Traffic Control and Management with Vehicle Automation and Connectivity for the 21st Century

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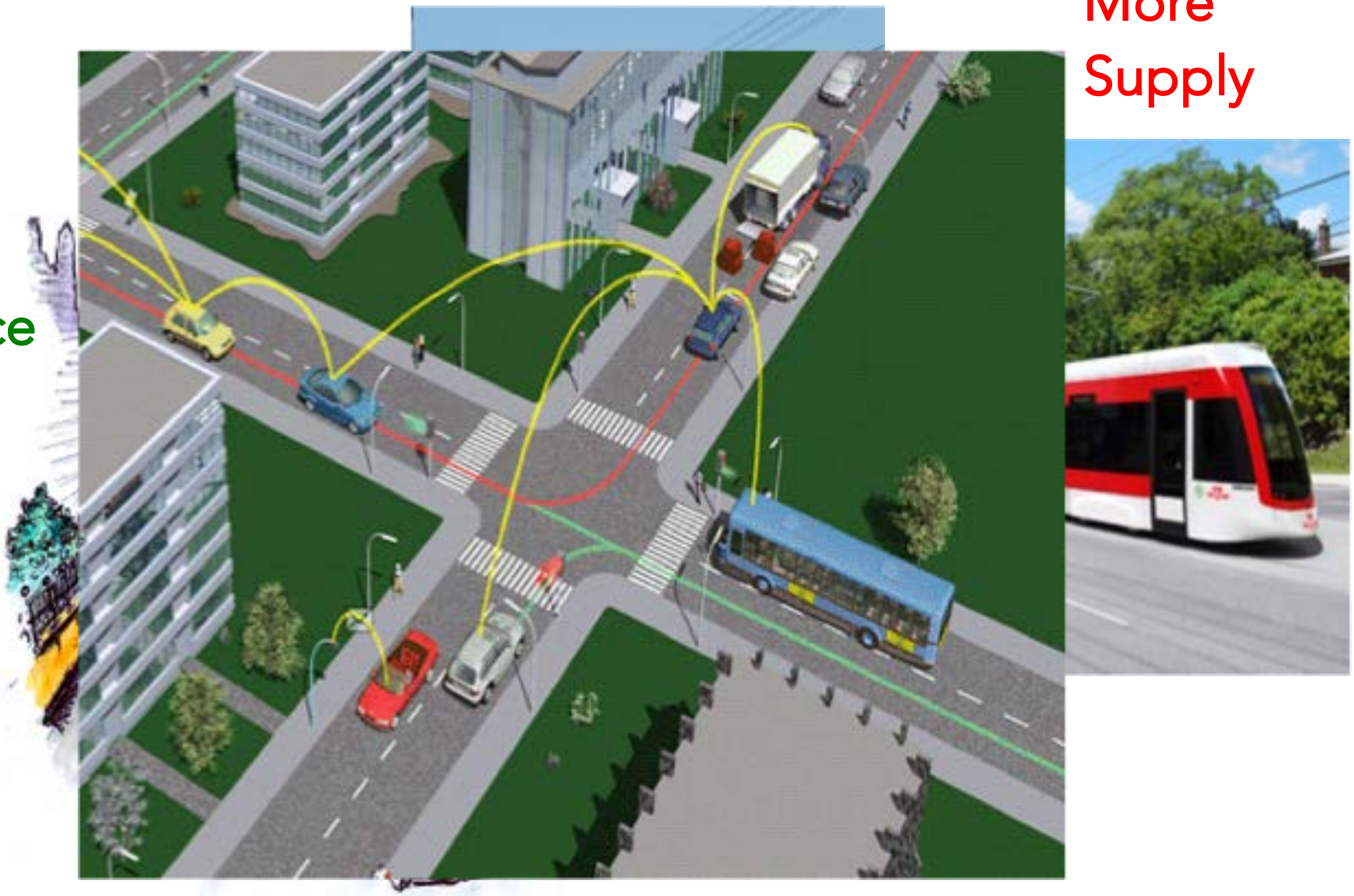
Congestion Solutions

More Supply

Intelligence

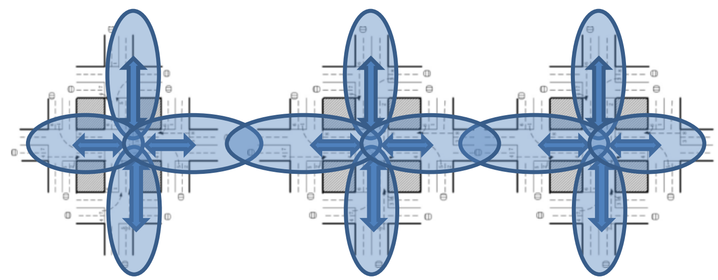


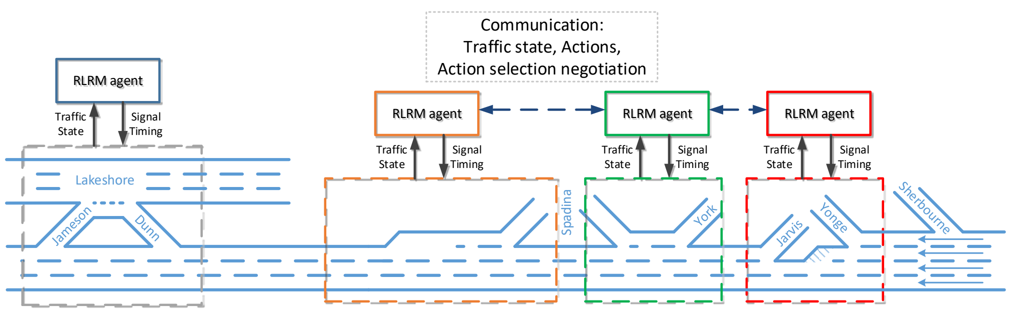
Less Demand

Our Hierarchical Traffic Control Approach

- Networkwide:
  - Demand Management Focus
  3. Dynamic Trip Pricing

- Nodes and Junctions:
  1. Adaptive Traffic Signals on Arterials
  2. Freeway Control





Part I

Deep Learning for Adaptive Traffic Signal Control

Soheil Alizadeh and Baher Abdulhai

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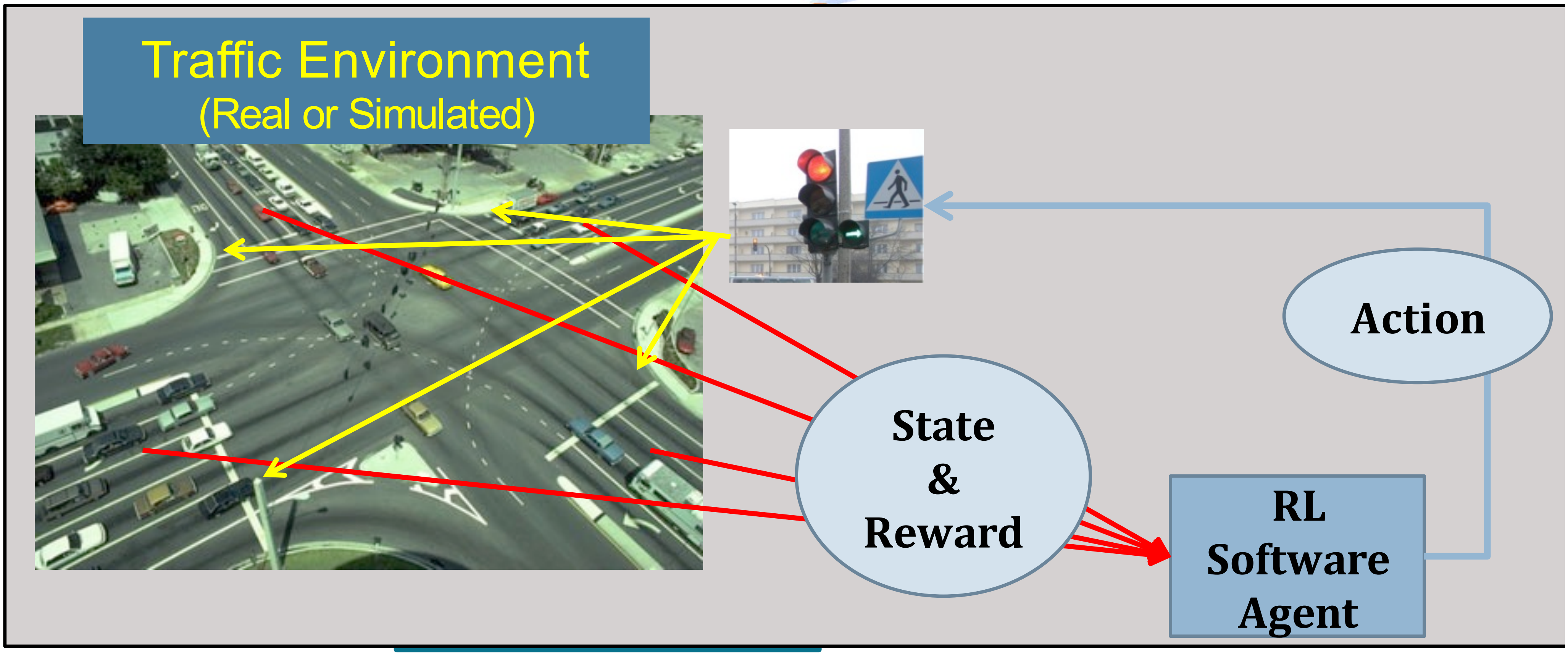
Can Traffic Lights Learn?

