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8th Conference
Sustainable Mobility
and Intelligent Transport
Systems

URANUS

Real-Time Urban Mobility Management via Intelligent UAV-based Sensing

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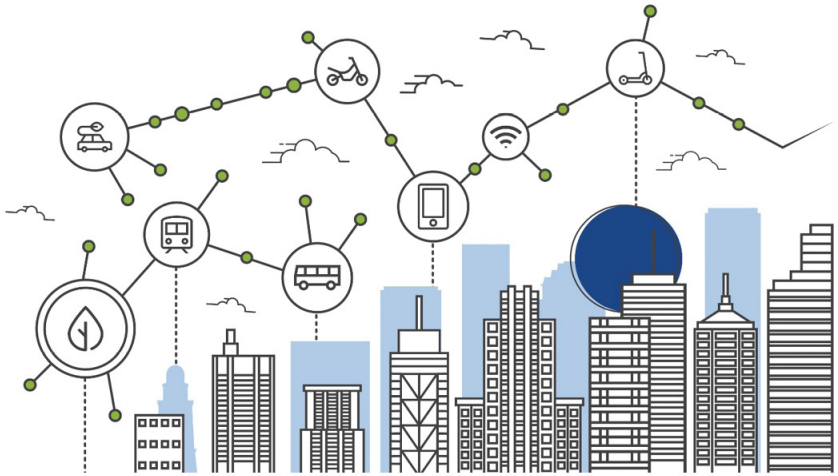

The Conference is implemented within the framework of the Cohesion Policy Programme "THALIA 2021–2027", Co-financed by the European Union.

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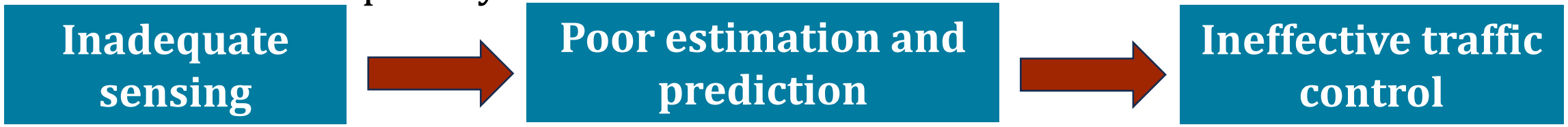
Motivation

Congestion still persists despite deployed technological solutions

Inadequate traffic sensing

- **Stationary sensors** (e.g. vehicle counters, cameras)
  - sparse
  - high installation and maintenance costs
  - inability to measure traffic parameters beyond their sensing location
- **Floating car data** (i.e., car position and speed):
  - proprietary or only available through commercial APIs
  - bound to the uncontrollable route of the collecting vehicle
  - sparse and hard to associate with traffic volumes
  - suffer from privacy issues



