# COMPUTER VISION AND INTELLIGENT SYSTEMS IN ROAD TRAFFIC CONTROL

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- **University of Zagreb, Croatia**
  - Established in 1669.
  - 29 faculties and 3 academies
  - 4.850 research staff members and 50.000 students
- **Faculty of Transport and Traffic Sciences**
  - Established in 1984.
  - 15 departments
    - Cover all transport modes, logistics, ITS, aeronautics
  - 100 research staff members / 2200 students
  - Publisher of the journal

    PROMET – Traffic&Transportation
    - Cited in SCIE, TRIS, Geobase, FLUIDEX, and Scopus

# Outline

- Introduction
- Computer vision in road traffic
- Experimental results
- Ramp metering
- Intelligent cooperative ramp metering
- Experimental results
- Conclusion & Future work

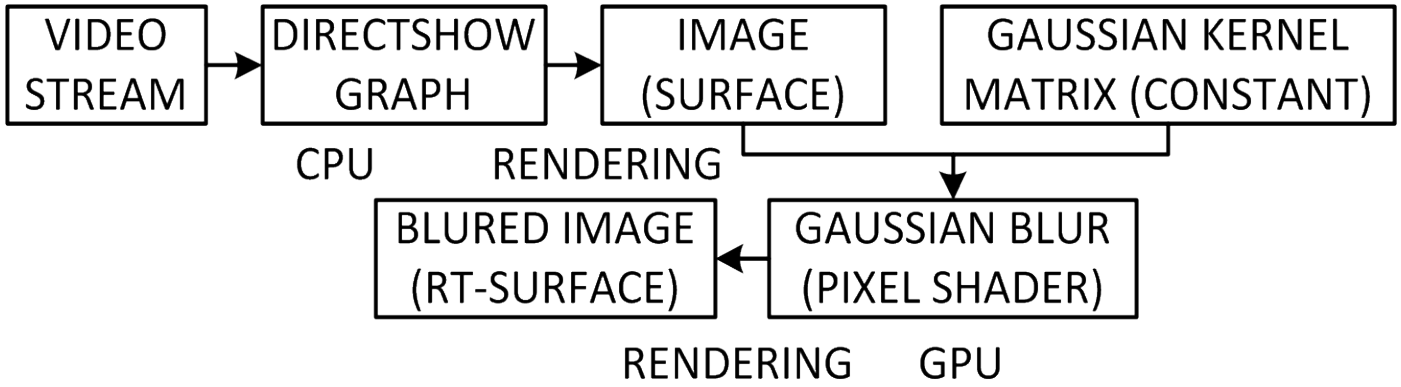
# Introduction

- **Today's local urban roads, urban highways and they interconnections cannot fulfil desired level of service (LoS) due congestions caused by**
  - Large demand for mobility at peak hours
  - Lack of space for infrastructural build-up
  - Urban network serves local and transit traffic
- **Solution in intelligent transport systems (ITS) based traffic control systems**
  - Ramp metering
  - Variable Speed Limit Control (VSLC)
  - Optimization of traffic lights signal planes
  - Various driver information systems, etc.

# Introduction

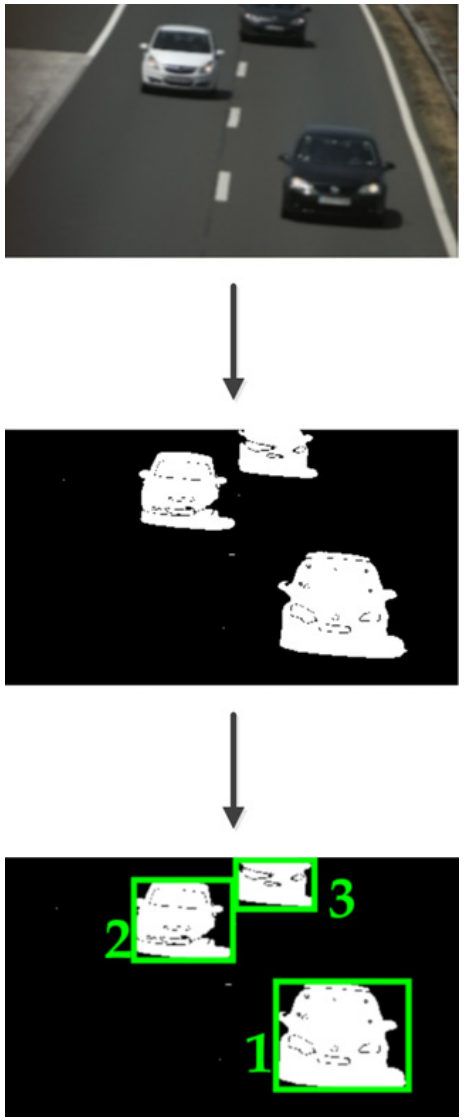
- **ITS state-of-the-art solution for urban traffic control**
  - Application of hybrid intelligent system in control
  - Cooperation between several traffic control systems
- **Reliable real-time measurements of traffic parameters is required for ITS control systems**
- **State-of-the-art solution is in real-time video surveillance and computer vision application**
  - Several traffic parameters can be estimated from road traffic video footage
    - Origin-Destination (OD) matrices
    - Vehicle class, trajectories and velocity
    - Estimation of vehicle country of origin using license plate recognition, etc.

