Quantifying the Impact of Driving Automation on Ontario's Freeways

Lina Elmorshedy, PhD Candidate

Dr. Toka S. Mostafa,
Dr. Islam Taha, and
Prof. Baher Abdulhai

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

Motivation

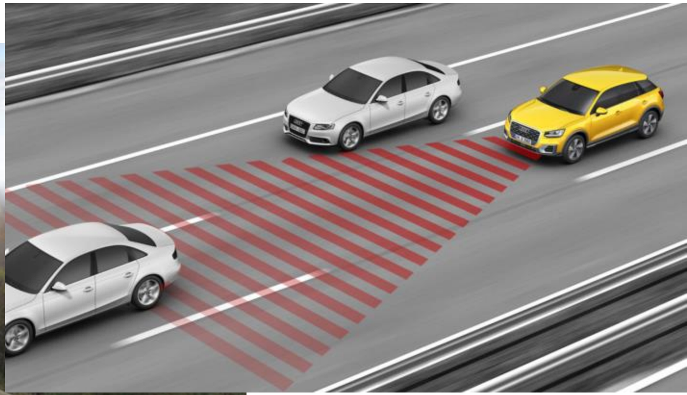
- VACS are focused on the individual vehicle (convenience & safety)
- Maybe myopic to the overall traffic system.
- Why?
- Opportunities and challenges
- What is needed?
  1. Modelling VACS
  2. Control with VACS

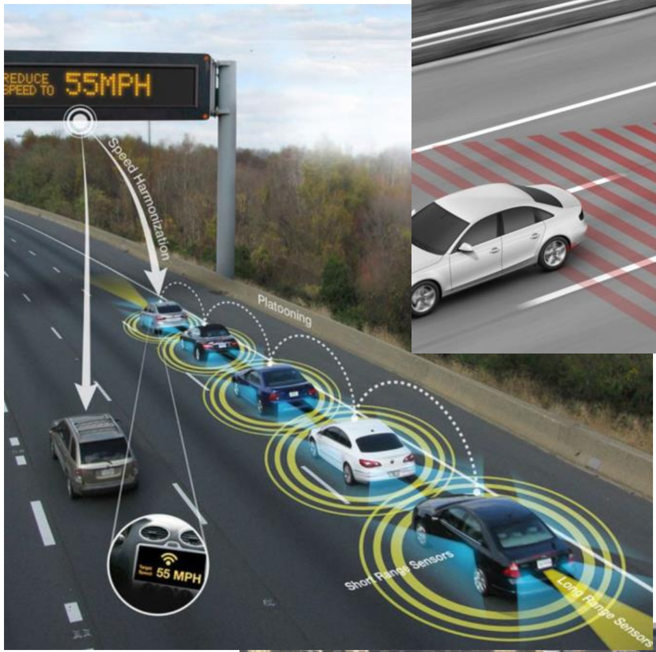
Traffic Management (TM) Components with VACS

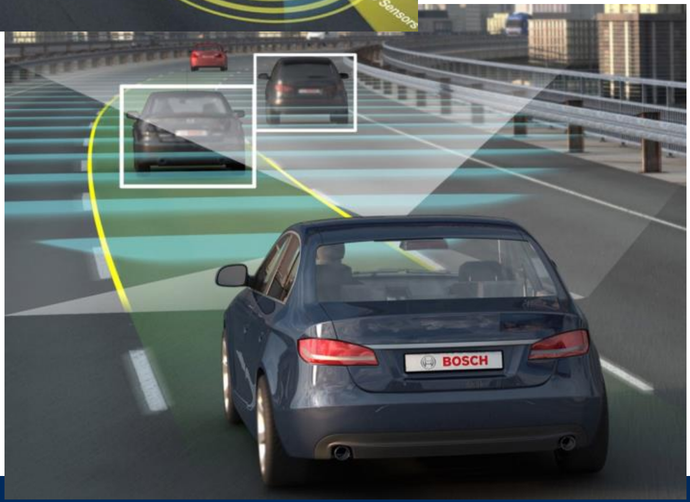
1. Adaptive Cruise Control (ACC).

