Coordinated traffic flow management in highway systems

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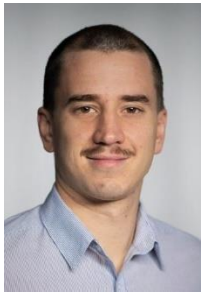
Dr. Anastasios Kouvelas
Traffic modelling, estimation, and control
Big data and machine learning
Neural networks and
Operations research

Dr. Michalis Makridis
Connected and automated vehicles
Traffic estimation and control
Traffic simulation and modeling
Machine learning

Dr. Shima Mousavi
control of mixed traffic systems

Zahra Ghandeharioun
Ridesharing
Travel time estimation
Optimization



Alexander Genser
Traffic management with deep learning
Signal phase and timing forecasting
Traffic state estimation

Kimia Chavoshi
Traffic control and optimization
Connected and automated vehicles

Zheng Shiteng
Traffic flow experiment and modelling
Traffic oscillation
Autonomous vehicle

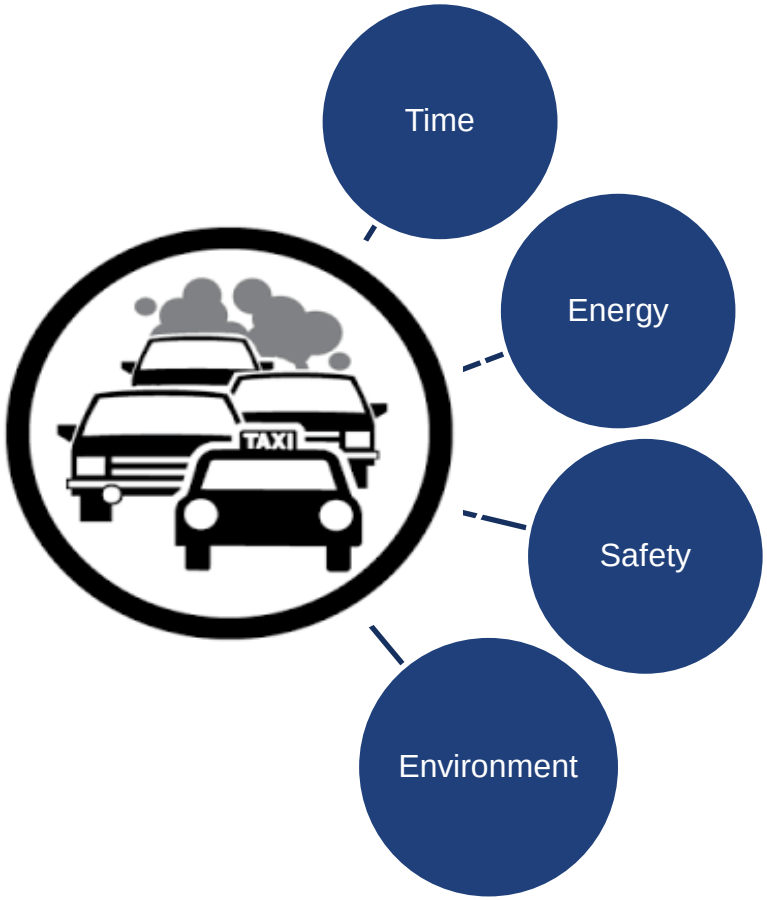
Yu Du
Connected and automated vehicle
Mixed traffic flow,
Cooperative vehicle - infrastructure

