Intelligent Transportation Systems

Stelios Timotheou

Assistant Professor

Department of Electrical and Computer Engineering

KIOS Research and Innovation Center of Excellence

University of Cyprus

Development of practically-oriented student-centred education in the field of modelling of Cyber-Physical Systems

Training School for Academics in Partner Countries

funded by:

Overview

- Importance of Intelligent Transportation Systems (ITS)
- The future of mobility
- Research Activities in ITS
- Educational Activities in ITS

Introduction

Motivation

- Road transportation systems account for (in the EU alone):
  - 25% of the total energy consumption, 75% of petroleum fuel consumption
  - 22000 fatalities/year
  - 18% of total GHG Emissions
  - Total cost
    - Fuel: ~ €160 B
    - Environmental effects: €176 B
    - Accidents: € 232 B
  - Congestion accounts for one work week/year per person.

Introduction

Potential solutions to traffic congestion

- Construct new roads
  - Difficult and costly to expand roads
  - Not likely to happen on a large scale
- Reduce Traffic
  - Alternative transportation means
  - Congestion charging
- Increase existing infrastructure capacity
  - **Intelligent Transportation Systems (ITS)**

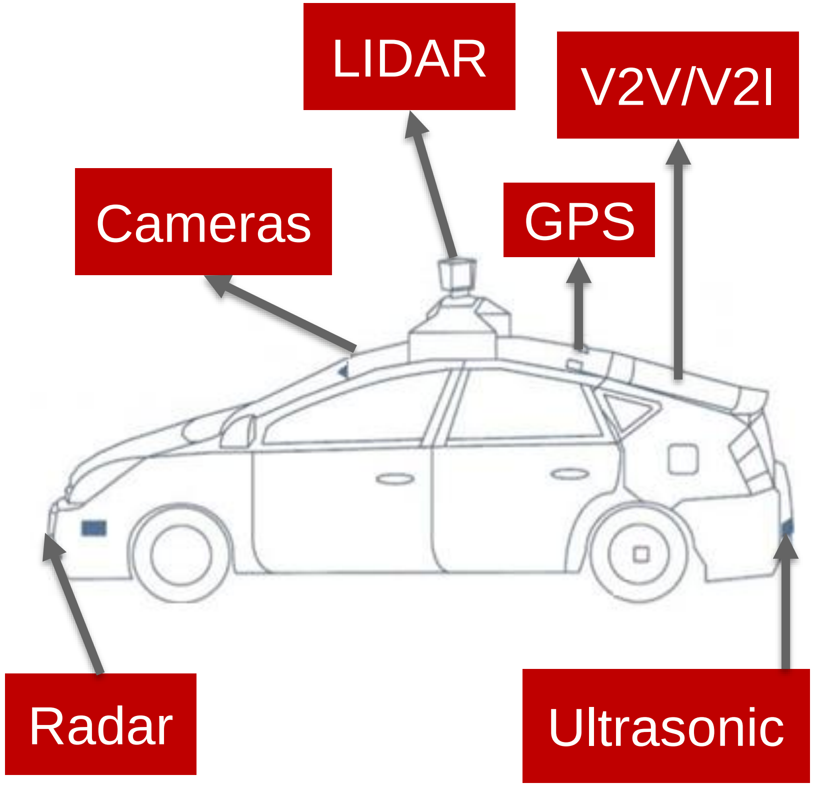
ITS application areas

- **ITS solutions** aim to reduce travel time, ease delay and congestion, improve safety, and reduce pollutant emissions by integrating electronic, sensing, information and communication technologies into the transportation system.

- **Main Application Categories**
  - Traffic Management
  - Transportation Pricing Systems
  - Traveler Information
  - Public Transportation
  - Vehicle Control Systems

Enabling ITS technologies

- **Location-based technologies** (GPS)
  - Navigation, warning systems, estimation of vehicle-miles travelled, data collection
- **Computing Platforms** (on-board computers, smart phones)
  - Navigation, data collection, driver services
- **In-car Sensors** (radars, cameras, lidars)
  - Driver assistive systems, autonomous driving
- **Communication solutions** (V2V and V2I)
  - Cooperation between infrastructure and vehicles
- **Intelligent Software Algorithms**
  - Optimal traffic management and control, optimal navigation, intelligent vehicle control

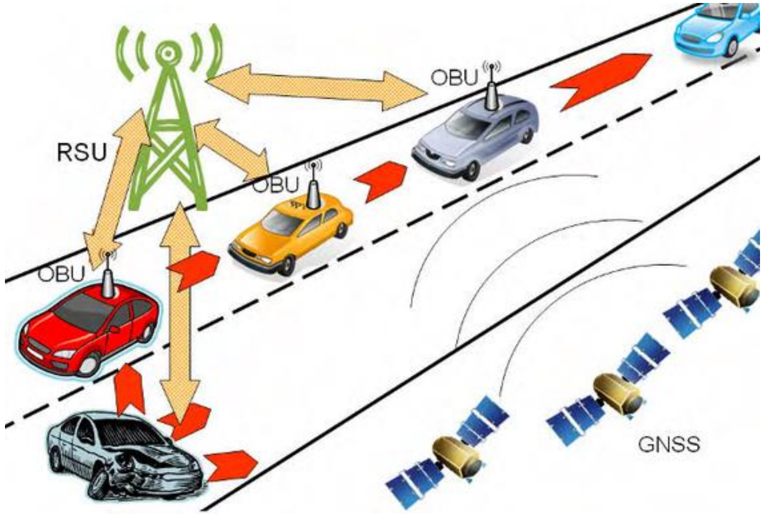


The future of mobility

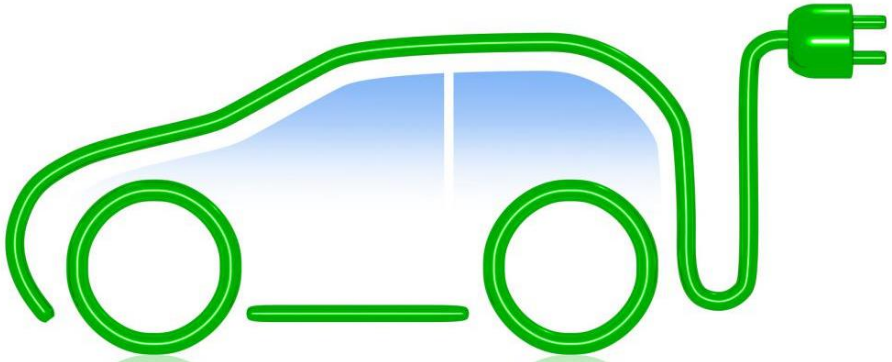
Transport revolution

Autonomous Vehicles

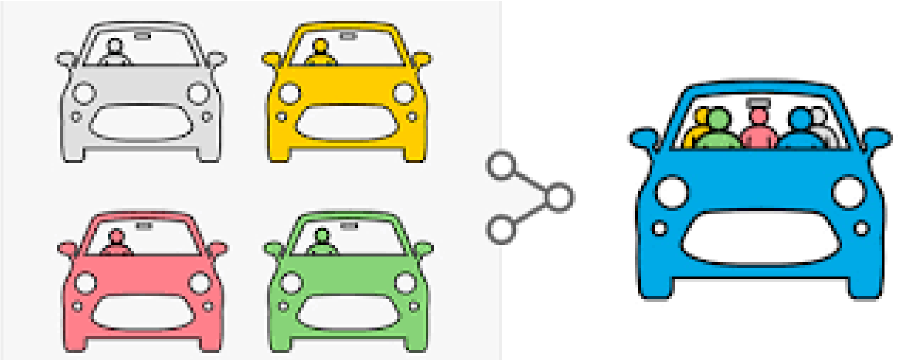
Connectivity



Electric Vehicles



Shared Mobility Services



Transport revolution

- Analysts claim that by 2030 95% of transport will be done by fleets of electric, connected and autonomous vehicles (**eCAVs**).

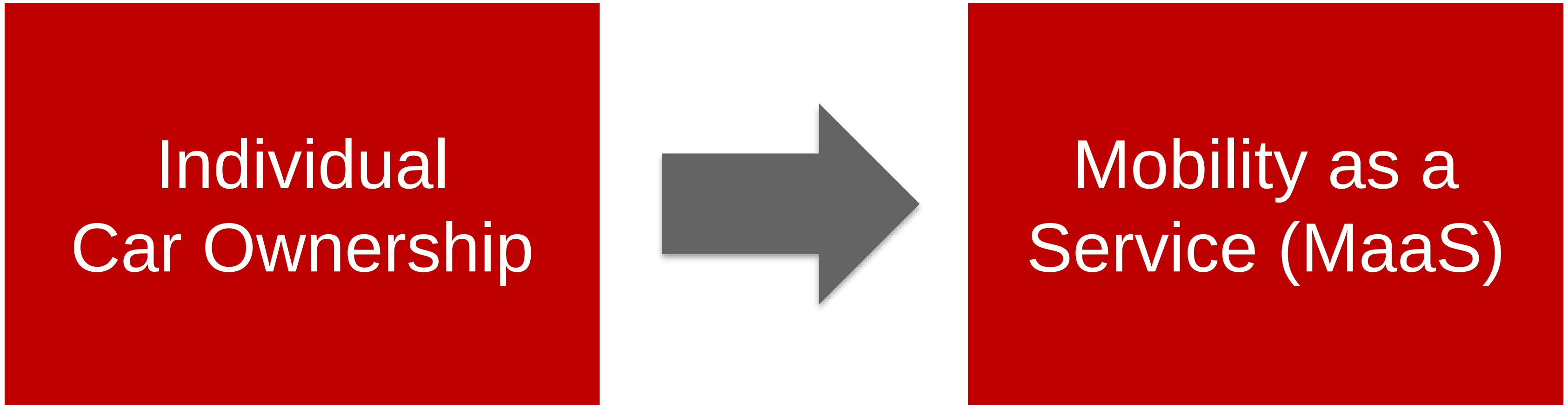
“We are on the cusp of the
fastest, deepest, most consequential disruption
of transportation in history”.