2. Cooperative Adaptive Cruise Control (CACC).

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







Project Scope and Objectives

1. What are the effects of automation on the current transportation network (quantification)?
    - ACC and CACC
    - Automated lane change

2. Can we exploit these technologies to improve the network performance and increase capacity (exploitation)
    - Exploitation of ACC and V2I technologies to introduce a dynamic traffic-state-specific control system
    - Using Cooperative lane change and merging, equipped with V2I technologies, to improve network performance under automation

Modeling Automated Cruise Control in AIMSUN

Lina Elmorshedy

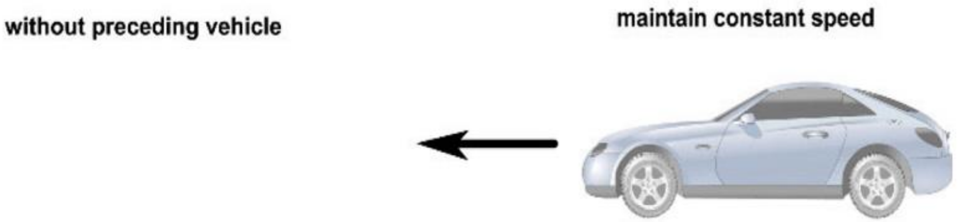
PhD Candidate

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

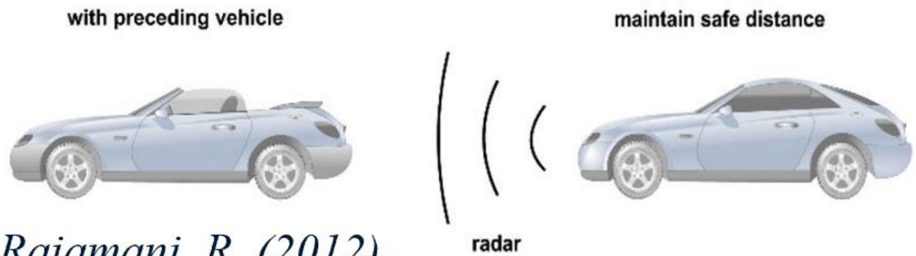
Modelling ACC systems

1- How they operate?

- Speed control mode.



- Gap control mode.



Rajamani, R. (2012).

- Transitions between the two objectives should be as smooth as possible, in order not to cause discomfort to the passengers.

2- Spacing selection policies

- Two main headway selection policies for ACC systems have been used in the literature:
  - **Constant Space-Headway** (CSH): the inter-vehicle spacing is constant for the whole speed range. However, it has been proven (Rajamani, 2012), that this type of spacing policy is not string stable
  - **Constant Time-Headway** (CTH): most common spacing policy used in ACC systems by researchers as well as automotive manufacturers where the inter-vehicle spacing is a linear function of the vehicle's speed.

General form for desired spacing → $L_{des} = h_d \dot{x}_i + s_0$

- L_{des}: Desired Spacing
- h_d: Time headway
- $\dot{x}_i$: Vehicle Speed
- s_0: Jam distance

3- ACC Control Laws

- **The control objective**
  - to eliminate the range error (error between actual and desired inter-vehicle distance) and the velocity error (difference between the speeds of leader and follower).

- The CTH policy is the **most common** spacing policy used in ACC systems nowadays.

- Surveyed existing control laws, used to control the velocities of ACC-equipped vehicles by implementing the CTH policy.

AIMSUN Default Car Following

- **Gipps Model- Free flow component (Acceleration component)**

This model states that, the maximum speed to which a vehicle (n) can accelerate during a time period (t, t+T) is given by

$$\dot{x}_a(n,t+T) = \dot{x}(n,t) + 2.5\ddot{x}(n)T\left(1-\frac{\dot{x}(n,t)}{\dot{x}^*(n)}\right)\sqrt{0.025+\frac{\dot{x}(n,t)}{\dot{x}^*(n)}}$$

$\dot{x}$ (n,t) is the speed of vehicle n at time t;

$\dot{x}$ *(n) is the desired speed of the vehicle (n) for the current section;

$\ddot{x}$ (n) is the maximum acceleration for vehicle n;

T is the reaction time of the vehicle.

AIMSUN Default Car Following

- **Gipps Model- Car following component (Deceleration component)**

The maximum speed that the same vehicle (n) can reach during the same time interval (t, t+T), according to its own characteristics and the limitations imposed by the presence of the leader vehicle is

$$\dot{x}_b(n, t+T) = d(n)T + \sqrt{d(n)^2T^2 - d(n)\left[2\{x(n-1,t) - s(n-1,t) - x(n,t)\} - \dot{x}(n,t)T - \frac{\dot{x}(n-1,t)^2}{d'(n-1)}\right]}$$

d(n) (< 0) is the maximum deceleration desired by vehicle n;

x(n,t) is position of vehicle n at time t;

x(n-1,t) is position of preceding vehicle (n-1) at time t;

s(n-1) is the effective length of vehicle (n-1);

d'(n-1) is an estimation of vehicle (n-1) desired deceleration.