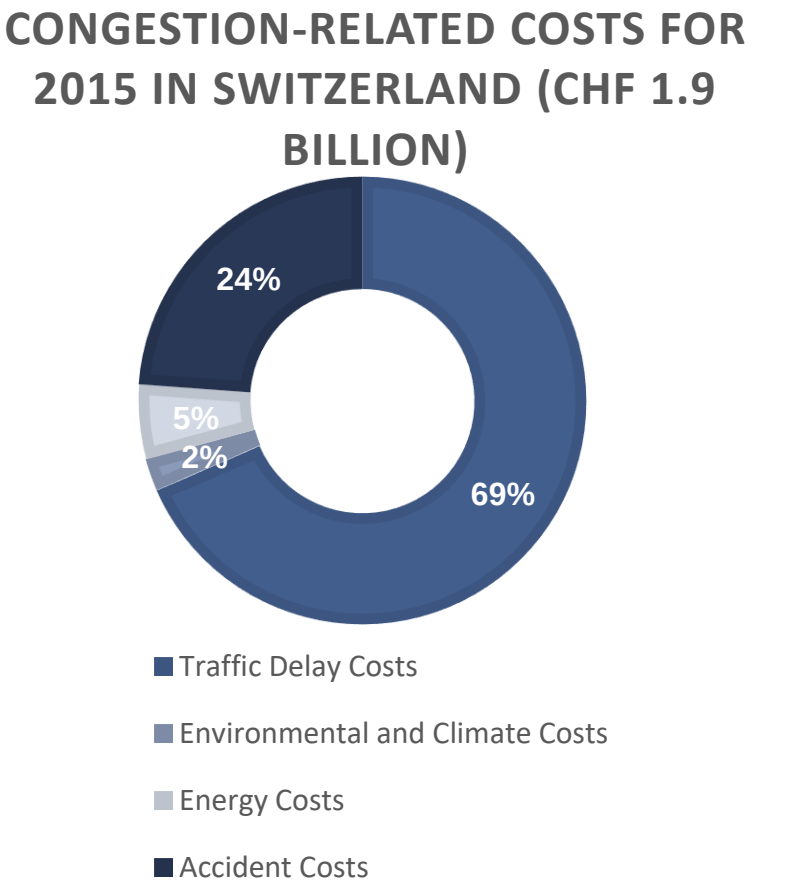
Outline

- Why is the traffic flow management in highway networks important?
- What are the tools for traffic flow management in highways?
- What are the challenges in developing a traffic control method?
- How to obtain an optimal real-time solution?

Why is the traffic flow management in highway networks important?

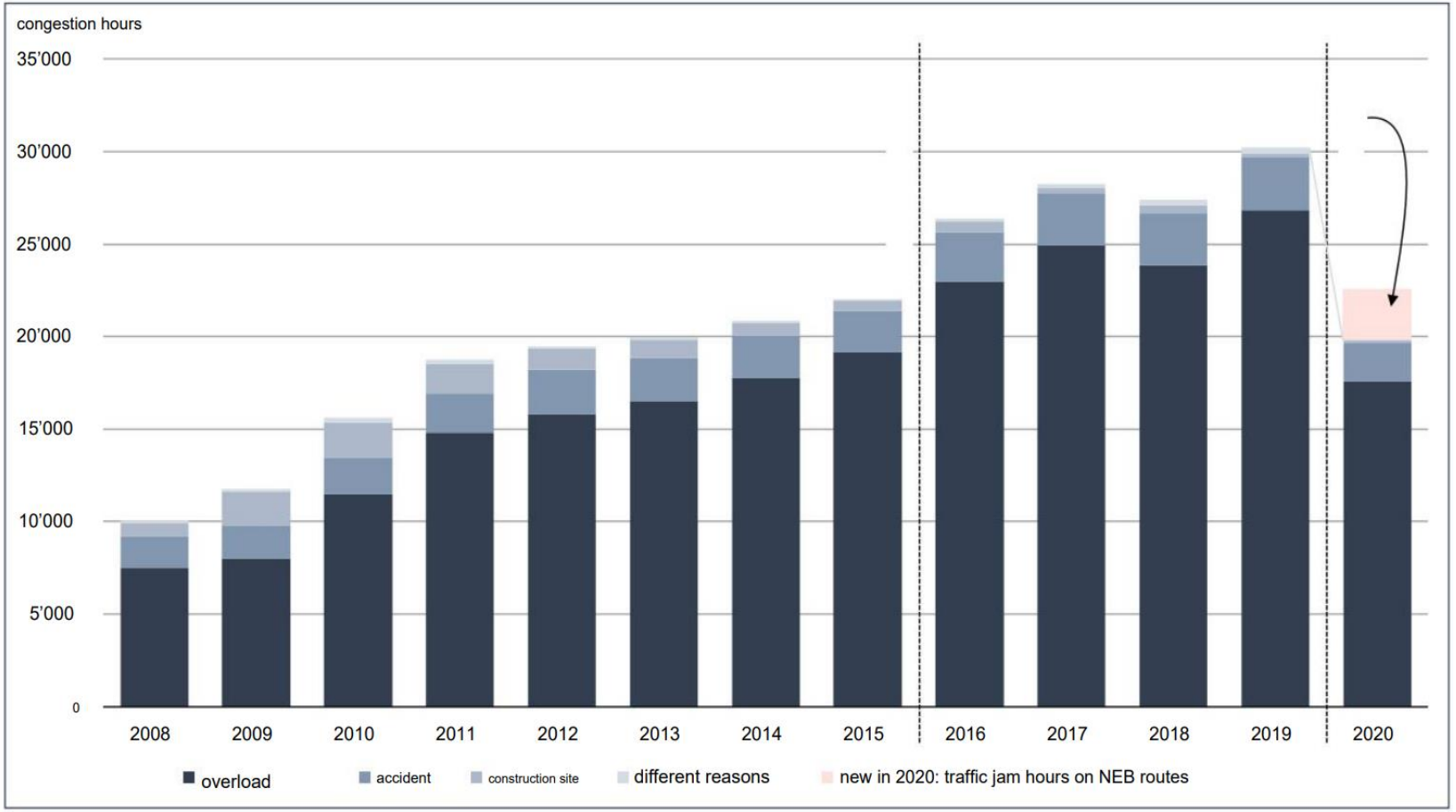
Motivation





Report of Federal Office for Spatial Development: Switzerland Congestion Cost 2015
https://www.are.admin.ch

Motivation



Development of traffic jam hours on national roads in Switzerland

Source: Bundesamt fur Strassen ASTRA, Verkehrsentwicklung und verkehrsfluss 2020, V1.02,June 2021.