Source: RethinkX (independent think tank)

“Autonomous vehicles
is the largest and most impactful industry on the planet.”

Source: Jensen Huang, NVIDIA CEO, CES 2018

Transport revolution

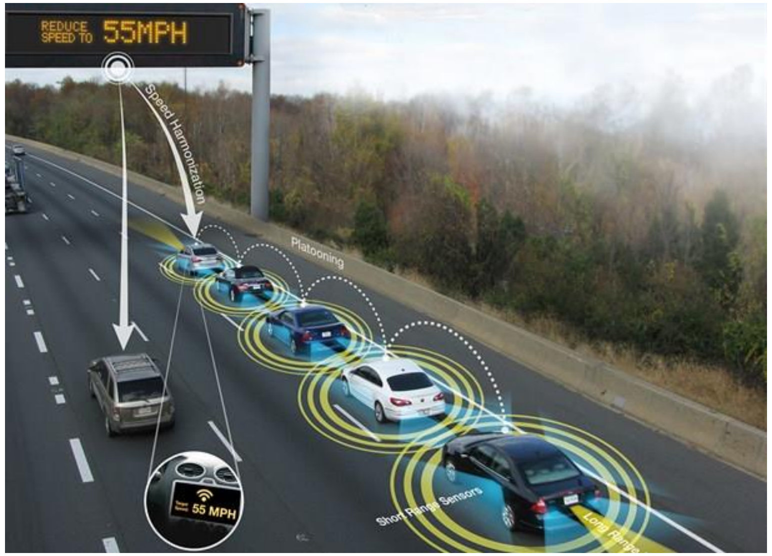


Challenges

Safety

Deadly accident of vehicle in autonomous driving mode

Traffic management



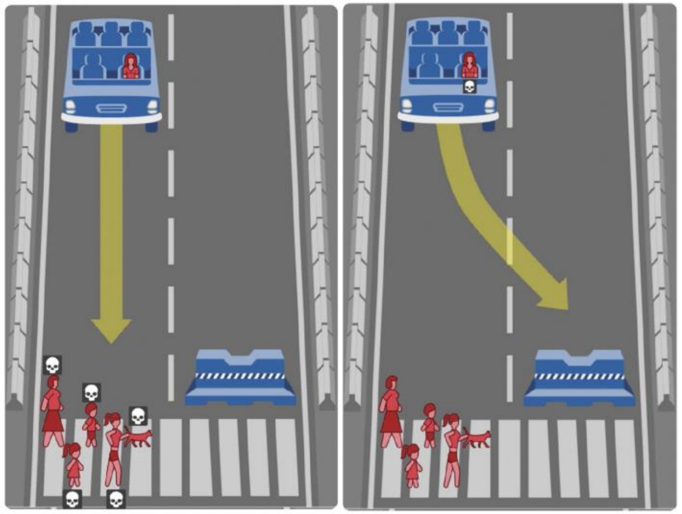
Coordination

Challenges

Cyber-security threats

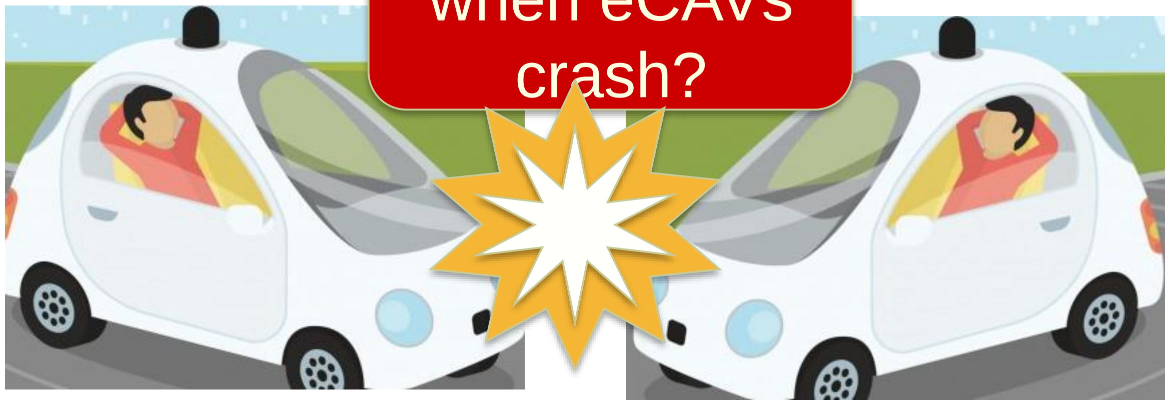
Human-Vehicle Interaction

Ethical Dilemmas



Legal Implications

Who is at fault when eCAVs crash?



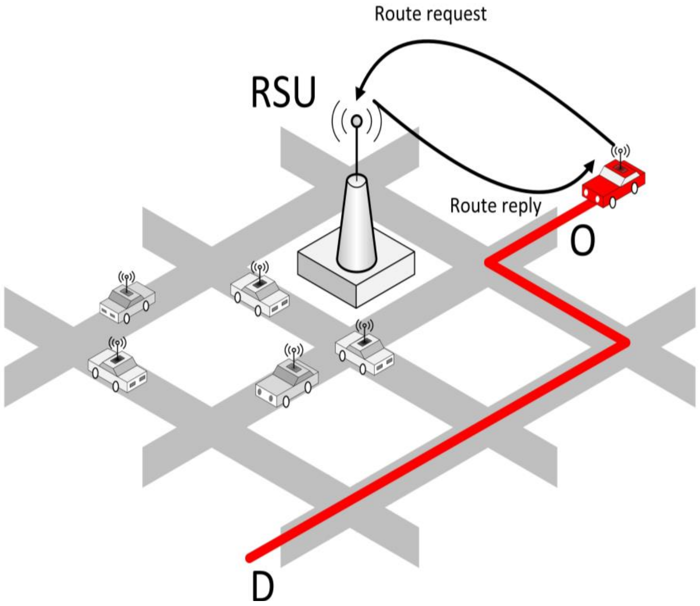
Research Activities in ITS

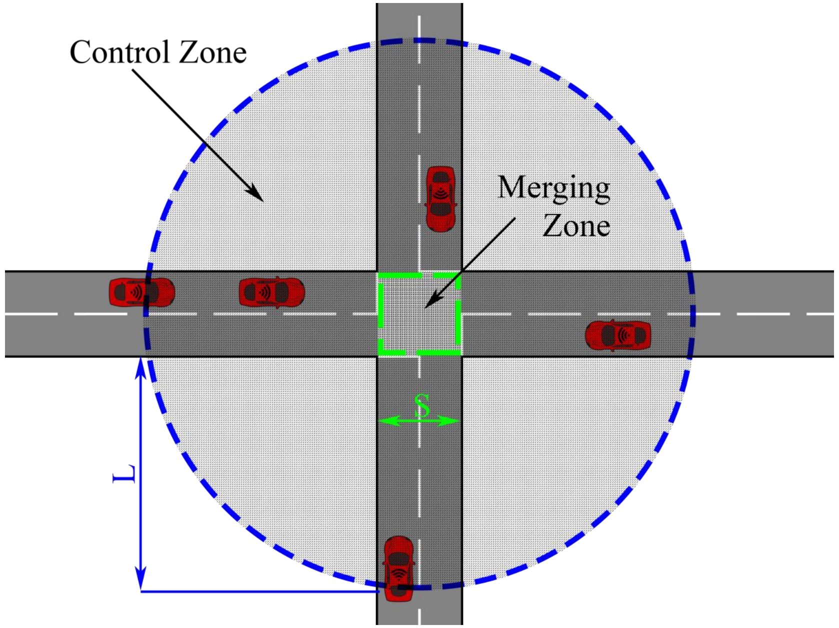
Research Directions

- Development of intelligent monitoring and control algorithms for real-time management of **contemporary** ITS:
  - Maximize efficiency and reliability
  - Estimation and prediction of the road conditions with emerging technologies
  - Traffic control strategies
  - Identifying the presence and alleviating the effects of sensors faults.
- Investigate challenges in **future** ITS
  - Involve the integration of connected and automated vehicles.
  - Develop novel architectures, protocols and algorithms for monitoring, control and security for road transportation systems.