Intelligent Driver Model

- Kesting et al., (2007) suggested that the Intelligent Driver Model (IDM) is suitable for modelling ACC-equipped vehicles.

Vehicle Speed — Desired Spacing

$$\dot{v}(s,v,\Delta v) = a\left[1-\left(\frac{v}{v_0}\right)^4-\left(\frac{s^*(v,\Delta v)}{s}\right)^2\right]$$

Acceleration — Free flow speed — Actual Spacing

Desired Spacing — Speed Error

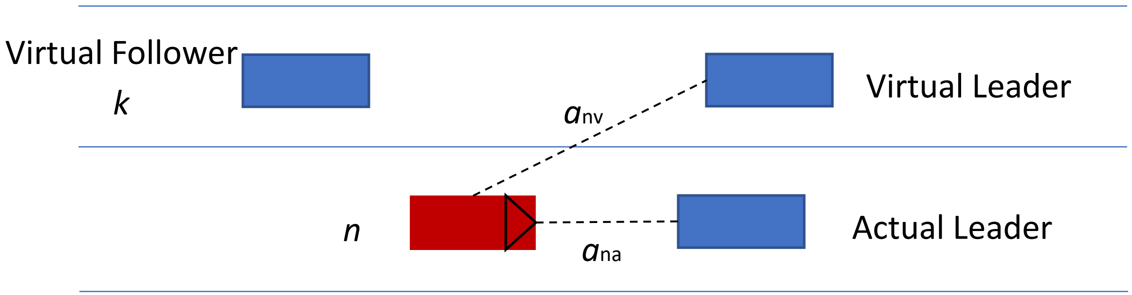
$$s^*(v,\Delta v) = \underbrace{s_0 + vT}_{L_{des}} + \frac{v\Delta v}{2\sqrt{ab}}$$

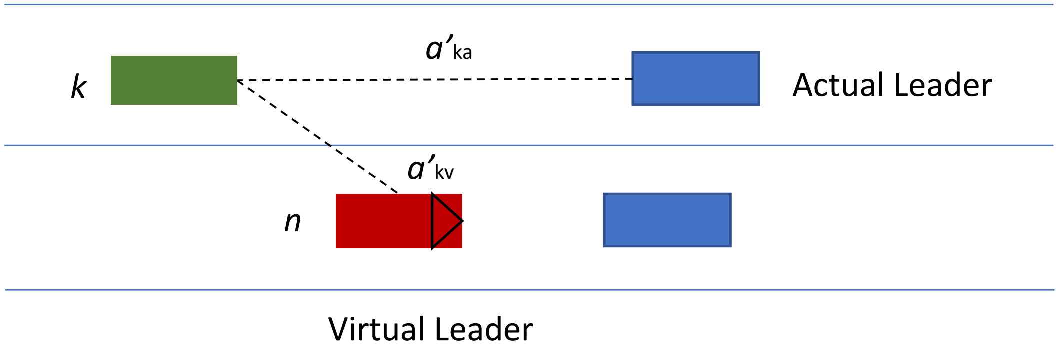
Comfortable deceleration

$$L_{des} = h_d \dot{x}_i + s_0$$

Lane Change under ACC operation (Automated Lane Change)