- **Problem with video cameras used for real time traffic parameters measurement**
  - Weather conditions
  - One camera per road lane
- **Tracking vehicles on multiple lanes simultaneously with only one camera**
- **Preprocessing algorithm**
  - Noise reduction
  - Gaussian filter with 5x5 matrix



- **Background subtraction method**
  (a) Creation of background image model
  (b) Detection of foreground objects

- **Object clustering method**
  - Check if adjacent pixels exist and combine them into cluster
  - If cluster area $A \leq threshold$, remove cluster



- **Object tracking method**
  - Compare all objects in the new frame with objects in the previous frame and combine only those with maximal weight $w$

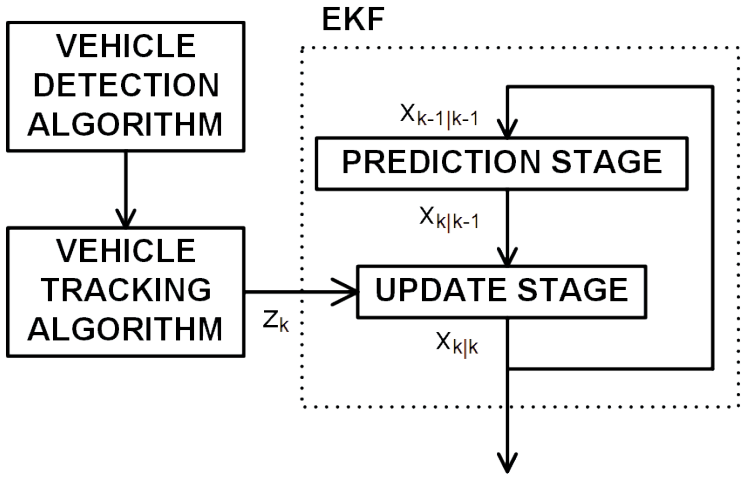
$$w_{dist} = 1 - \frac{d - d_{min}}{d_{max} - d_{min}}$$

$$w_{area} = 1 - \frac{a - a_{min}}{a_{max} - a_{min}}$$

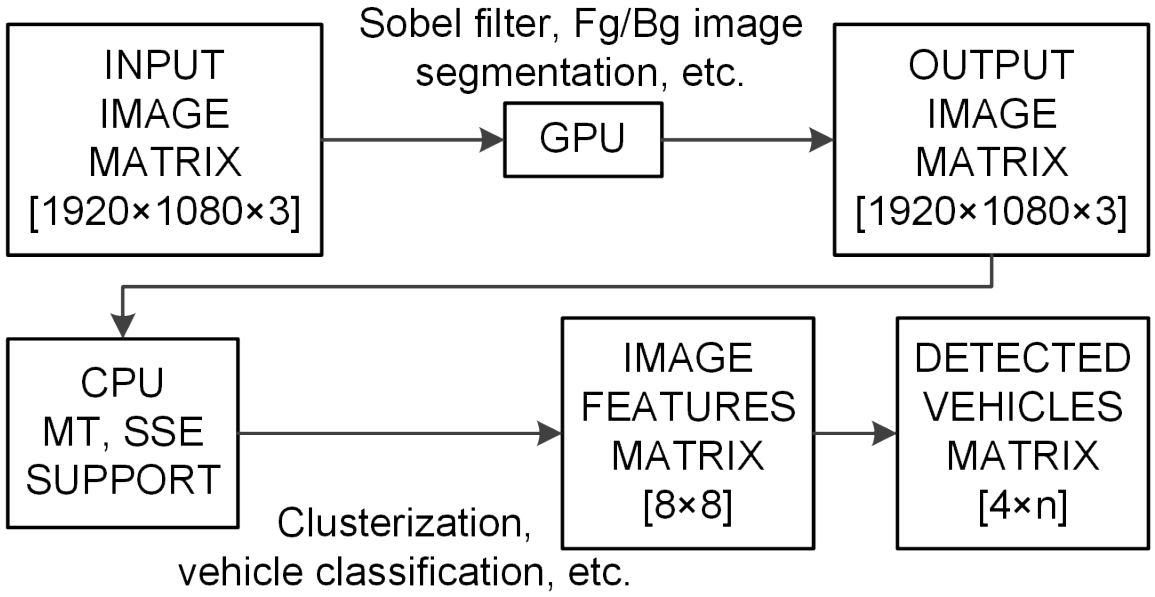
$$w_{cover} = \frac{a_{is}}{max(a_{obj}, a_{cl})}$$

$$w = \frac{w_{dist} + w_{area} + w_{cover}}{3}$$

- **Postprocessing object location**
  - Extended Kalman Filter (EKF)
  - Histogram for computing average values of position ($x$, $y$), velocity ($v$), acceleration ($a$), direction ($\varphi$), angular velocity ($\omega$) based on EKF output
  - Setting initial values of state vector $x$ by histogram