Motivation

Unmanned Aerial Vehicles (UAVs) or **Drones**

- Emerging vision-based sensing technology



Advantages

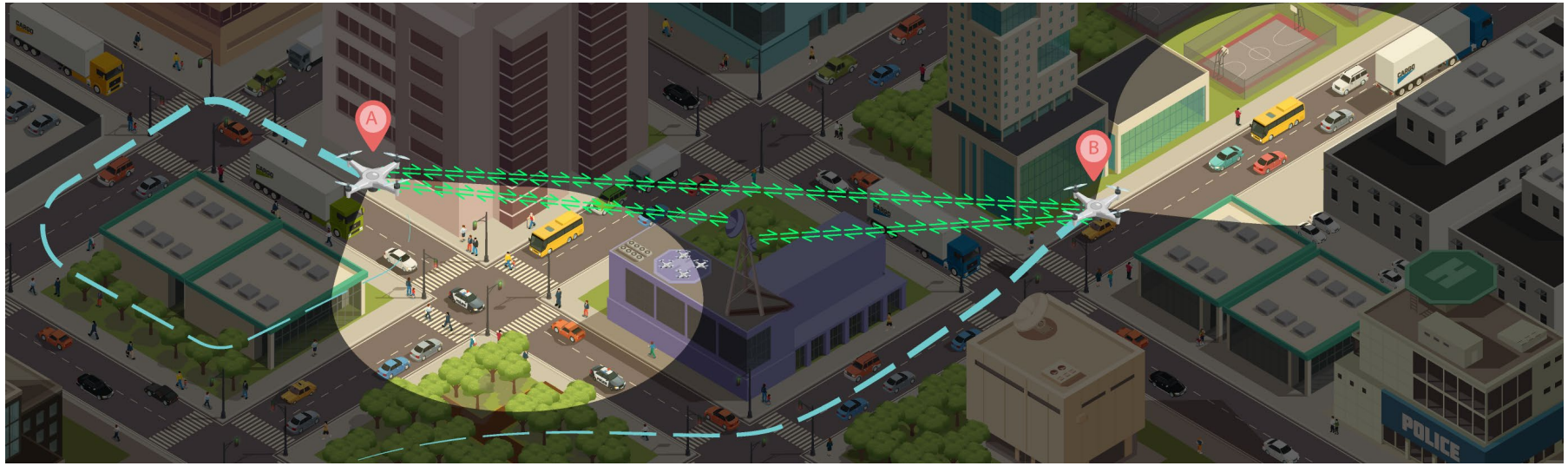
- Unrestricted movement
- Non-invasive technology
- Fast deployment
- Economic viability
- Simultaneously measure multiple parameters (e.g., vehicle trajectories, spacing, traffic density, turning ratios, and queue lengths, average speeds).