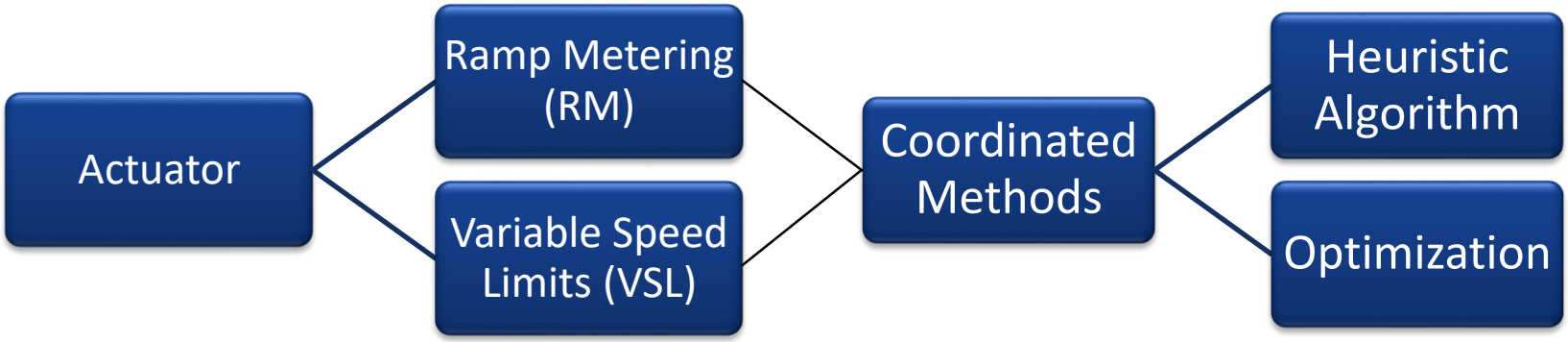
What are the tools for traffic flow management in highways?

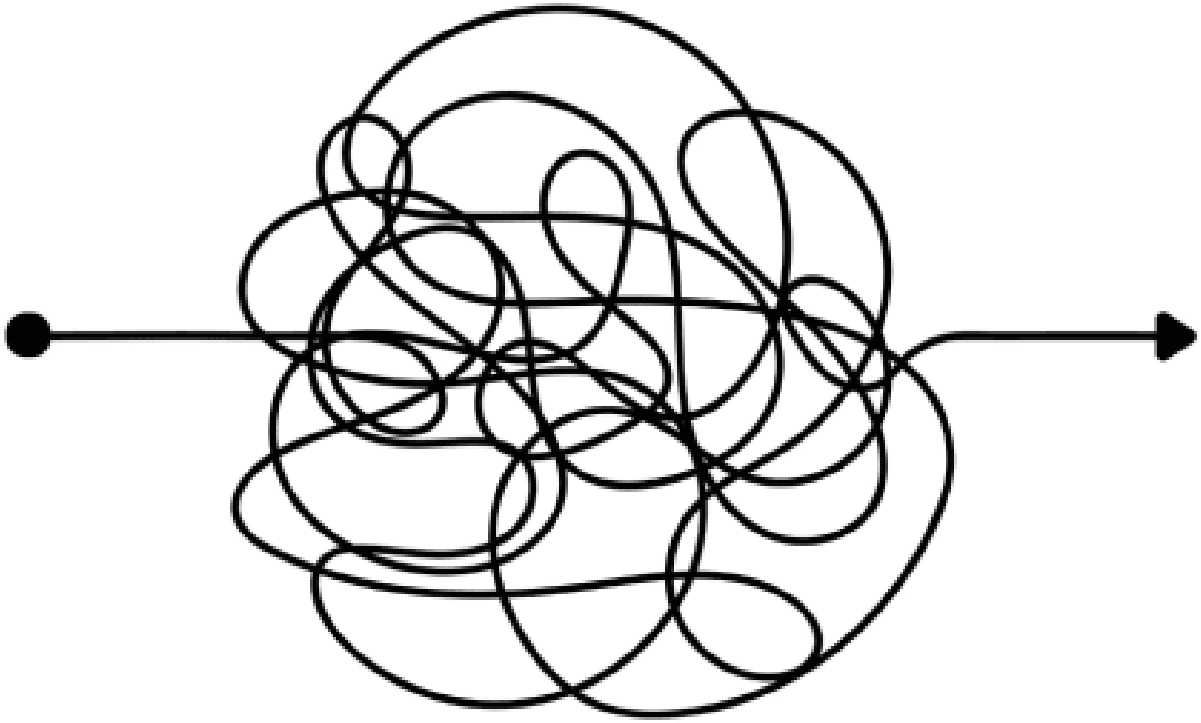
Introduction to traffic control in highway systems

- Variable Speed Limits (VSL)

- Ramp Metering (RM)

Literature review



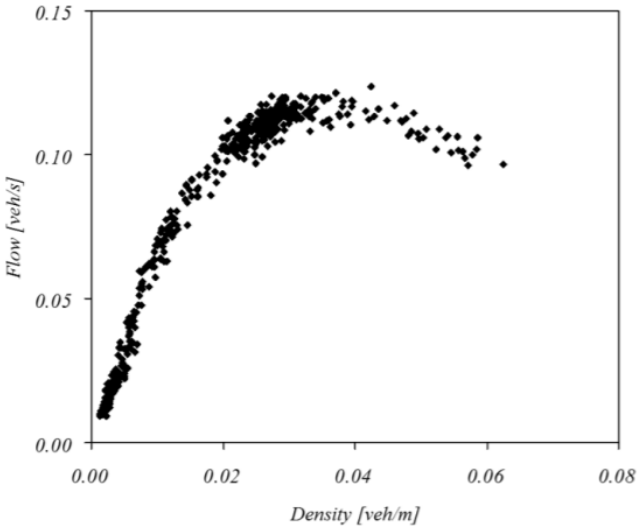


What are the challenges in developing a traffic control method?

