Optimality vs fragility: from transport disruption to supply chains
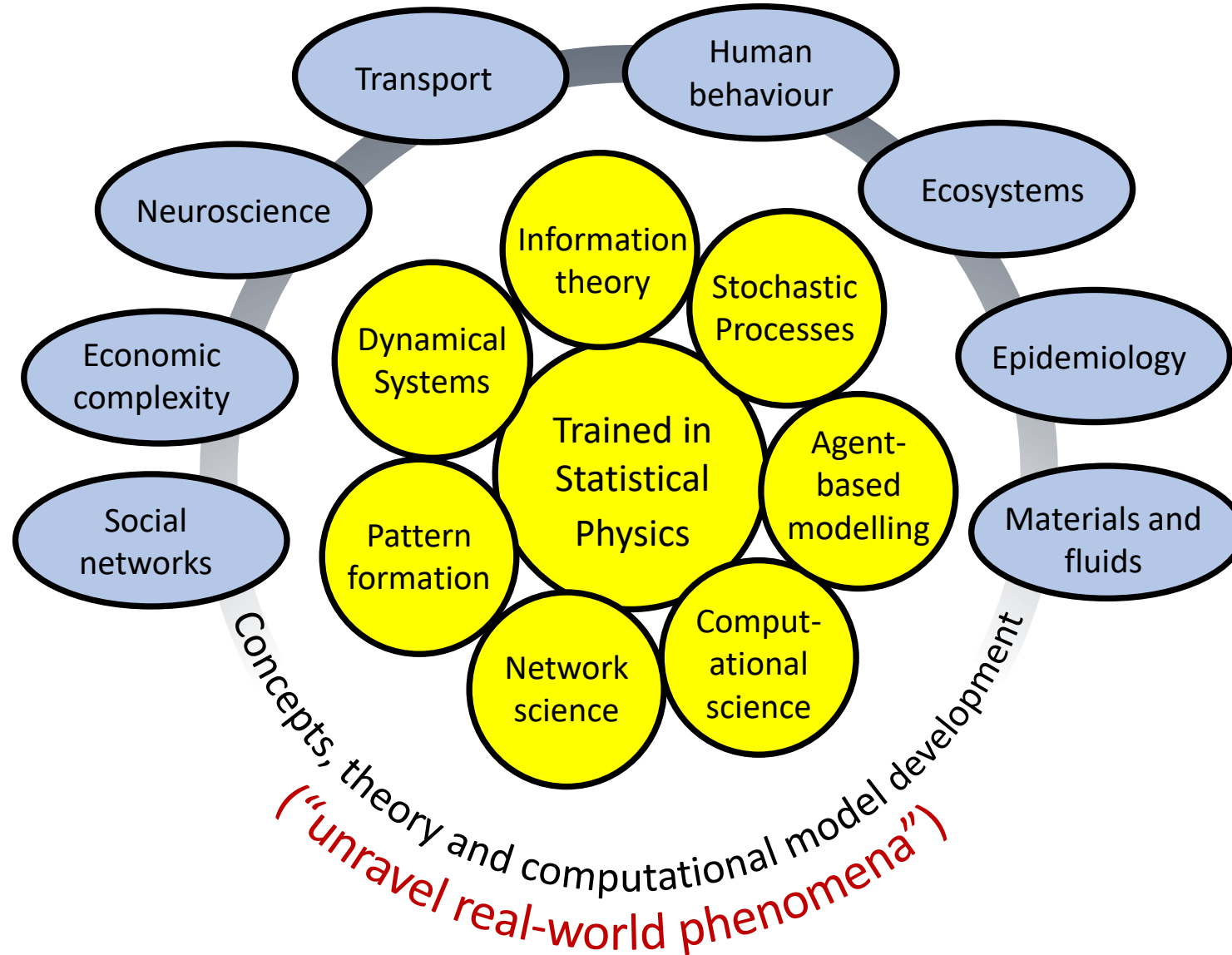
Deb Panja
(Computer Science and CCSS, Utrecht University)
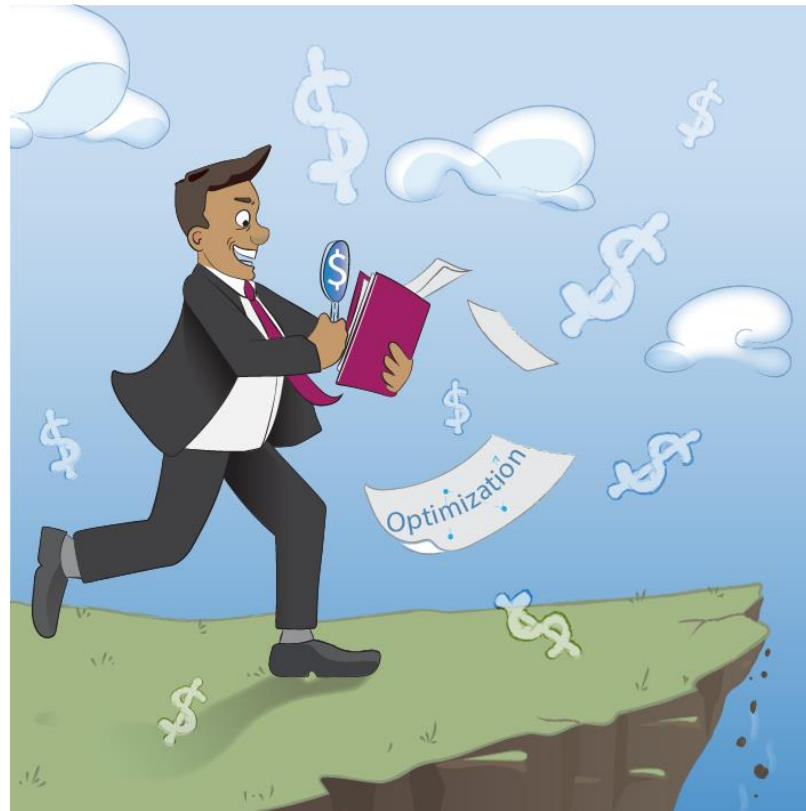
ETH Zürich
November 21, 2023
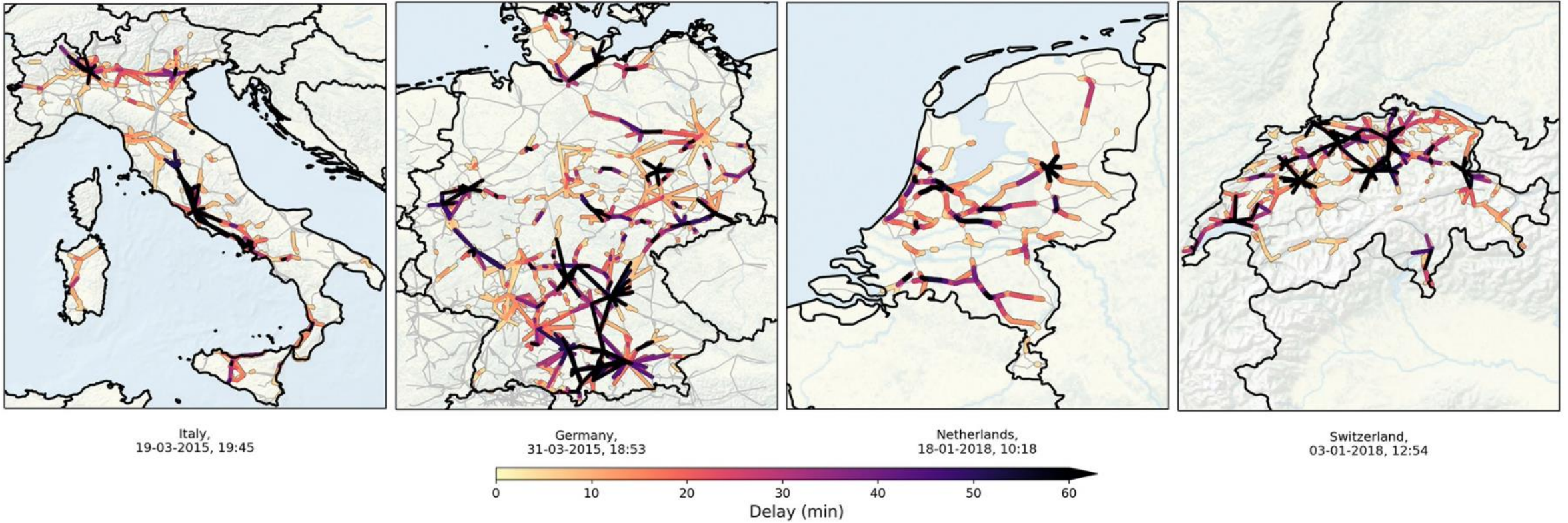
I am a Complex Systems scientist

