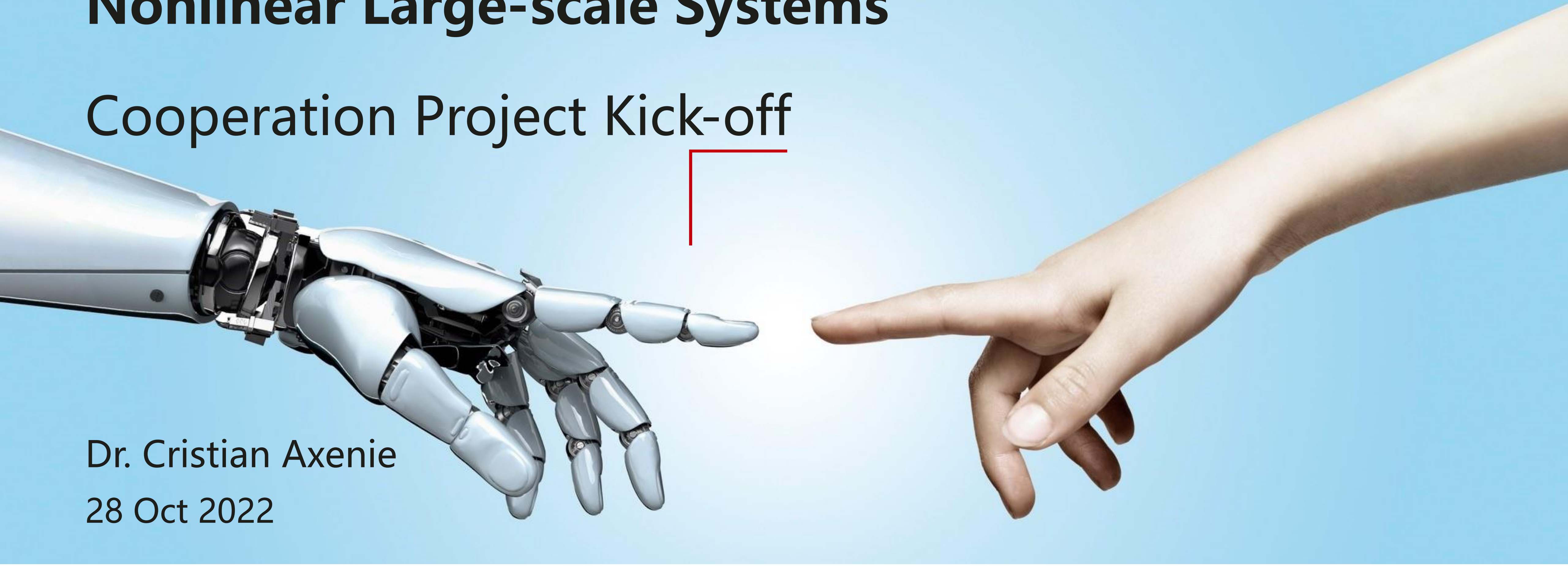
ANTIGONES: Antifragile Optimization of Nonlinear Large-scale Systems

Cooperation Project Kick-off



Dr. Cristian Axenie

28 Oct 2022

ETH zürich

Institut für Verkehrsplanung und Transportsysteme

HUAWEI

Outline

1. **Antifragility and traffic control**
    - The concept of antifragility
    - Induced Antifragility

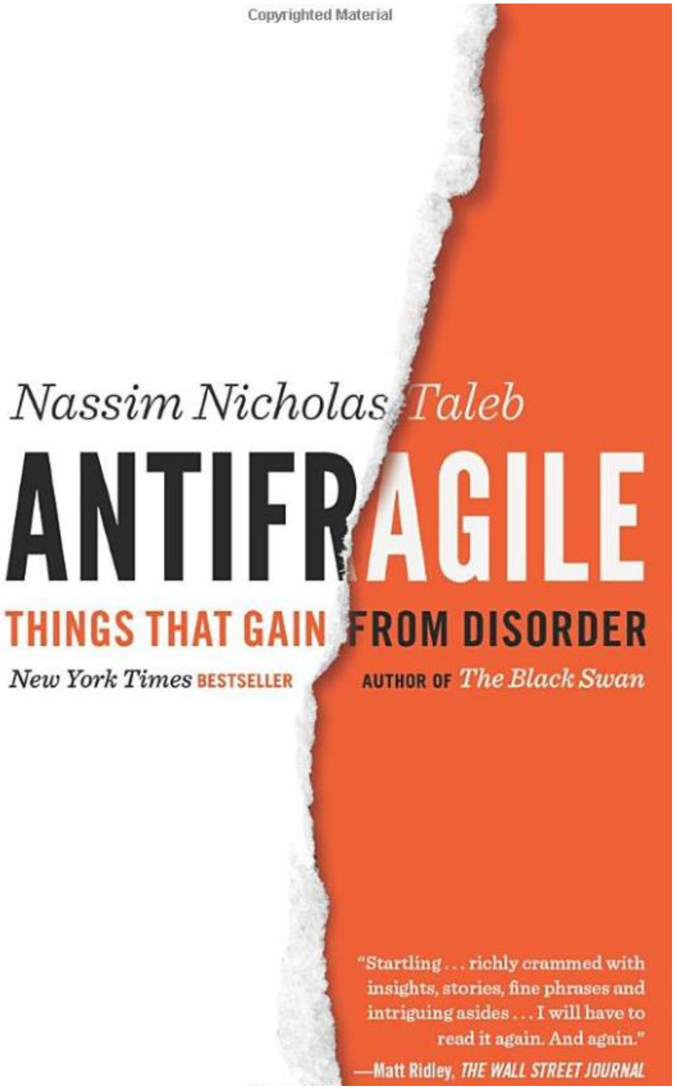
2. **ANTIGONES Project**
    - Core idea
    - Development
    - Expected results

Antifragility

The notions of **fragility** and **antifragility** were introduced by **Taleb** (2011).