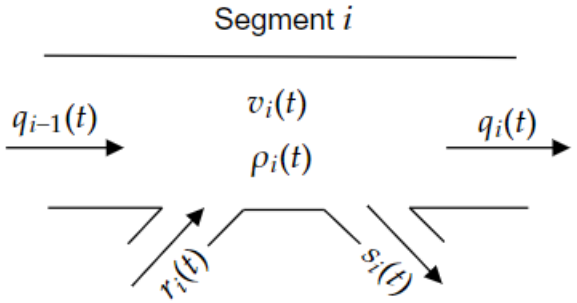
Where does the complexity come from?

- Macroscopic traffic flow models

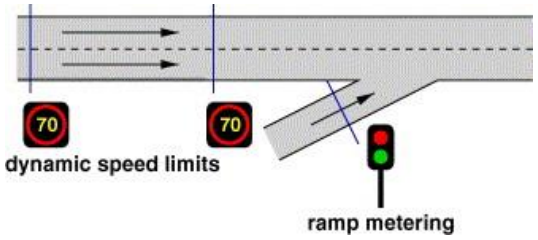
Relations between Flow, Speed, and Density



System dynamics



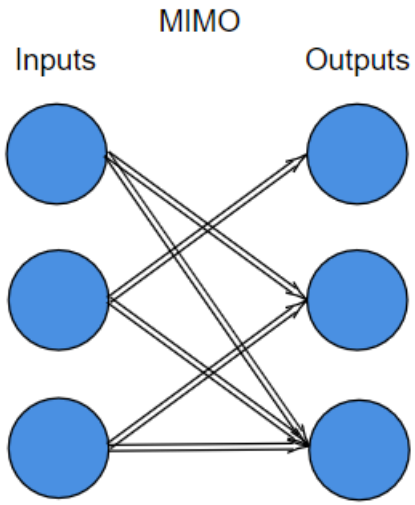
Impacts of control signals on the macroscopic features



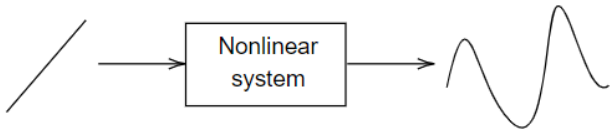
What are the challenges?

- Macroscopic traffic flow models

Multiple inputs
multiple outputs



Nonlinear System

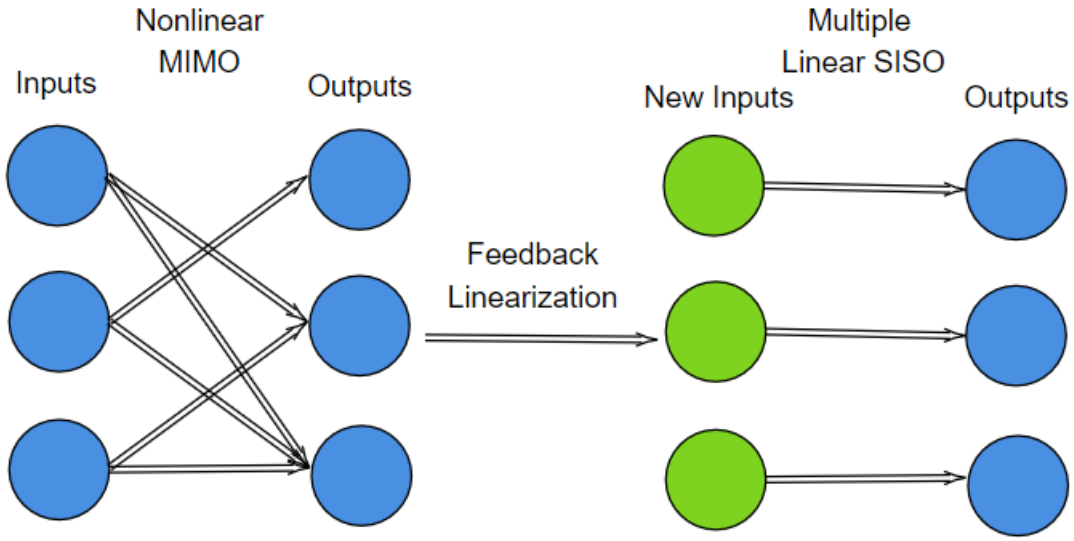


Disturbances

How to obtain an optimal real-time solution?

