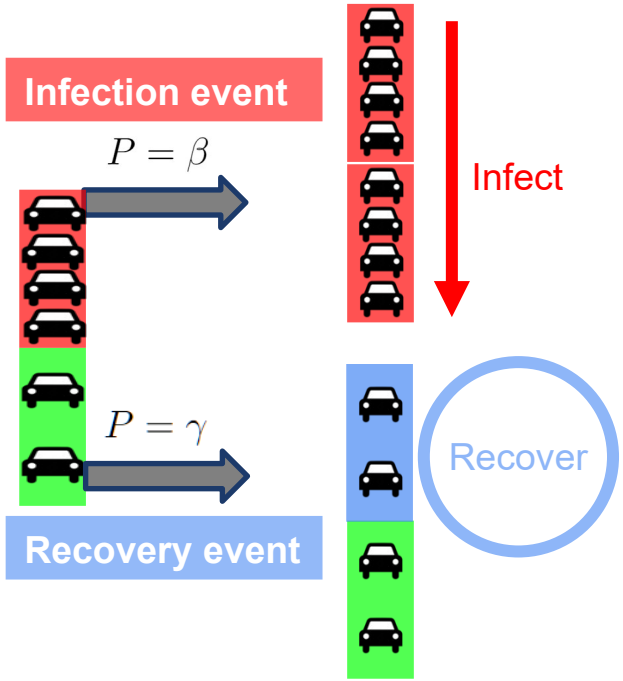


Diagram of the SIR-Model with beta = 0.0004 and gamma = 0.04. credit: Klaus-Dieter Keller, CC-BY

Network SIR model



Network model keeps certain **mesoscopic** details:

- Respect the network structure
- Can describe geographical changes

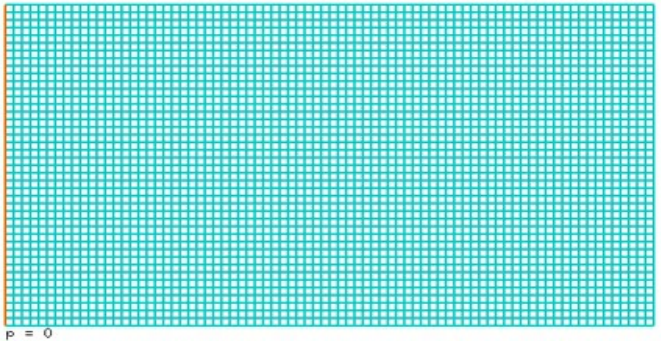
Ignores certain **microscopic** details

- Vehicle to vehicle/lane interactions
- Road width and geometries
- …

β: probability for the disease to spread to a neighbour
γ: probability to recover from infection

Percolation on network & phase transition

- Percolation process: roads are infected (jammed) with probability p.
- Small p: many small infected/jammed components – little systemic impact
- Large p: one giant infected/jammed component – huge systemic impact.
- Small p → large p: percolation **phase transition** at critical threshold p_c.