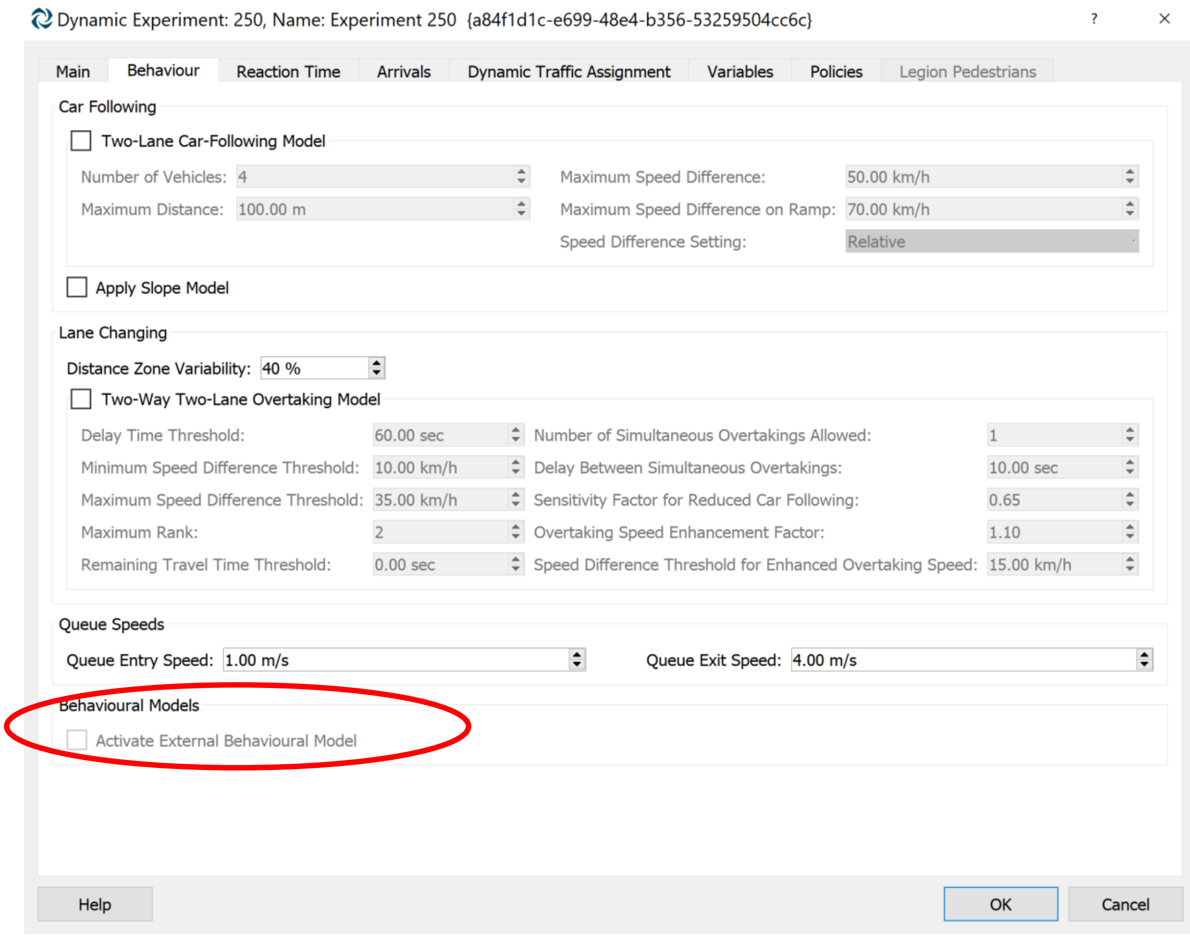
- The lane change algorithm is based on IDM (i.e. accelerations are calculated according to IDM).
- Feasibility of lane change and gap acceptance are based on IDM.
- Dual-leader lane change algorithm.