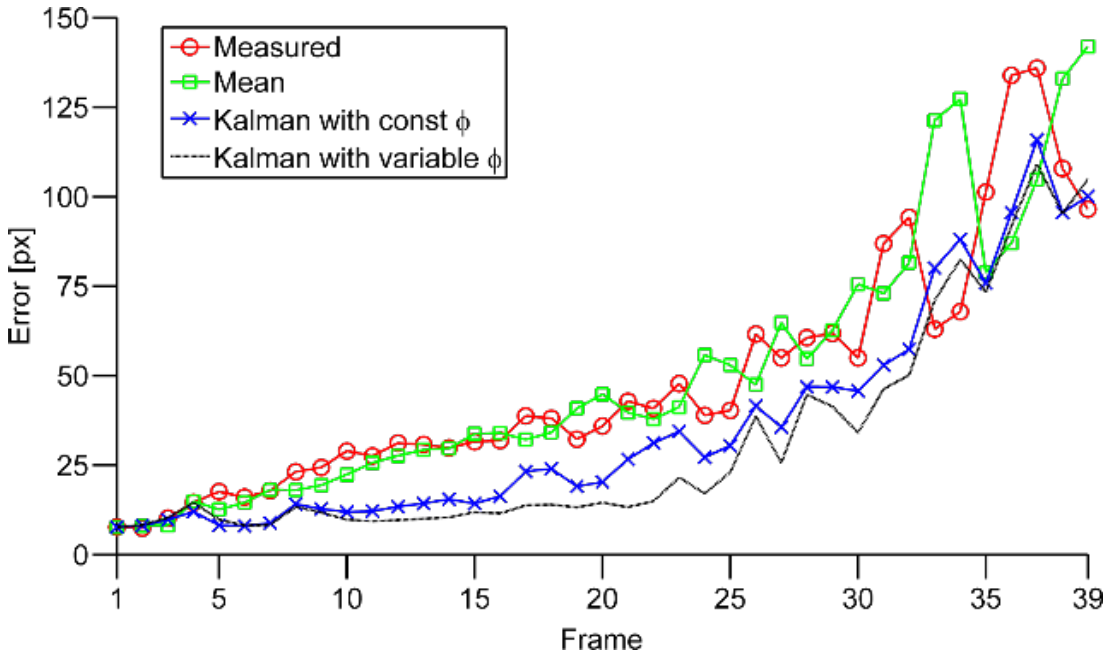
- **Optimization for real-time execution**
  - Executing algorithms on GPU as much as possible
  - Adding support for CPU SIMD instructions to algorithms which are incapable to run on GPU
  - Performing computations using multiple threads
    - Parallelization of image processing algorithms

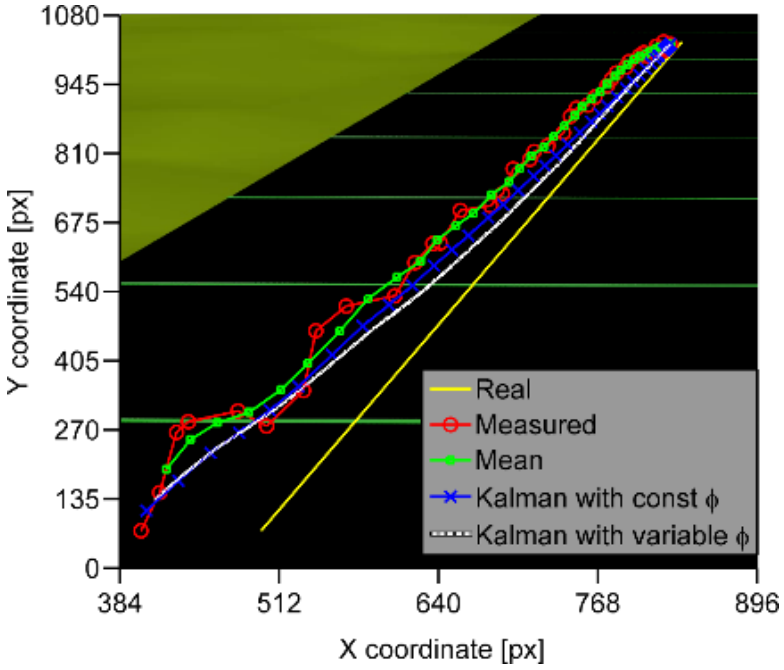


- **Vehicle counting approaches**
  - Check if vehicle bounding box / trajectory is overlapping with one of virtual markers

