

A **New Traffic Paradigm** and Related Opportunities in the **CAV Era**



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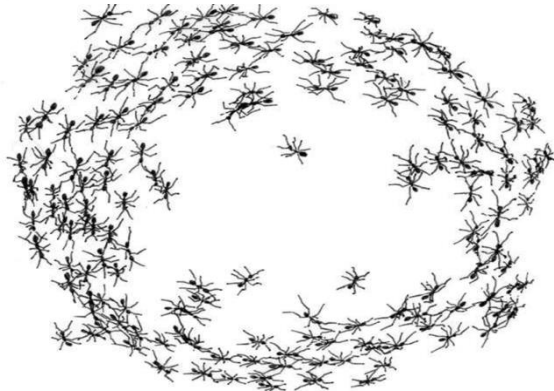
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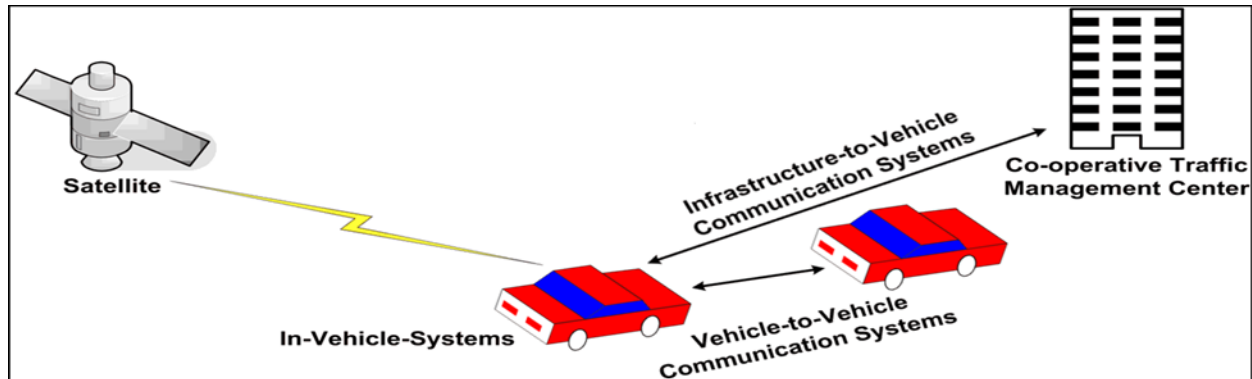
- **Technology** has made huge **advances** in the last decades in many domains, but ...
- ... daily road **traffic congestion** remains a big societal **problem**
 - delays, safety, fuel consumption, pollution
- Even **ants** address their transportation problems efficiently, see:

*I.D. Couzin and N.R. Franks: "Self-organized lane formation and **optimized traffic flow** in army ants", Proc. R. Soc. Lond. B (2003) 270, 139–146*



Emerging **VACS** (Vehicle Automation and Communication Systems)

- **Significant efforts:** Automotive industry, Research community, Government agencies
- In-vehicle systems (**automated vehicles**), e.g. **ACC** ... full automation
- Developments mostly **vehicle-centric**: safety, convenience
- VII or cooperative systems (**connected vehicles**)



Implications/Exploitation for traffic flow efficiency?

- **TRAMAN21**: TRAffic MANagement for the 21st Century (**ERC Advanced Investigator Grant**)
<http://www.traman21.tuc.gr/>
(2013-2018)
- **Mixed** traffic, different **penetration rates**

TrafficFluid

(Lane-Free Artificial-Fluid Environment for
VehicularTraffic)

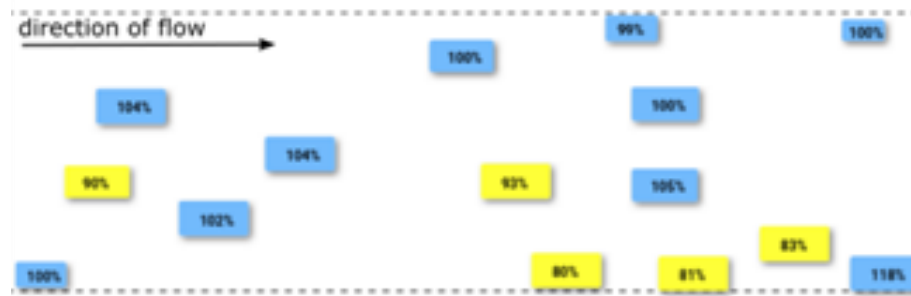
ERC Advanced Investigator Grant
(2019-2024)

Papageorgiou, M., Mountakis, K.-S., Karafyllis, I., Papamichail, I., Wang, Y.: Lane-free artificial-fluid concept for vehicular traffic. *Proceedings of the IEEE109* (2021), pp. 114-121.

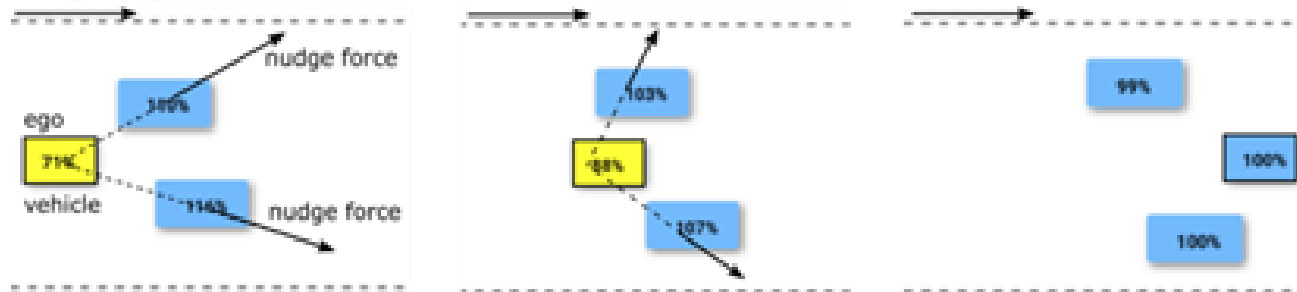
A new paradigm for CAV traffic

➤ Based on **two main principles**

- **Lane-free** traffic



- **Nudging** of front vehicles



Lane-free traffic

- Parallel uni-directional lanes were introduced in the **1950s**
 - **Easier manual driving**: Only front vehicle monitoring
 - Accident-prone **lane-changing** (10% of all accidents)
- **Lane width**: 3.5 m on highways
 - Car width 1.8 m
 - Truck width 2.5 m
 - Non-optimal lane assignment of vehicles
 - Lateral occupancy < 50 %
 - Reduced **static capacity**