Why feedback linearization is a potential solution?

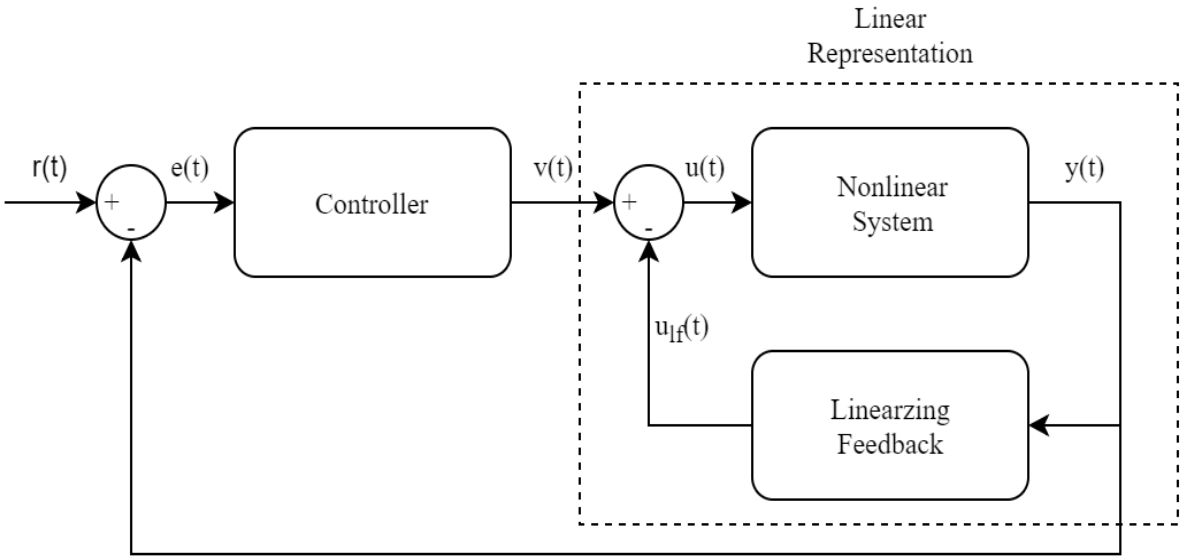
- Feedback Linearization
  - Exact linear representation for nonlinear system
  - Clear map between transformed inputs and outputs
  - Disturbance decoupling



- MIMO Nonlinear system ➡ Multiple linear systems

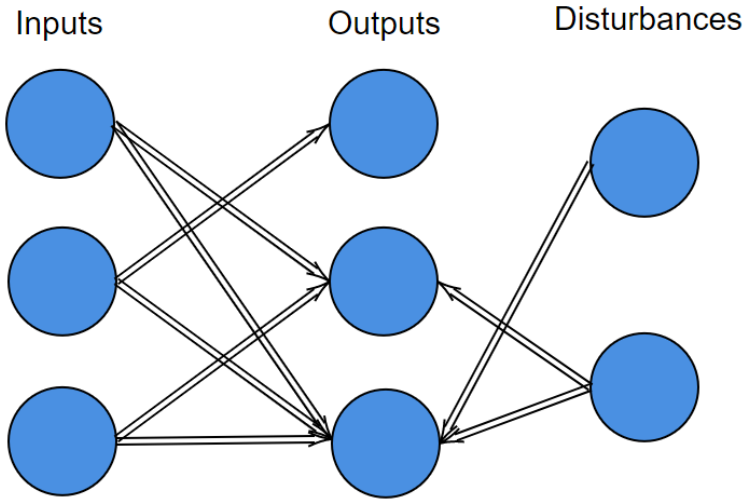
How to apply feedback linearization?

- Feedback Linearization
  - New system dynamics → linear, SISO, disturbance decoupled
  - Designing a controller for the linearized model
  - Transforming the control signal to be applicable on the original nonlinear system



What is the relative degree and why is it important?