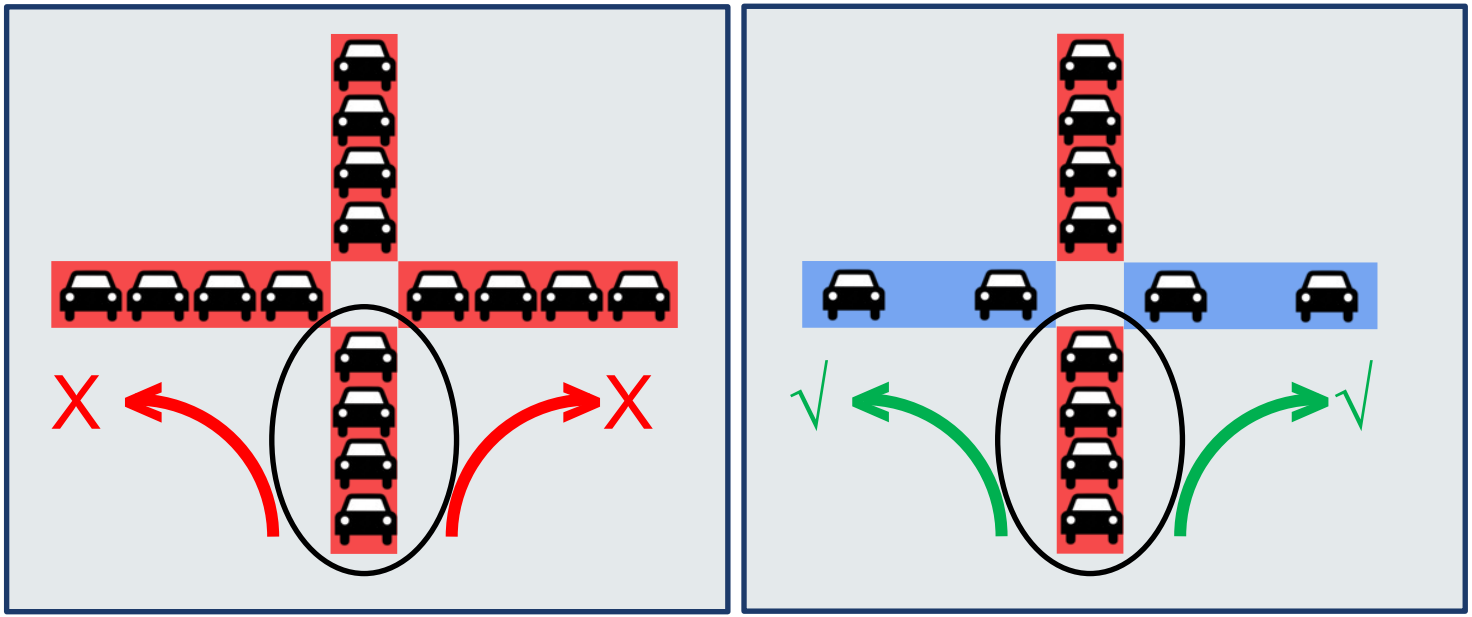


Percolation on a square lattice visualized. Phase transition happens at p=0.5. credit: Nils Berglund, CC-BY
https://www.youtube.com/watch?v=cl_B9iqsB9E

SIR process on Network is essentially a percolation process.

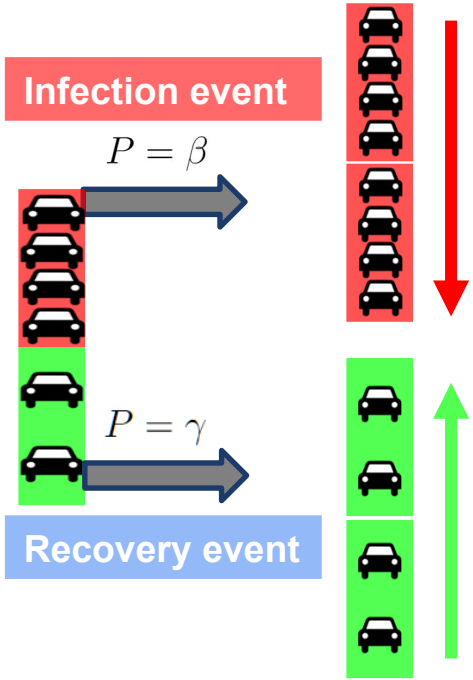
Zeng, G., et al.(2020). Multiple metastable network states in urban traffic. PNAS, 117(30), 17528-17534.

Recovery is not spontaneous



The circled road on the right should recover more easily.
→The recovery probability is dependent on the adjacent roads.