➤ **Dynamic capacity** losses due to lane-changing

- **Higher road occupancy** by lane-changing vehicles
- **Congestion trigger** at critical traffic conditions
- **Accidents** and non-recurrent congestion

➤ Should CAVs **mimic human driving?** – **No!**

- **360°** monitoring (simultaneously, reliably, fast)
- **V2V, V2I** communication
- **Fast and efficient** movement **decisions**

CAV “floating” on lane-free 2-d road surface renders lane-changing **obsolete** and is:

➤ **easier**

- **Smooth** 2-d vehicle movements without **discontinuous** lateral displacements

➤ more **efficient**

- Sensible increase of **static capacity**
- Less **dynamic capacity** consumption
 - **Incremental road widening possible**

➤ **safer**

- Less front-back **pile-up crashes**
- **No accident-prone** lane changes



Vehicle Nudging

- Vehicular **traffic** flow is very similar to **water** flow
 - Kinematic waves
 - Shock waves
 - Flow-density characteristic

- ... but **conventional** traffic is **anisotropic**: Drivers are influenced only by **front vehicles**
 - Water particles “**push**” front particles
 - Implications for **emerging macroscopic flow behaviour** (capacity and stability)

- CAVs **can** be influenced by traffic behind them
- **Nudging** (based on sensors or V2V communication)
 - Nudging **limits**: **Convenience** of nudged vehicle, traffic **safety**
 - No **anisotropy** restriction: A **fossil** from the era of manual driving

Generalisation: **Artificial Fluid**

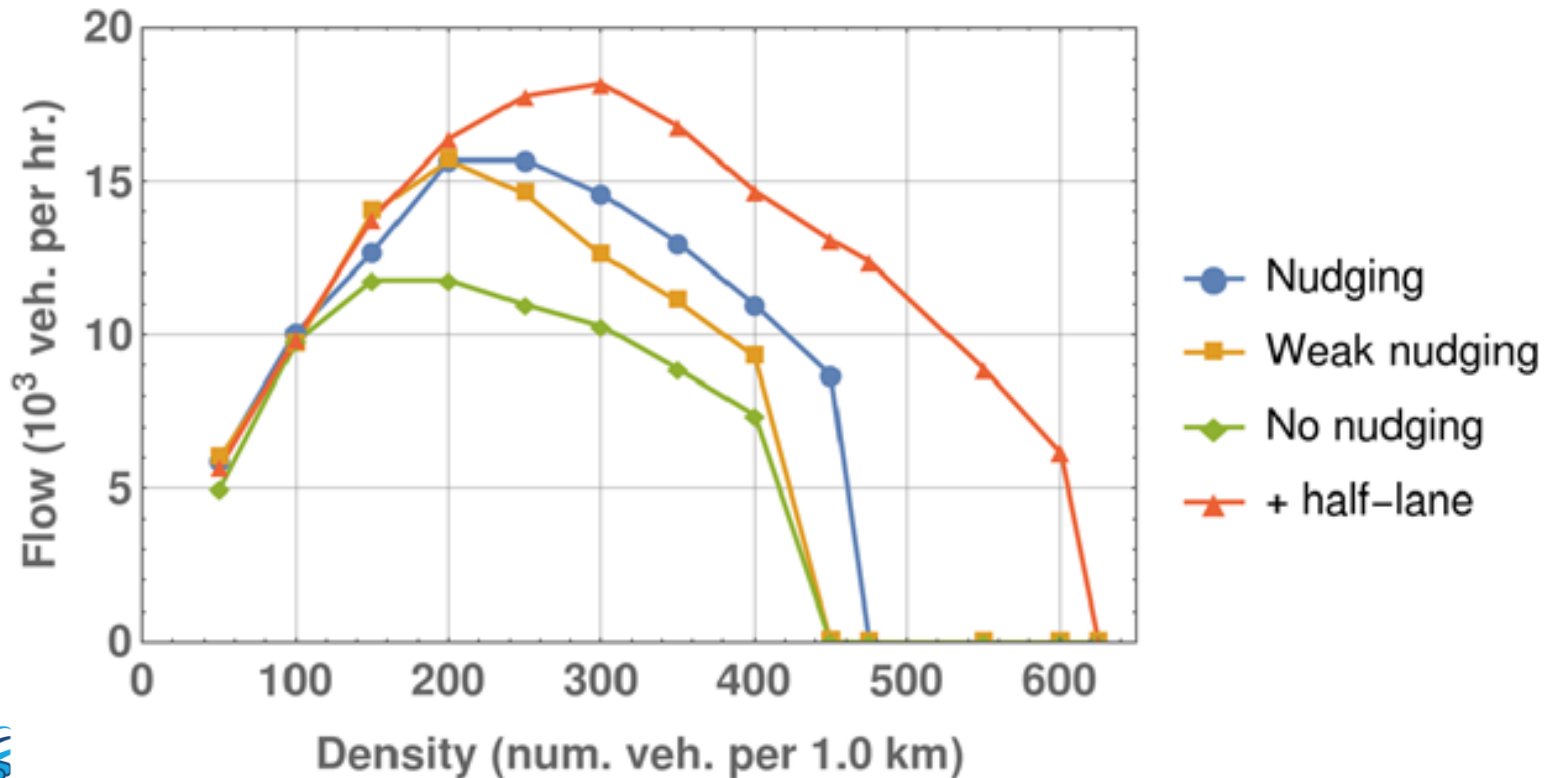
- Unprecedented possibility to actively **design** (rather than **model**) the **traffic flow characteristics** in an **optimal** way
- ... subject to **constraints**
- ...but **without** the need to satisfy anisotropy or lane **restrictions** stemming from the era of human driving.
- Problem of **actively designing**, for the first time since the automobile invention, the **properties** of the traffic flow as an **artificial fluid**.