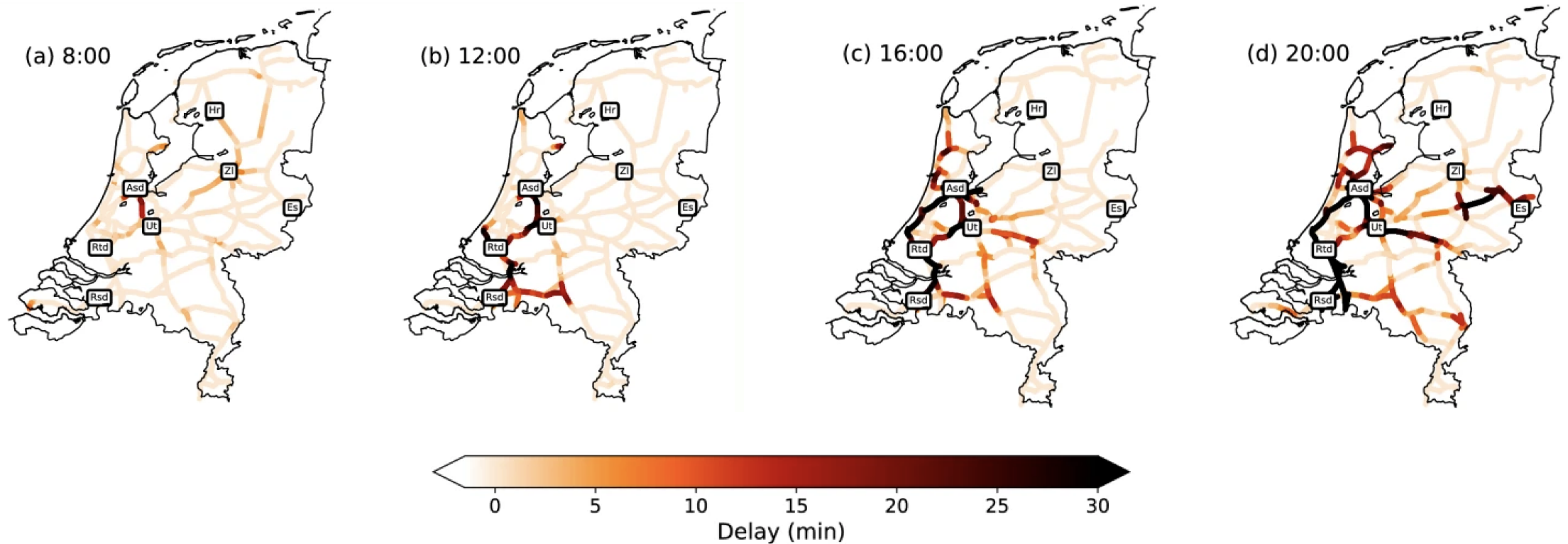# Today, "optimality vs fragility": the unknown price of doing "too much" with what is available
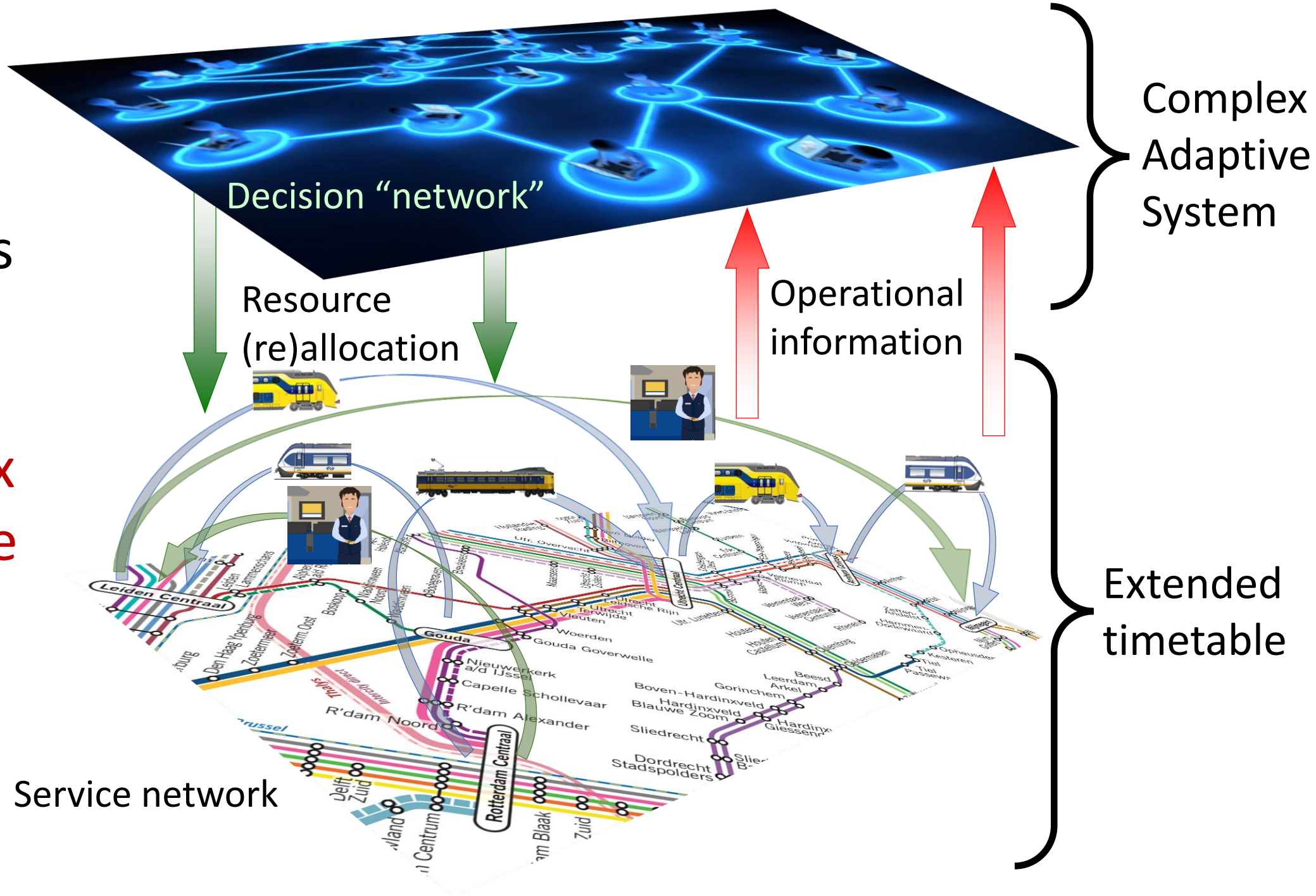
A case for rail transport