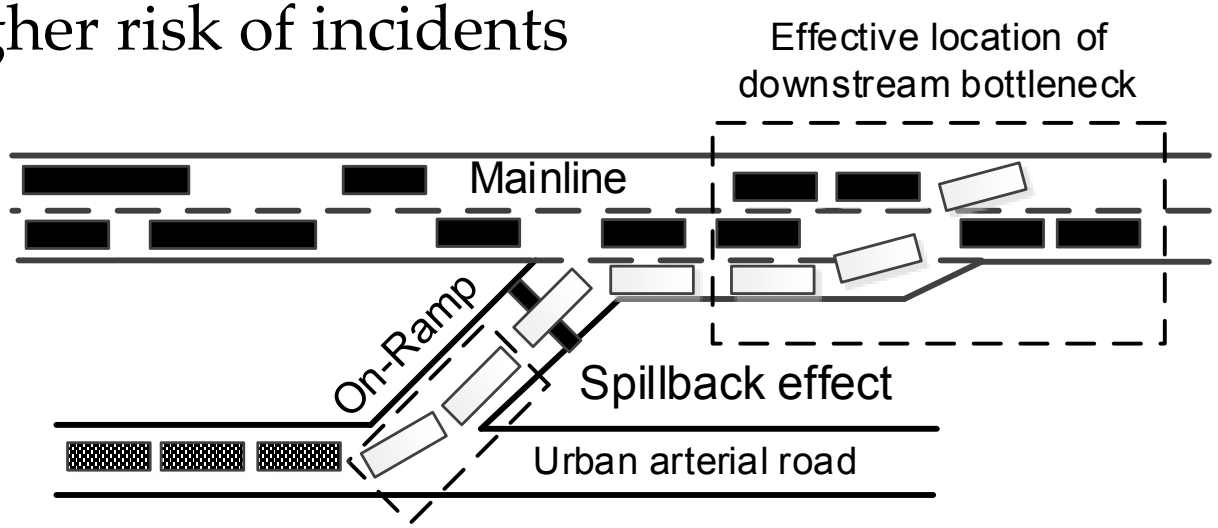
| Approach | | Vehicle count per lane | | |
|---|---|---|---|---|
| | | Total | Left | Right |
| Overlap check | Hits | 126 | 65 | 61 |
| | FP / FN | 0 / 6 | 0 / 5 | 0 / 1 |
| | Accuracy | 95,6% | 92,9% | 98,4% |
| Trajectory check | Hits | 129 | 68 | 61 |
| | FP / FN | 1 / 4 | 0 / 3 | 1 / 1 |
| | Accuracy | 96,2% | 95,8% | 96,8% |
| True vehicle count | | 132 | 70 | 62 |

- **Simulation of 3D road traffic scene with known parameters**
  - Synthetic environment designed in Autodesk 3ds Max
  - Noise added to measured trajectory