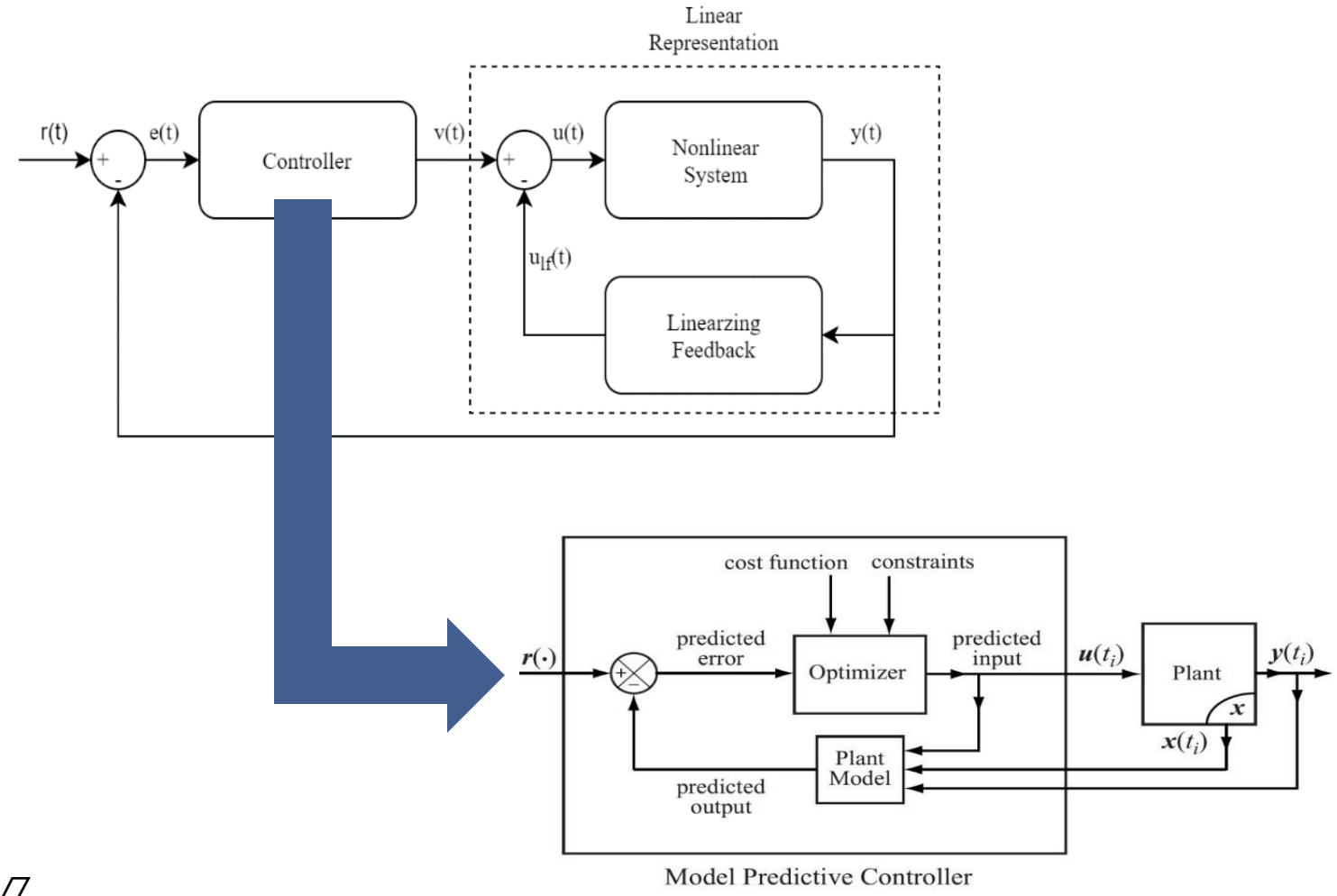
- Relative Degree: How direct is the effect of an input or a disturbance on an output.



- It is important to ensure
  - Disturbance elimination
  - Input and output decoupling (clear and unique map between every pair of (y_i, v_i))

Controller Design

- Linear MPC for the linearized model



Summary

- Objective: Real-time optimal solution for the coordinated control of highway networks
- Challenge: Complexity of the macroscopic traffic flow models
- Methods:
  - NLMPC: + Straight forward control method
    + Optimal solution
    - Time consuming
  - FLMPC: - More analysis in the background
    +Real-time optimal solution