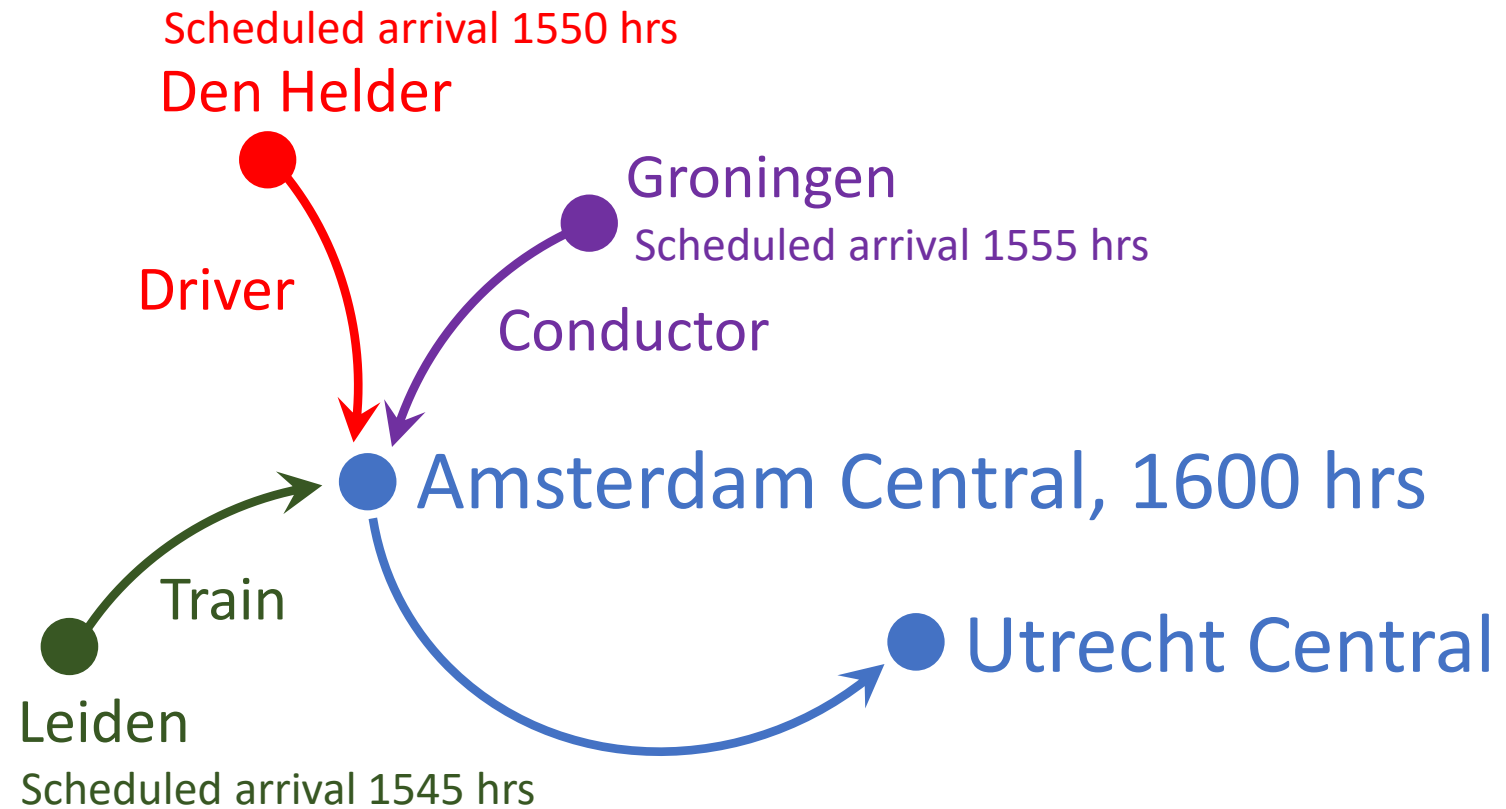# Large-scale (system-wide) disruptions in railways