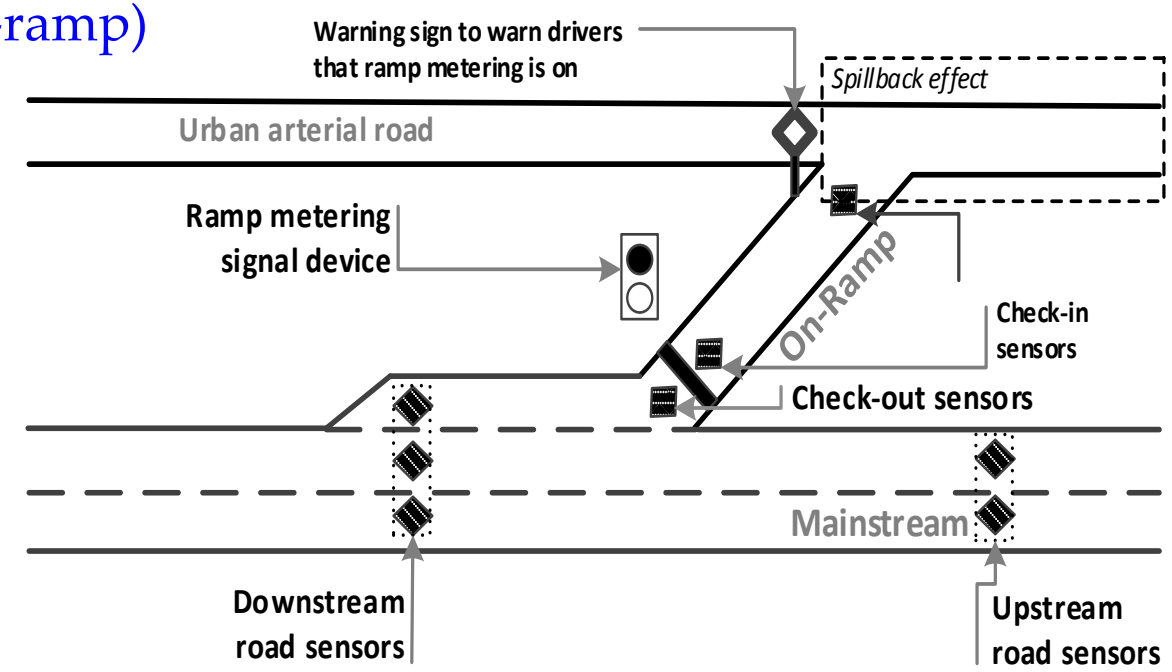


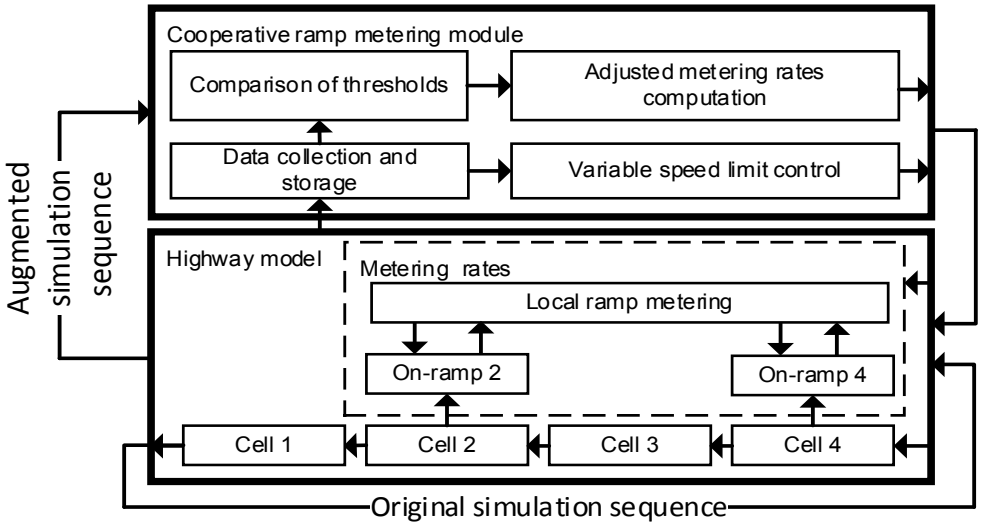
- **Uncontrolled platooned vehicle entry from on-ramps (urban arterial roads) into mainstream (urban highway) induce**
  - Slowdowns in mainstream
    - Downstream bottleneck
    - Traffic „shock wave" upstream back-propagation
  - Queues at on-ramps
    - Traffic can spill over onto urban arterial roads
  - Higher risk of incidents

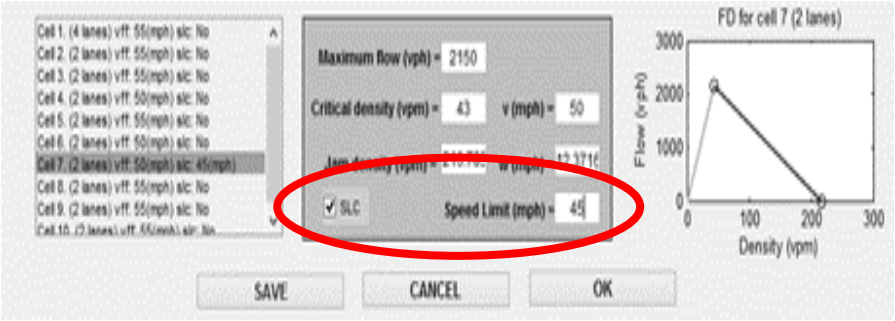


- **Urban highway control approach <u>ramp metering</u>**
  - Special road signals (traffic lights) at on-ramps
  - Ramp metering algorithm determines the "*access rate reduction*„ according to traffic data from sensors
  - Ramp metering control algorithm
    - Local (only one on-ramp)
      - **ALINEA**
      - Demand-Capacity
    - Cooperative
      - Competitive
        - » **SWARM**
        - » Bottleneck
      - Comparative
        - » **HELPER**
        - » LINKED
      - Integrated
        - » *Fuzzy* logic based, MATALINE, etc.