KIOS CoE Research Contributions

- Dynamic traffic demand management and control using connected vehicles (V2I communications)
- Unsignalized intersection crossing using Connected and Autonomous Vehicles (CAVs) (V2I or V2V communications)
- Other contributions

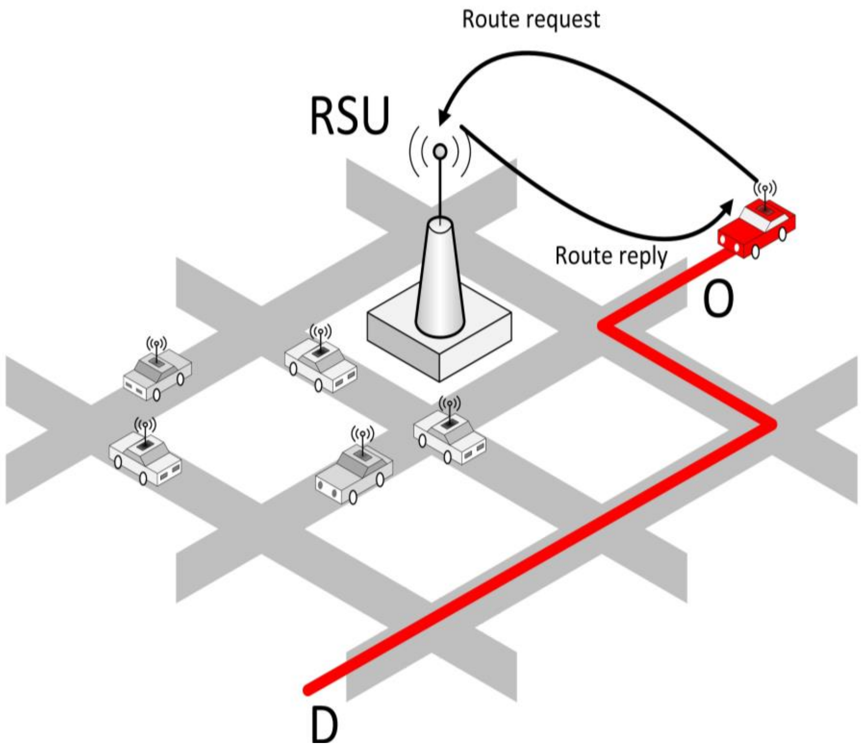




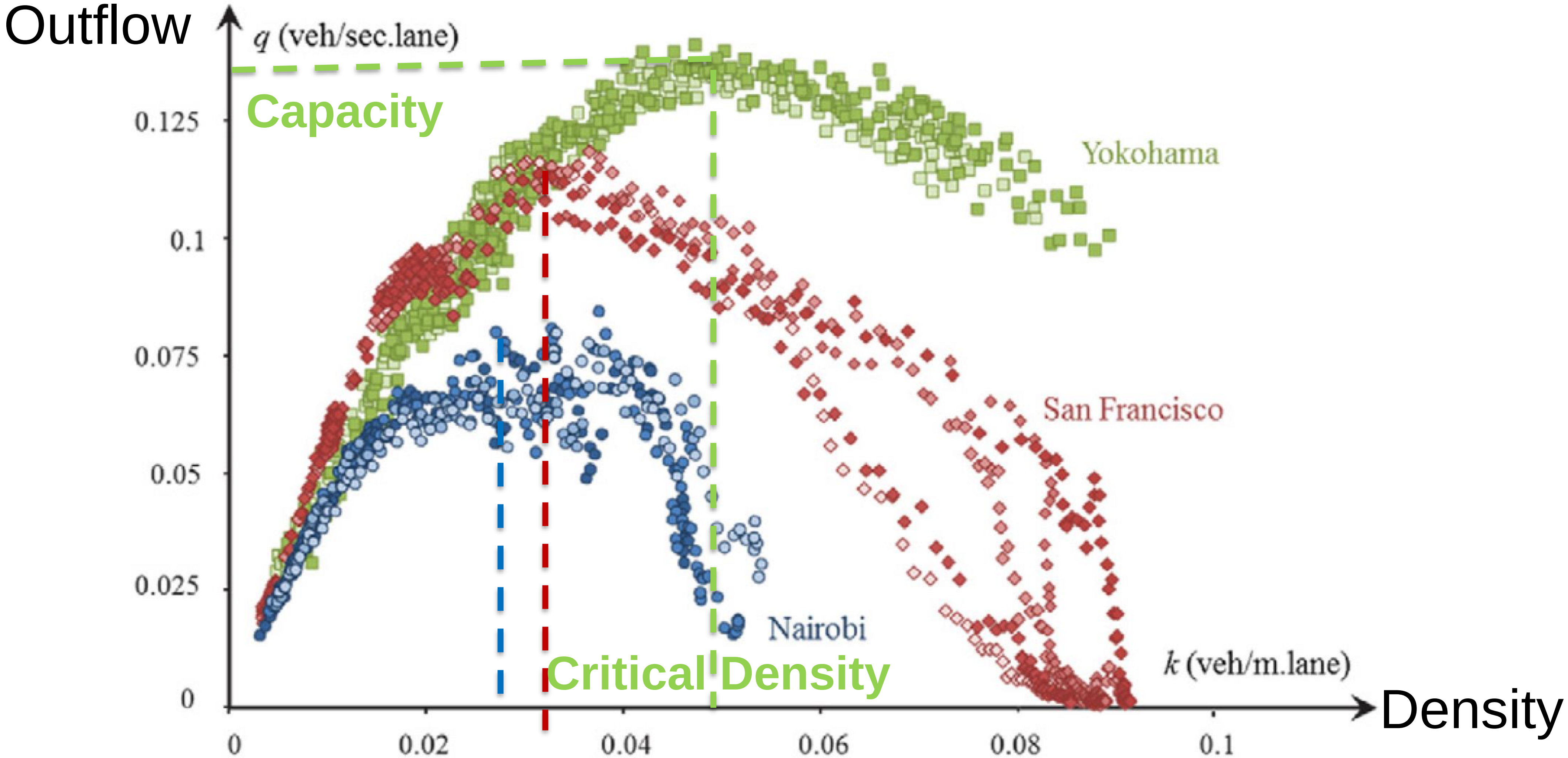
Dynamic traffic demand management and control

Problem Statement

- **Inputs**
  - Specific road transportation system with connected vehicles
  - Vehicle requests to enter the network (time and O-D pair)
- **Objective**
  - Minimize the total travel time of all vehicles
- **Outputs**
  - Route followed from each vehicles in the network

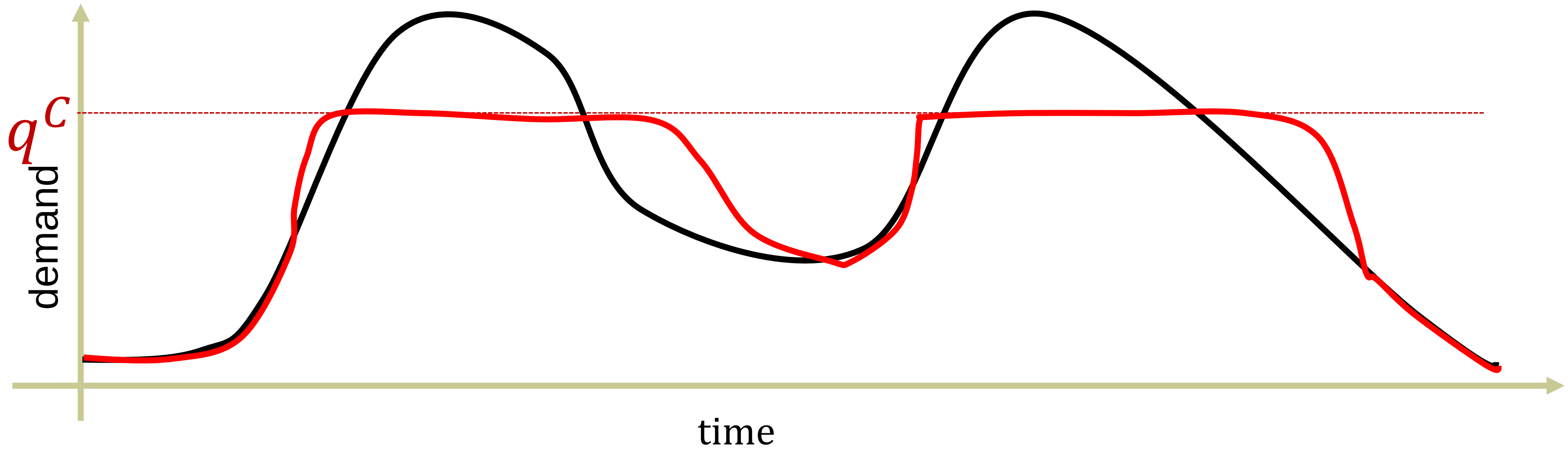


Macroscopic Fundamental Diagram



- Load vehicles in the network until the *critical density* is reached.