Italy,
19-03-2015, 19:45

Germany,
31-03-2015, 18:53

Netherlands,
18-01-2018, 10:18

Switzerland,
03-01-2018, 12:54

Delay (min)

Large-scale (system-wide) disruptions in Dutch railways [February 3, 2012]

Complex
Adaptive
System

Decision "network"

Railways
as a
layered
Complex
Adaptive
System

Resource
(re)allocation

Operational
information

Extended
timetable

Service network

# Complexity of delay propagation in (Dutch) railways

Complexity of delay propagation in (Dutch) railways

Table 1. An example calculation of delay propagation in case of resource transfers. All values are stated in seconds.
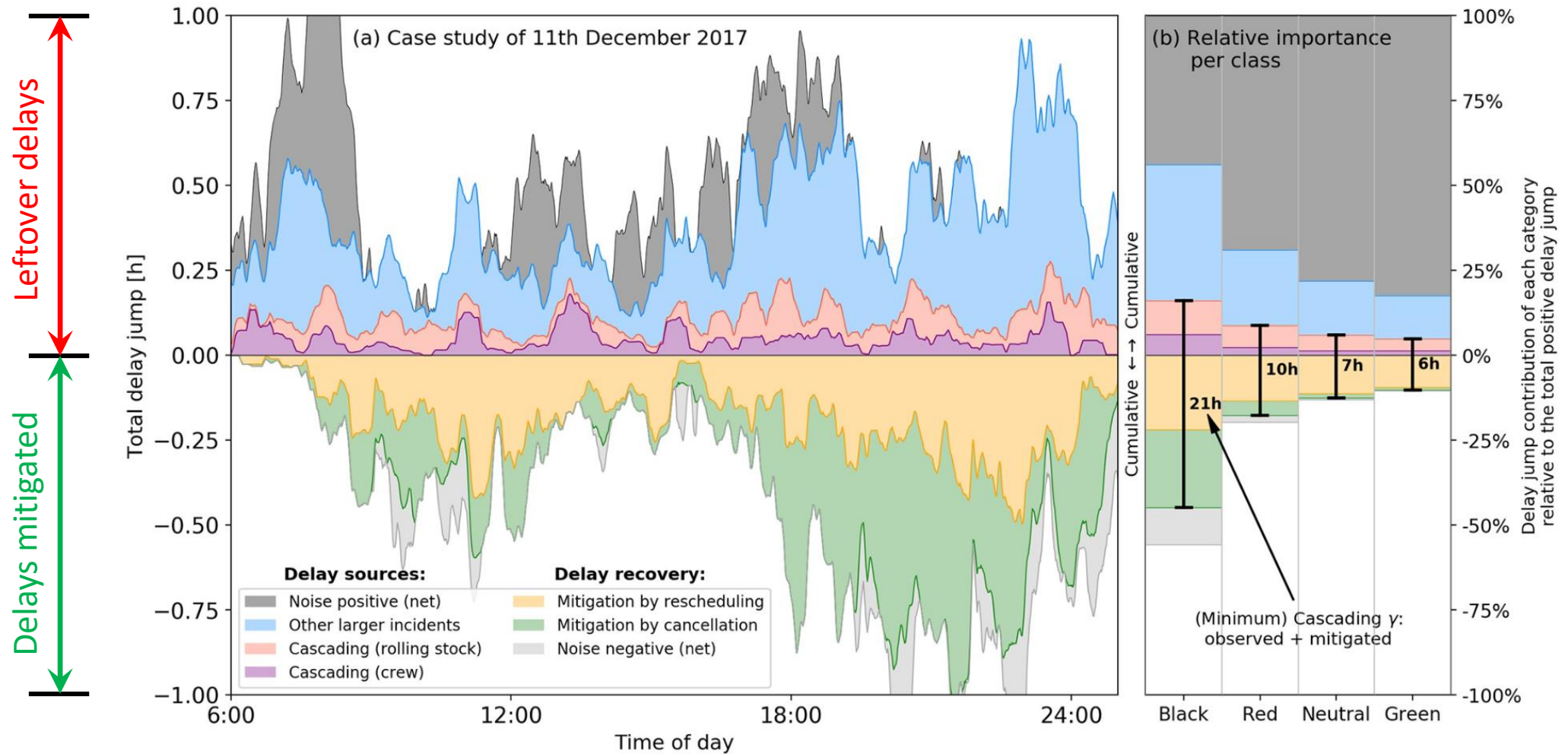
Resource	Delay d	Buffer β	Potential contribution
Train service	30	0	30
Rolling stock	300	120	180
Crew member I	720	600	120
Crew member II	540	600	0