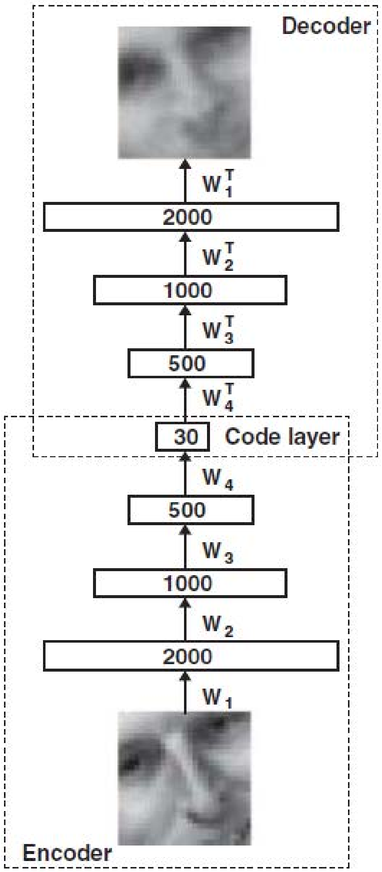
AI: Reinforcement Learning



New Opportunities:

Emergence of New Technologies and Deep Reinforcement Learning

- Emergence of Deep Neural Networks
- Emergence of Deep Learning



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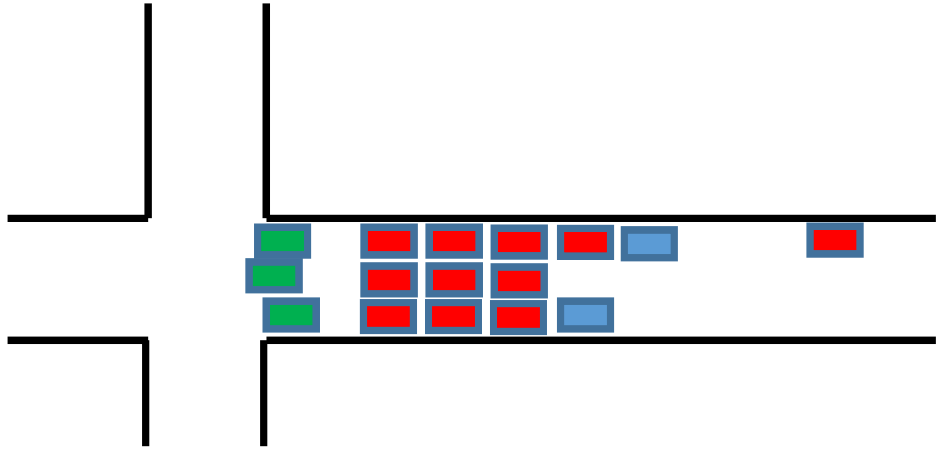
- Evolution of sensor technologies

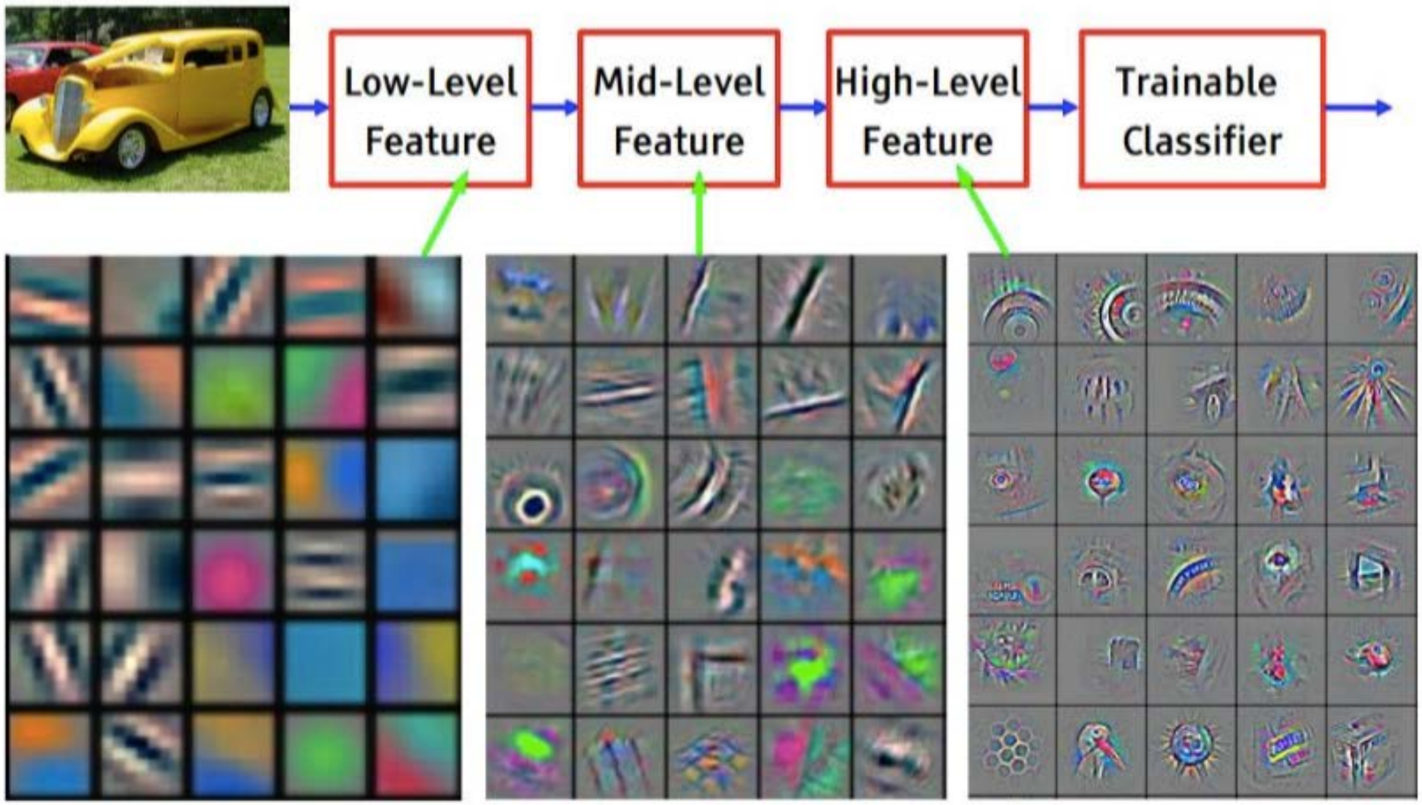
New Opportunities:

Emergence of New Technologies and Deep Reinforcement Learning

- Emergence of Deep Neural Networks
- Emergence of Deep Learning
- Evolution of sensor technologies
- Rich Microdata and Deep Learning:
  - No need for defining or measuring queue
  - No need for data pre-processing
  - Straight from rich sensory data to control