Traditionally limited to:

- Surveillance of road networks
- Offline traffic data collection

URANUS ERC Project

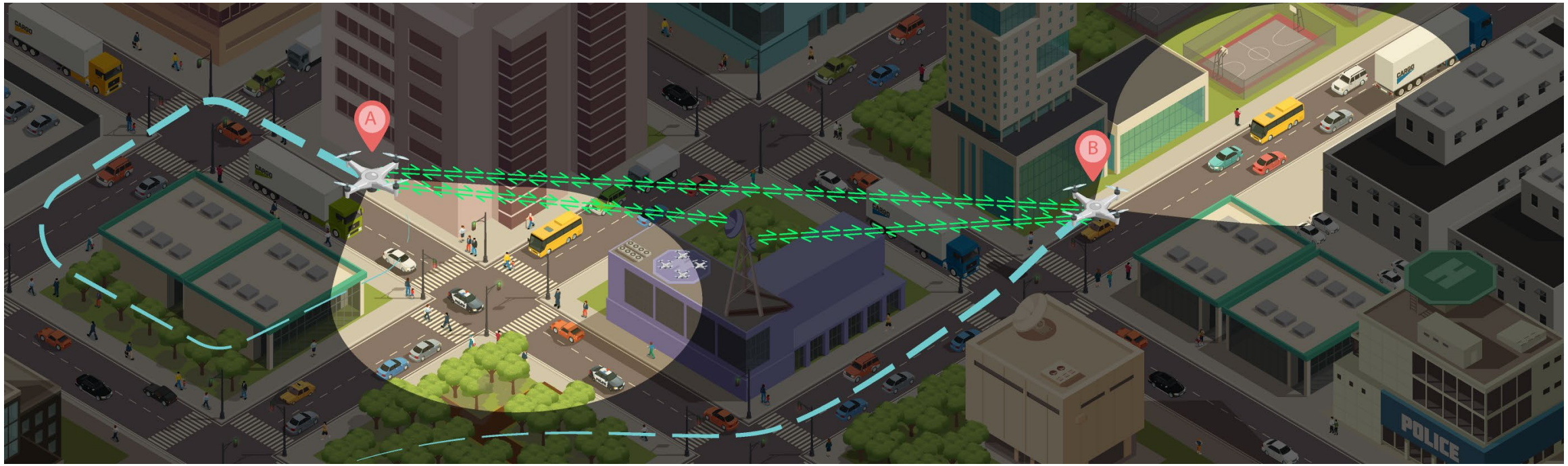
Concept	Use of autonomous Unmanned Aerial Vehicles (UAVs) for ***continuous***, ***active***, ***intelligent*** and ***multi-parameter*** traffic sensing
Ultimate Goal	Holistic framework for ***real-time*** Urban Mobility (UM) management