Fragility is related to how a dynamical system **suffers** from the **variability** of its environment **beyond** a certain preset **threshold**, while **antifragility** refers to when it **gains** from this **variability**.

The **key** is to consider a **fragile-robust-antifragile continuum** in system`s **design**, **parametrization** and **control**.



Antifragility

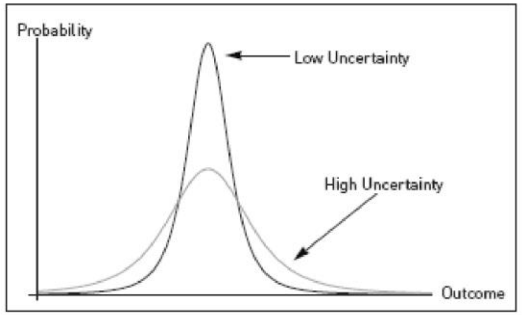


FIGURE 25. *Case 1,* ***the Symmetric Case.*** *Injecting uncertainty into the system makes us move from one bell shape—the first, with narrow possible spate of outcomes—to the second, a lower peak but more spread out. So it causes an increase of both positive and negative surprises, both positive and negative Black Swans.*

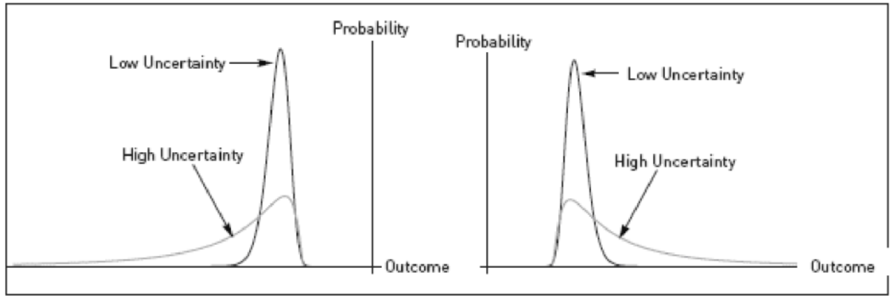
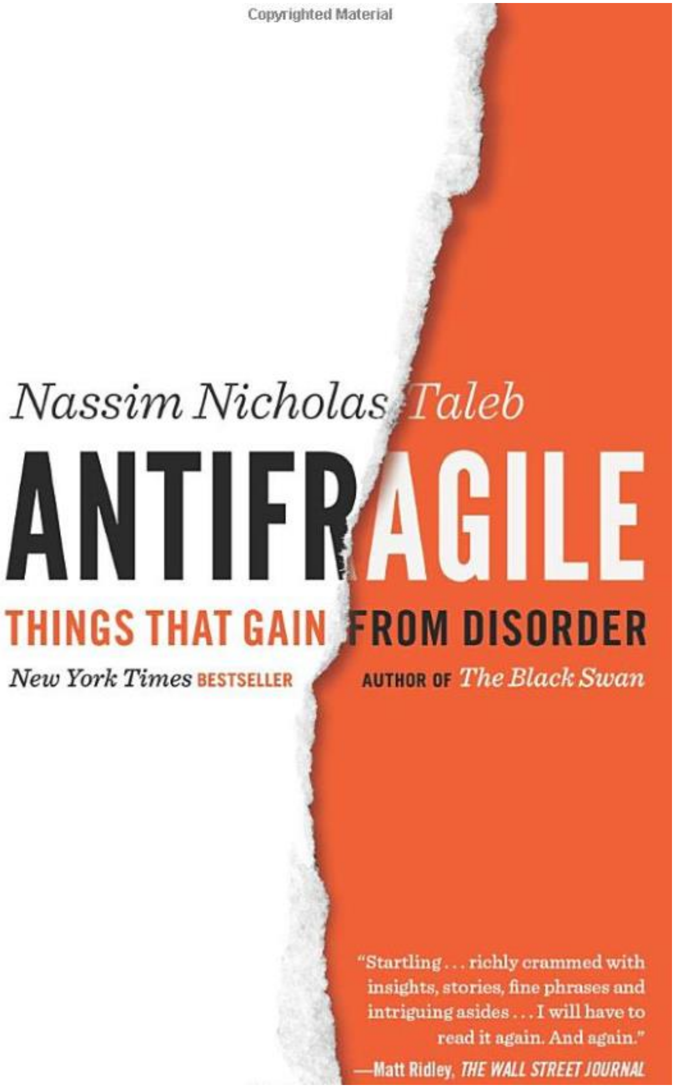
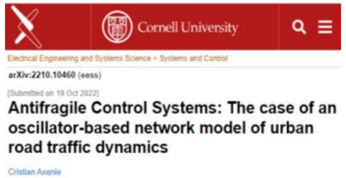