Delay propagation ≡ Delay cascading

Predicting delay cascading in (Dutch) railways
[December 11, 2017]
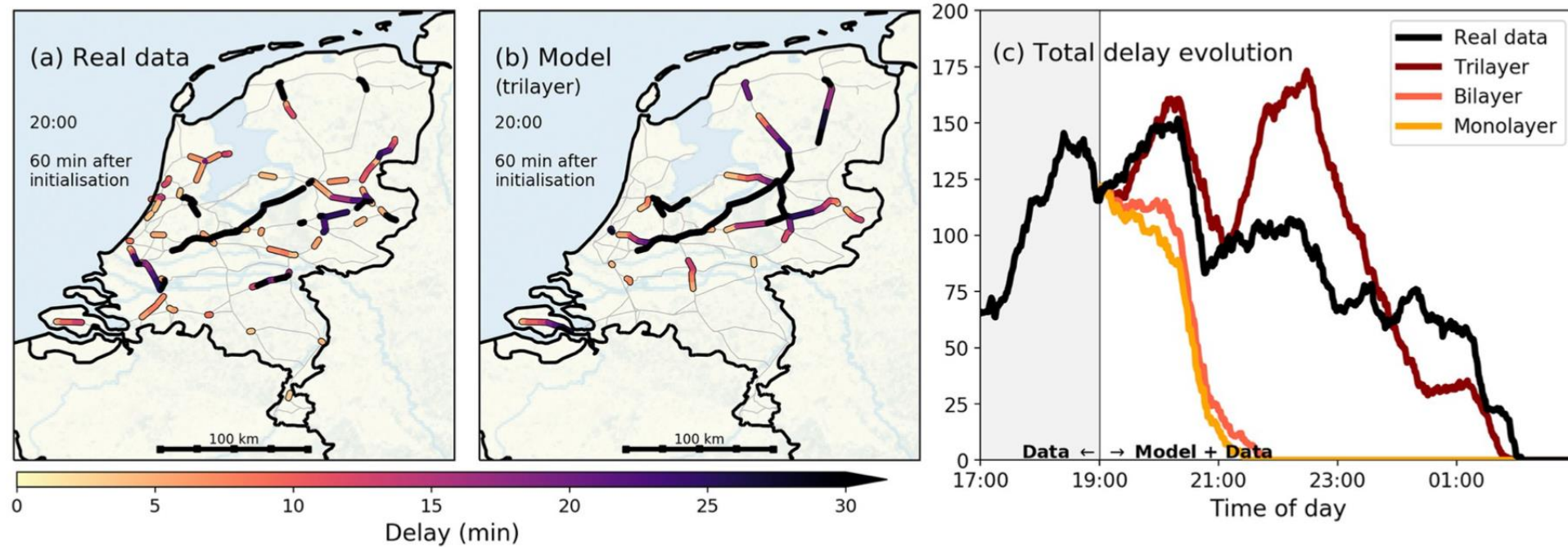
Delay cascading ⟹ large-scale disruptions in (Dutch) railways [December 11, 2017]

Intermezzo: summary part 1

- Large-scale disruption ⟺ Delay cascading (emergent effect)

- Increasing buffers is a mitigation measure, but that clashes with optimality

- Dutch railways do a good job in arresting cascading by rescheduling

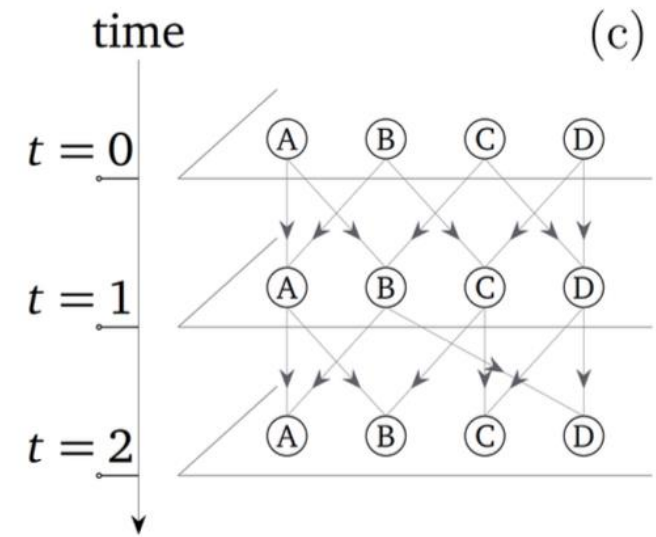- Disruptions in supply chains is no different