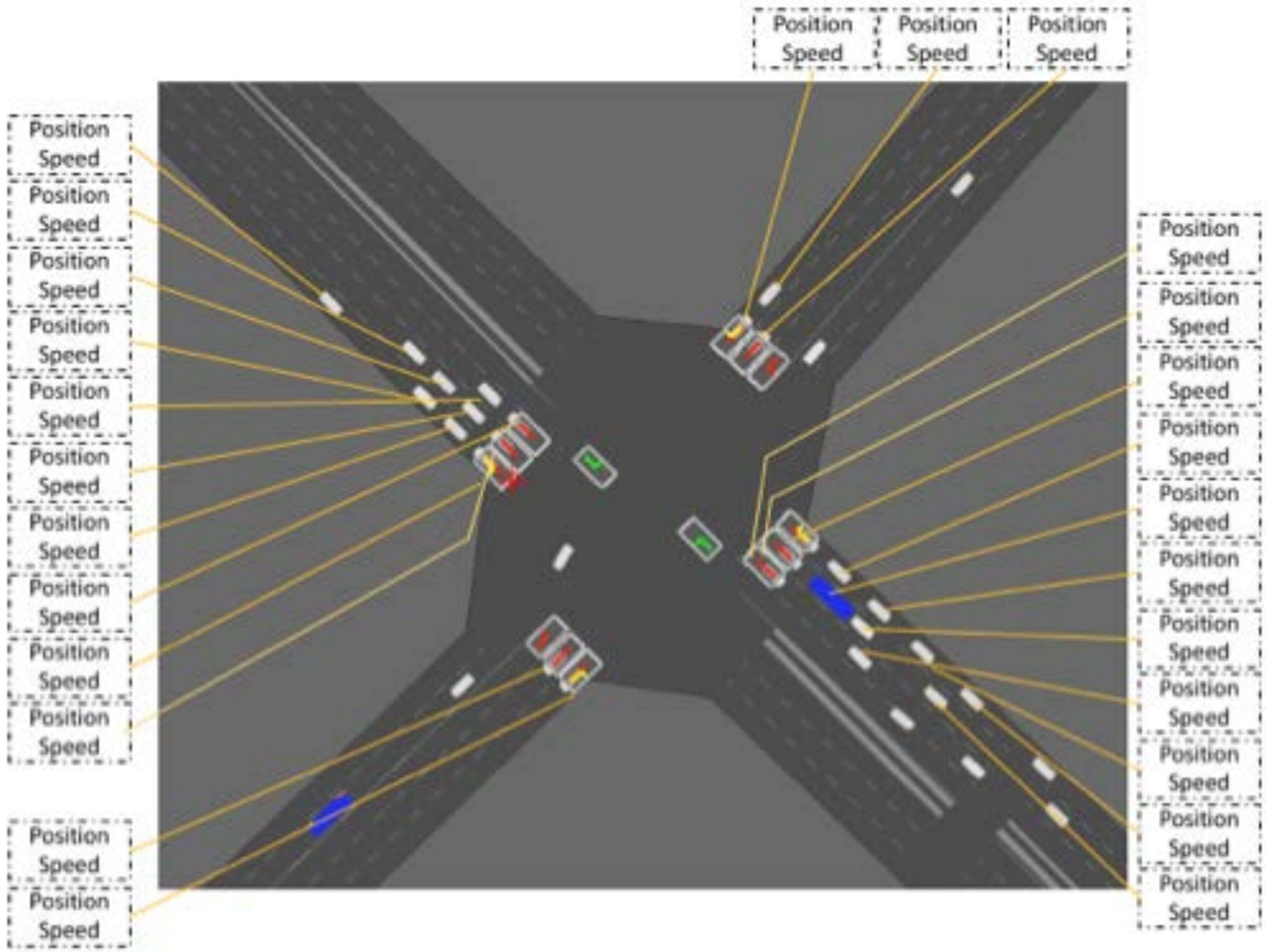
Why Deep Convolutional Neural Networks?



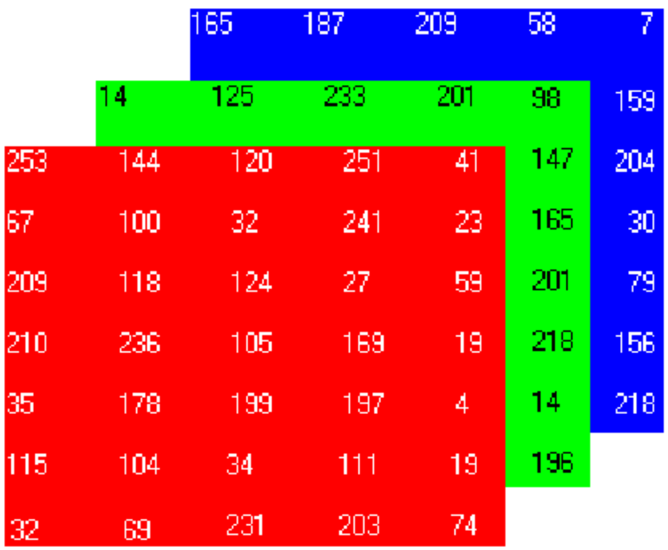
Feature visualization of convolutional net trained on ImageNet from [Zeiler & Fergus 2013]

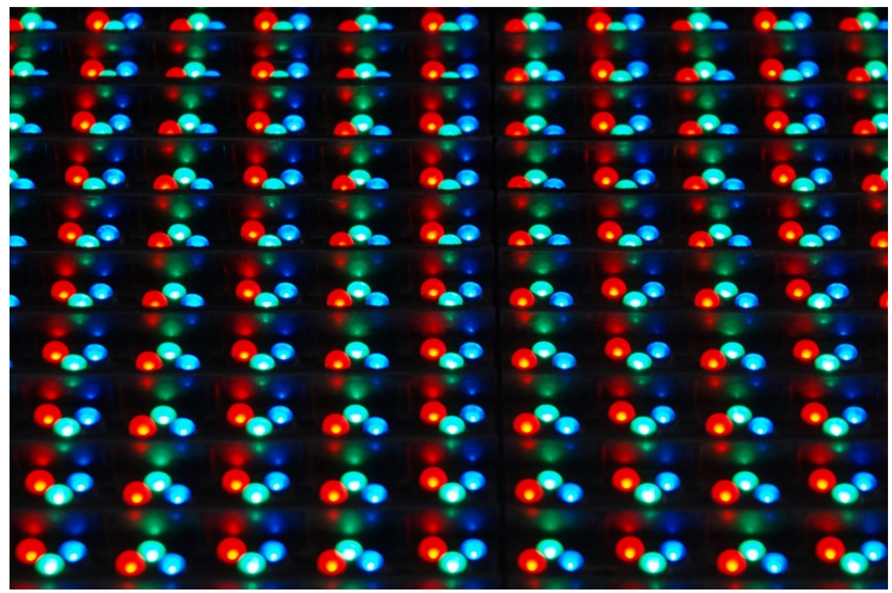
Why Deep Learning?