Aimsun MicroSDK

Activate external behavioral models in Aimsun- on the experiment level



Aimsun MicroSDK

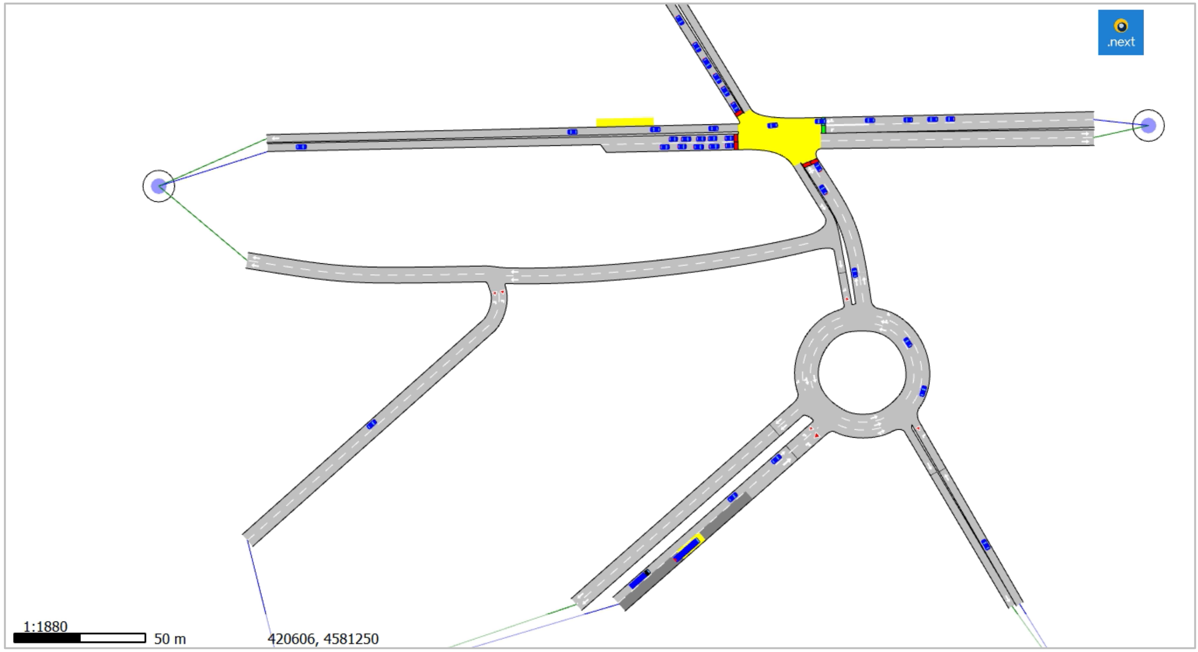
```
bool UseIDM=true;
```

```
double behavioralModelParticular::computeCarFollowingAccelerationComponentSpeed(A2SimVehicle
*vehicle,double VelActual,double VelDeseada, double RestoCiclo){
double VelPropia = 0;
if (UseIDM){
VelPropia = getIDMAccelerationSpeed((simVehicleParticular*)vehicle,VelActual,VelDeseada,RestoCiclo);
}else{
VelPropia =
getGippsAccelerationSpeed((simVehicleParticular*)vehicle,VelActual,VelDeseada,RestoCiclo);
}
return VelPropia;}
```

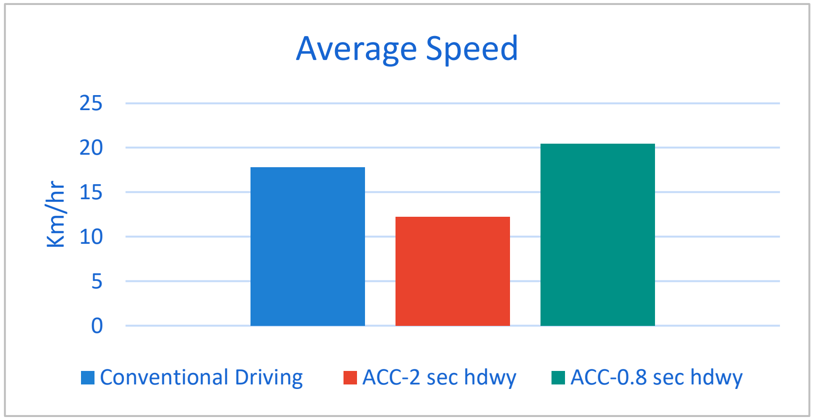
```
double behavioralModelParticular::computeCarFollowingDecelerationComponentSpeedCore(A2SimVehicle
*vehicle, double VelAnterior, A2SimVehicle *vehicleLeader, double VelPreAnterior, double
GapAnterior, double DecelEstimadaLeader){
double VelImpuesta = 0;
if (UseIDM) {
VelImpuesta = getIDMDecelerationSpeed((simVehicleParticular*)vehicle, VelAnterior,
(simVehicleParticular*)vehicleLeader, VelPreAnterior, GapAnterior);
}
else {
VelImpuesta = getGippsDecelerationSpeed((simVehicleParticular*)vehicle, VelAnterior,
(simVehicleParticular*)vehicleLeader, VelPreAnterior, GapAnterior, DecelEstimadaLeader);
}
return VelImpuesta;}
```