Research Needs

- **Vehicle movement strategies** on a 2-d road surface
 - Many possible methodological **approaches**
 - Information **architecture** (only sensors, V2V, V2I, ...)
 - Various road **infrastructures** (motorway, arterial, urban, ...)
 - **Special** vehicles (manually driven, emergency, ...)
- Emerging **macroscopic** models (and **interplay** with micro-behaviour)
- **Traffic management** measures (traffic-responsive)

Please join us in an exciting research journey!

- Preliminary demonstration results using an ad-hoc lane-free vehicle moving strategy on a **10.2 m wide (3 “lanes”)** ring-road



➤ Undercritical Flow

- No nudging

Movie S1: First 120s of simulation

- With nudging

Movie S2: First 120s of simulation

➤ Overcritical Flow

- No nudging

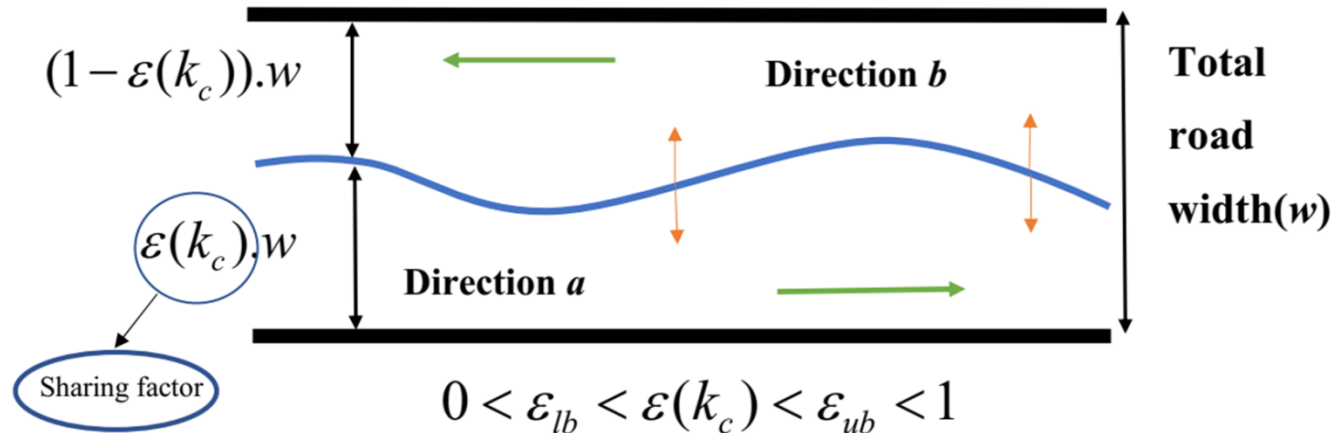
Movie S3: First 120s of simulation

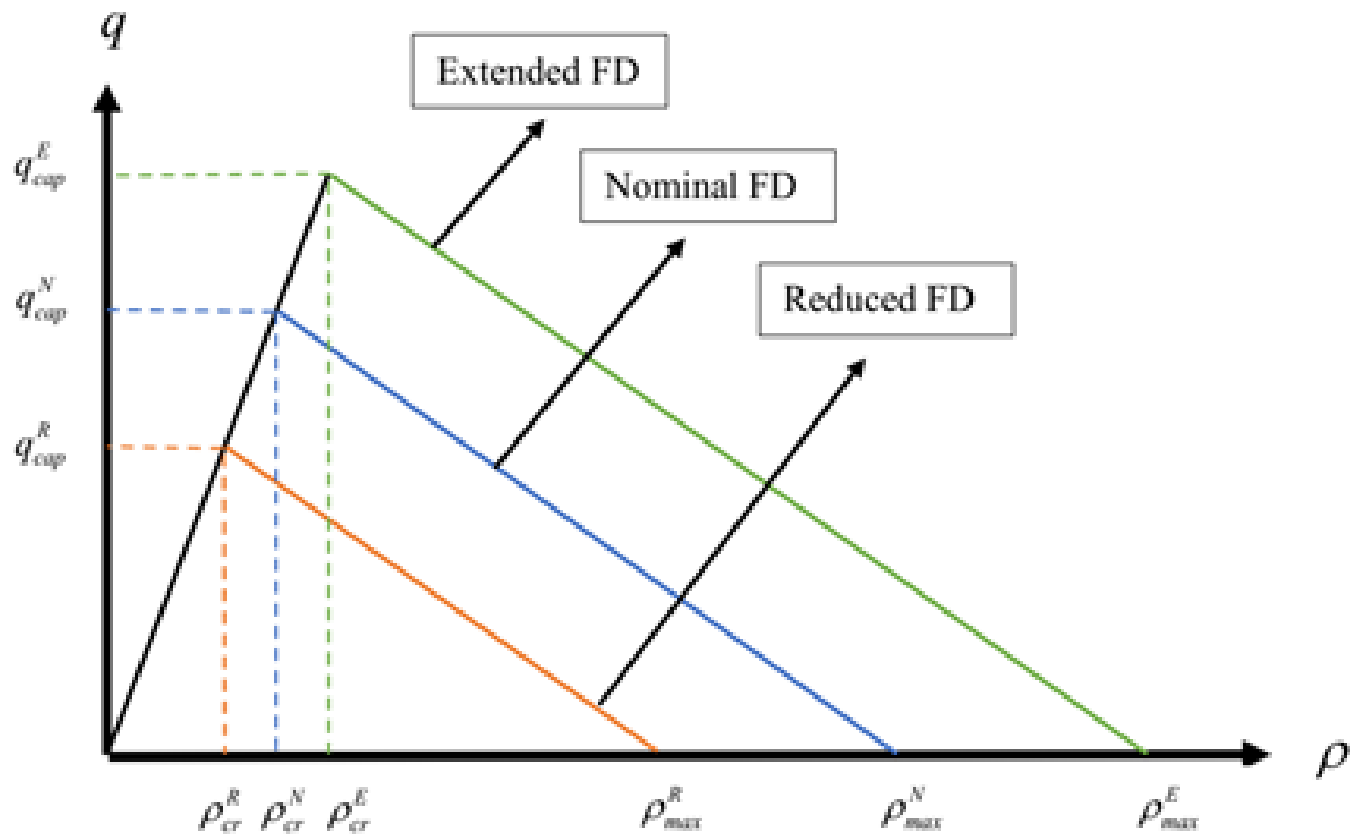
- With nudging

Movie S4: First 120s of simulation