Intelligent Traffic Signal with VACs and DRL

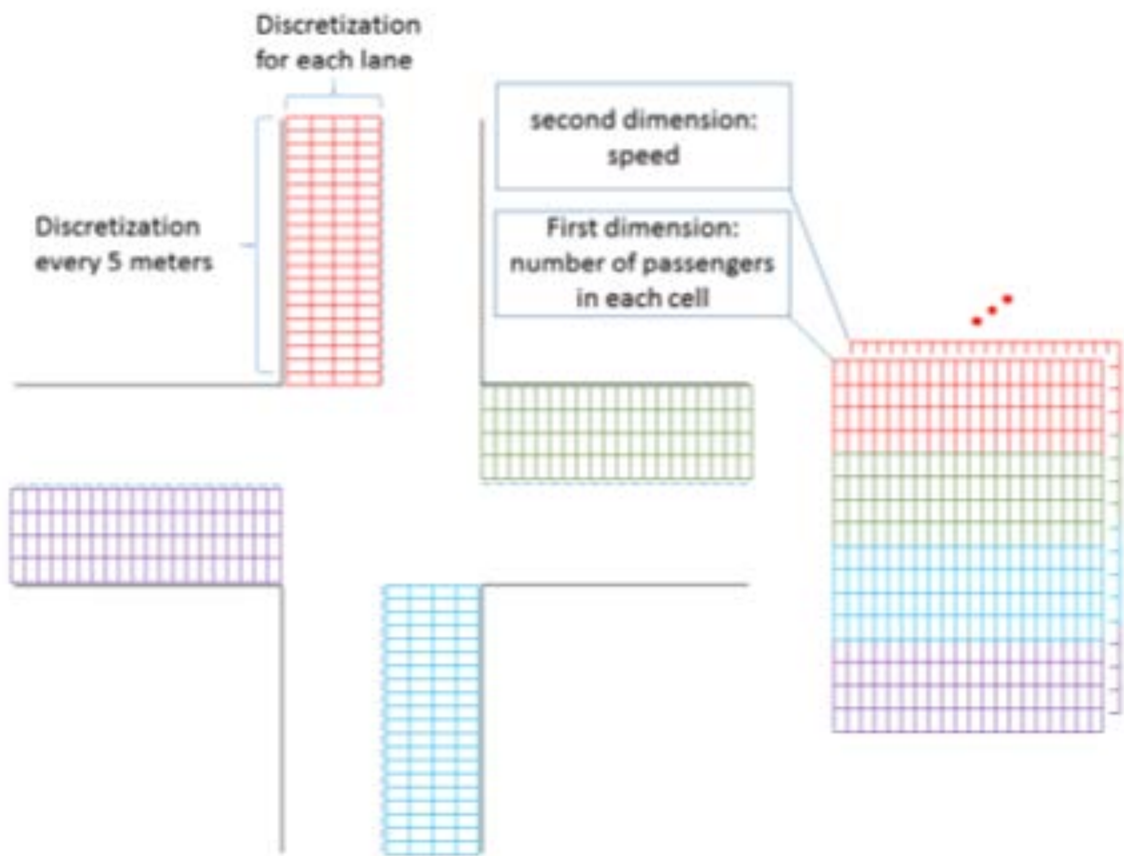


Like Image Inputs to a Deep Neural Network



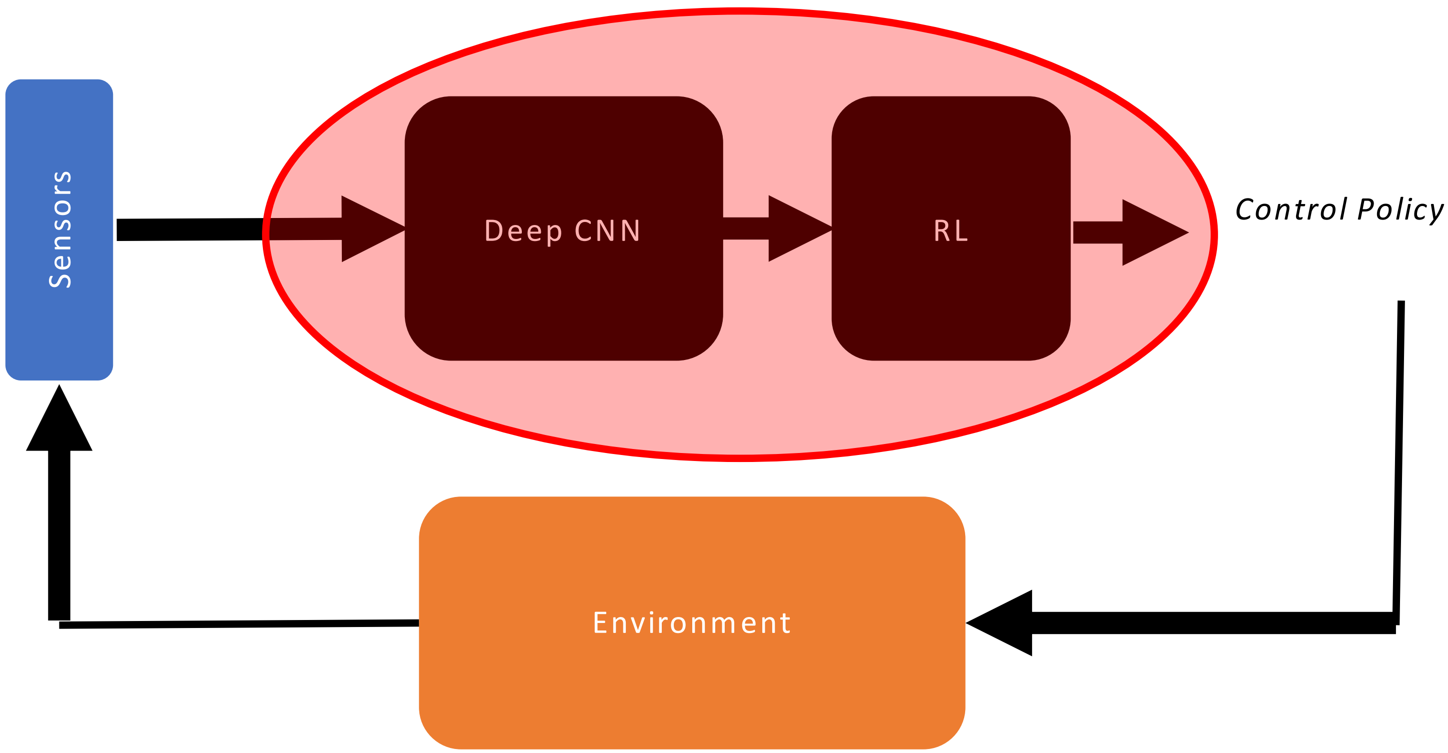


Like VACs Inputs to a DRL Traffic Signal Controller



The Resulting System

MiND: Multimodal intelligent Deep ATSC



Performance in Simulation

[sec] / (vs. Actuated)	Actuated	Cont. RL	MiND					
			100%	80%	60%	40%	20%	0%
Intersection Delay	72.0	56.6 (21.39%)	54.3 (24.62%)	53.8 (25.34%)	55.0 (23.59%)	56.4 (21.62%)	65.0 (9.78%)	263.5 (-266%)
Network Travel Time	153.2	137.2 (10.44%)	135.2 (11.42%)	134.6 (12.14%)	135.6 (11.54%)	137.7 (10.15%)	147.2 (3.97%)	1182.0 (-263.7%)

	MIND (40% penetration)			
Precision	5 m		10 m	
Noise	0%	10%	0%	10%
Intersection Delay	56.4	58.1 (-3.01%)	57.0 (-0.95%)	57.1 (-1.24%)
Network Travel Time	137.7	139.0 (-0.97%)	137.5 (0.15%)	137.5 (0.15%)

Part II

Freeway Management with Vehicle Automation and Communication Systems (VACS)

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Motivation

- VACS evolved with focus on the individual vehicle
  - convenience & safety

- May or may not help traffic
- Why?
- Opportunities and challenges
- What is needed?
  1. Modelling VACS (Quantifying Transformation)
  2. Control with VACS (Enabling Positive Transformation)

Traffic Management (TM) Components with VACS

1. Adaptive Cruise Control (ACC).

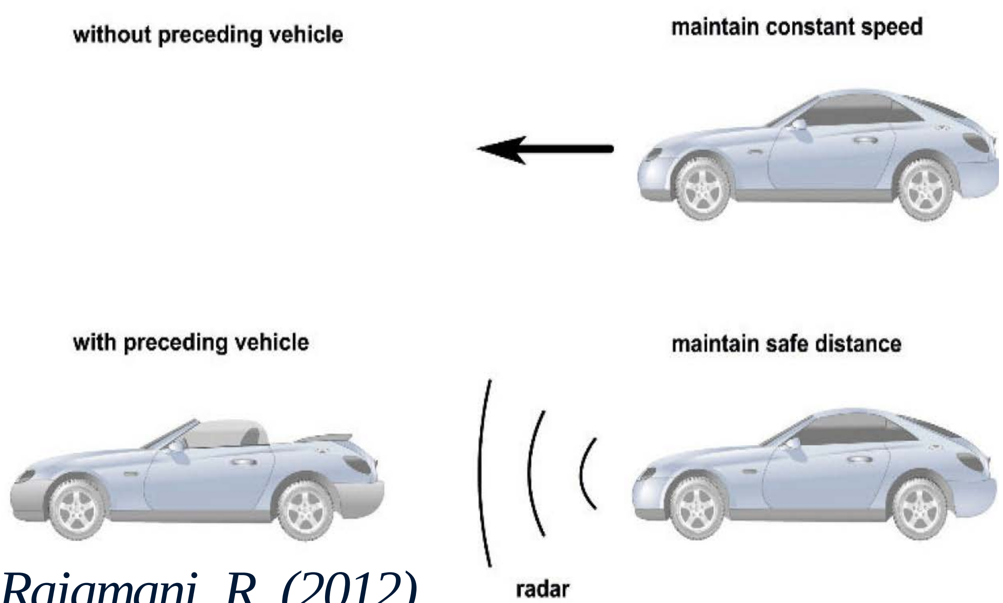
2. Cooperative Adaptive Cruise Control (CACC).

3. Dynamic Speed Adaptation (DSA).

4. Cooperative merging and lane changing (CM & LC)

ACC

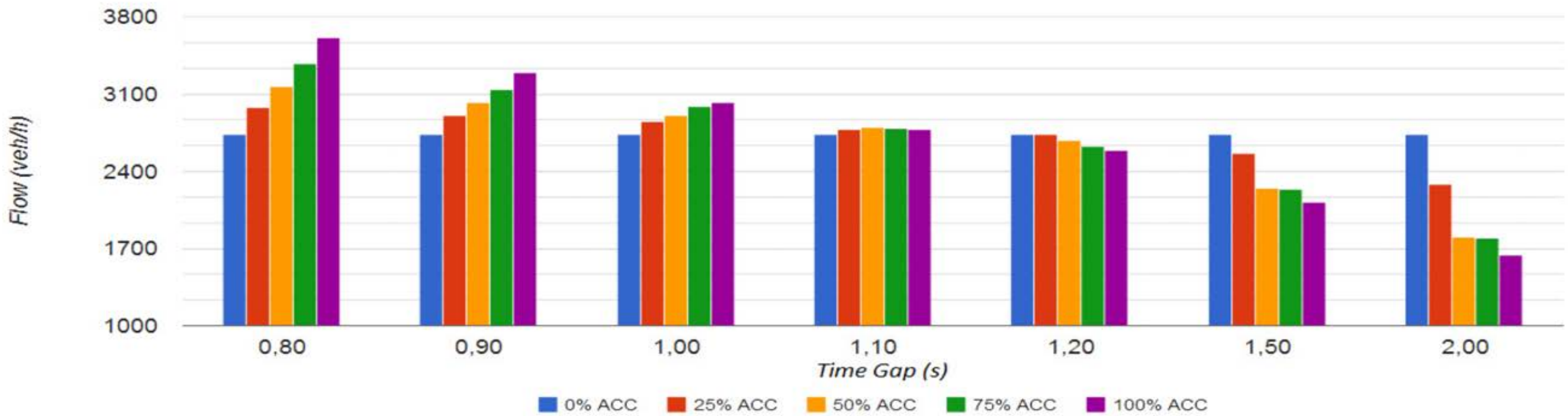
- Adaptive Cruise Control (ACC)
  - Maximum Speed + Time gap.
  - Gap/Headway sensors.
  - Speed control mode.
  - Headway/Space control mode.



Rajamani, R. (2012).

ACC Challenges & Opportunities

- **ACC**: Efficiency depends on system parameters selected.