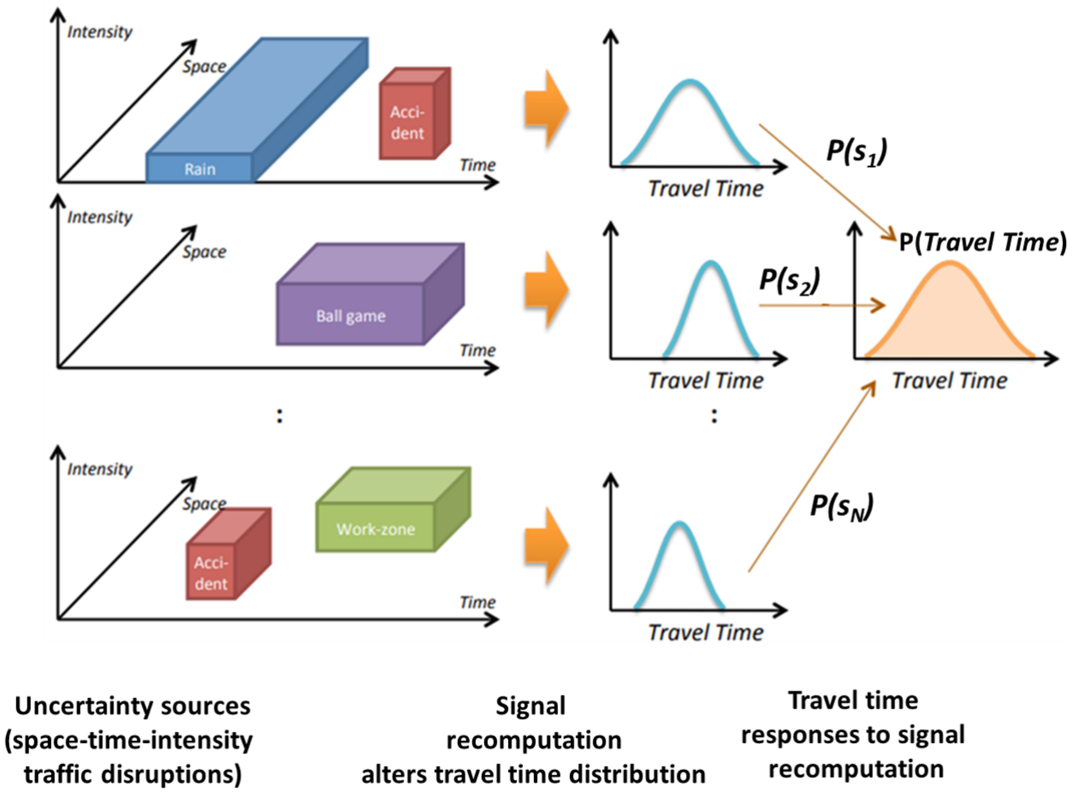
FIGURE 26. *Case 2 (left):* ***Fragile.*** *Limited gains, larger losses. Increasing uncertainty in the system causes an augmentation of mostly (sometimes only) negative outcomes, just negative Black Swans. Case 3 (right):* ***Antifragile.*** *Increasing randomness and uncertainty in the system raises the probability of very favorable outcomes, and accordingly expand the expected payoff. It shows how discovery is, mathematically, exactly like an anti–airplane delay.*