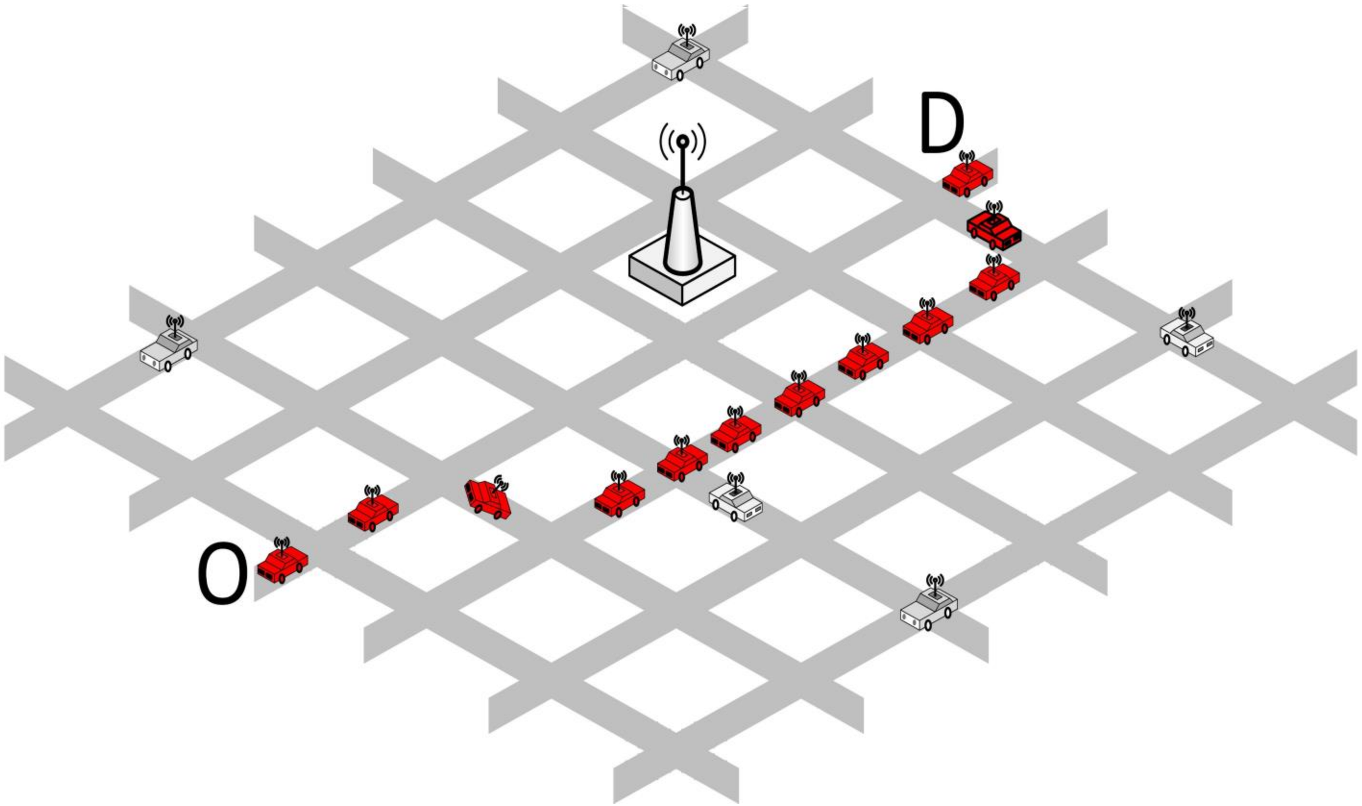
Demand Management



Traffic Demand Management

- Shift (in-time) → delay vehicles at the origin
- Shift (in-space) → utilize alternative paths

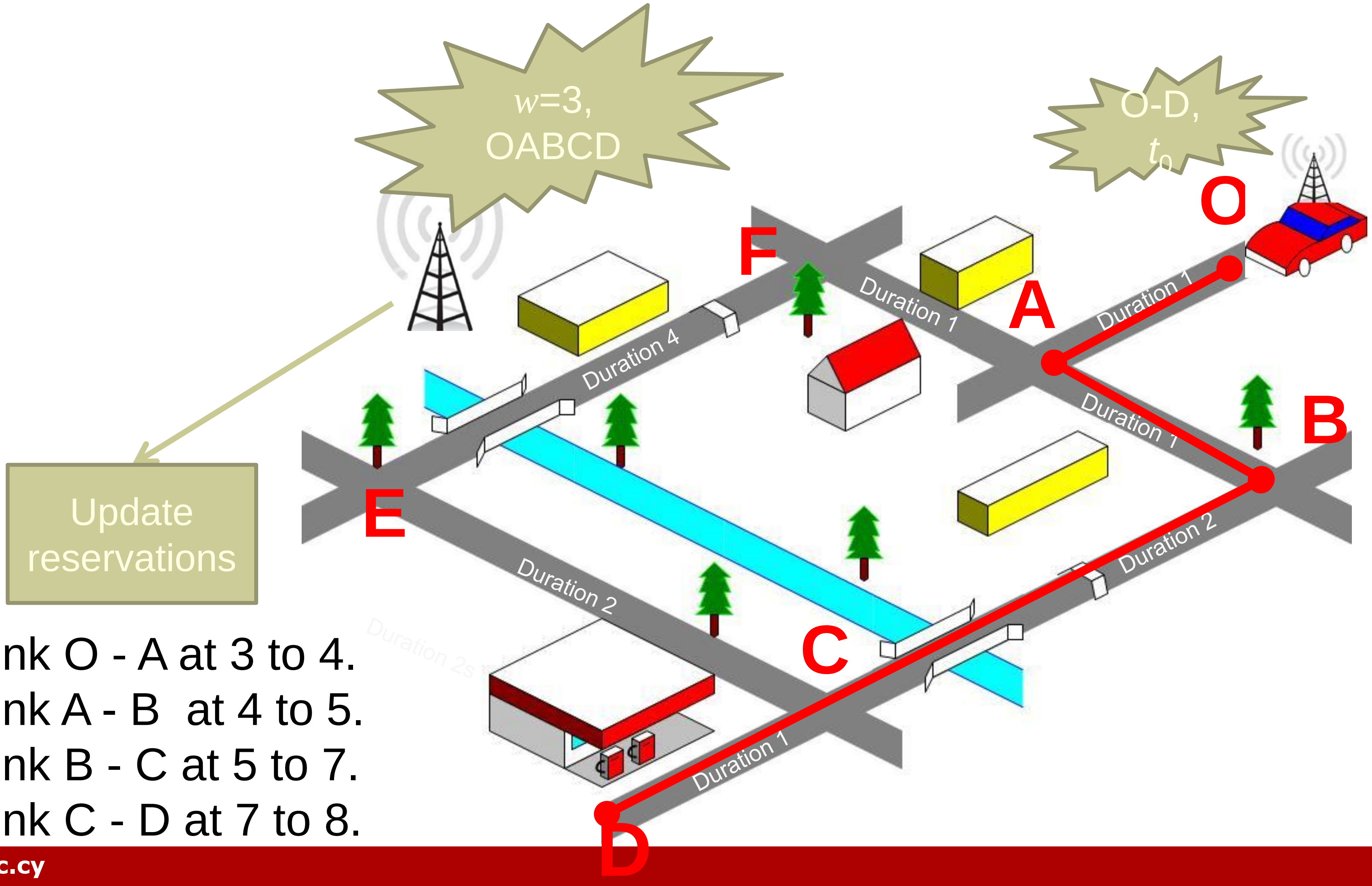
Individual vs Collective Optimum



- Routing methods should consider the benefit of the "whole" as opposed to the benefit of the individual [*]

[*] *Çolak, Serdar, Antonio Lima, and Marta C. González. "Understanding congested travel in urban areas." Nature communications 7 (2016): 10793.*