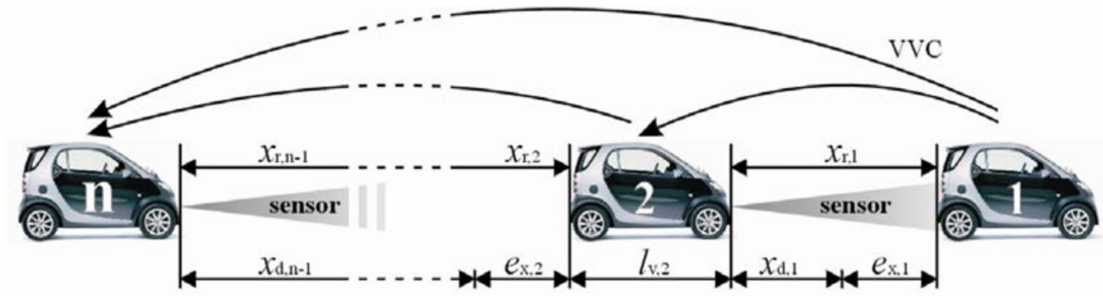


Ntousakis et al., 2015

- **Challenges**:
  - 2 sec default time-gap (vs. 1.2 sec for manual vehicles).
  - Capacity reduction.
- **Opportunities:**
  - Capacity increase for time-gaps <1.2 sec

CACC Challenges & Opportunities

- **Cooperative ACC (CACC)**
  - Communication among vehicles
  - Follow the platoon
  - Smaller headway
    - e.g. 0.5 sec

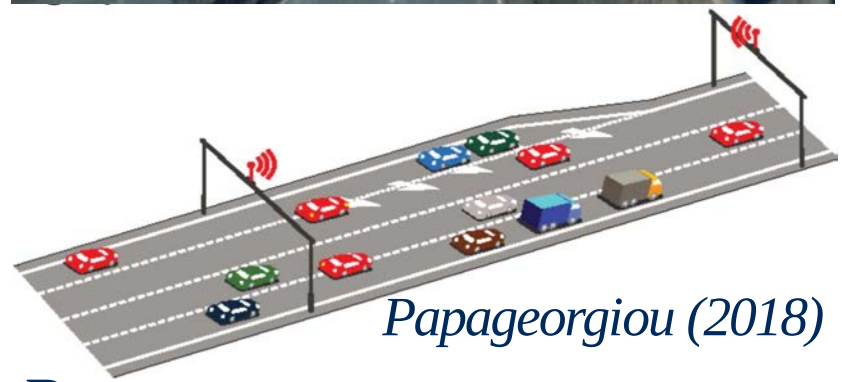


Van Arem et al., 2007

- **Challenges**
  - Needs high market penetration rates.
  - Very small time gaps: merging problems.
  - Need for modified infrastructure: dedicated CACC lanes.
  - Underutilized dedicated lanes problem.
- **Opportunities**
  - Very small time-gaps: Capacity increase

DSA Challenges & Opportunities

- **Dynamic Speed Adaptation**
  - Variable Speed Limits (VSLs)
  - Regulate mainstream flow to avoid capacity drop.
  - With VACS: automatic compliance.



Papageorgiou (2018)

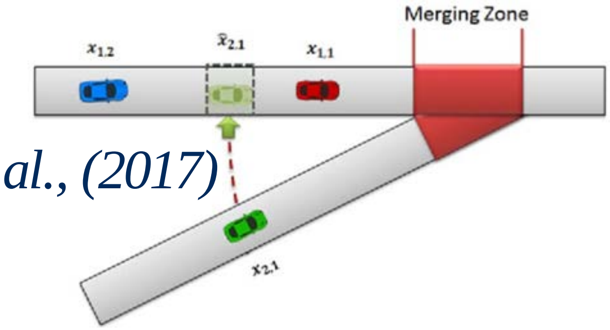
- **Challenges**
  - No automation: VSLs Compliance Rates.

- **Opportunities**
  - Imposing VSLs – more strict AV compliance.

CMLC Challenges & Opportunities

Cooperative merging and lane changing

- Cooperative Merging (CM): Assist driver to merge
- Cooperative lane changing: Equalizing densities across lanes



Rios-Torres et al., (2017)

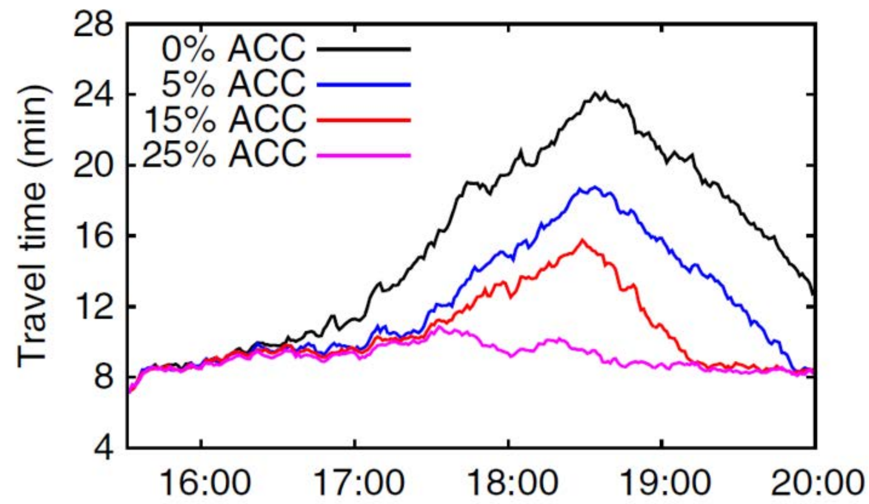
Roncoli et al., (2016)

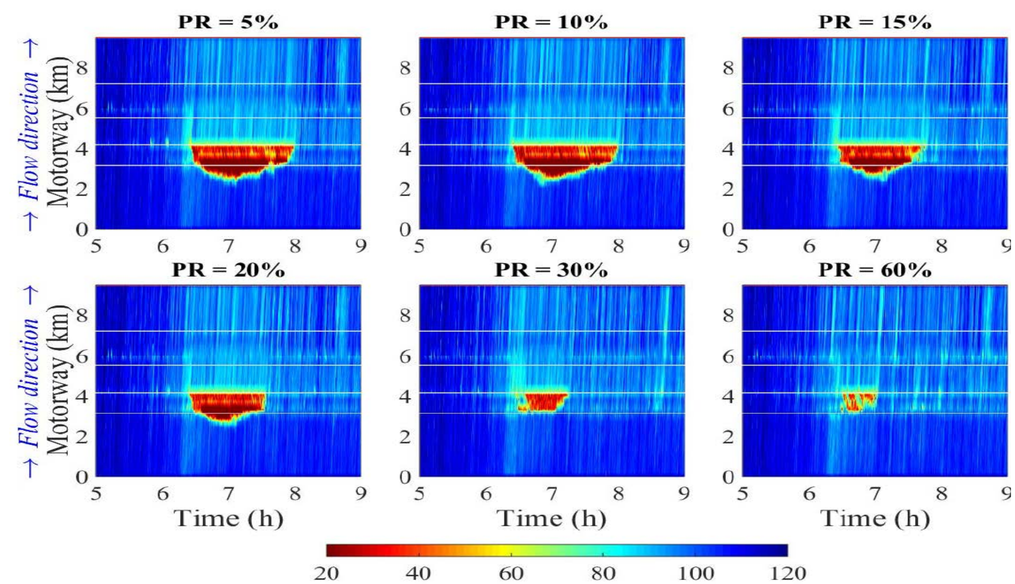
- **Challenges**
  - Capacity reduction if more conservative merging or lane-changing systems.
- **Opportunities**
  - Capacity Increase: Merging sequence algorithms to minimize unnecessary decelerations
  - Equalize densities/flows across lanes.