- **Title:** Real-Time Urban Mobility Management via Intelligent UAV-based Sensing
- **Funding Source**: European Research Council (ERC) Consolidator Grant
- **Funding**: ~2 Million Euro
- **Duration**: July 2023 – June 2028 (5 years)

Research Questions

- How to make intelligent UAV-based sampling decisions?
- How to estimate traffic using sparse spatiotemporal measurement?
- How to manage traffic under dynamic uncertainty?
- How to co-optimize sensing, monitoring and control?



Research results

01 UAV-based sensing

Traffic data acquisition

02 Traffic analysis of UAV-obtained data

From vehicle trajectories to to useful traffic information

03 Traffic simulation integrating UAV-based sensing

UAV-enabled simulation

04 Traffic calibration with sparse UAV data

Data-driven high-fidelity traffic models

05 UAV-based traffic state estimation

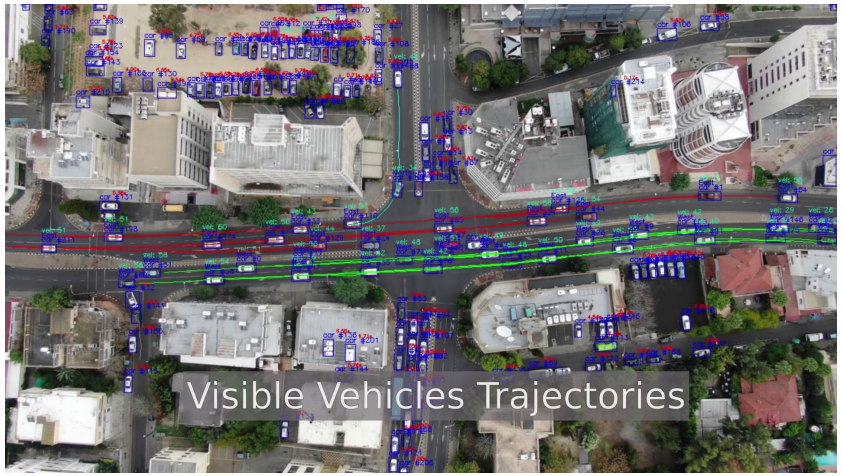
Reconstructing network conditions

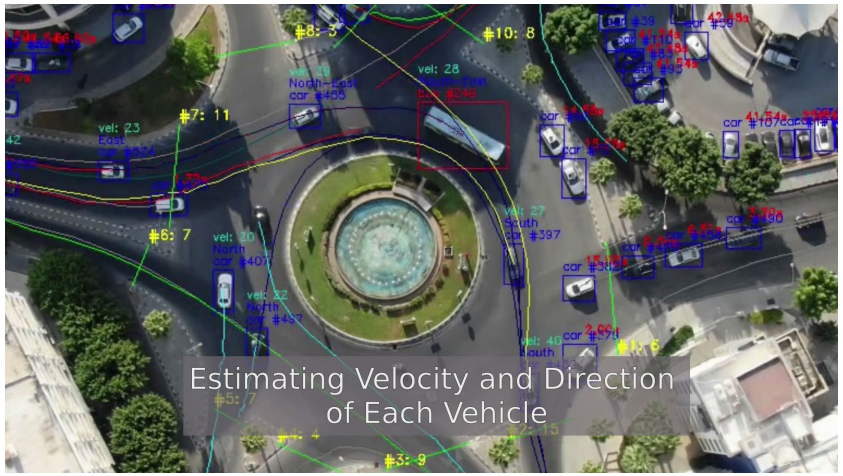
06 Traffic control

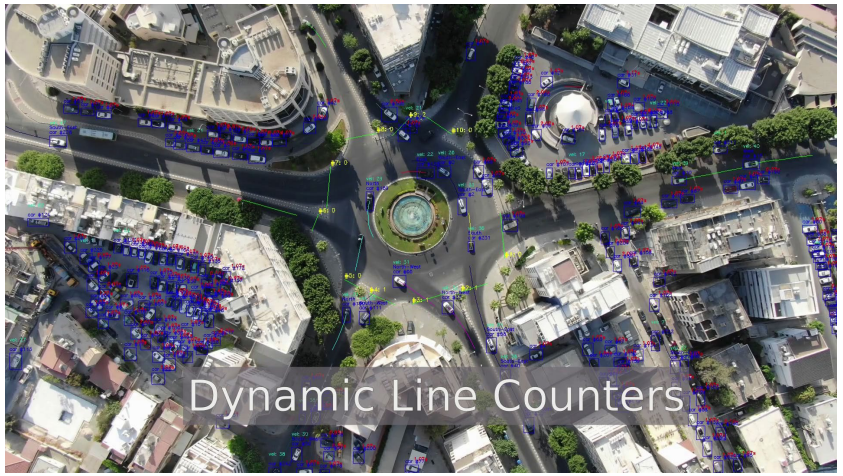
Reducing traffic congestion and promoting sustainable mobility

UAV-based sensing

UAV Operations → Videos → **Video Processing** → Vehicle Trajectories, Classification → **Data Analysis** → Traffic Parameters → **Operational Center**