Internal road boundary control for lane-free automated vehicle traffic

- Share total road width (\rightarrow capacity) among the two traffic directions of a highway or arterial
- Flexibly: in space and (real) time
- According to the prevailing traffic conditions



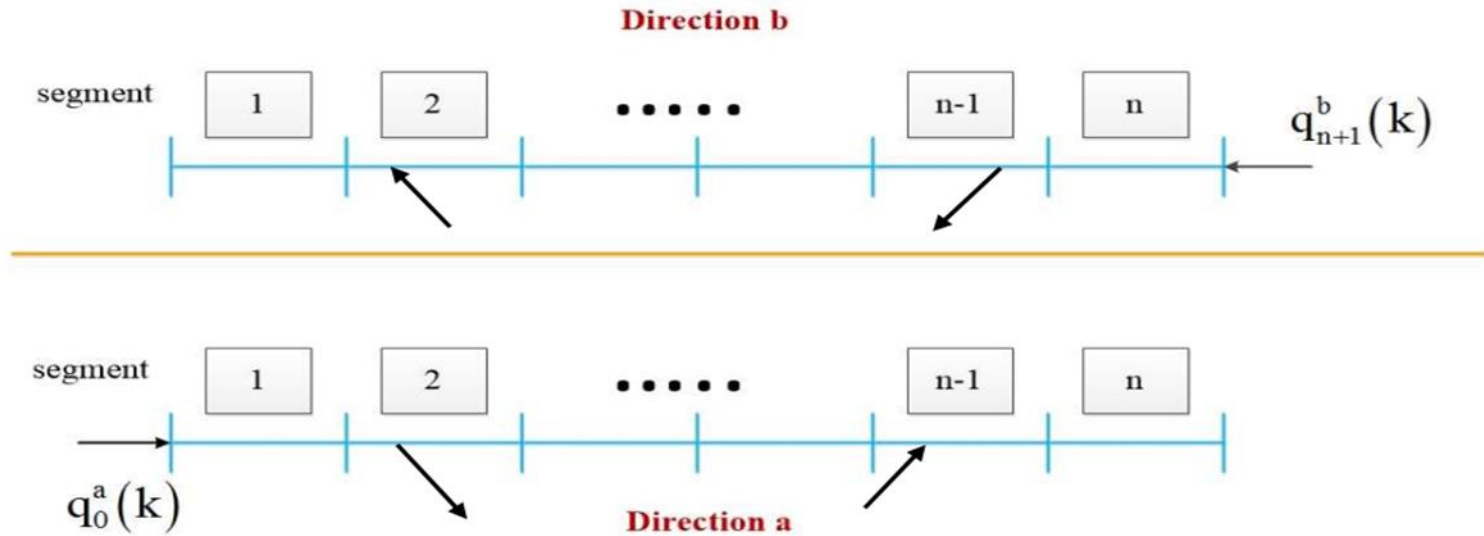


➤ Lane-based reversal lane control

- **Conventional** vehicle traffic
 - ✓ **Steady** operation (holidays, evacuation, work zones, ...)
 - ✓ **Real-time** operation: High **switching delays** → Low **switching frequency**
- **CAV** traffic (real time)
 - ✓ Low sharing **resolution** (1 lane)
 - ✓ Vehicle **merging** and **diverging** issues

➤ Lane-free internal boundary control

- **Flexibility** in space and time
- High sharing **resolution**
- **No** serious **merging** and diverging problems
- **Real-valued** control or optimisation problem



$$q_{i,cap}^a(k_c) = \varepsilon_i(k_c) q_{cap}, \quad q_{i,cap}^b(k_c) = (1 - \varepsilon_i(k_c)) q_{cap}, \quad i = 1, 2, \dots, n$$