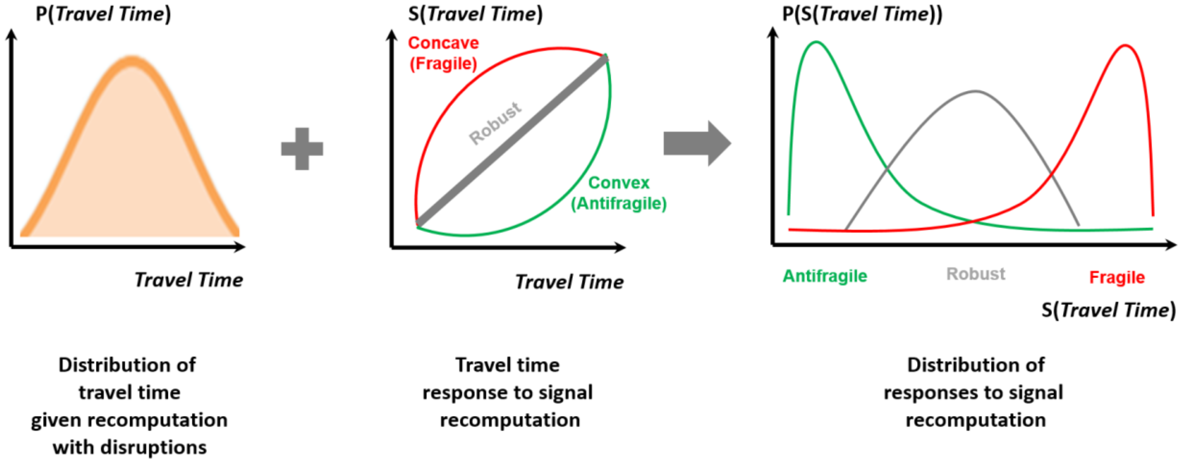


Antifragility and traffic control

The concept of antifragility

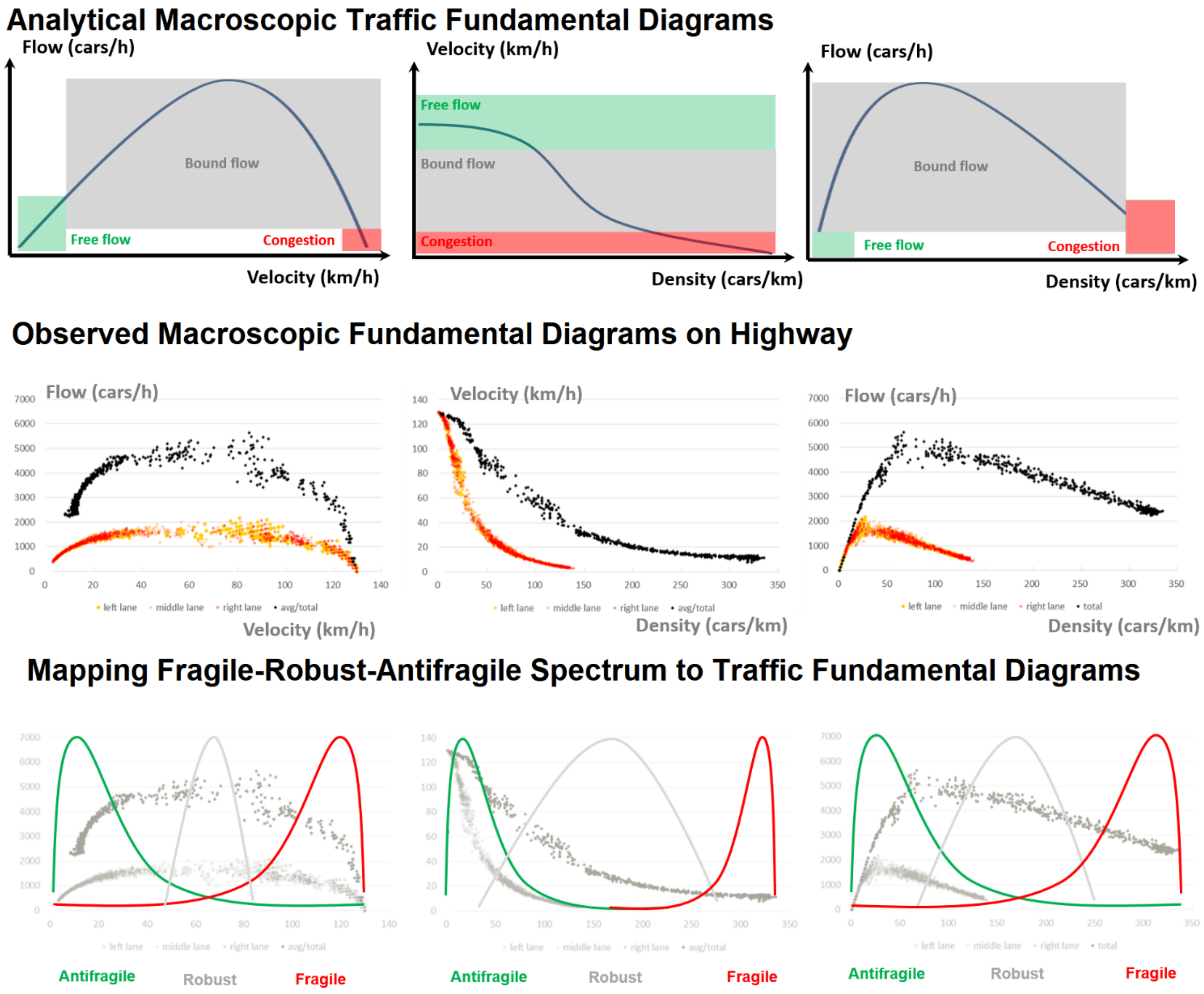

Cornell University
Electrical Engineering and Systems Science > Systems and Control
arXiv:2210.10460 (eess)
[Submitted on 19 Oct 2022]
Antifragile Control Systems: The case of an oscillator-based network model of urban road traffic dynamics
Cristian Axenie