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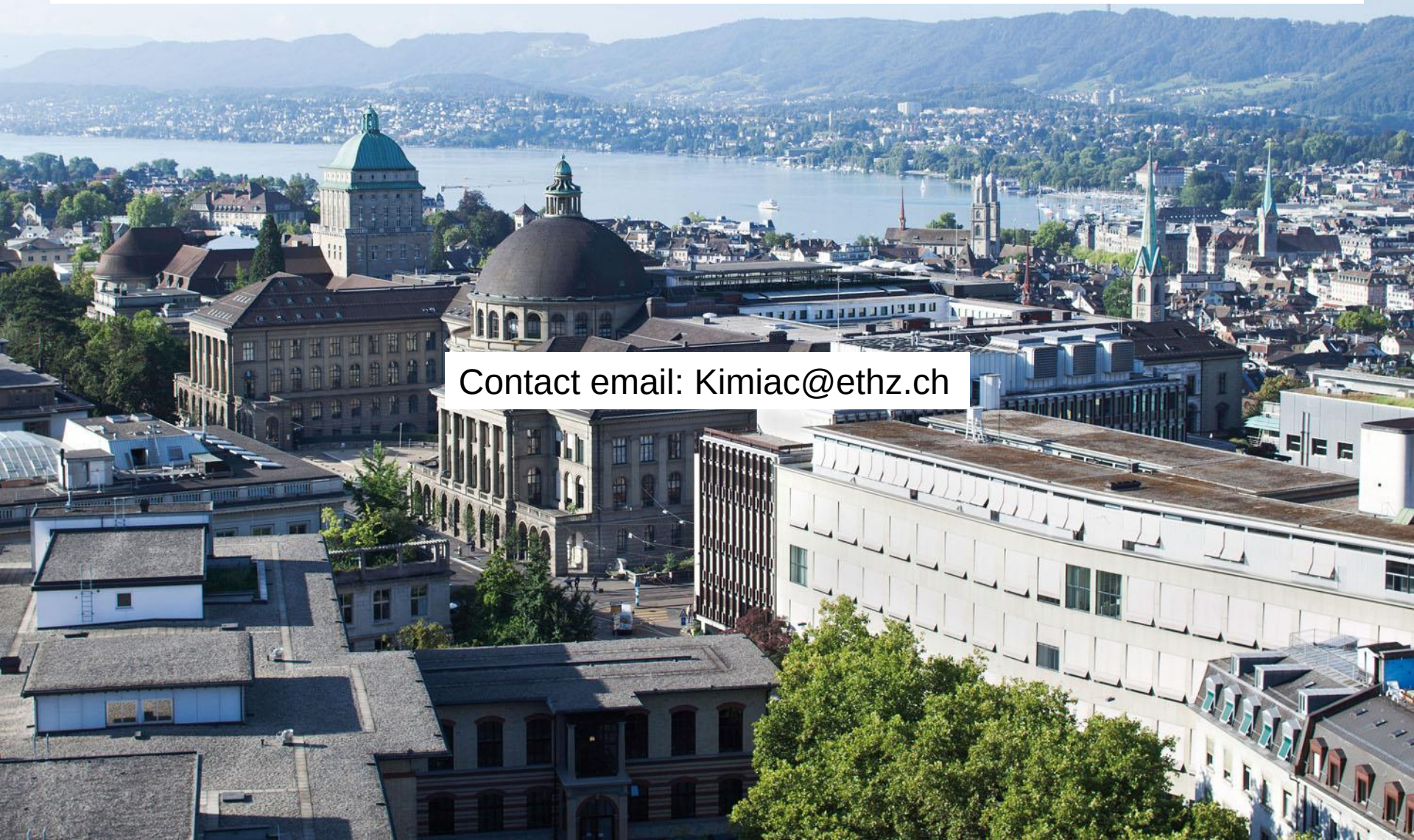
Discussion



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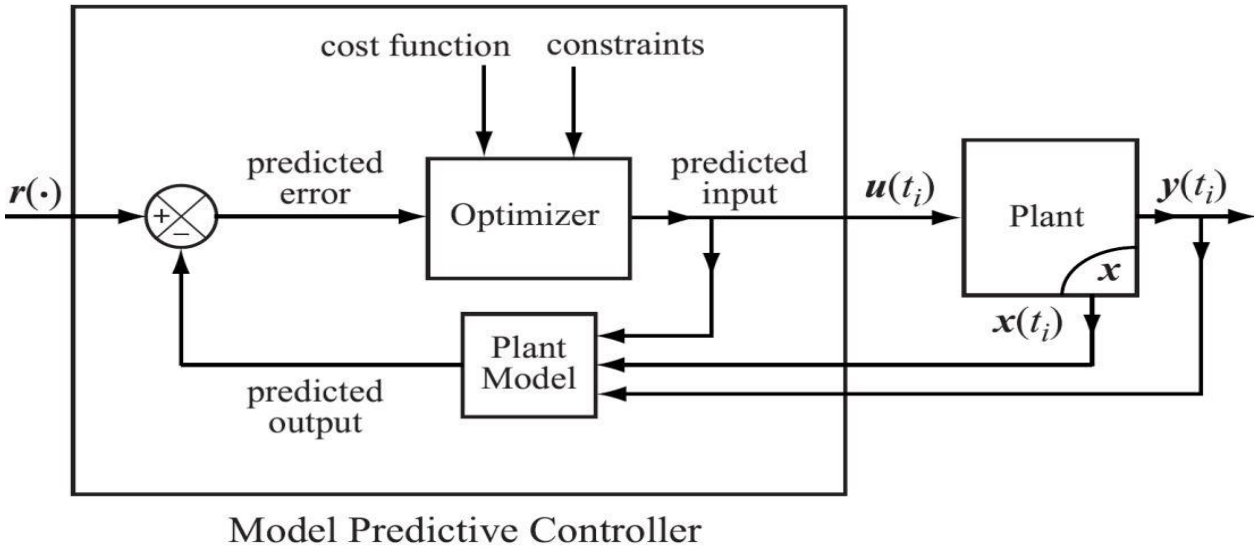
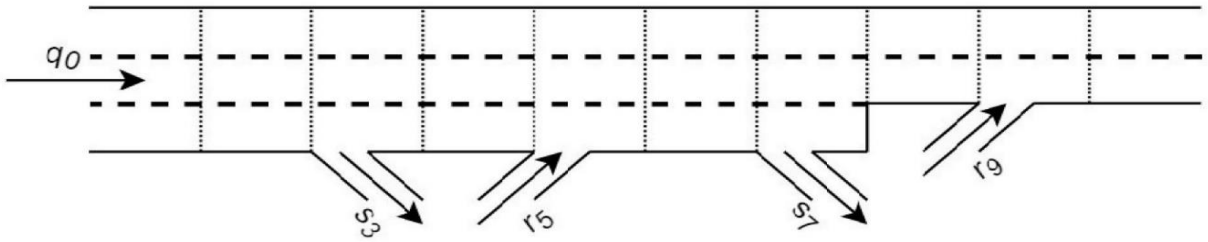
Nonlinear MPC method