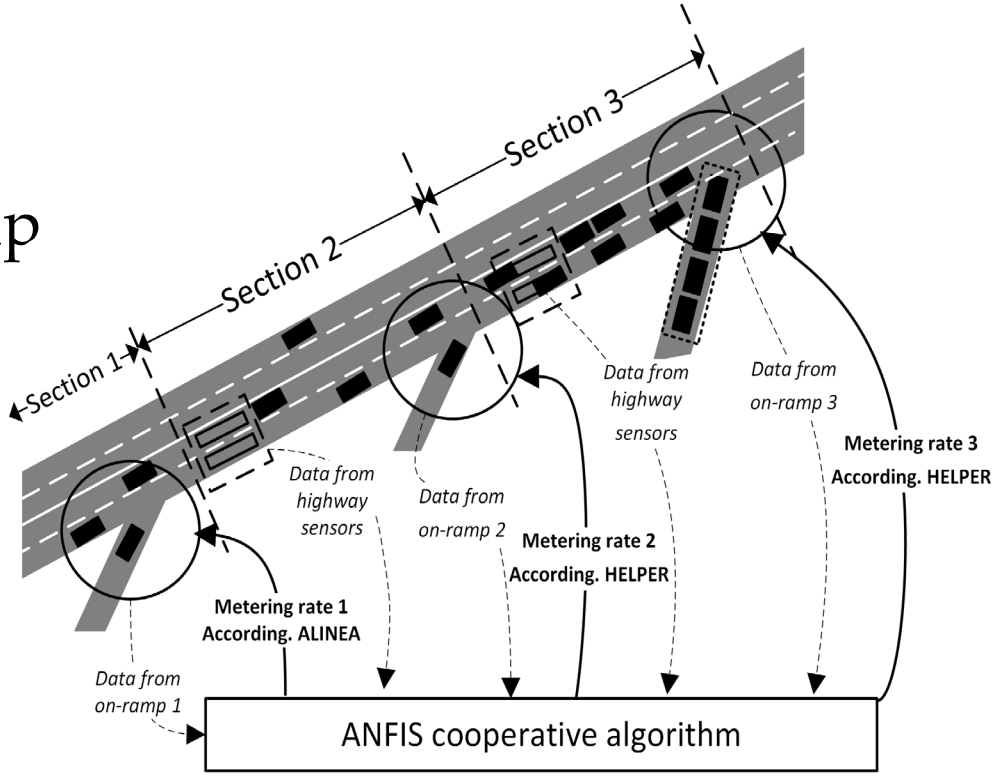


- **Matlab based macroscopic highway traffic simulator for ramp metering evaluation**
  - Based on the Asymmetric Cell Transmission Model
- **Original version contains local ramp metering only**
- **Augmentation for cooperative ramp metering and VSLC**

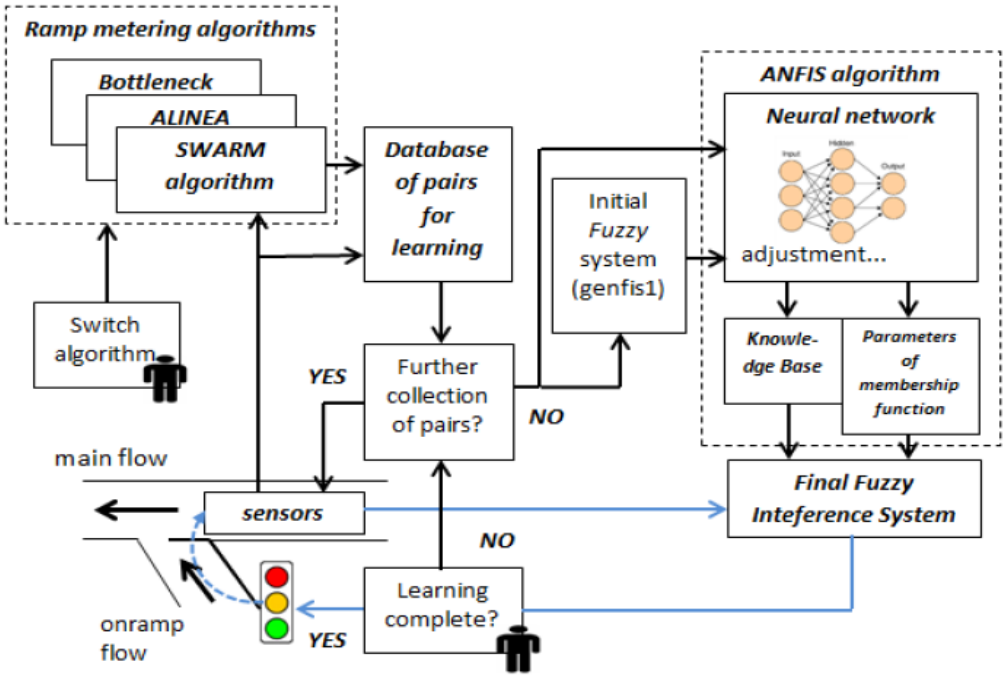


- **Fluctuations in traffic demand is a significant traffic problem on urban highways**
  - One metering strategy cannot respond on every traffic situation
- **Learning framework for intelligent cooperative ramp metering**
  - Summarized knowledge from several different ramp metering strategies into one control structure
  - Cooperation between different ramp metering strategies



- **Application of hybrid intelligent system in ramp metering control**
  - Adaptive neural-fuzzy inference system (ANFIS)
    - Neural Network (ANN) – learning component
    - Fuzzy Inference System (FIS) – uncertainty component
  - ANFIS algorithm learned using several standard ramp metering algorithms
    - HELPER - cooperative knowledge
    - ALINEA – local control
    - SWARM – predictive component



- **Zagreb bypass urban highway, section between nodes Lučko and Jankomir as use case**
- **Congestion created near node *Lučko***
- **Quality measures**
  - Travel time (TT)
  - Delay
  - LoS categorization according to HCM 2010
  - Average on-ramp queue length


| No Control | No Control | ALINEA | SWARM | HELPER | VSLC | HELPER + VSLC | ANFIS |
|---|---|---|---|---|---|---|---|
| LoS | E | D | A | C | E | C | B |
| Average TT [min] | 14.32 | 5.61 | 3.99 | 4.41 | 11.01 | 4.63 | 6.42 |
| Average Delay [vh] | 5.42 | 20.53 | 24.18 | 10.94 | 4.51 | 7.62 | 6.75 |
| Average Queue [v] | 0 | 79 | 89 | 58 | 13 | 57 | 38 |