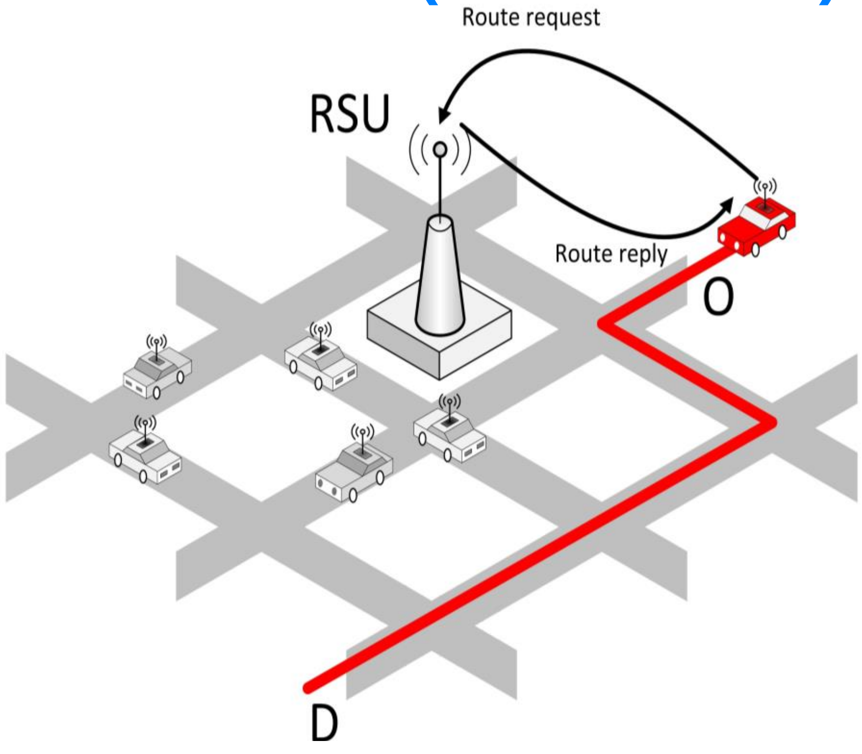
Road Reservations Architecture



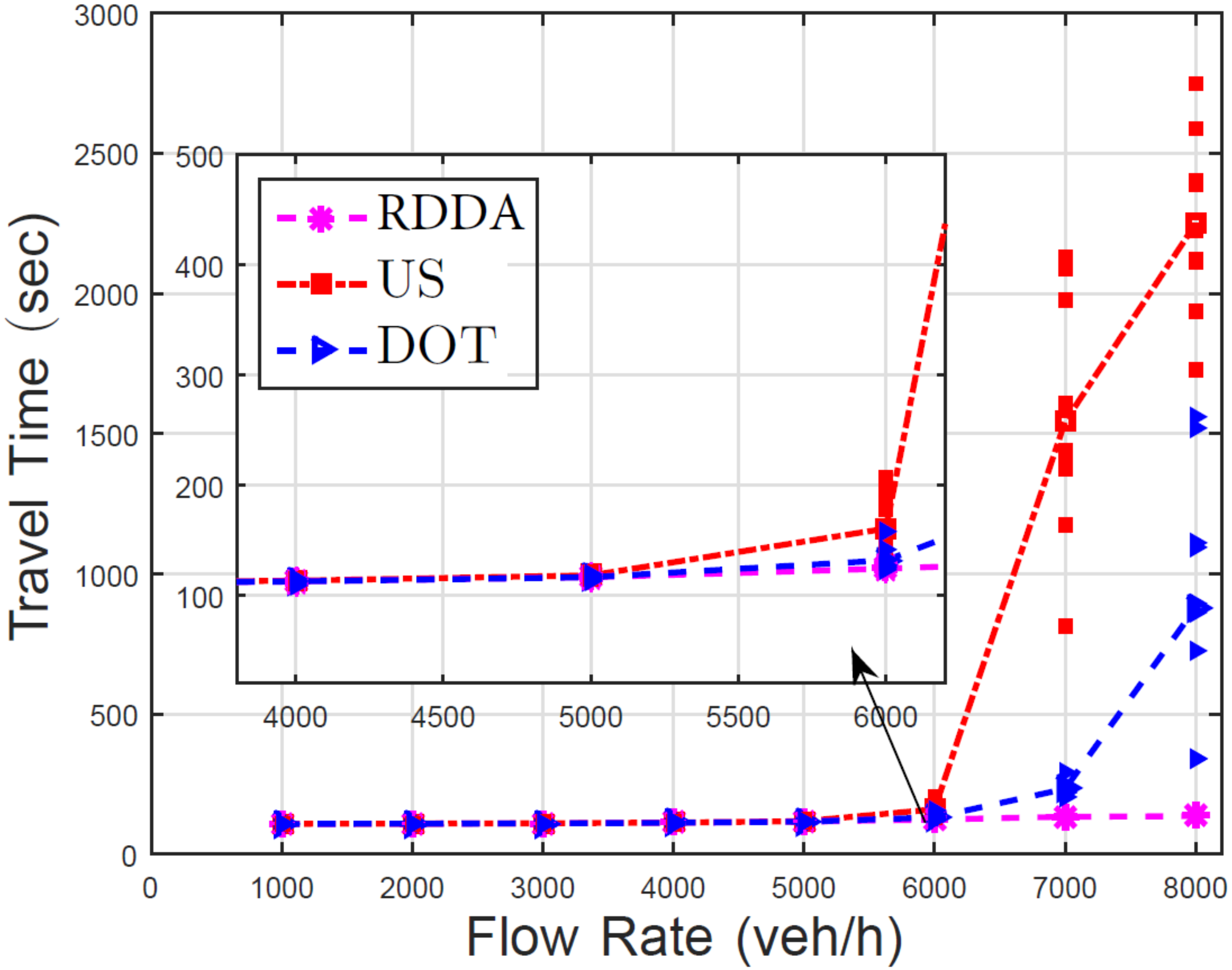
Link O - A at 3 to 4.
Link A - B at 4 to 5.
Link B - C at 5 to 7.
Link C - D at 7 to 8.

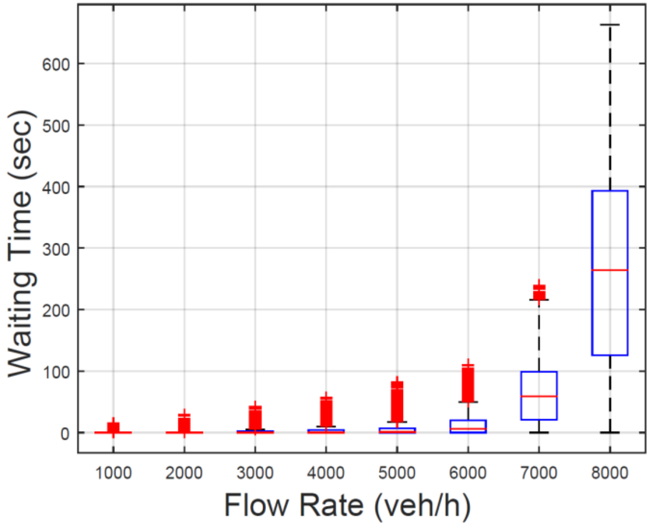
Problem Solution

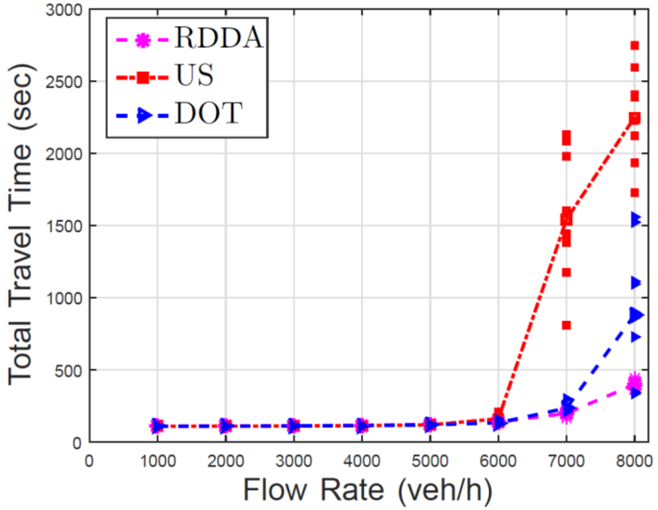
- **Inputs**
  - Specific road transportation system with connected vehicles
  - Vehicle requests to enter the network (time and O-D pair)
  - **State of different road links at present and future times (reservations)**
- **Objective**
  - Minimize the total travel time of all vehicles
- **Outputs**
  - Route followed from each vehicles in the network
  - **Delay at the origin node for each vehicle**