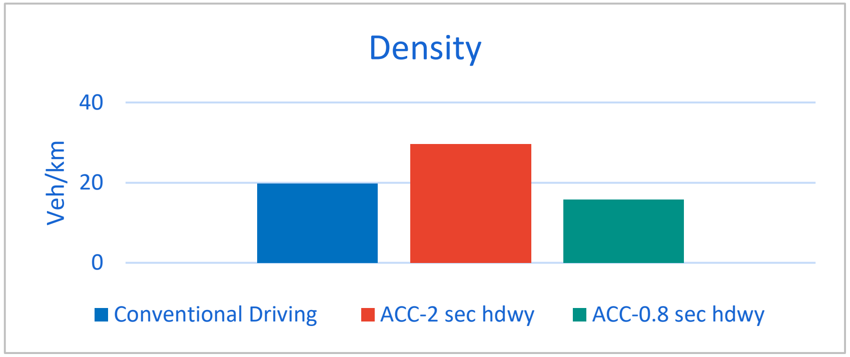
Preliminary Results

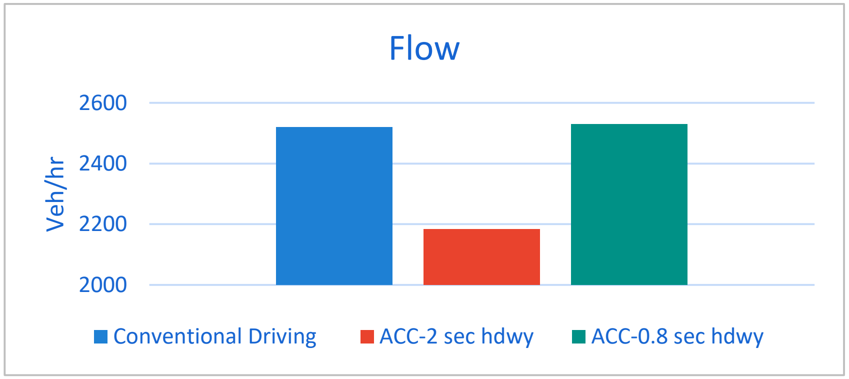
- Testing on a sample network:
  - Base case: conventional driving
  - 100% penetration of ACC-vehicles with 2.0 second headway
  - 100% penetration of ACC-vehicles with 0.8 seconds headway