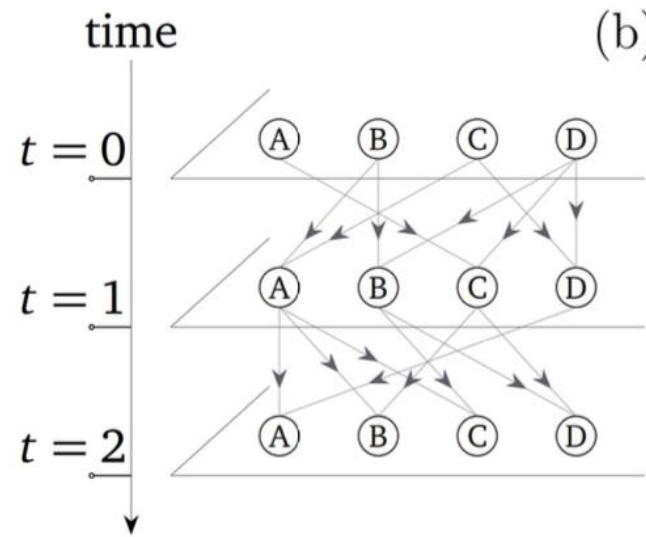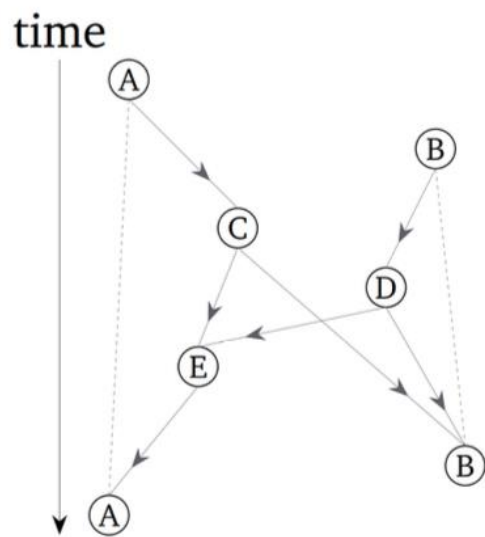Supply chains: why is temporal buffer important?
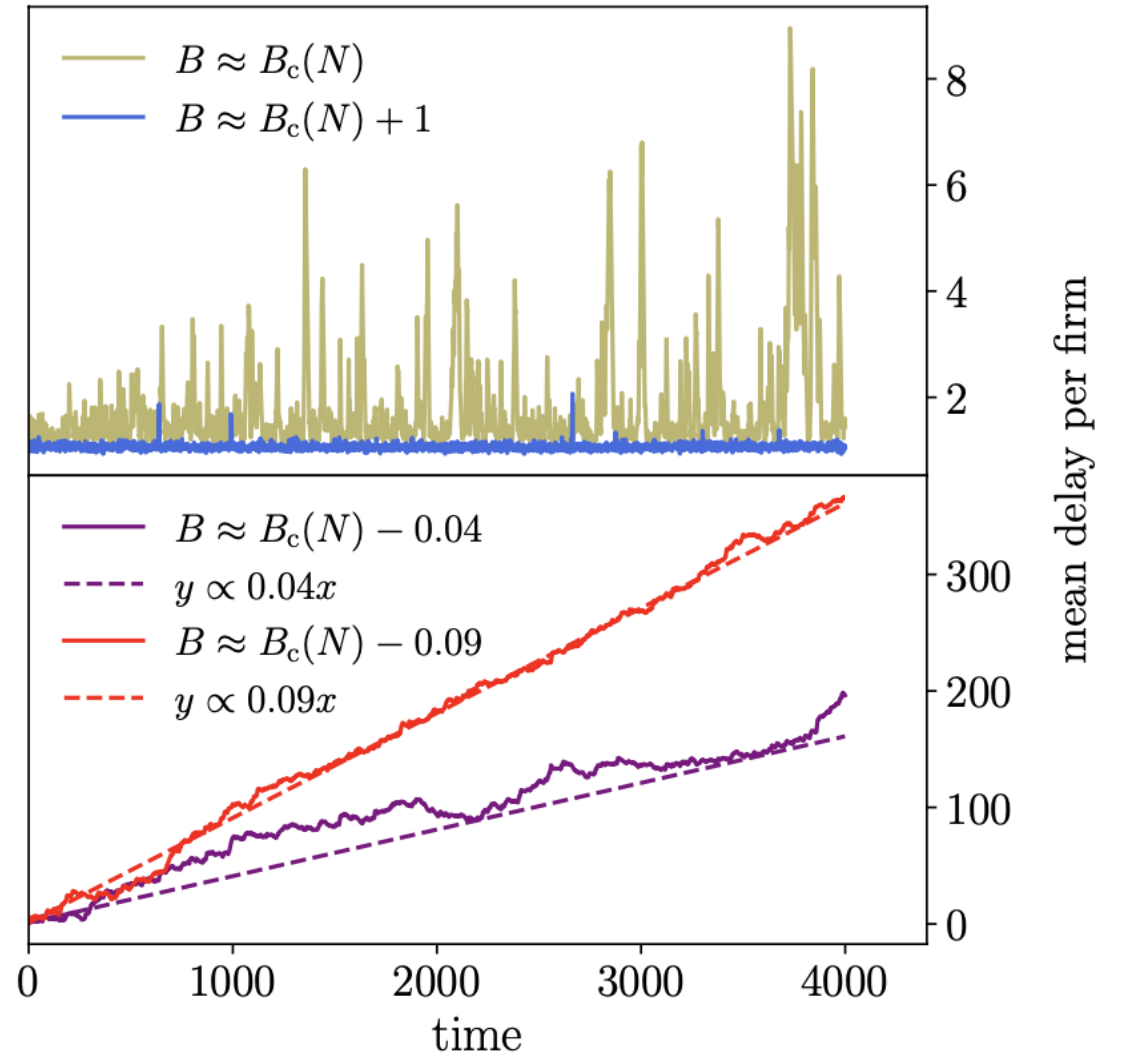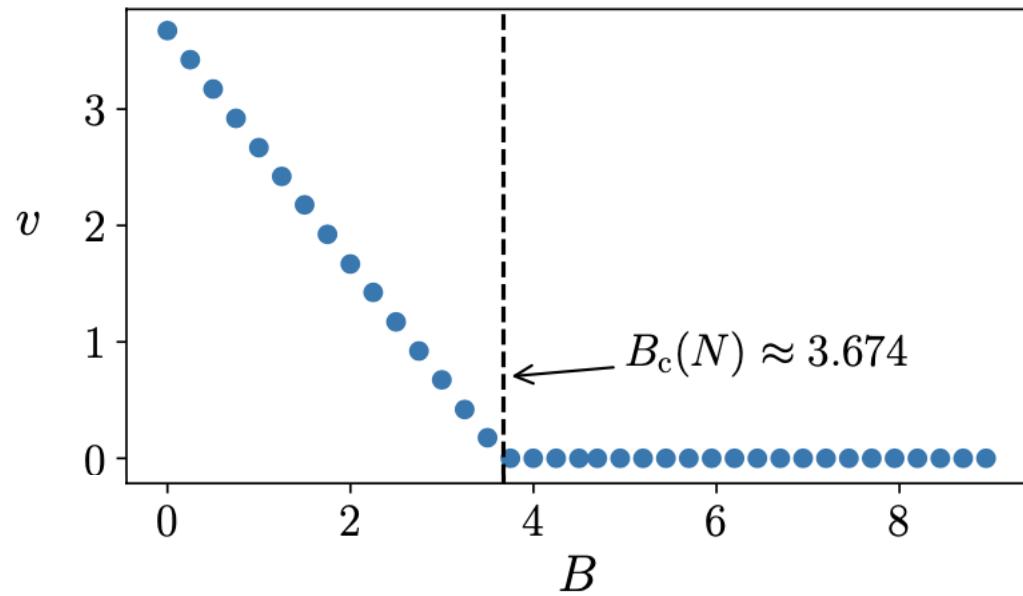
Taking it to an abstract level...