# Conclusion & Future work

- **System based on computer vision methods is capable to**
  - Detect and track vehicles
  - Provide traffic flow measure
  - Easily be integrated in existing road traffic measurement systems
  - Obtain traffic data from multiple lanes using only one camera
- **System is tested on video footage from Croatian highways**
  - Obtained accuracy of the system is over 95%
- **Intelligent cooperative ramp metering algorithm realized through an ANFIS control structure**
  - Produce balanced ratio between TT and Delay, second best LoS
- **Cooperation between ramp metering and VSLC**
  - Improved results compared to the standalone VSLC and HELPER application
- **Future work**
  - Vehicle type classification from road traffic video footage
  - Augmentation of ANFIS learning with on-line learning

# Acknowledgement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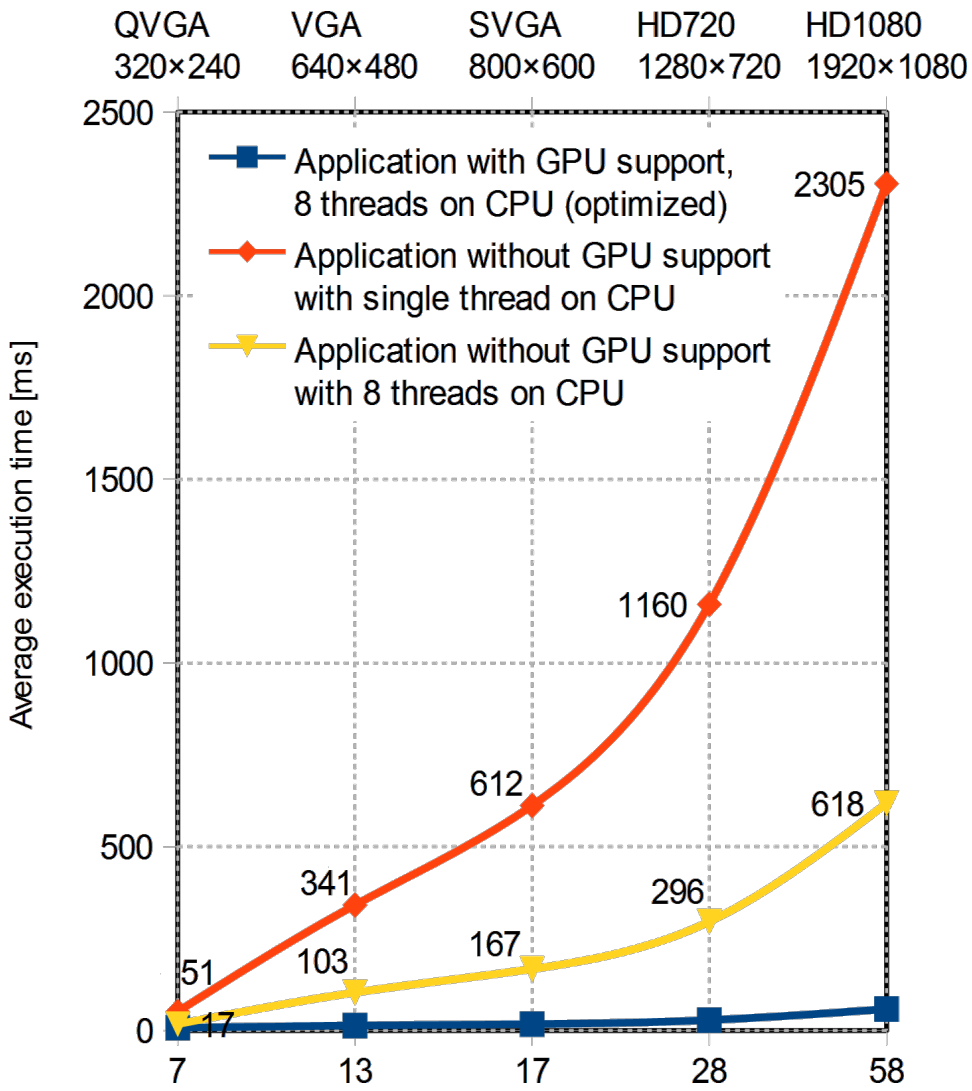
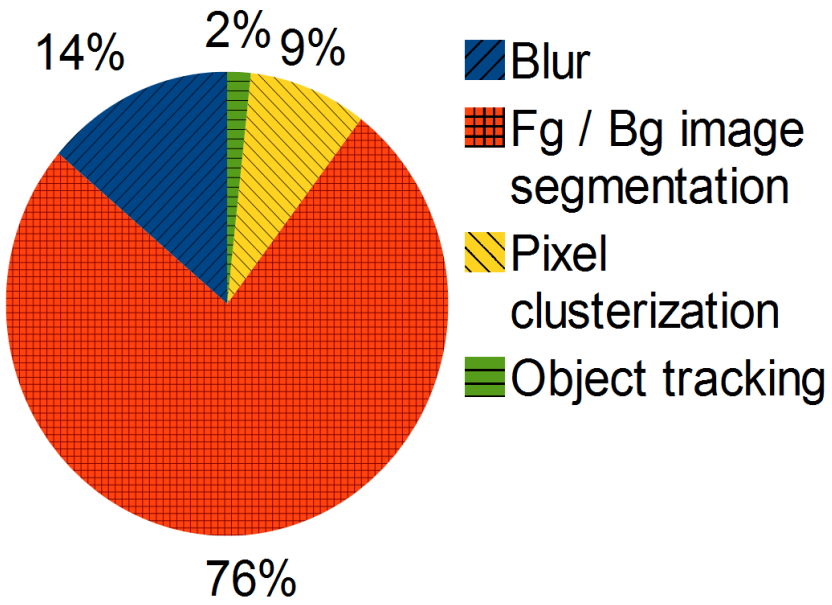
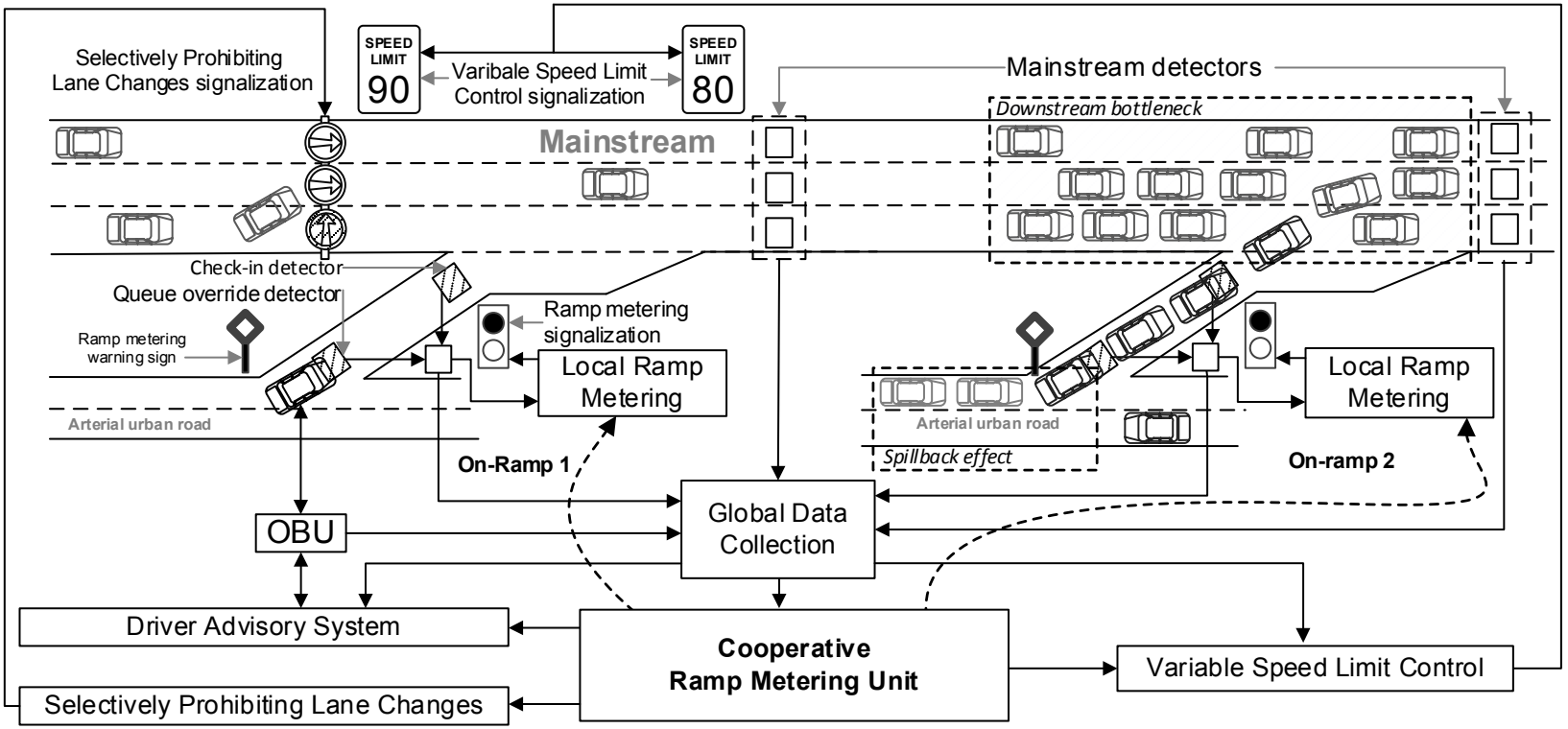
## Overall execution time




## Execution time distribution per image processing component



- **Standalone urban highway control strategies not efficient enough to resolve congestions**
- **Cooperation between ramp metering and**
  - VSLC, Selectively prohibiting lane changes, Vehicle On-Board-Unit (OBU) and Driver information systems



- **Cooperation between HELPER and VSLC produces smaller Delay compared to standalone HELPER algorithm**
- **ANFIS produces lowest Delay values compared to other ramp metering algorithms**