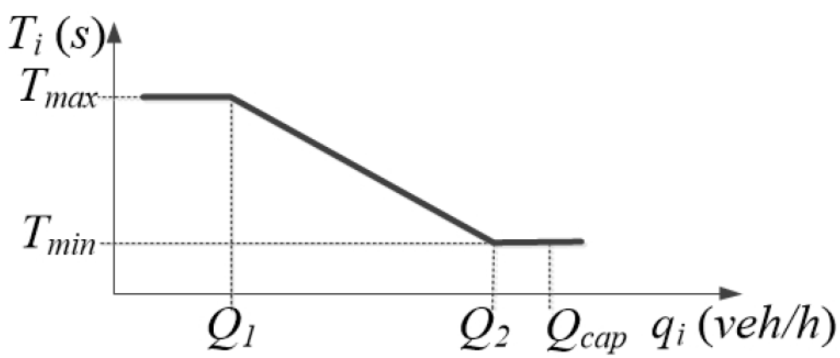
VACS for Traffic Control

Promising Early Results in Literature

- ACC Exploitation
  - *Kesting et al., 2008.* Free traffic- Upstream jam front- Congested traffic- Downstream jam front- Bottleneck sections
  - *Spiliopoulou et al., 2017* (adapt time-gaps to traffic conditions)



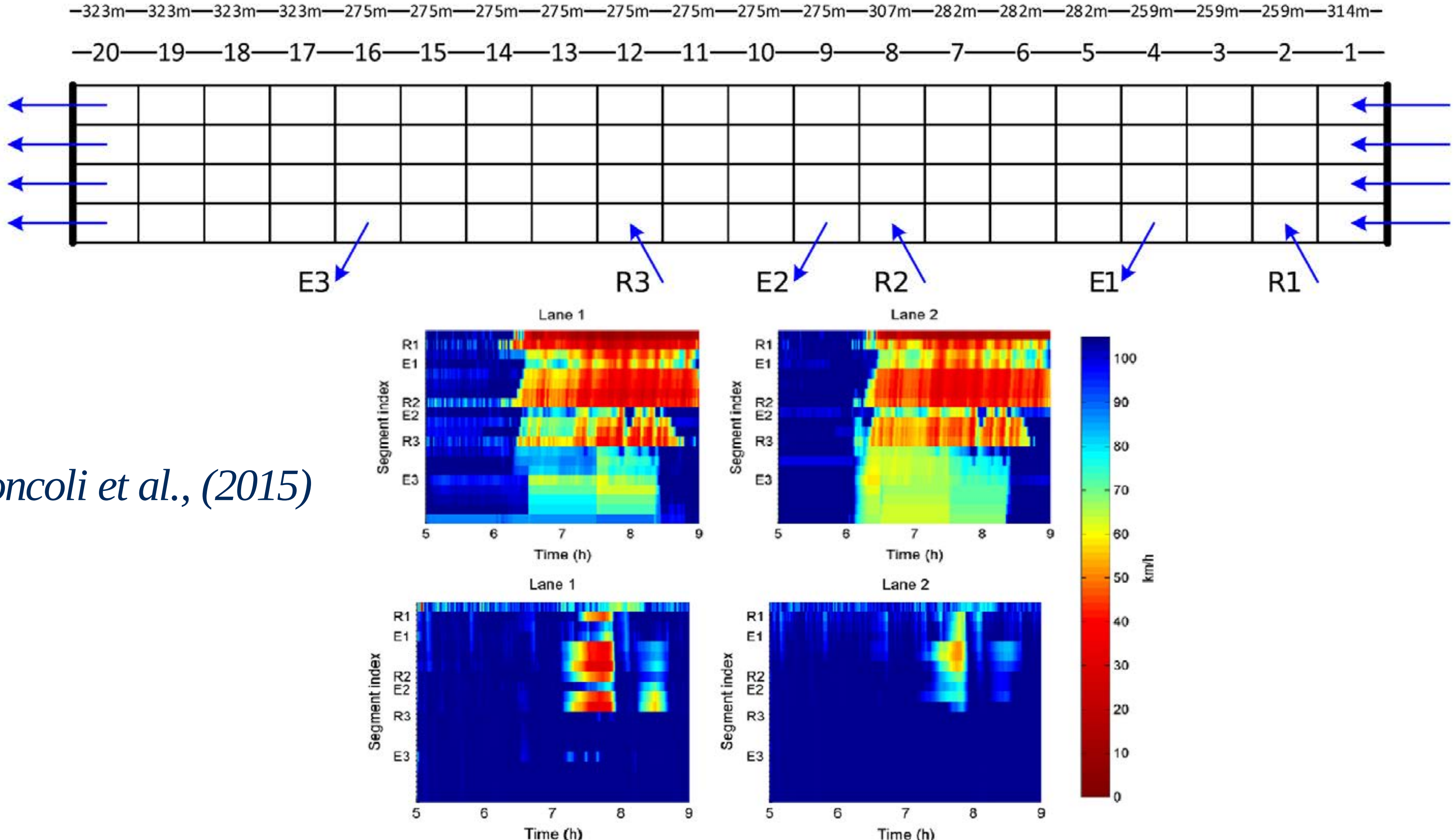




VACS for Traffic Control

Promising Early Results in Literature

- Ramp Metering (RM) + VSLs + Lane Change



Roncoli et al., (2015)

iCity - CATTS – In progress

Phase 1

Quantifying Transformation

- Project 1.5:
  - Dynamic transportation system modelling of the GTHA in the context of automation.

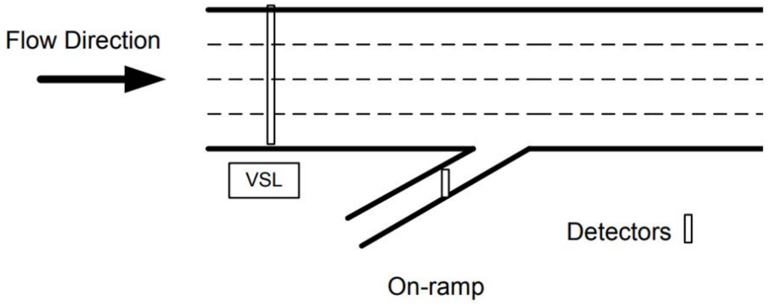
Phase 2

Enabling Positive Transformation

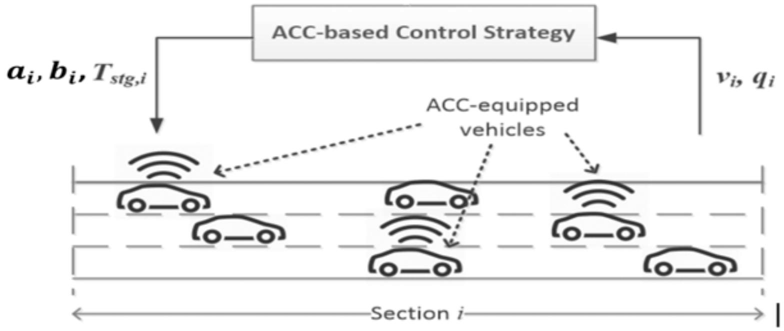
- Project 2.2:
  - Traffic control and management of transportation systems under automation.

Enabling Positive Transformation on the Gardiner and QEW

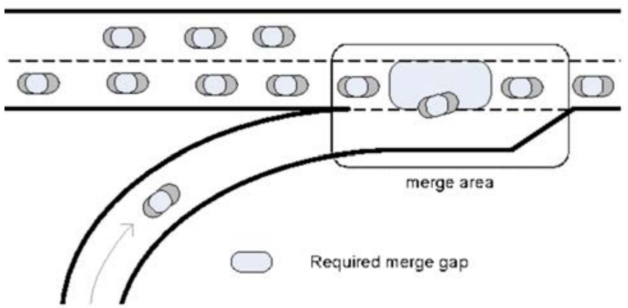
- Ramp Metering with Variable Speed Limits (Point-level- Cooperative)



- Optimization of ACC systems parameters
  - Time-Gap, other parameters (acceleration, deceleration)

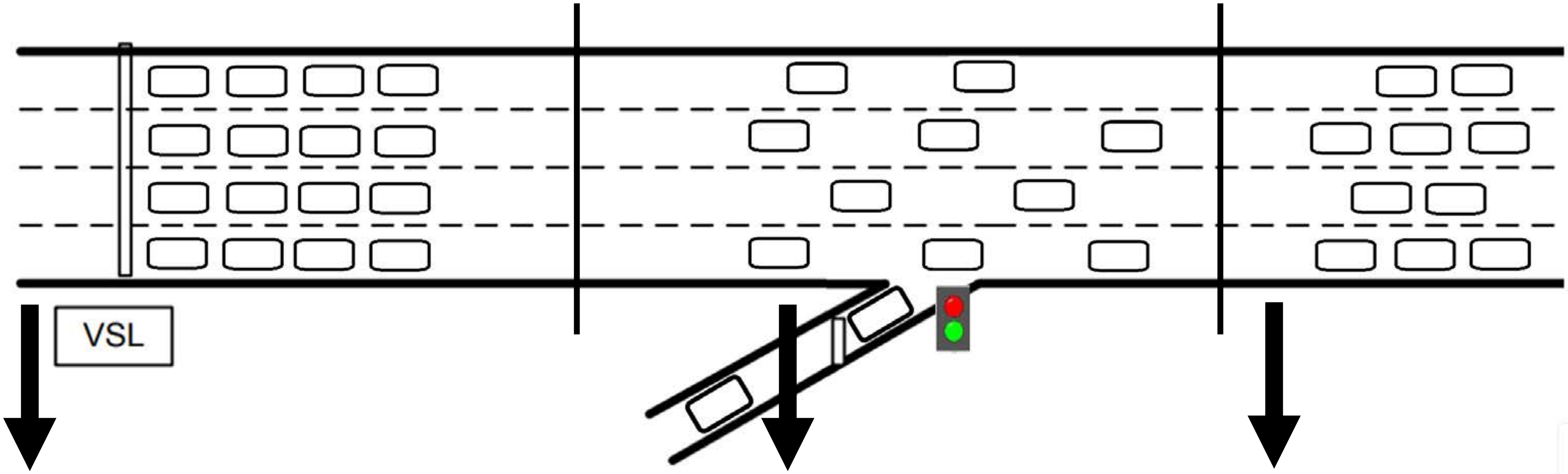


- Automated merging



Enabling Positive Transformation

Desired Collective Behaviour



Approaching congestion:

- Reduce speed via VSLs
- Reduce deceleration
- Minimum headways

Bottleneck (Merging vehicles):

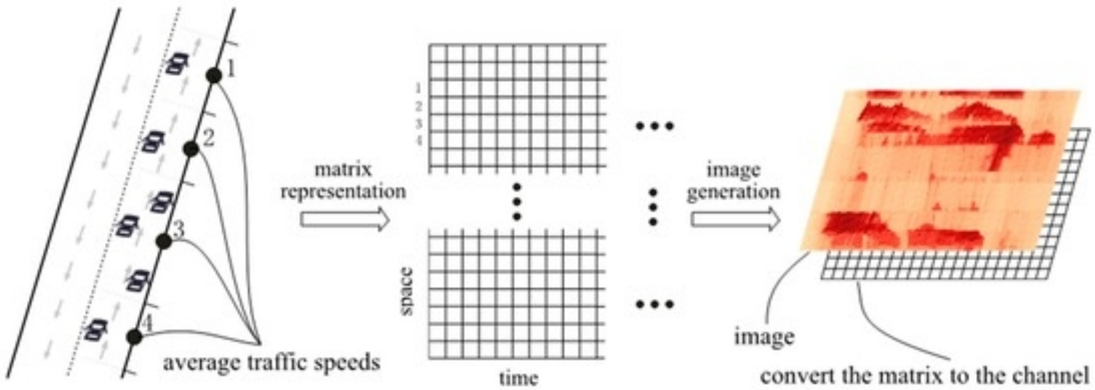
- Increase headways

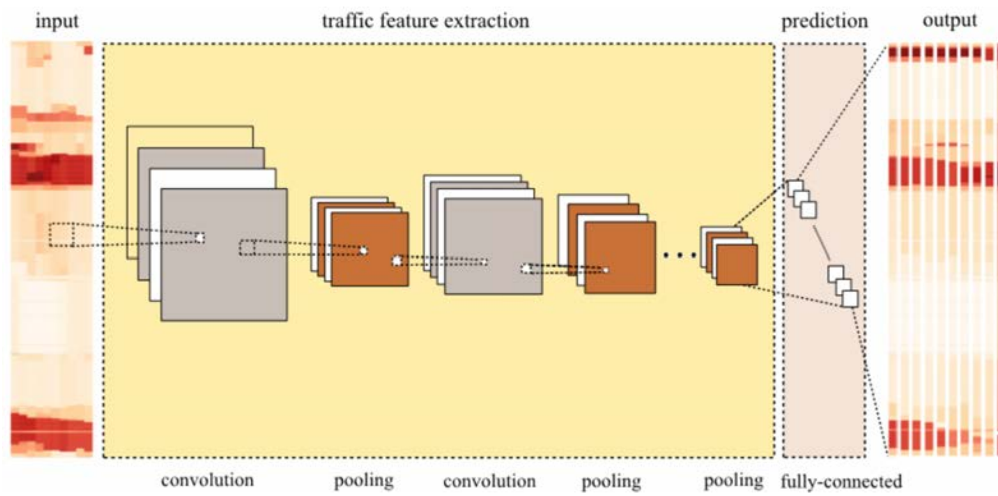
Bottleneck downstream:

- Minimum headways
- Increase acceleration at head of congestion

Methodology

- Exploring deep learning.





Part III

Trip Reservation Integrated with Trip-Level Congestion Pricing (TRiP):

The Context of Pervasive Connectivity, Driving Automation and MaaS

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Motivation

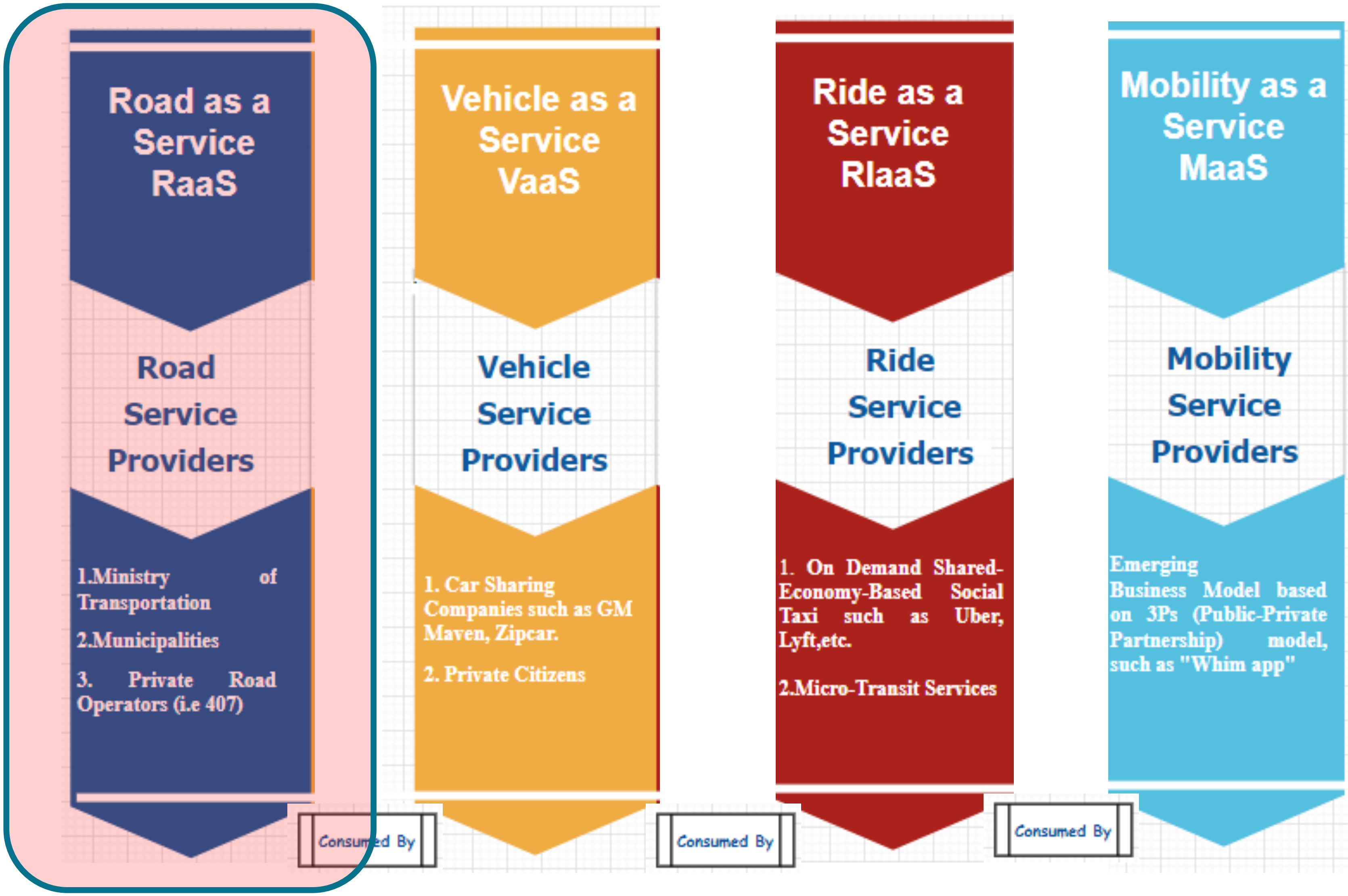
2. The pervasive connectivity will make the implementation of the new strategies of demand management possible

1. A potential sharp increase in vehicles kilometre travelled (VKT)

Potential Impacts of Disruptive Mobility

- Increase in Vehicle Kilometers Traveled (VKT)
  - Roaming: The current hired rate of ride sourcing companies is only 50%.
  - Zero Occupant Vehicles (ZOV) are coming with autonomous vehicles.
  - Latent demand (more people will have an access to cars)
  - Mode shift to the car (potentially away from transit)