Optimality vs fragility must hold for *any* scheduled-based operation

Taking it to an abstract level of stylised models involving temporal networks (e.g., of firm economy)
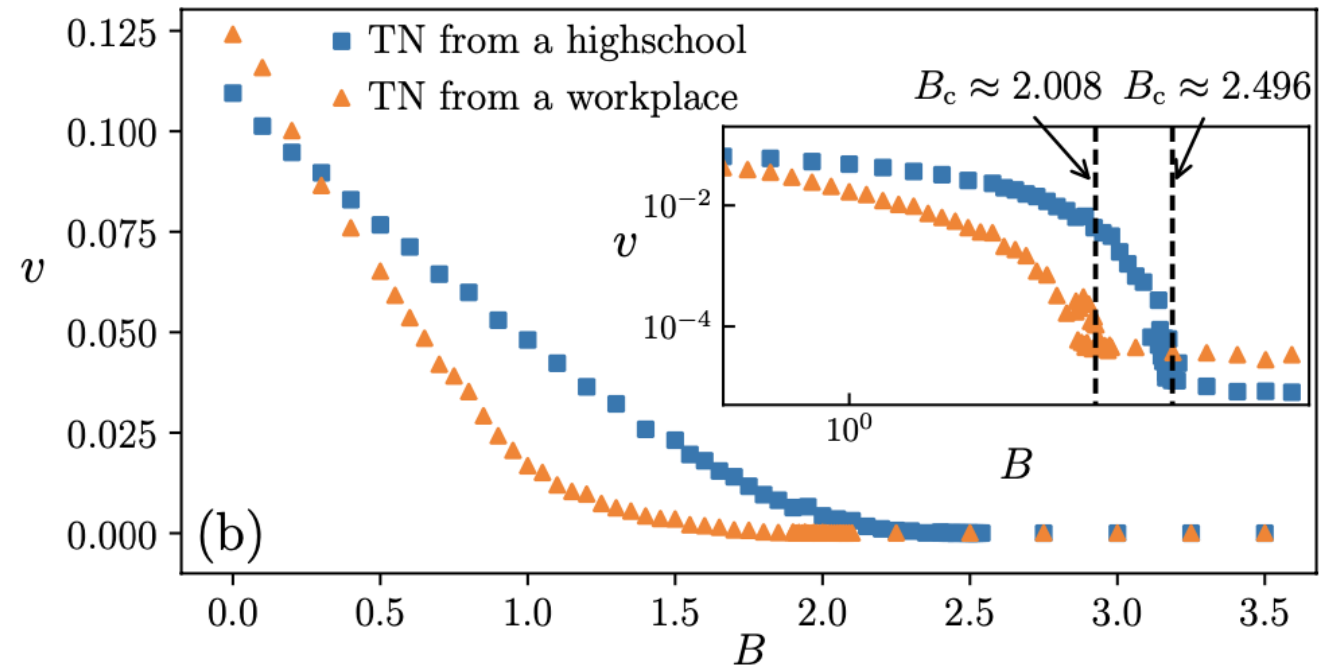