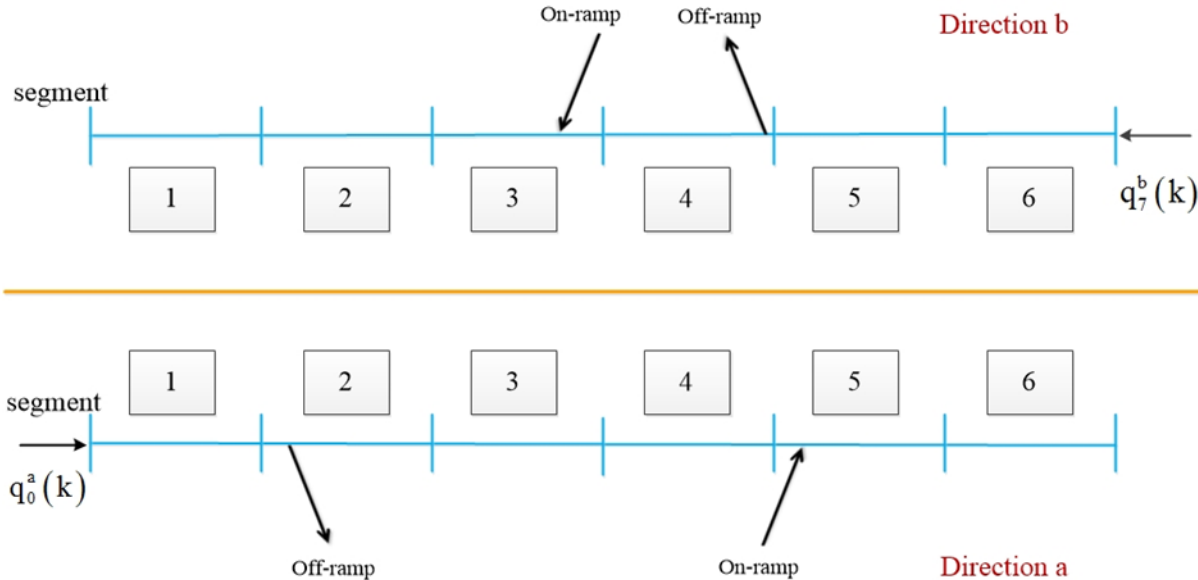
$$\rho_{i,cr}^a(k_c) = \varepsilon_i(k_c) \rho_{cr}, \quad \rho_{i,cr}^b(k_c) = (1 - \varepsilon_i(k_c)) \rho_{cr}, \quad i = 1, 2, \dots, n$$

- Use of the **Cell Transmission Model (CTM)** for controller design and simulation testing

- Control approaches:
 - Model-based convex **QP Optimisation**
 - Feedback control with **LQ regulator**

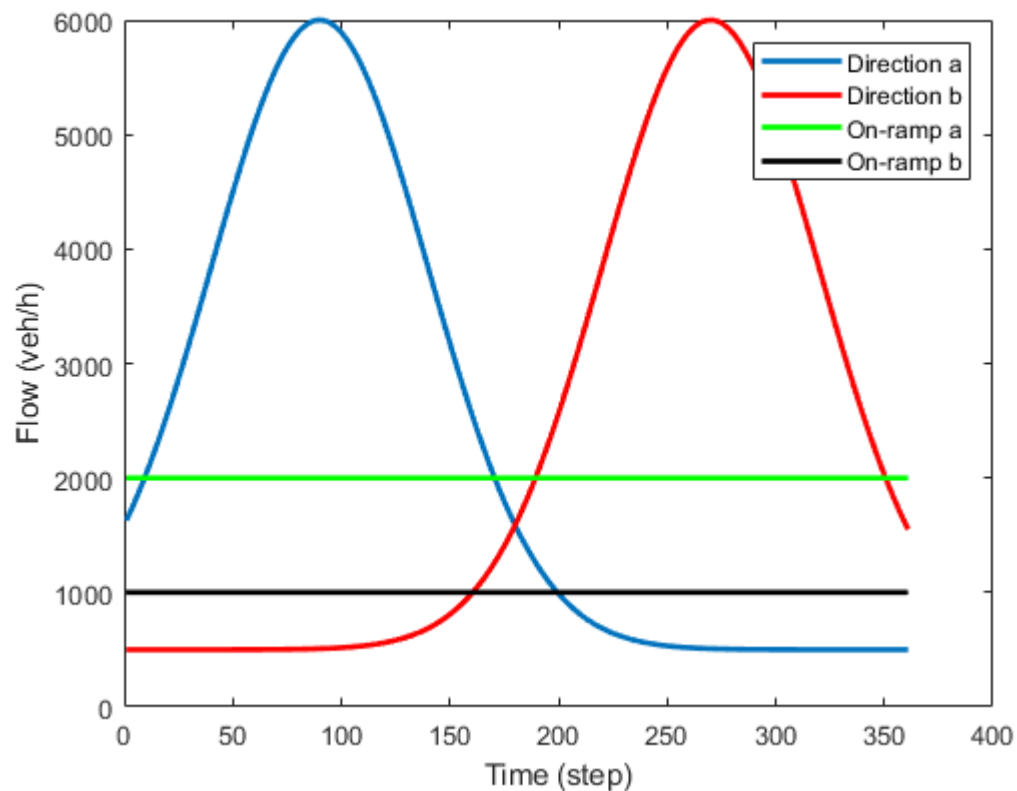
- **Performance** criteria:
 - **TTS** minimisation
 - **Moderate** boundary changes (**in space and time**)
 - **Balancing** of capacity reserves for the two traffic directions