Simulation Results

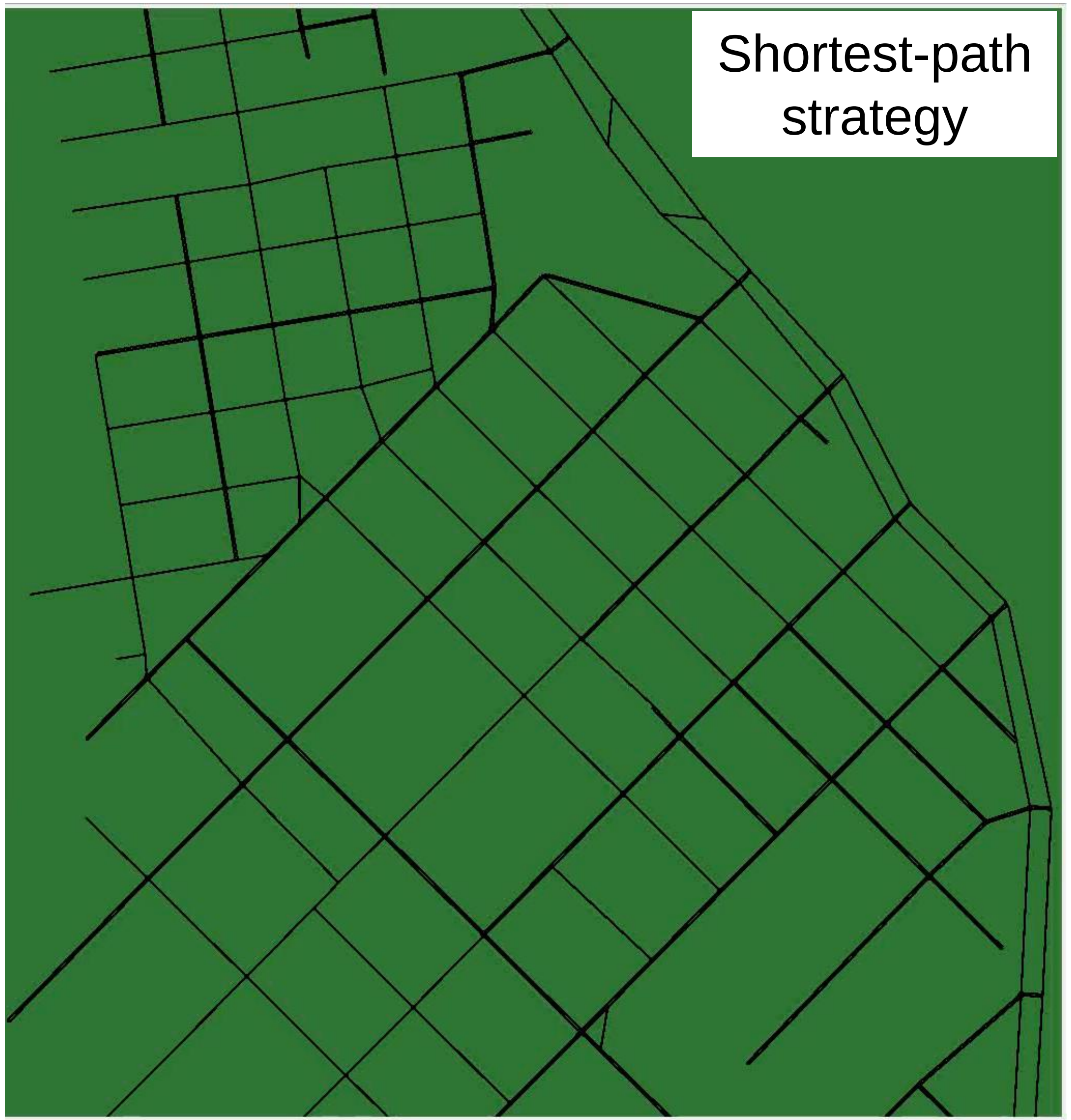


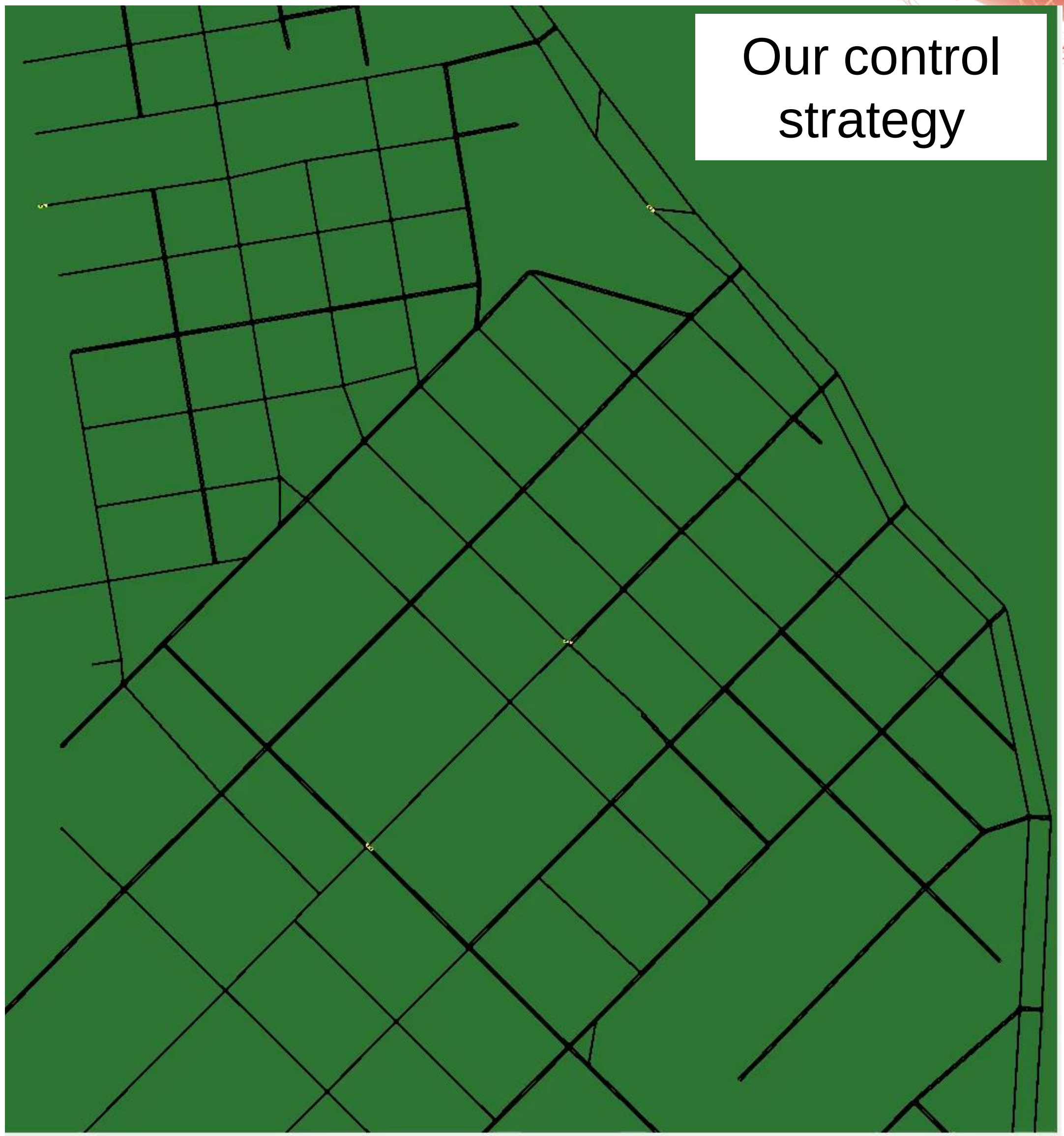




Total Time = Travel Time + Waiting Time

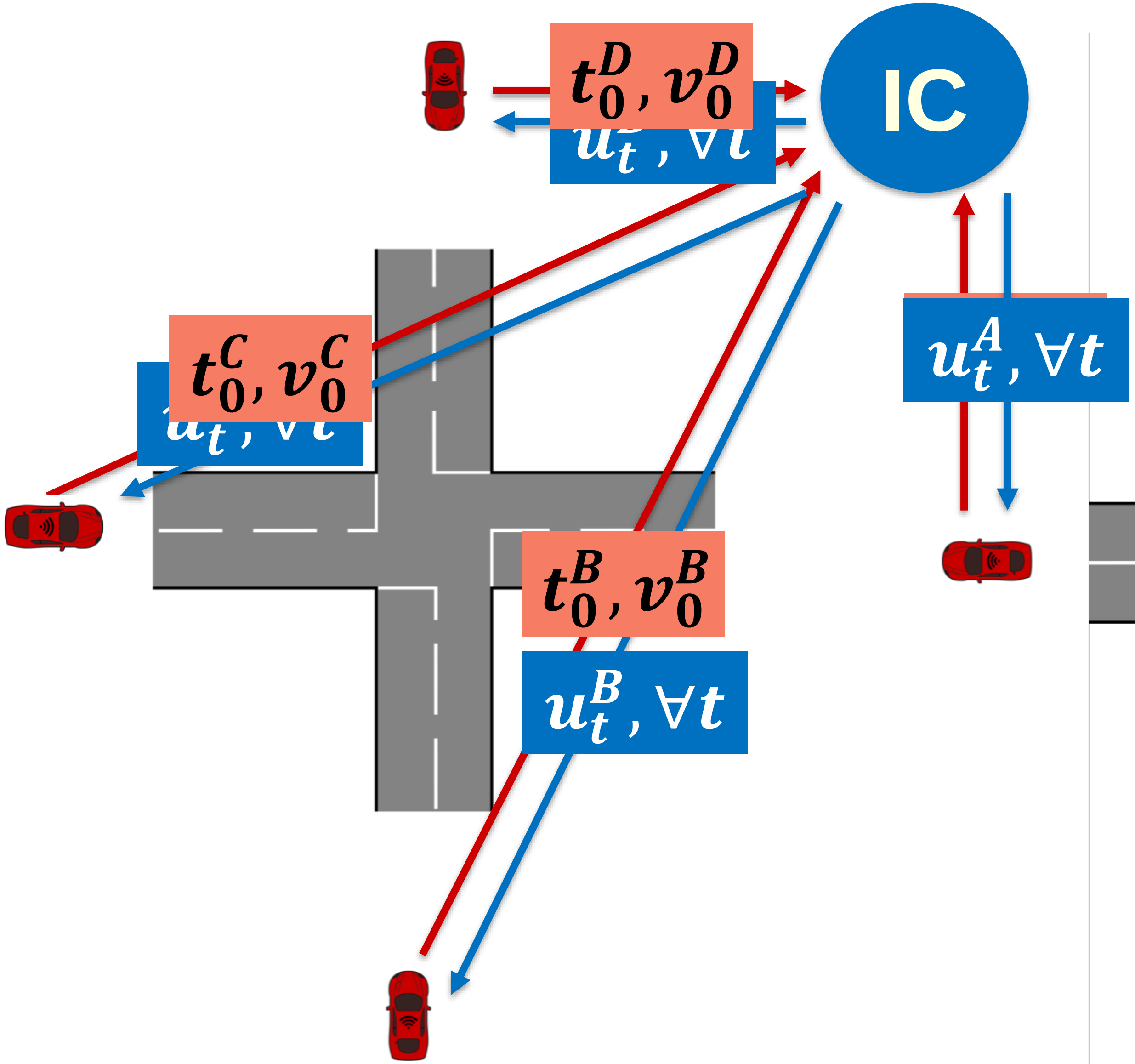
Demonstration

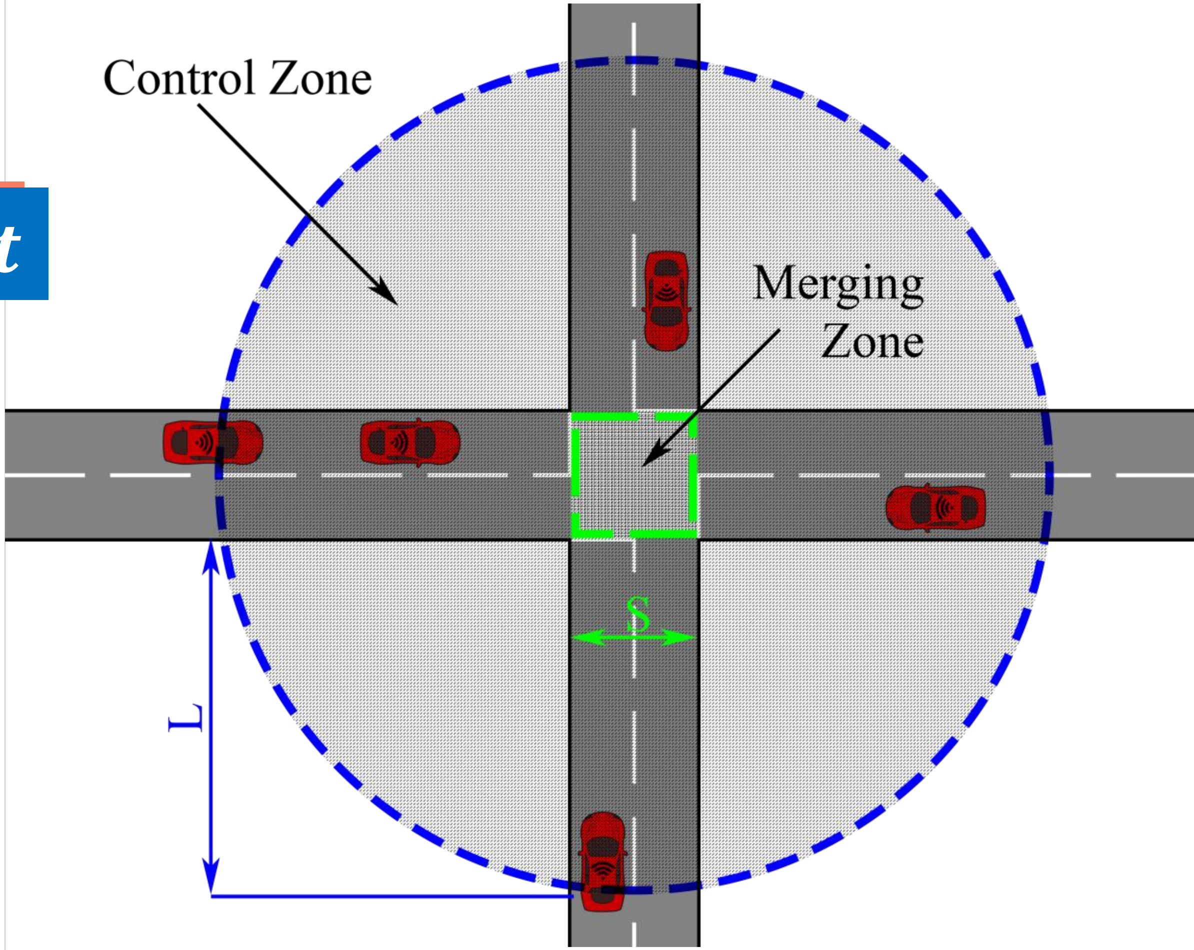




Unsignalized intersection crossing using CAVs

Architecture





Problem Statement