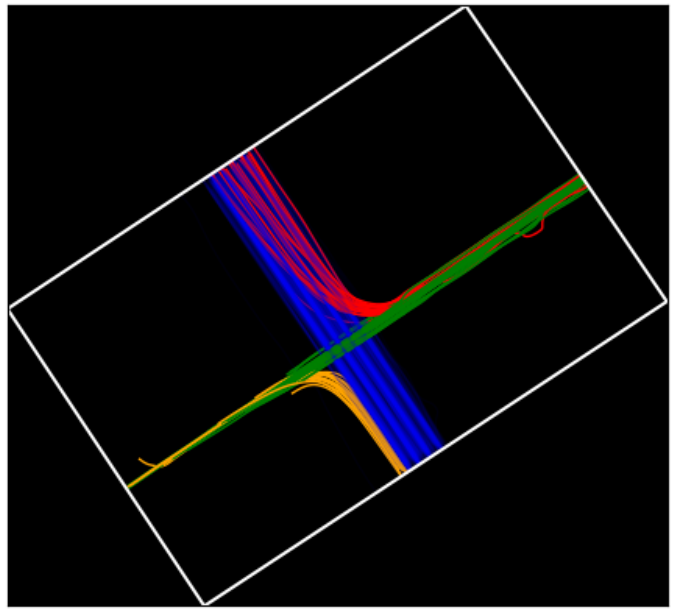


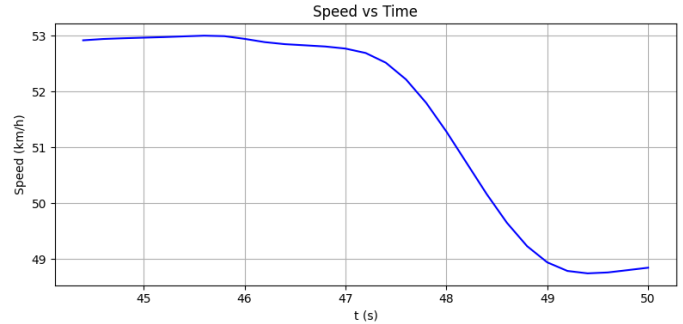


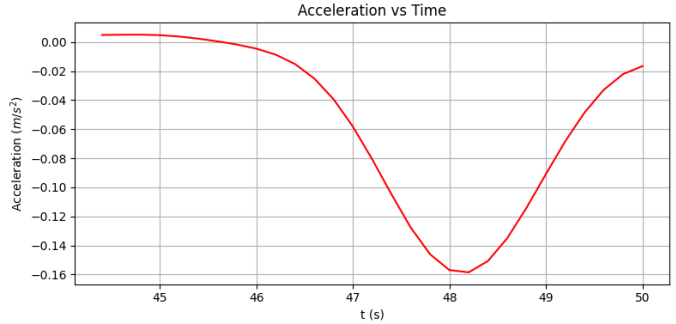
Traffic analysis of UAV-obtained data

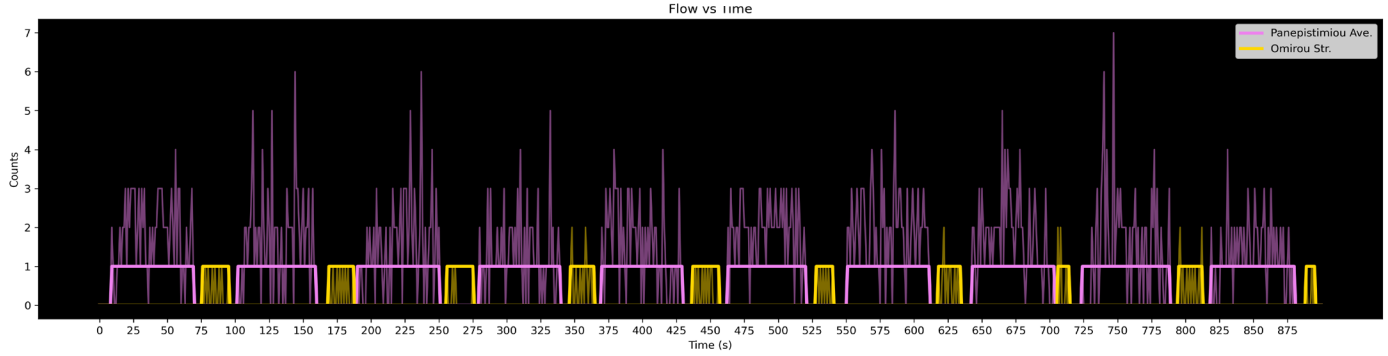
UAVTrafficPy: A Python package for analysis and visualization of UAV-based traffic data

- Speed, Acceleration
- Gaps & relative speeds
- Turn ratios at intersections
- Traffic light phases
- Queue length
- Lane extraction