(analytical solution possible)

arXiv:2307.03546
arXiv:2309.15070

For a stylised model of firm economy

$B_c(N) \approx 3.674$
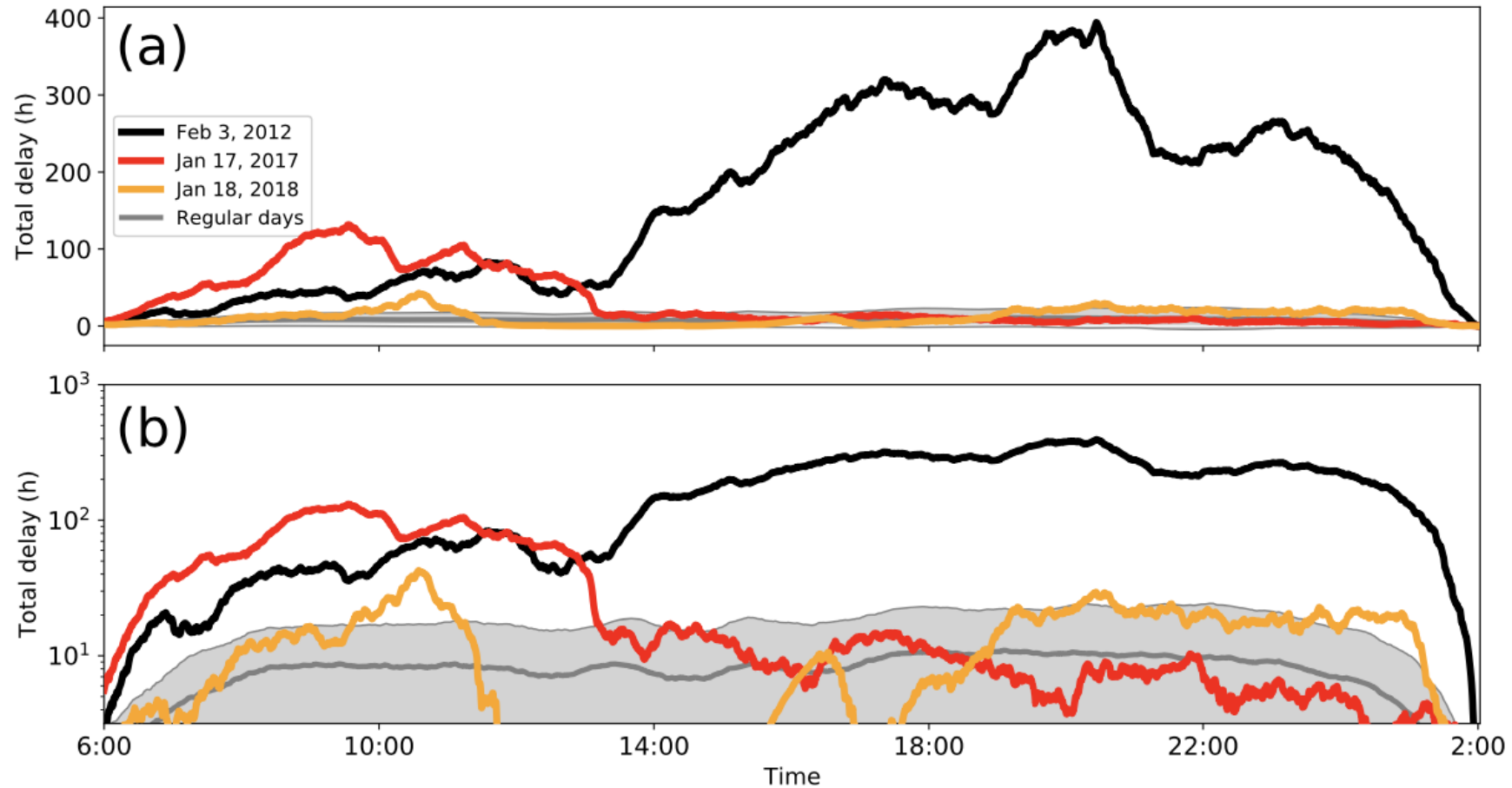
arXiv:2307.03546
arXiv:2309.15070

For real-world temporal networks
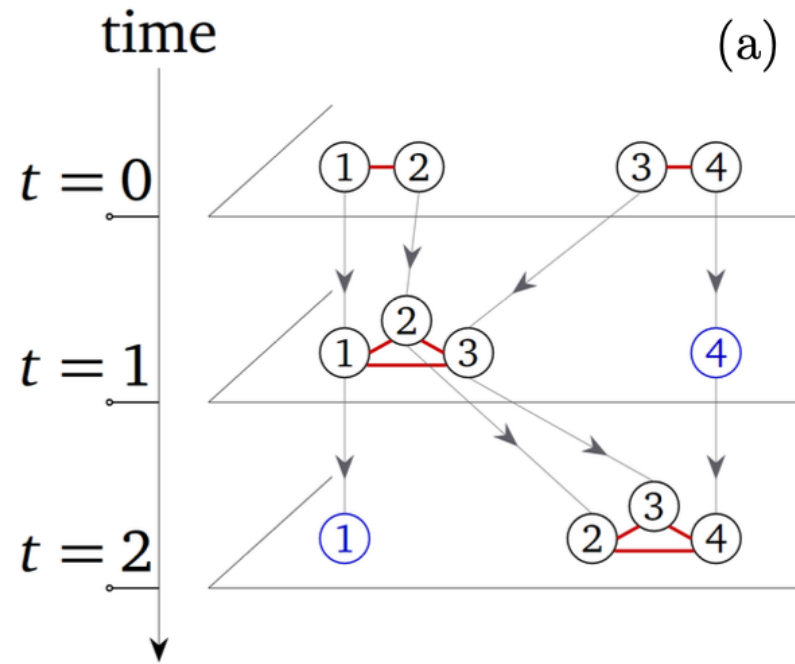
arXiv:2307.03546
arXiv:2309.15070

Reality check? (data from Dutch railways)

Summary part 2

- Large-scale disruptions in schedule-based operations can be critical phenomenon

- Different "phases" of the system separated by (sharp) boundaries

- One of these phases is fragile phase, where delays accumulate

Optimality vs fragility: final reflections

- Scheduling should take into account the risks of fragility (e.g., stay safely away from criticality, or optimise with a different objective function)

- But for that we first need to determine how close to criticality do (transport) systems operate, and consider social aspects

- If not, then optimality + resource rescheduling ("rewiring" for firm economy) is an option; but rewiring for firms *is* expensive

Acknowledgements

Mark Dekker, ex-PhD candidate
and many other collaborators

Finally...
Thank you for listening!