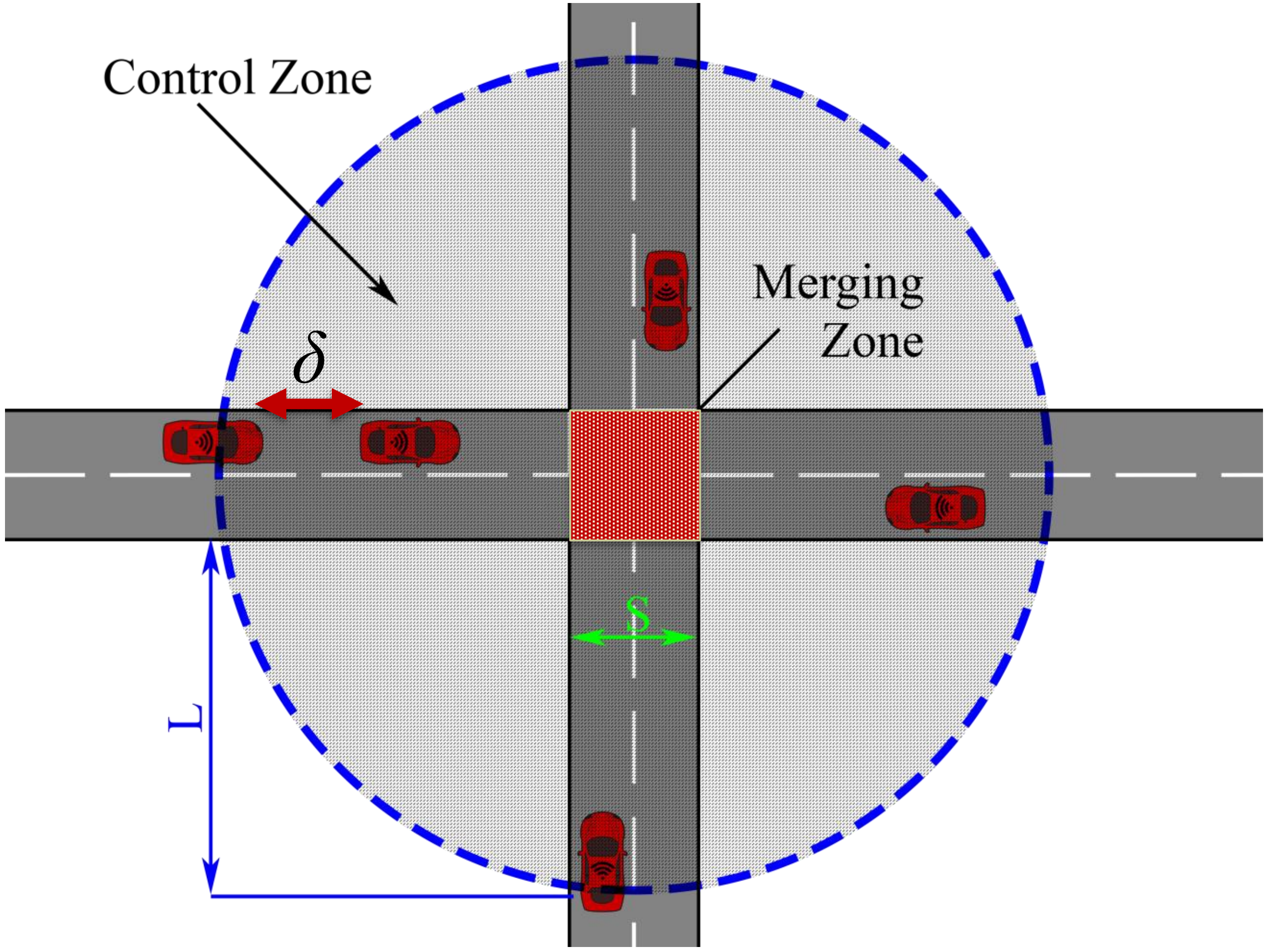
Objective: Optimize tradeoff between travel time and fuel consumption

Constraints

- Vehicle dynamics
- Lateral collision safety
- Rear-end collision safety
- Physical constraints

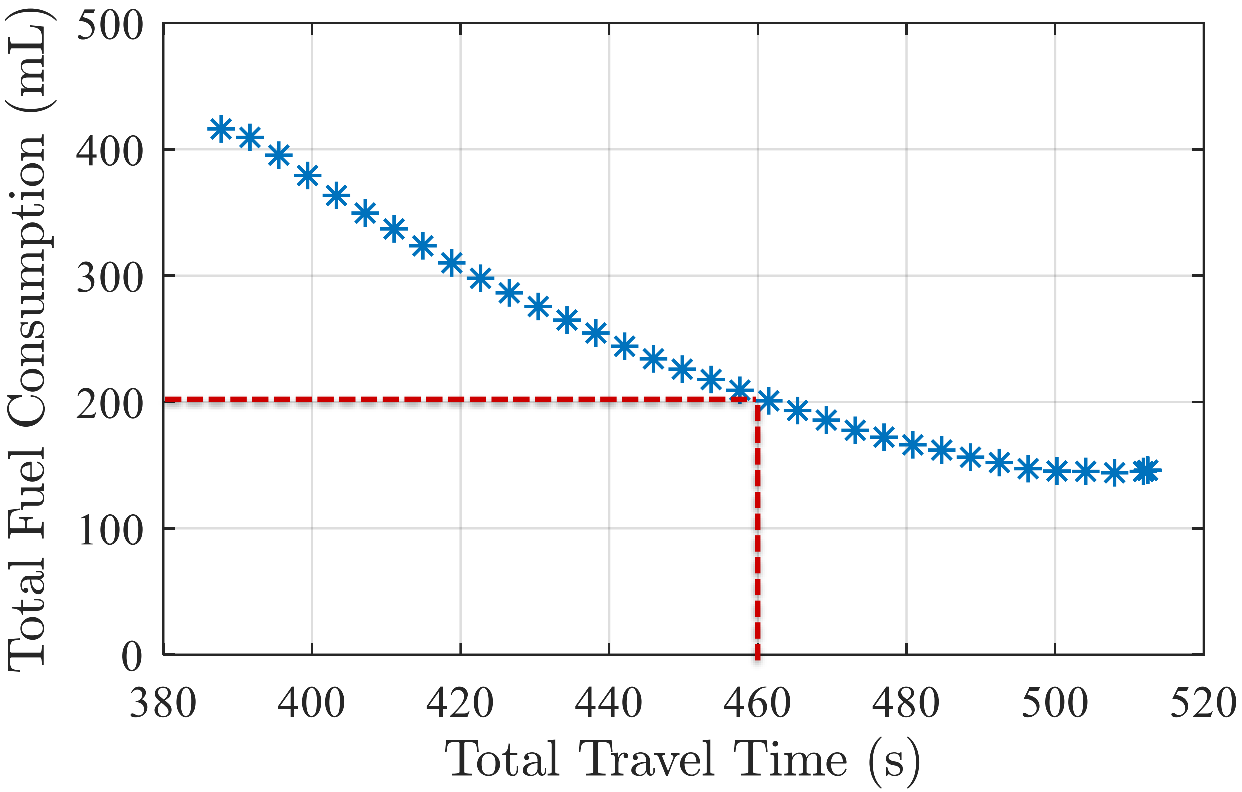
Assumptions

- Controller uses a FIFO Policy
- No other road users (i.e. bicycles, pedestrians)