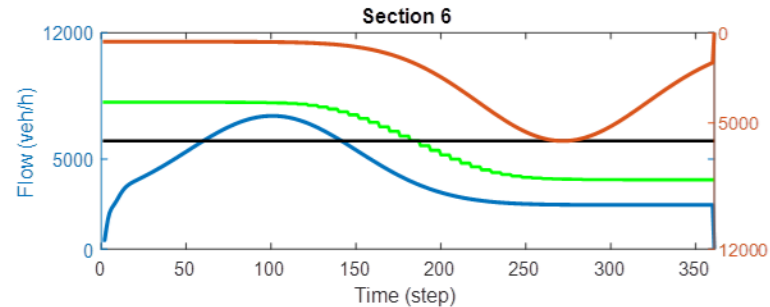
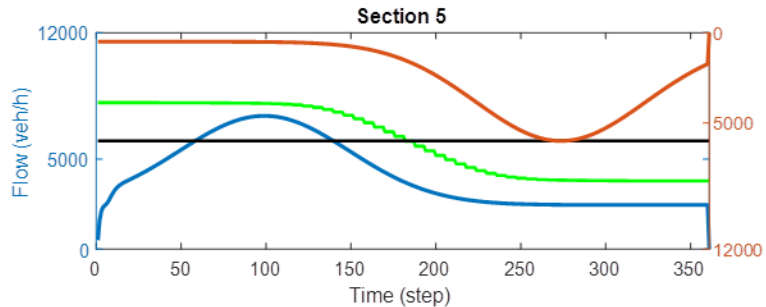
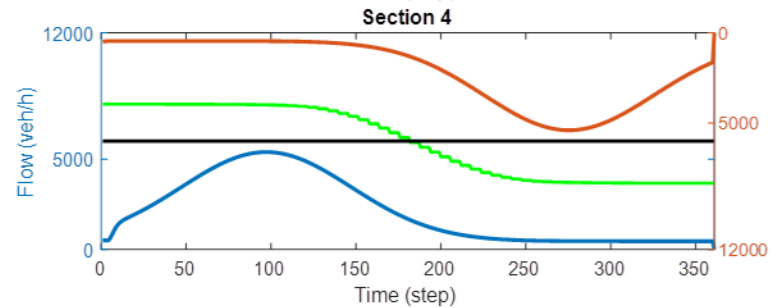
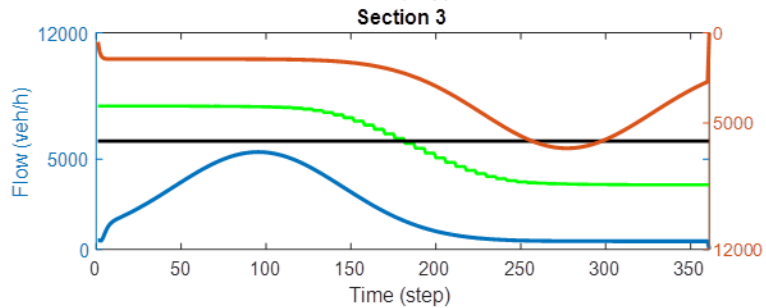
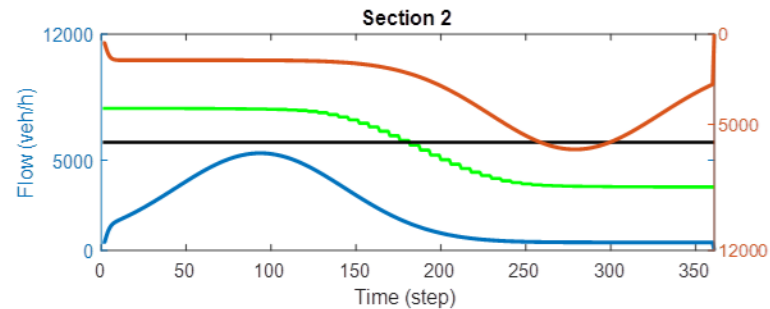
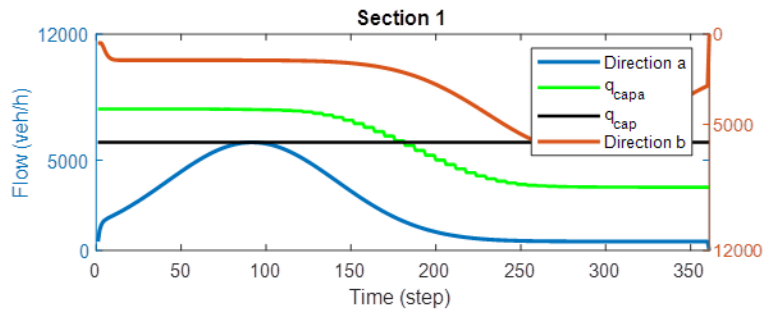
Demonstration Example



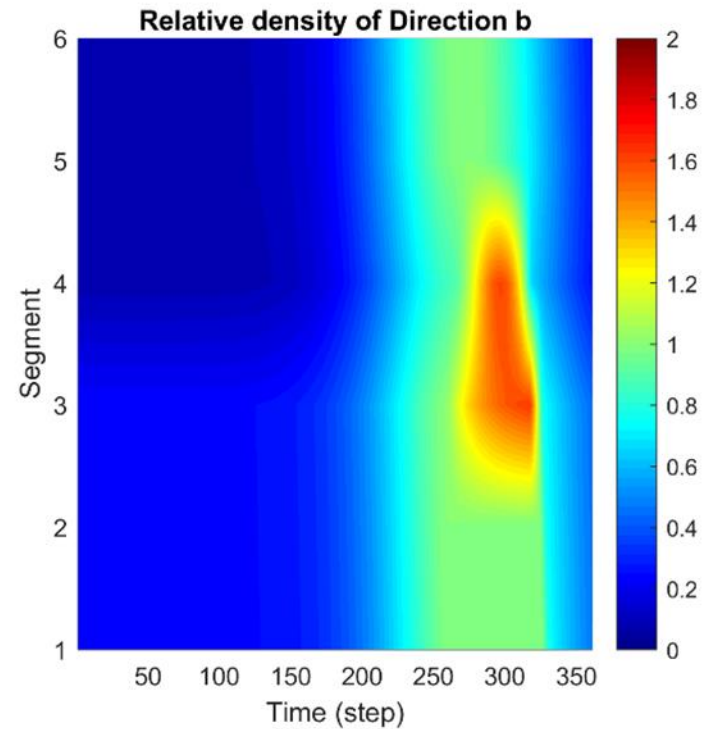
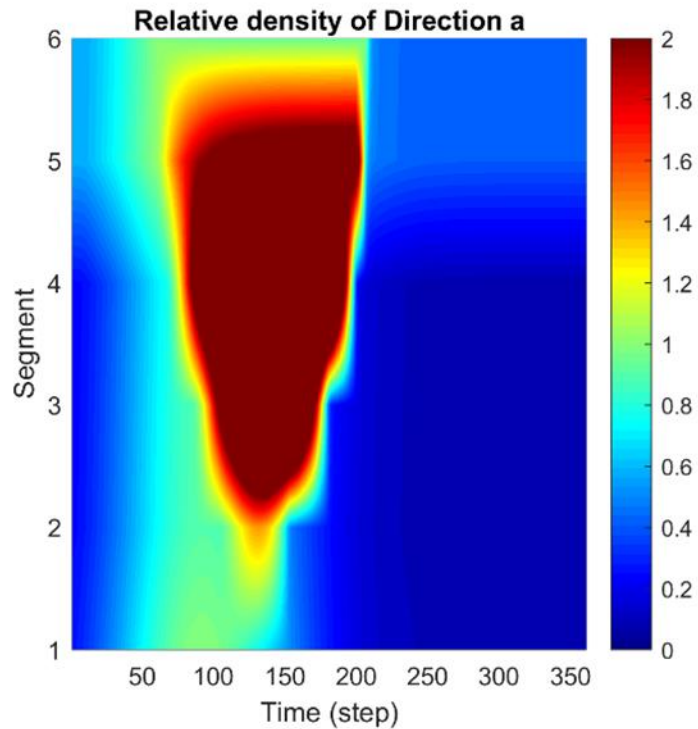
- Highway stretch of **3 km** → **6 sections** of 500 m
- **Total capacity** 12.000 veh/h
- Control time step **1 min**