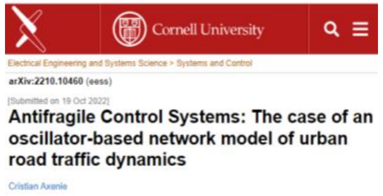




Antifragility in traffic control

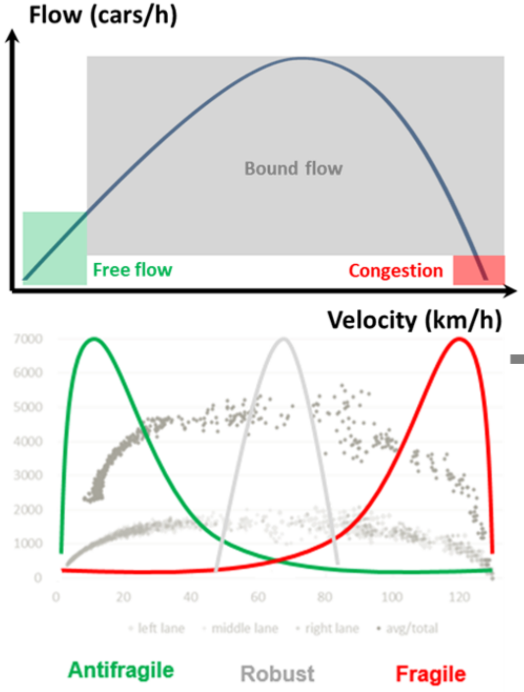
The concept of antifragility



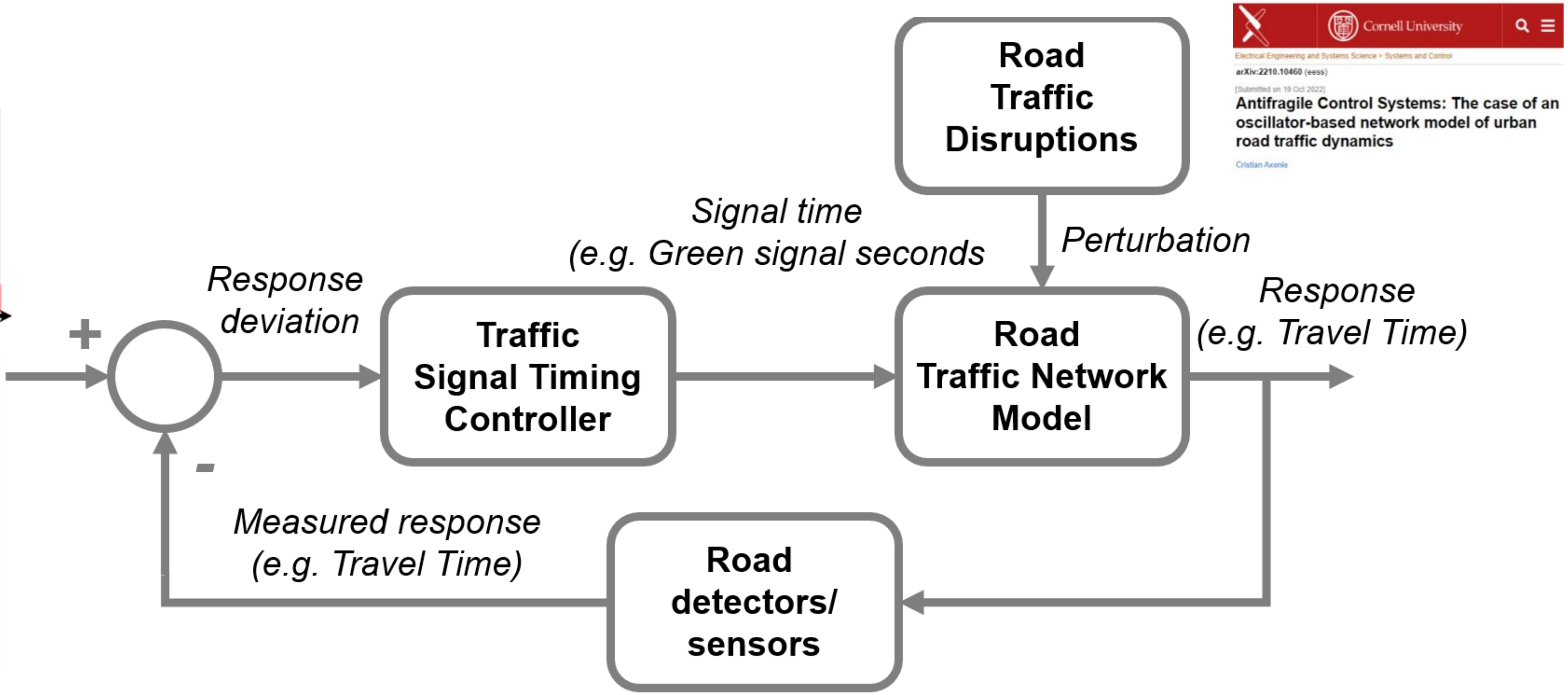


Antifragility in traffic control

Induced Antifragility



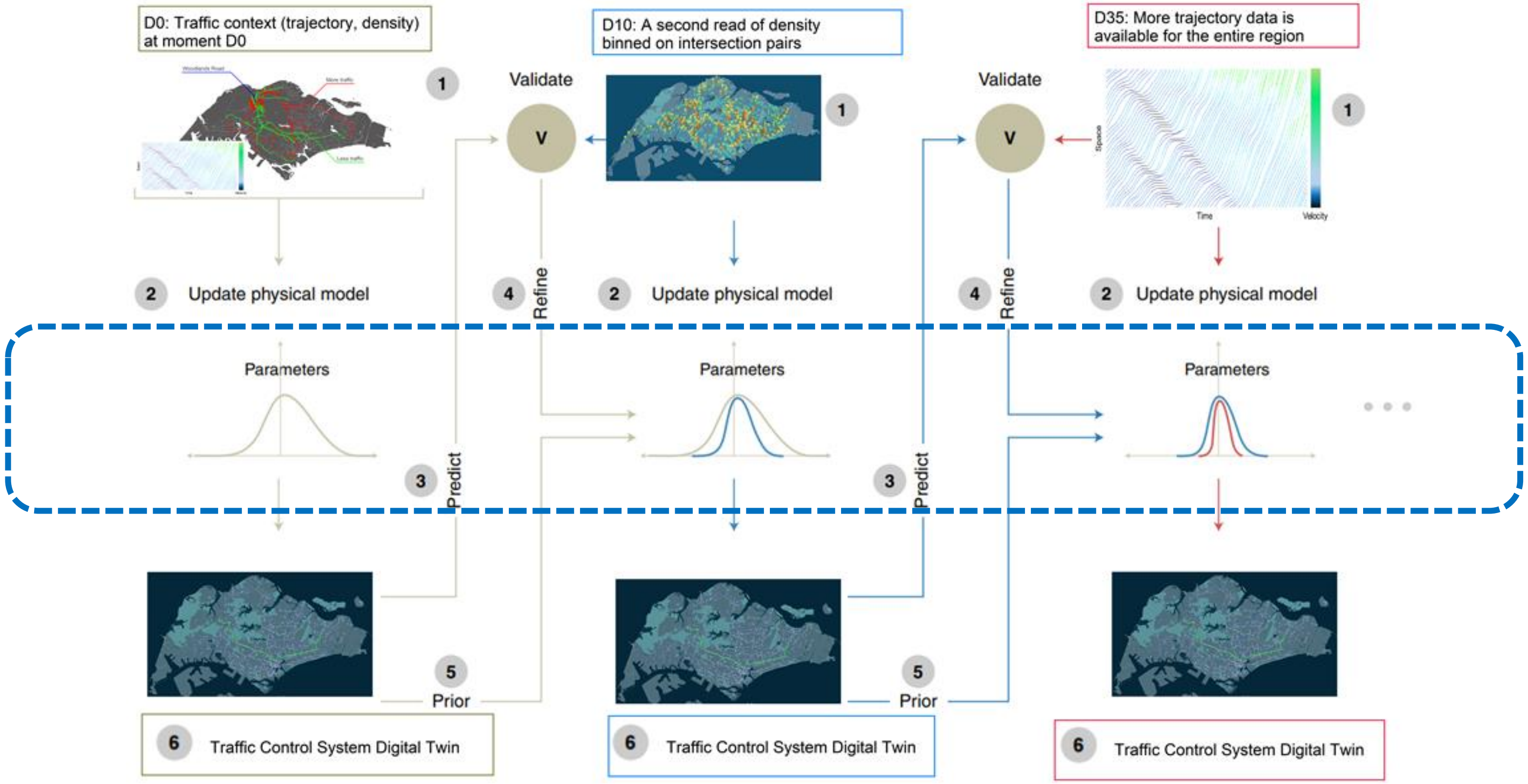
Stabilization into the antifragile region of MFD



ANTIGONES Project

Core idea

*Fundamentally, the key technology is a **physics-informed machine learning framework** that amounts to introducing appropriate observational, inductive or learning **biases** that can **steer the learning process** towards identifying physically consistent solutions of the **closed-loop control**. Such a solution give the system the unique property that it **gains structural integrity** and **performance gain** as it is **exposed** to **increasing** levels of traffic **pressure…hence become antifragile.***