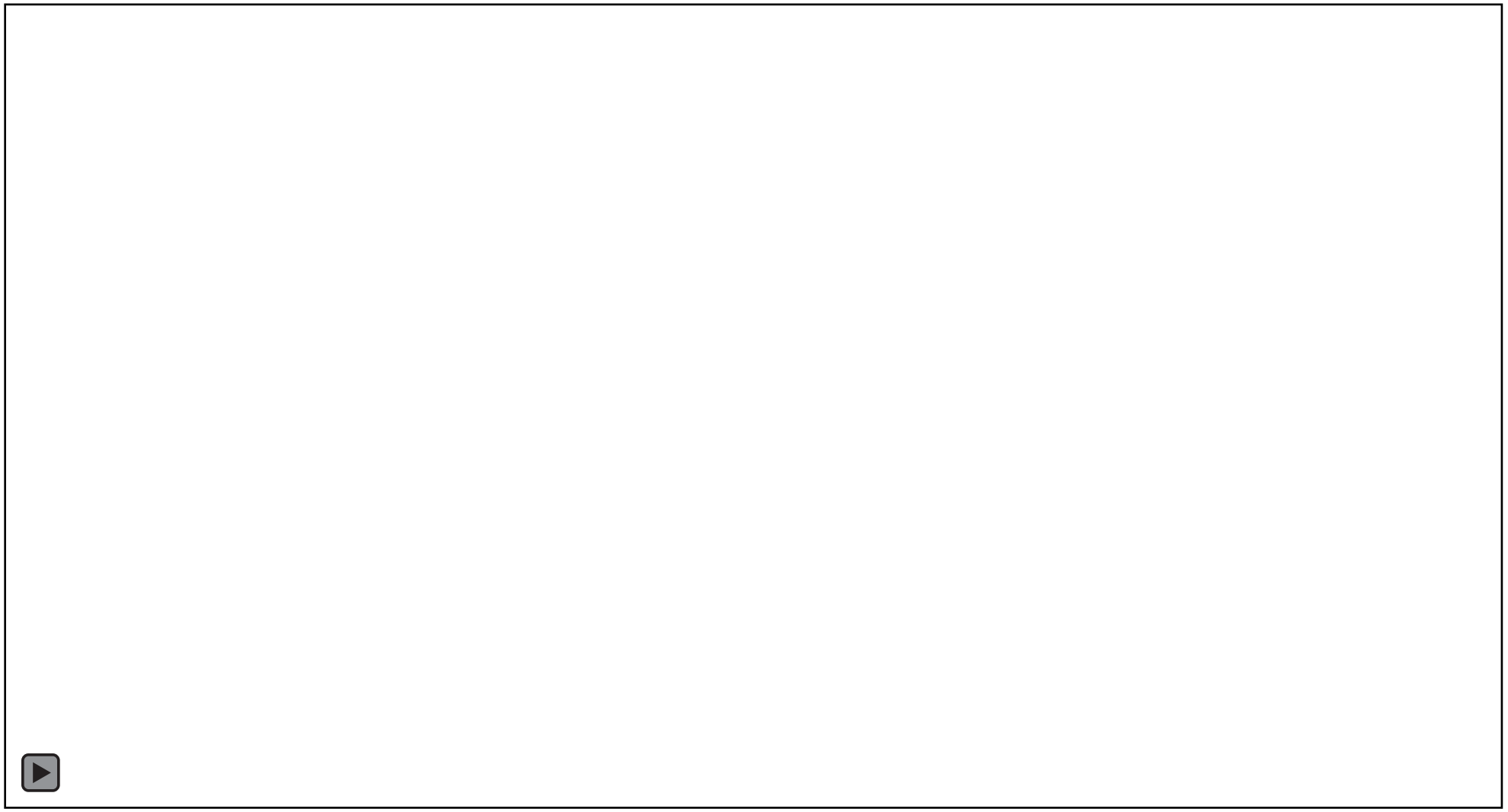






Traffic simulation integrating UAV-based sensing

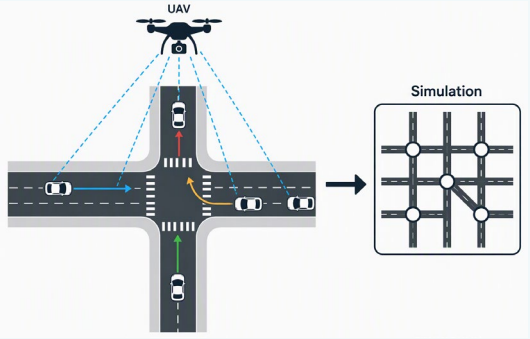
SUMO-UAV-Py: A Python Plugin for UAV Sensing in SUMO Traffic Simulator



Traffic calibration with sparse UAV data

01 The Problem

How can we accurately calibrate traffic simulation models so they accurately reproduce real-world traffic conditions?



02 The Challenge

- Limited traffic observations from existing sensors
- Sparse and fixed sensor locations
- UAVs cannot continuously observe intersections.
- Flights are short and often interrupted.

03 Our Solution

- UAV-based traffic calibration framework using UAV data over key intersections.
- Signal cycle-based calibration algorithm

UAV sensing → **Computer Vision & Data Analysis** → **Calibrated Simulation**

04 The Impact

Higher-fidelity traffic simulations

Achieved 95% simulation calibration performance compared with continuous observations, using less than 20% of the initial observation coverage.

Take-home message: Sparse UAV data bridges the gap between simulated and real-world traffic behavior.