➤ Demand scenario (1 hour)

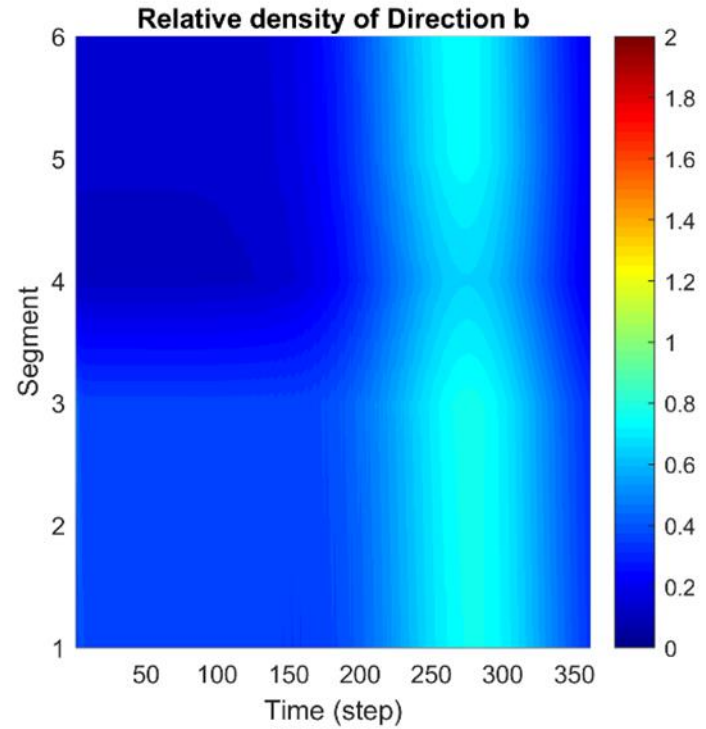
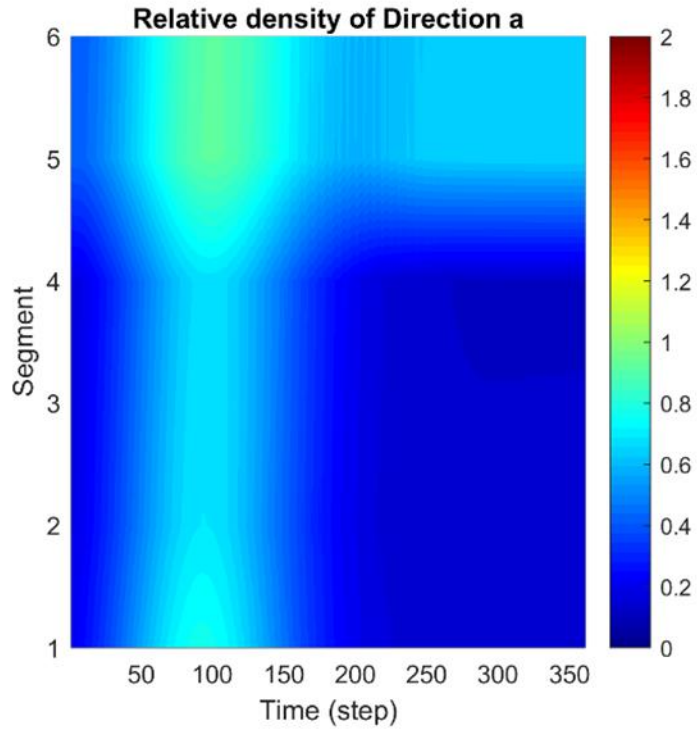