Enabling Positive Transformation:
From RaaS to MaaS and XaaS

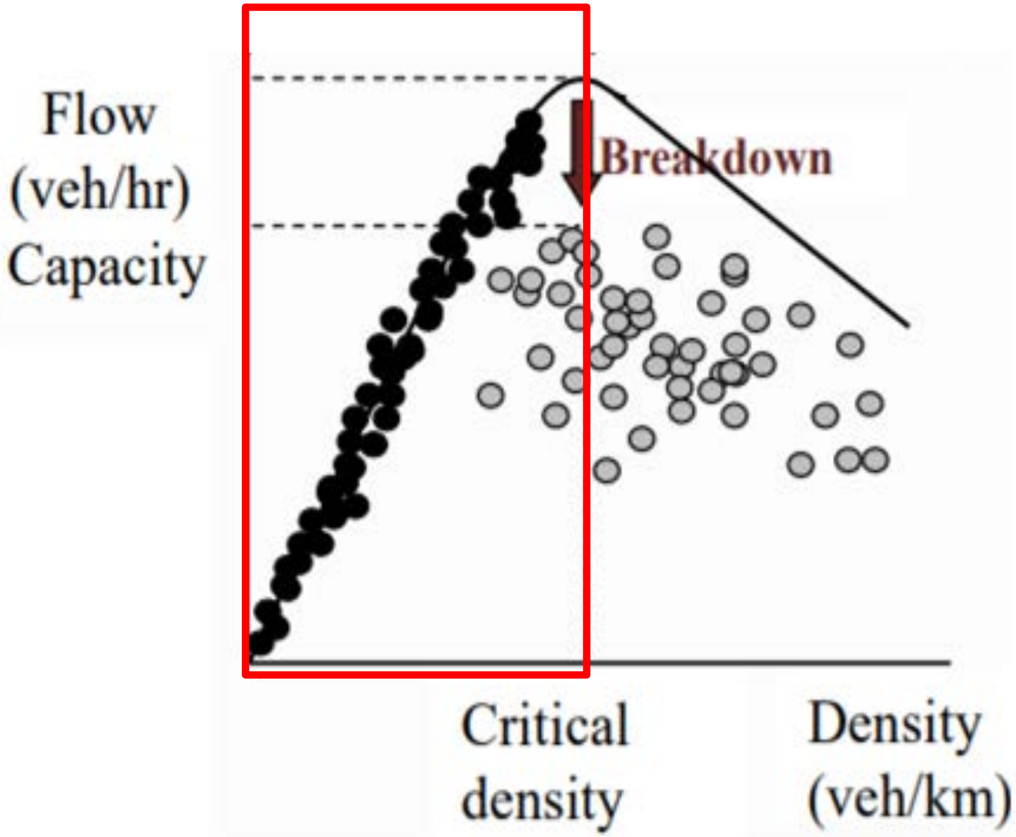


Trip Reservation integrated with trip-level congestion Pricing (TRiP)

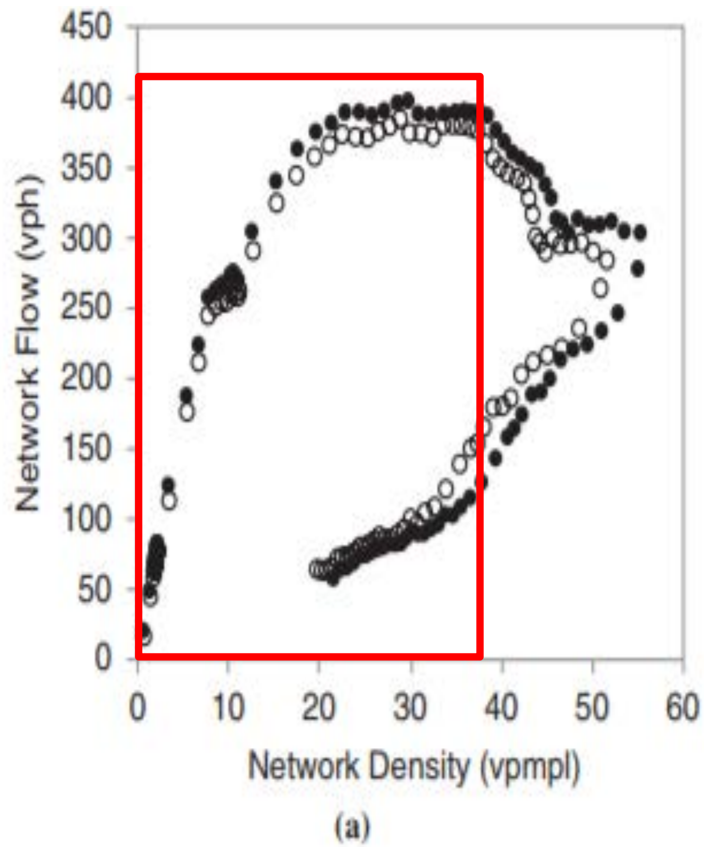
- TRiP is a network-wide traffic control and management mechanism in the era of Pervasive Connectivity, Driving Automation and MaaS

- TRiP aims to dynamically distribute travel demand over *space(path choice)*, *time* (departure time choice) and *mode (sharing ride choice)* to prevent demand for auto travel from exceeding the capacity.

Protect Capacity



Link Level



Network Level

TRiP as a Traffic Control Strategy

Intersection	**Traffic Signal**
Freeway	**Ramp Metering**
Network	**TRiP Metering**

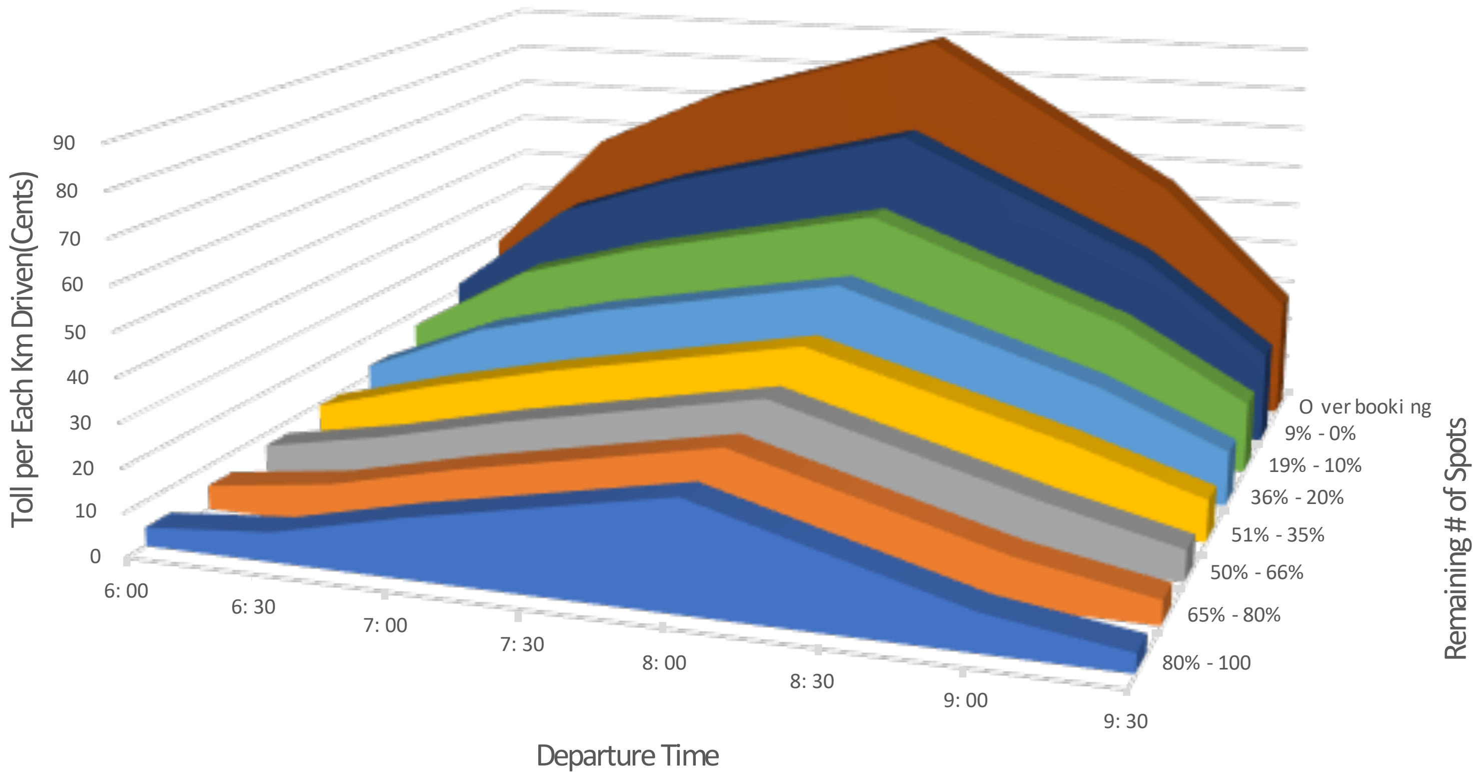
TRiP as Congestion Pricing Methodology
RaaS

- **Facility Based (Tolled Expressway)**
- **Zone (Cordon) Based** (Stockholm)
- **Zone (Area) Based (London)**
- **Network wide (TRiP)**

Potential Pricing Structure

(1) Location and time-dependent dynamic trip pricing

(2) Price-escalating reservation system



Research Questions

Pricing / Capacity	Disaggregate Level (Link Price) Spatiotemporal	Aggregate Level (Zone Price) Temporal
Disaggregate Level (Link Level Capacity)	Reserve **time** slot and **path** / Spatiotemporal demand pacing to protect capacity of **all** links.	Reserve a **time** slot / Temporal demand pacing to protect capacity of the **busy** links.
Aggregate Level (Network Capacity)	Reserve **time** slot and **path** / Spatiotemporal demand pacing to protect the **network** capacity.	Reserve a **time** **slot** / Temporal demand pacing to protect the **network** capacity.

Q&A

Thank you

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