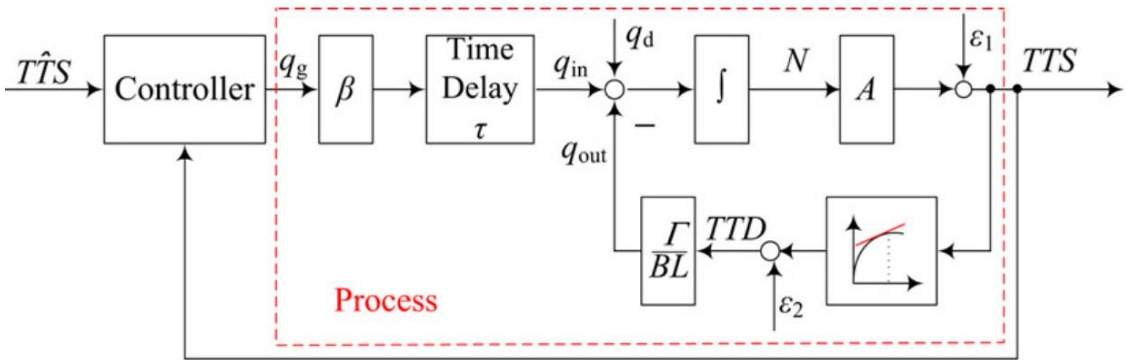
ANTIGONES Project

Exploration directions

Robust control design

To avoid congestion-caused degradation (i.e. a TTD decrease), the critical value (i.e. the value of TTS at which the maximum TTD is attained) in the fundamental diagram is considered as the set value for the controller. The **control goal** is to keep the **traffic state of the region around the set value**, so that **TTD is maximized** and the **network does not enter the over-saturation** area in the fundamental diagram.

Total Traveled Distance (TTD in veh km per h),
Total Time Spent (TTS in veh h per h)

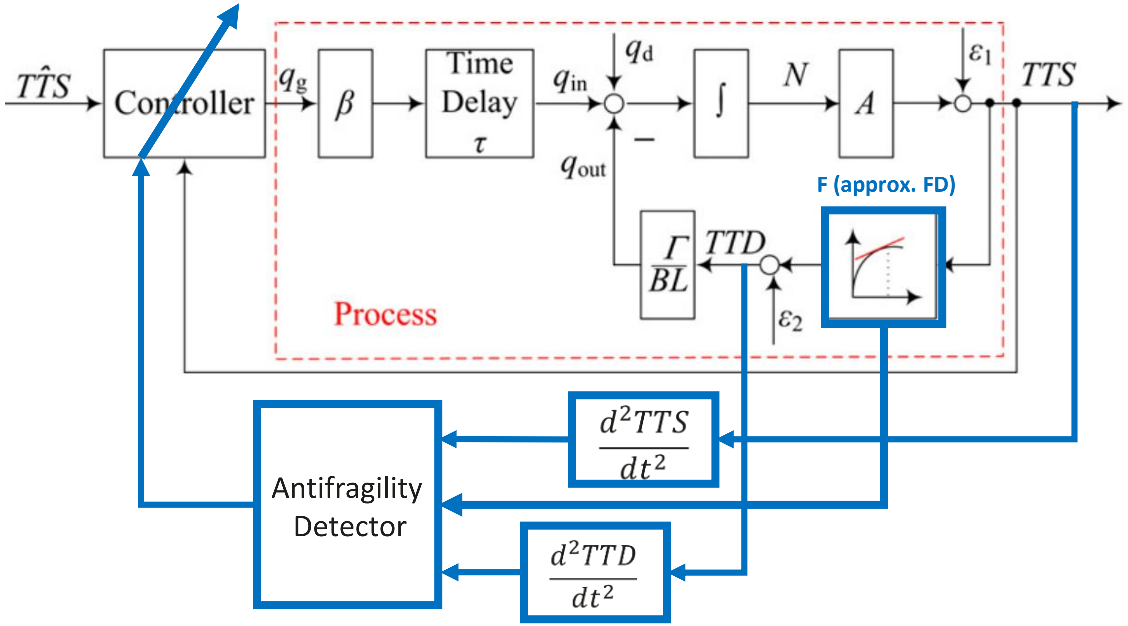


Exploiting the fundamental diagram of urban networks for feedback-based gating

Mehdi Keyvan-Ekbatani [a,*], Anastasios Kouvelas [b], Ioannis Papamichail [a], Markos Papageorgiou [a]

Antifragile control design

In order to **drive the system towards the desired region of the fundamental diagram** mapped to fragile-robust-antifragile continuum, the **antifragile controller is updated based on the curvature of both TTS and TTD** (i.e. second order effect) and **the learnt F** (i.e. learnt approximation of the fundamental diagram form observations). The **antifragility detector** applies some heuristics (i.e. statistical) to **update the parameters** of the controller.

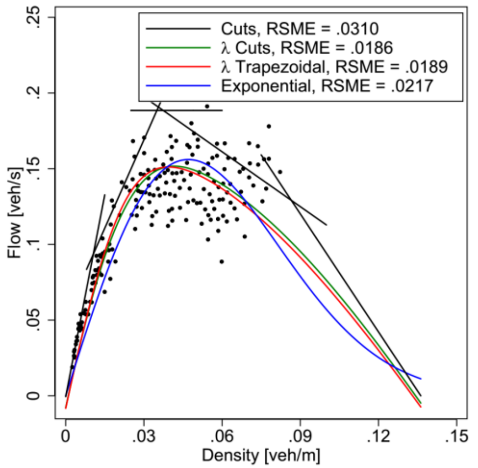


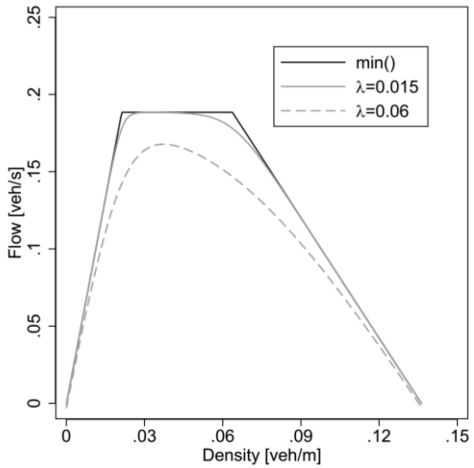
ANTIGONES Project

Exploration directions

Functional forms of the fundamental diagram

Introducing **a new parameter (λ)** that can be useful in many future MFD applications from analyzing urban congestion to traffic control. In this functional form, the **fundamental diagram can** be either estimated from measurements or defined a-priori, either **analytically** or with **additional measurements** in the network, while the smoothing is quantified with a single parameter λ.