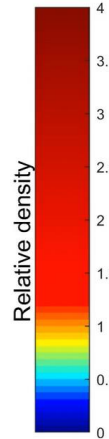
No-control case



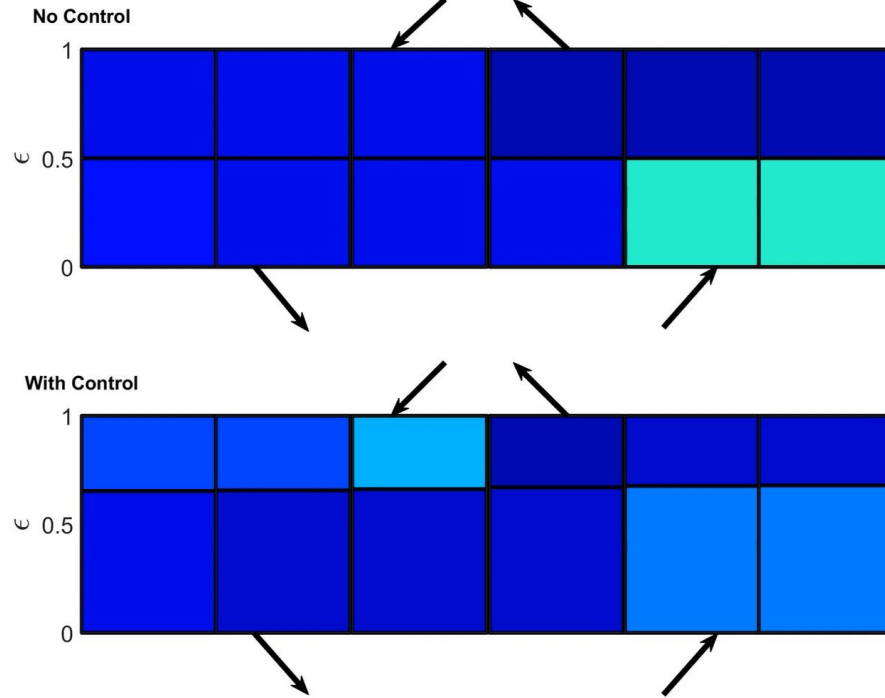
Control case



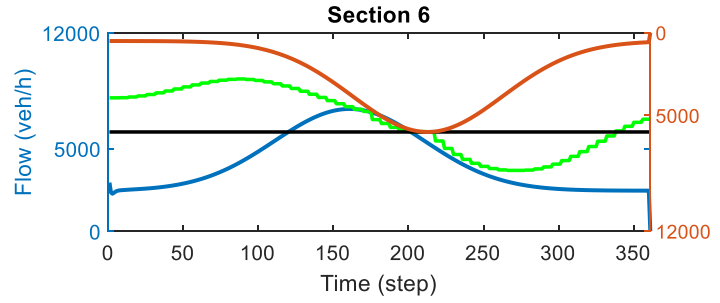
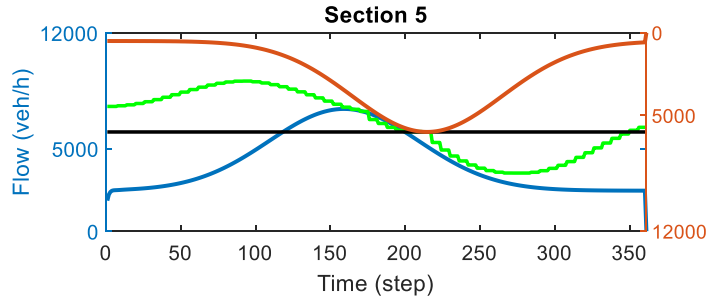
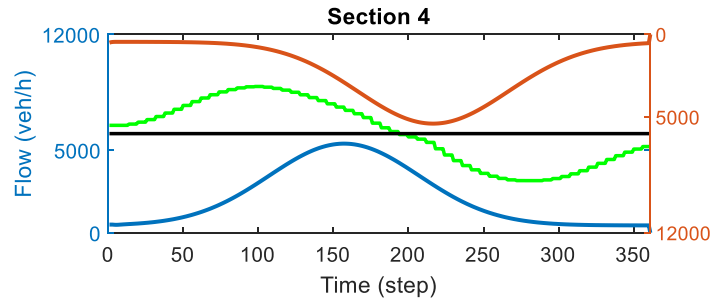
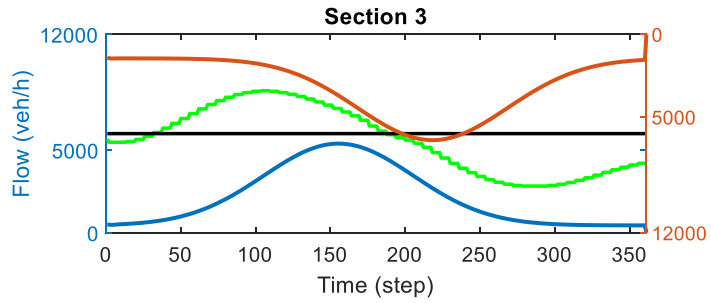
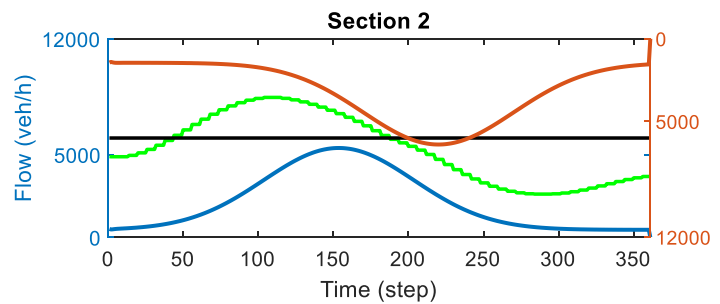
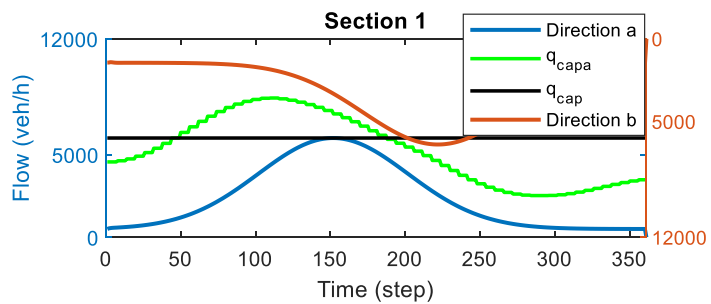
Visualization



Internal Boundary Control (Quadratic Programming)



➤ Bottlenecks concern both traffic directions simultaneously





Time Step
0 / 2400



Vehicle Theme

Simulation Speed



x6



- Internal boundary control is one of the **strongest advantages** for the **TrafficFluid** paradigm.

For more information on **TrafficFluid** :
<http://www.trafficfluid.tuc.gr/>