2-Type model and fitting result



2 types of disease: infection & congestion

Singaporean data shows:
Changing probability
= spreading + spontaneous

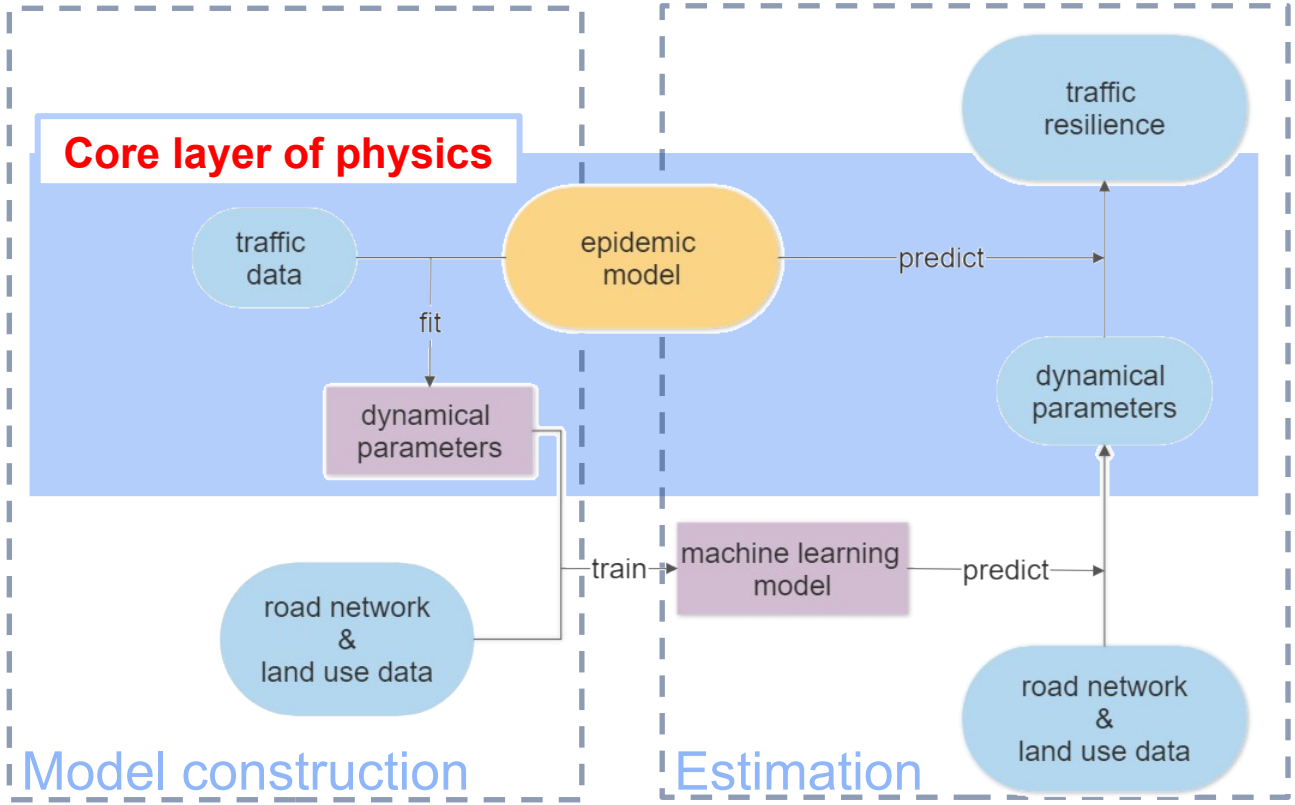
spreading spontaneous

$$P(I|k_{\text{out}}, k_{\text{out,I}}, \beta_I) \approx 1 - (1 - \beta_I)^{k_{\text{out,I}}} + p_0$$

$$p_{SG} = 0.285 \ll p_c \approx 0.4$$

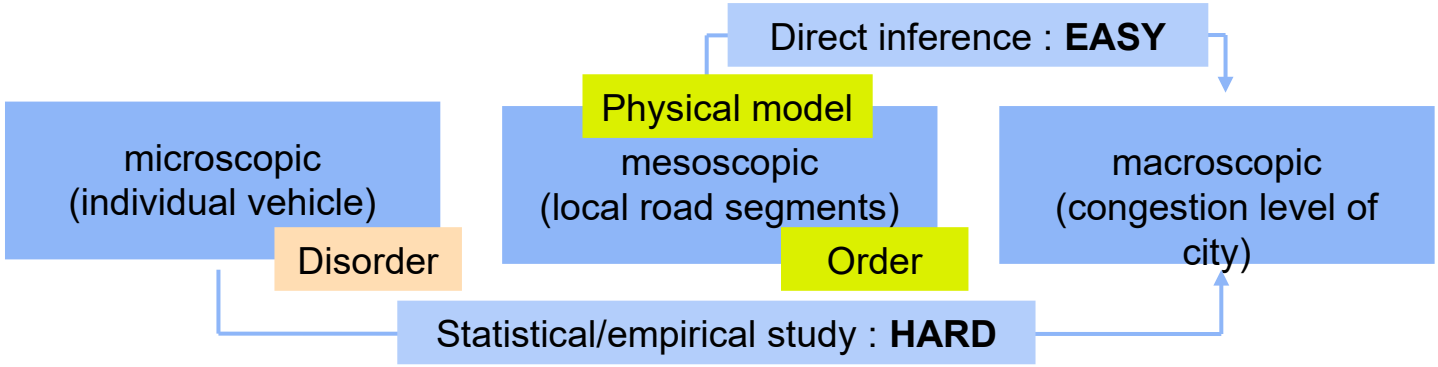
Empirical *p* in SG is lower than the percolation threshold
→ Only small localized congestion possible

How could this model help urban design?



Final thoughts – Look through scales for order

One way to understand an **emergent phenomenon**:



https://pixabay.com/photos/highway-traffic-germany-streets-2909336/

https://pixabay.com/photos/long-exposure-cars-highway-traffic-1232709/

Thank you