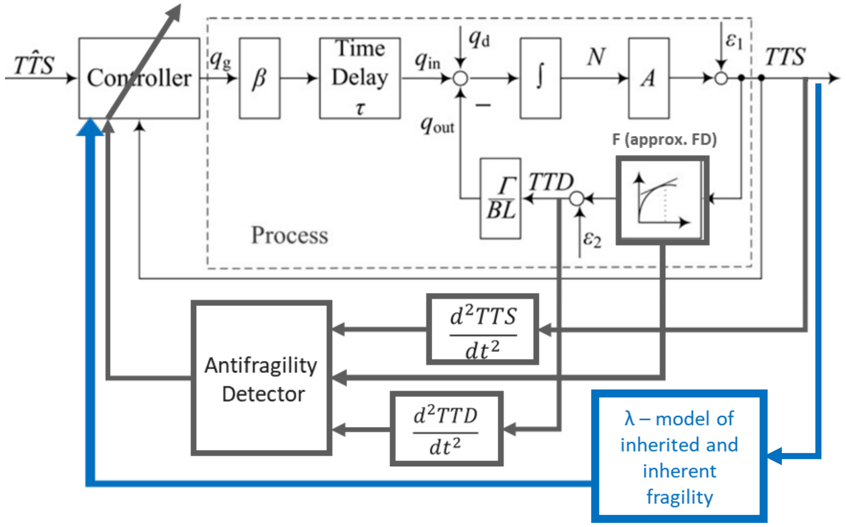
A functional form with a physical meaning for the macroscopic fundamental diagram

Lukas Ambühl[a], Allister Loder[a,*], Michiel C.J. Bliemer[b], Monica Menendez[c,d,a], Kay W. Axhausen[a]

Antifragility quantification

In order to drive the system towards the desired region of the fundamental diagram mapped to fragile-robust-antifragile continuum, the **antifragile controller uses λ**. The parameter **λ becomes then a collective and network-wide quantification of flow reducing factors**, caused by infrastructure, between-vehicle interactions, and other means of transportation such as cycling and walking.

For the same fundamental diagram, **flow values decrease with increasing values of λ. Smaller values of λ indicate that the infrastructure is used more efficiently** and that performance losses due to vehicle interactions are smaller.

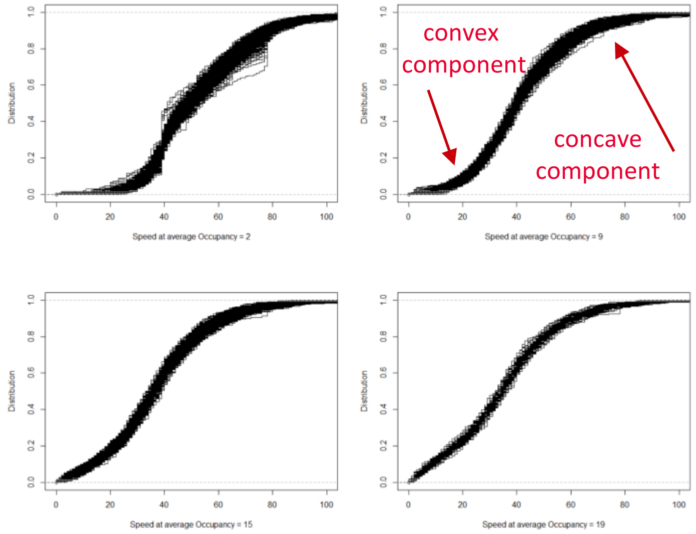


ANTIGONES Project

Exploration directions

Fundamental diagram robustness

Observing the **stable relationship between the space-averages of speed, flow and occupancy** are not sufficient to infer a robust relationship and the emerging fundamental diagram cannot be guaranteed to be stable if traffic Interventions (i.e. traffic light control to react to disruptions) are implemented. **Second order effects in responses** (i.e. speed distributions) to adapt controller operation.



Emergence of a urban traffic macroscopic fundamental diagram

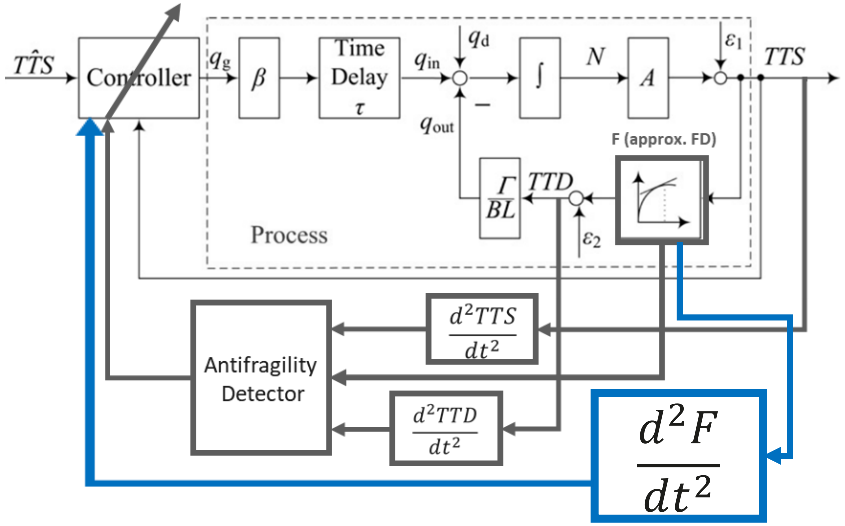
Ranjan, Abhishek and Fosgerau, Mogens and Jenelius, Erik

Antifragile control using fundamental diagram curvature

What does this imply for the use of an fundamental diagram for traffic control? **Metering would affect the observed shape of the fundamental diagram a**nd that it therefore does not predict the effect of metering.