- Model Predictive Control (MPC)



- Cost function is based on the Vehicle Hour Traveled (VHT) during the prediction horizon

Case study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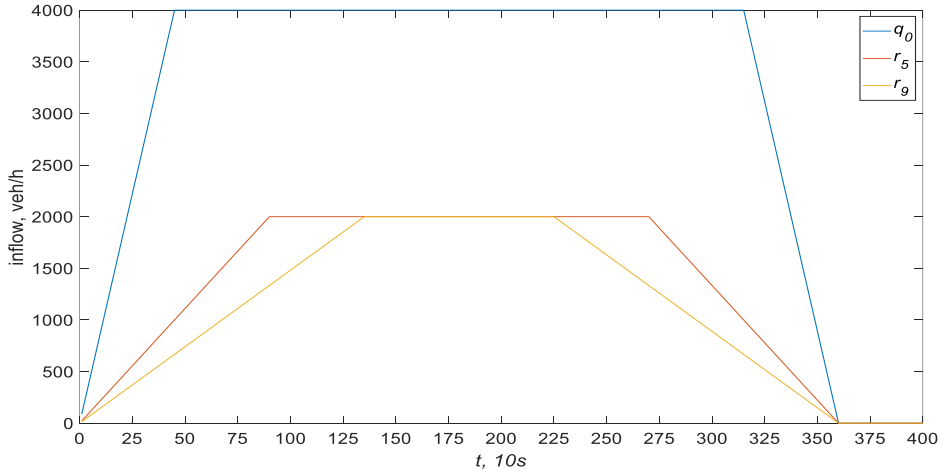
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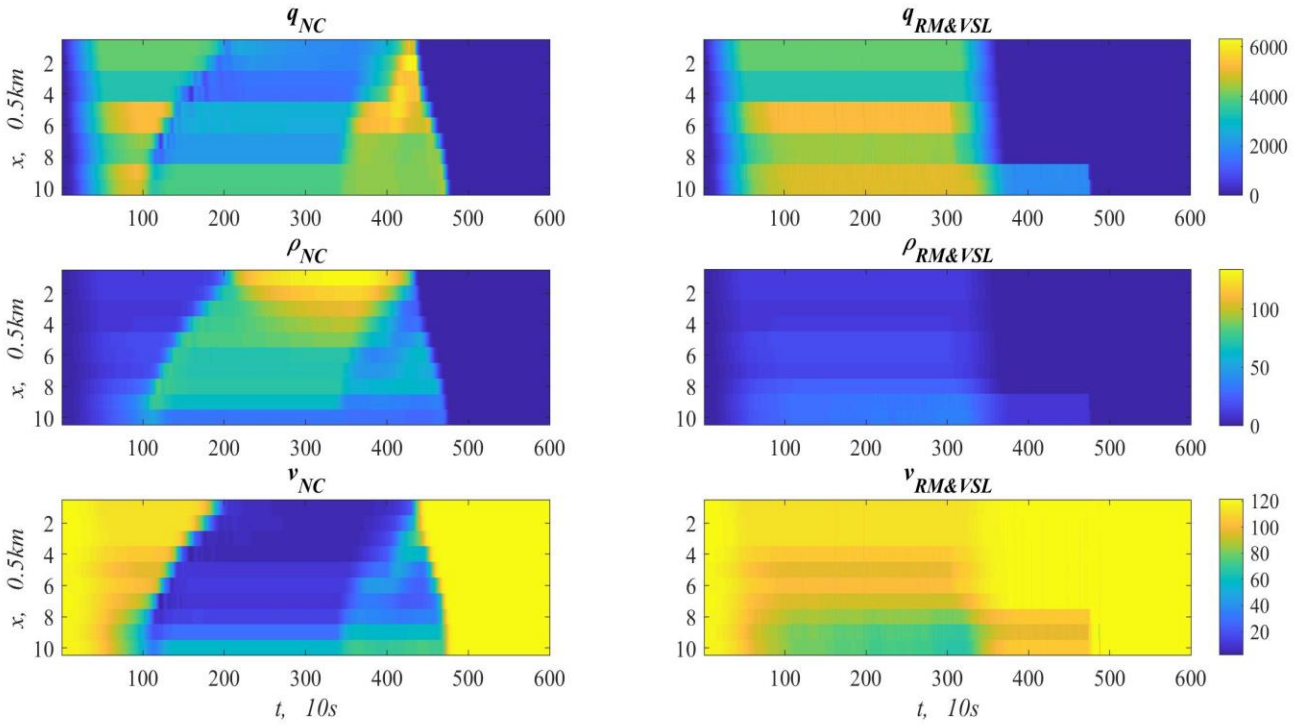
Simulation results



- 45.8% improvement in term of VHT

Why NLMPC is not a proper approach?

- High computational time
- Computation cost increases exponentially by increasing the dimension of problem

- Objective: Real-time optimal solution for the coordination of VSL and RM in large networks