Simulation results

- Use of empirical fuel consumption metamodel

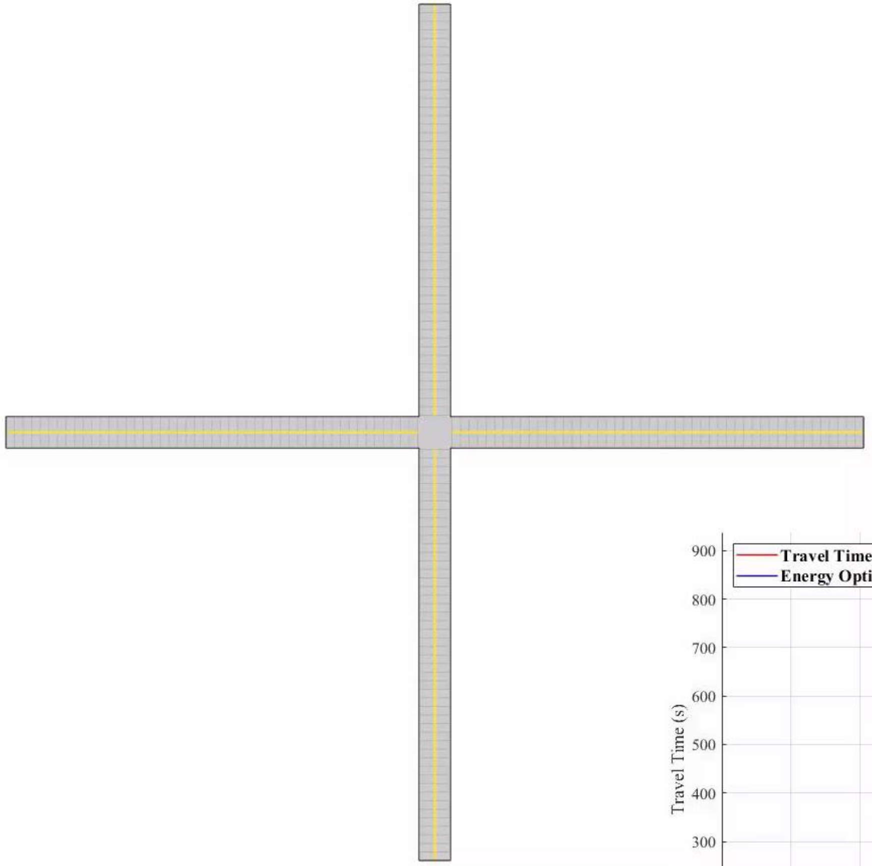


- Increase in travel time of 20% leads to a 50% reduction in fuel consumption

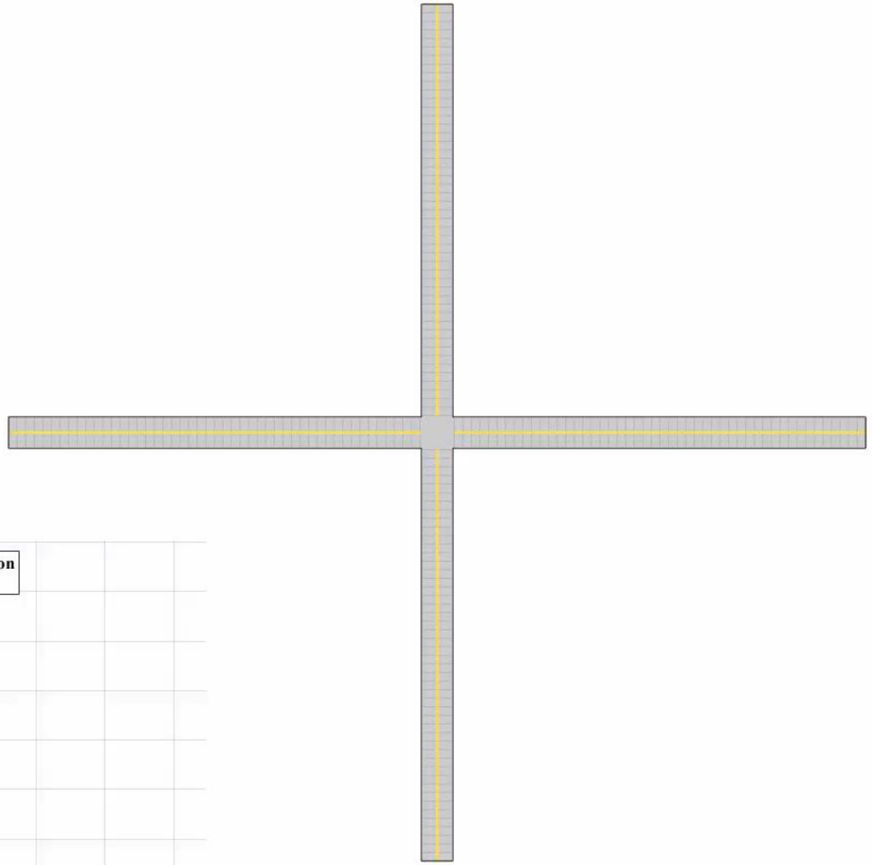
KOIOΣ
Research and Innovation Center of Excellence

Autonomous Intersection Crossing

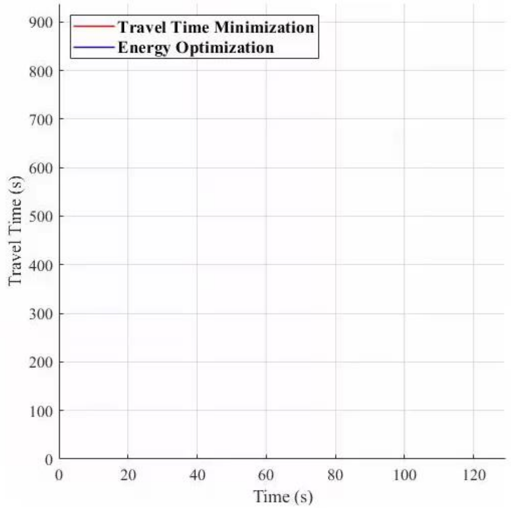
Energy Optimization

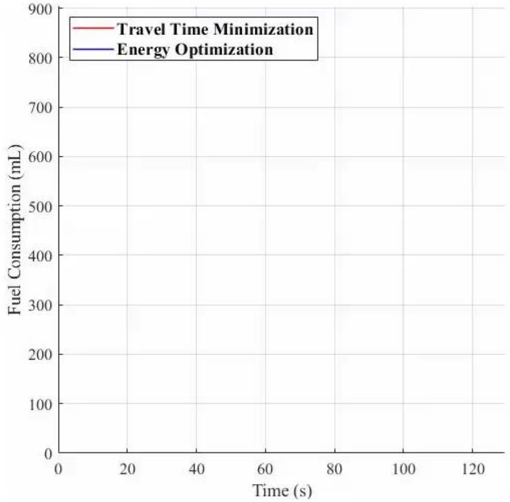


Travel Time Minimization



(2x speed)





University of Cyprus
Imperial College London

Funded by:

Coded by Andreas Hadjigeorgiou

Other Contributions

Other Contributions

- Traffic state estimation with bound guarantees
- Fault-tolerant traffic state estimation
- Event-based communications in public transportation systems
- Data offloading transfers through intervehicle communication transmissions
- Electric vehicle routing with charging in transportation networks using probabilistic models
- Distributed network traffic signal optimization (using I2I)
- Origin-destination matrix estimation using Bayesian theory and mathematical programming

KIOS CoE Interests and Expertise in ITS

- **Problems of interest**
  - Traffic control of urban and highway networks (conventional/CAVs)
  - Traffic Estimation and prediction
  - Fault-tolerance in traffic networks and CAVs
  - Communication Protocols in CAV-rich environments
  - Coordination among fully autonomous vehicles
- **Areas of expertise**
  - Optimization
  - Control
  - Fault diagnosis
  - Communications

Educational Activities in ITS

Educational Activities in ITS

- ECE 807: CIS Applications I – Fundamentals (6 hours)
- **Lecture 1 (2 hours)**
  - Introduction to Intelligent Transportation Systems (ITS)
  - Monitoring Control and Security of ITS
  - Future Mobility
- **Lecture 2 (2 hours)**
  - Fundamental concepts of traffic flow theory
  - Microscopic modelling
- **Lecture 3 (2 hours)**
  - Macroscopic modelling
- **Tutorial Session (2 hours)**
  - SUMO microscopic traffic simulator
- **ITS-related Project**
  - Simulate and examine traffic phenomena in SUMO (link to traffic flow theory)

Educational Activities in ITS

- ECE 808: CIS Applications II – Advanced (6 hours)
- **Lecture 1: Estimation and Control in Highway Networks (3 hours)**
  - Estimation of traffic state variables using KF and MHE
  - Traffic estimation in the presence of faulty measurements
  - Investigation of traffic control strategies using techniques from control and optimization
- **Lecture 2: Estimation and Control in Urban Traffic Networks (3 hours)**
  - The concept of the Macroscopic Fundamental Diagram
  - Estimation of regional parameters
  - Regional Control Strategies for Urban Traffic Networks (Route Guidance, Perimeter Control, Demand Management)
- **Tutorial Session (2 hours)**
  - How to utilize practical optimization tools for traffic estimation and control
- **ITS-related Project**
  - Traffic estimation using KF and MHE for a realistic transportation network

Educational Activities in ITS

- **Thesis Dissertations in ITS**
  - Practical and Research-oriented topics on monitoring and control of ITS
  - Utilize traffic flow theory and mathematical theory from courses related to control, optimization and estimation
  - Different types of theses: theoretical, simulation-based, experimental
  - Integrate students pursuing their thesis in the KIOS ITS research group
- **Seminars in ITS**
  - External keynote lectures
  - Internal lectures from UCY researchers

Educational Activities in ITS

- **Teaching Philosophy**
  - Apply meaningful rather than rote learning
    - Help students link traffic concepts with everyday-life examples
  - Have learning transfer in mind
    - Help students to be able to transfer what they learn in other application contexts
  - Teach state-of-the-art concepts and methods
  - Use different audiovisual means to illustrate concepts
  - Expose students to experts working in ITS
  - Help students learn state-of-practice software tools
    - Traffic simulation, optimization, estimation
  - Link theory to real-world problems

Conclusions

- Intelligent Transportation Systems is an exciting area for various engineering disciplines
- Transport is at the cusp of a **revolution** brought by electric, connected and automated vehicles, as well as shared mobility
- ITS provides great opportunities to:
  - Perform exciting research
  - Undertake a professional career
- Important to incorporate in educational activities

Thank you for listening