So it should now be clear that **merely observing a stable relationship between space-averages of speed or flow versus occupancy is not sufficient to infer the existence of a robust relationship** that can be used for traffic control.

Quantifying the **curvature of individual responses** to **signal re-computation/metering** could enable a **correction** of the fundamental diagram **approximation in F**.

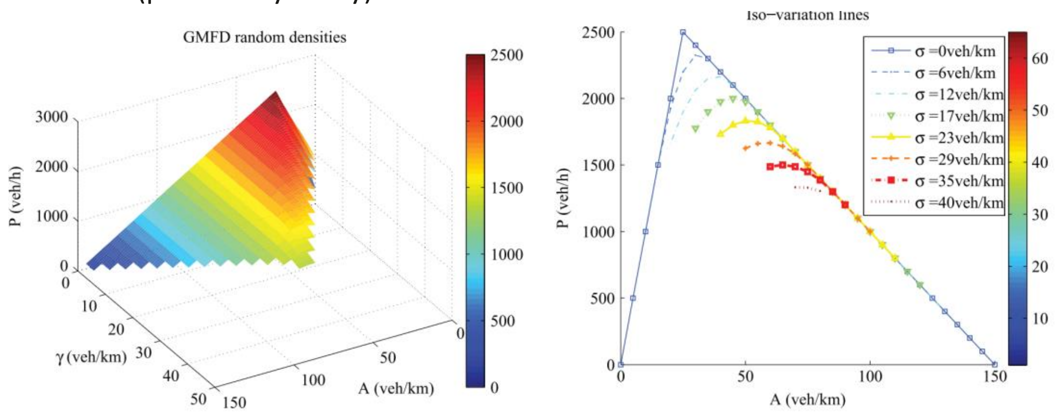


ANTIGONES Project

Exploration directions

Fundamental diagram with density inhomogeneity and nonlinearity

Macroscopic Fundamental Diagram (MFD) when aggregated over an area, describes the relationship between accumulation and production and is quite crisp. This can be an aspect of the law of large numbers: **the more data is aggregated, the less influence the differences in drivers characteristics have.** For control purposes, it is very useful to have a **strict relationship on the basis of which control can be applied**. Traffic dynamics in congested networks inherently leads to **traffic inhomogeneity**, because, under increasing traffic volume loaded onto the network at some point congestion will set in at one of the (potentially many) bottlenecks in a network.



(a) The generalized macroscopic fundamental diagram. To improve visibility of the surface, the graph is rotated such that the axis of density increases from right to left.

(b) Macroscopic fundamental diagrams with constant levels of spatial inhomogeneity of density.

Fig. 1. The generalized macroscopic fundamental diagram based on independent road stretches.

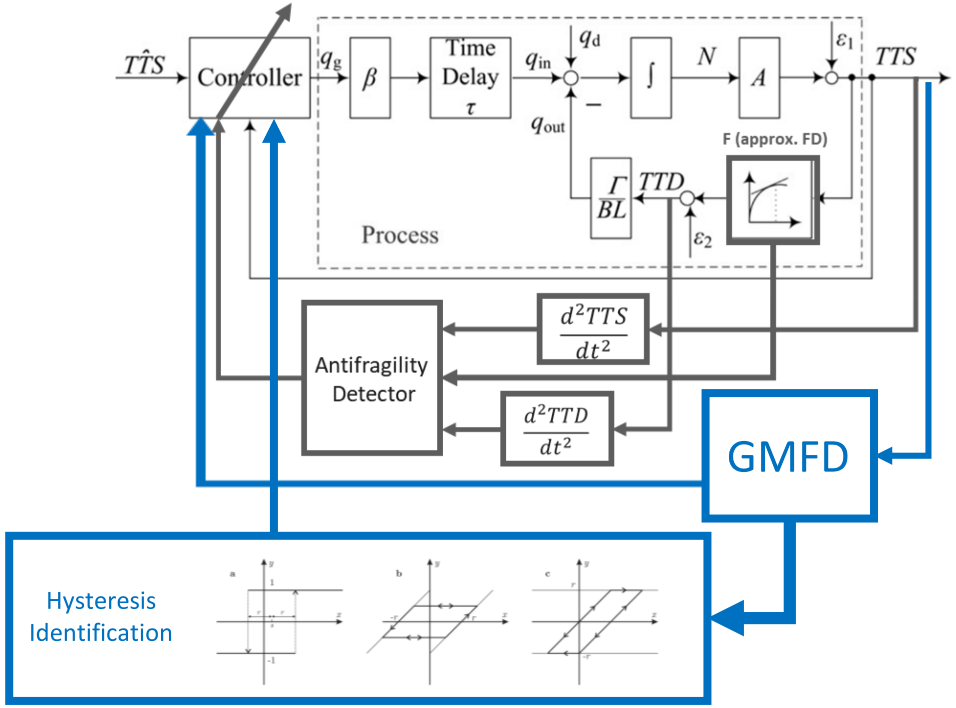
Traffic dynamics: Its impact on the Macroscopic Fundamental Diagram

Victor L. Knoop*, Hans van Lint, Serge P. Hoogendoorn

Antifragile control exploiting traffic dynamics (inhomogeneity and nonlinearity)

Exploit the fact that **production is a continuous function of accumulation and spatial inhomogeneity of density and learn the production function** ((i.e., the average flow of vehicles per unit of time)).

Capture **the hysteresis effects** found in the **MFD** using the GMFD to employ in the antifragile control scheme. For instance, it can be used for **estimating speed in a (sub-) network, and traffic can be guided over the faster routes**.



Thank you.

把数字世界带入每个人、每个家庭、
每个组织，构建万物互联的智能世界。

Bring digital to every person, home and organization for a fully connected, intelligent world.

HUAWEI