UAV-based traffic state estimation

01 The Problem

How to accurately understand traffic conditions using sparse UAV data?



02 The Challenge

- Sparse data from traffic sensors
- Large scale nature of traffic networks
- Nonlinear traffic dynamics

03 Our Solution

Combine sparse UAV-based sensing with intelligent estimation

UAV sensing → **Probabilistic Estimation** → **Model-based Optimization** → **Real-time TSE**

04 The Impact

Fast and accurate real-time TSE with sparse UAV data

Proposed solution approach is accurate, robust to noise and 100x faster than state-of-the-art solvers

Take-home message: UAV-based sensing can help cities understand and manage traffic more effectively.

Traffic control – Reservation-based shared bus lane utilization

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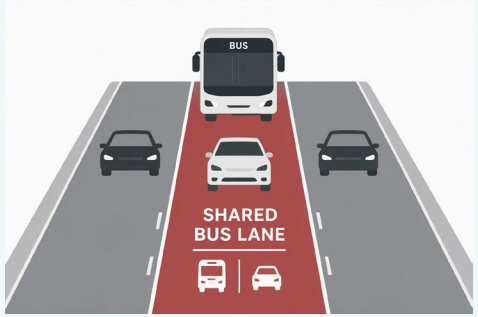
01 The Problem

How can we increase the capacity of urban road networks by utilizing underused bus lanes without degrading bus service quality?



02 The Challenge

- Allocating limited bus lane capacity to cars & buses
- Maintaining low travel times for buses
- Reducing travel times of reservation users
- Applying it with minimal infrastructure changes

03 Our Solution

Commuters can share bus lanes using reservations. Controller reserves occupancy on bus lanes.

Bus lane capacities & Bus schedules → **Reservation State & Controller** ← **Commuter: Reservation Request**

04 The Impact

- Can accommodate 38% more demand without congestion.
- No bus travel time increase.
- No changes to existing infrastructure.

Take-home message: Shared bus lanes using reservations increase network capacity without affecting bus schedules.

Traffic control – A Multi-Modal Reservation Framework

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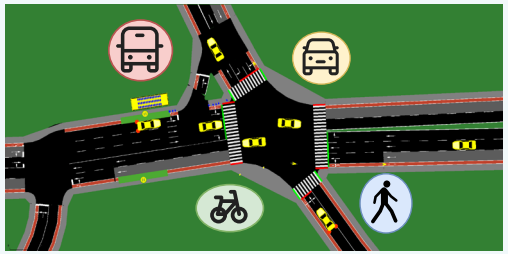
01 The Problem

How can we optimize multi-modal travel while respecting capacity limits and ensuring reliable arrivals?



02 The Challenge

- Combining heterogeneous mobility elements
- Constraining the occupancy of mobility elements
- Ensuring user preferences
- Timely responding with reliable arrival guarantees

03 Our Solution

Controller reserves multi-modal elements (road capacity, bus seat, parking spot) for commuters.

Multi-modal Network Elements → **Reservation State & Controller** ⇄ **Commuter: Reservation Request**

04 The Impact

Efficiently utilizing multi-modal options:

- 2x commuters with 40% less travel time

From	1%	5%	94%
To	12%	23%	65%

Take-home message: Reservation-based multi-modal optimization improves traveler experience while increasing network capacity.

Conclusions

1 **FLEXIBLE TRAFFIC SENSING**

UAVs enable fast, non-invasive and multi-parameter monitoring of urban traffic.

2 **VALUE FROM SPARSE DATA**

Limited UAV observations can support high-fidelity traffic simulation and calibration.

3 **BETTER TRAFFIC INTELLIGENCE**

Traffic states and travel demand can be estimated very well from sparse UAV observations.

4 **TOWARDS INTELLIGENT CONTROL**

Integrating sensing, estimation and control can support more responsive urban mobility management.

Key message: Sparse intelligent aerial observations can reveal much more about citywide traffic.

Publications

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Thank you for your attention!

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