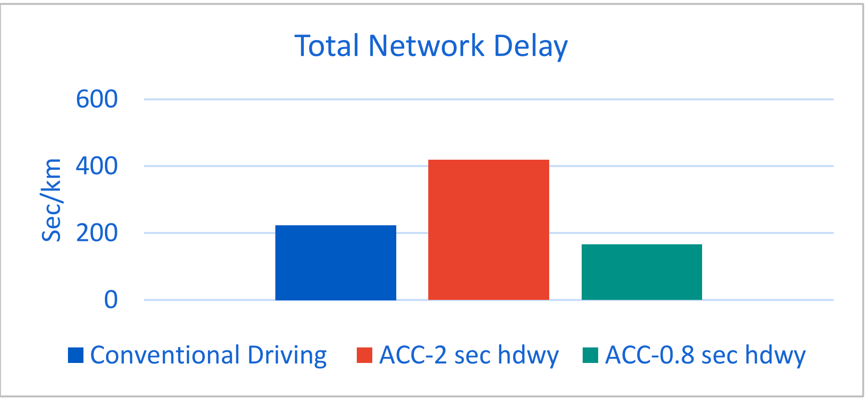
Preliminary Results

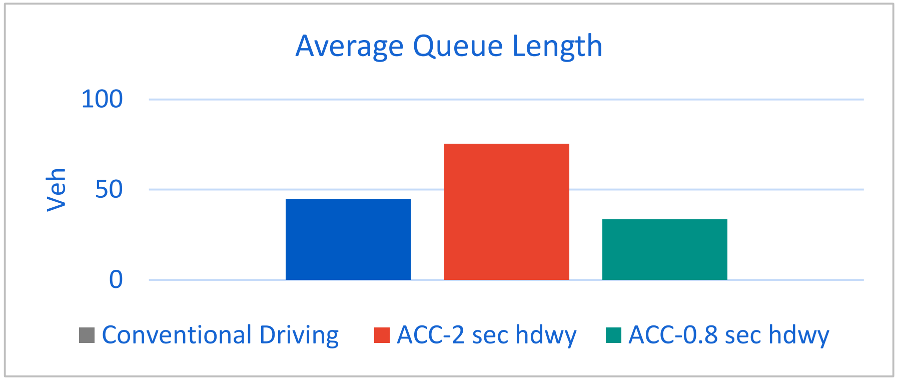


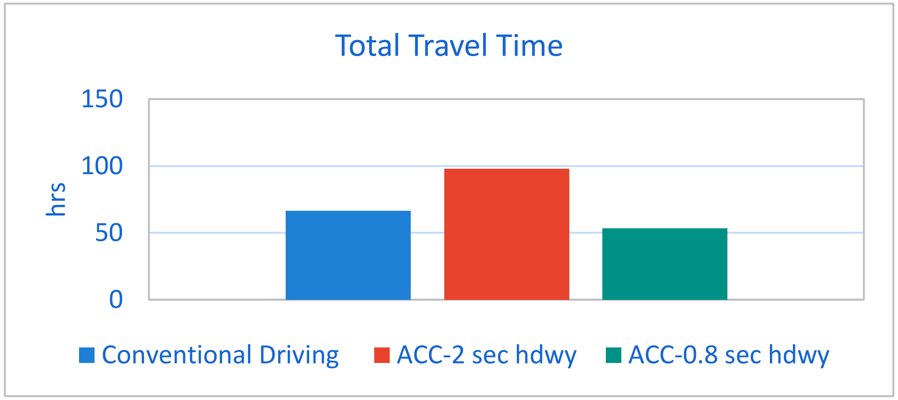




Preliminary Results

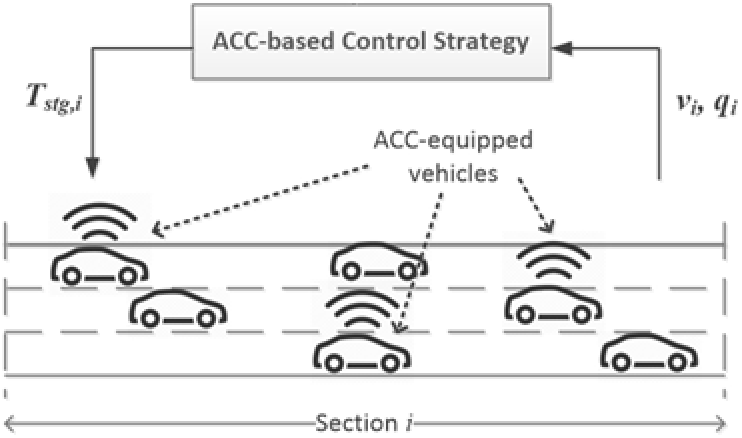


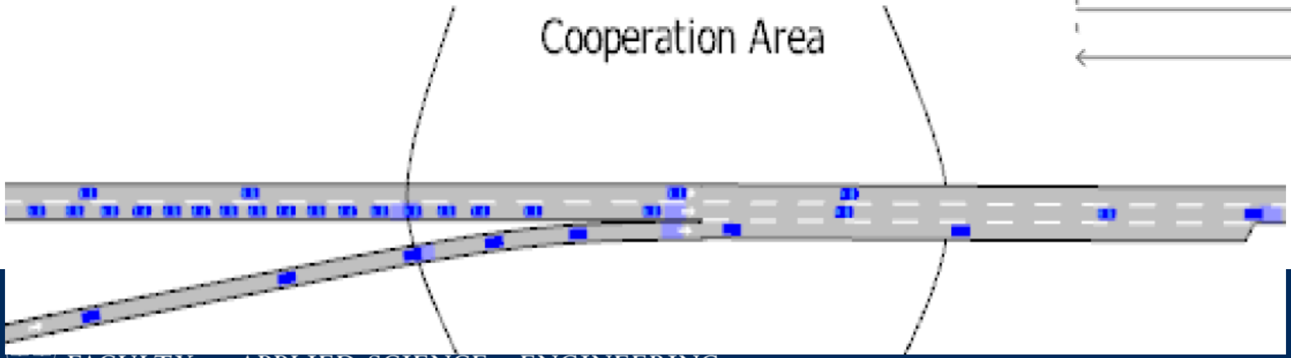




Next Steps

- Implement the IDM in the QEW network.
- Using different penetration rates and different time-gap values.
- Add a communication layer to model CACC.
- Exploitation of ACC.
- Cooperative lane changing and merging.





Building the road network in AIMSUN

Islam Kamel Taha

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

Building the Road Network in AIMSUN

Network Size

- Boundaries and more

Demand and Traffic Zones

- Extracted from a larger model

Microscopic Calibration

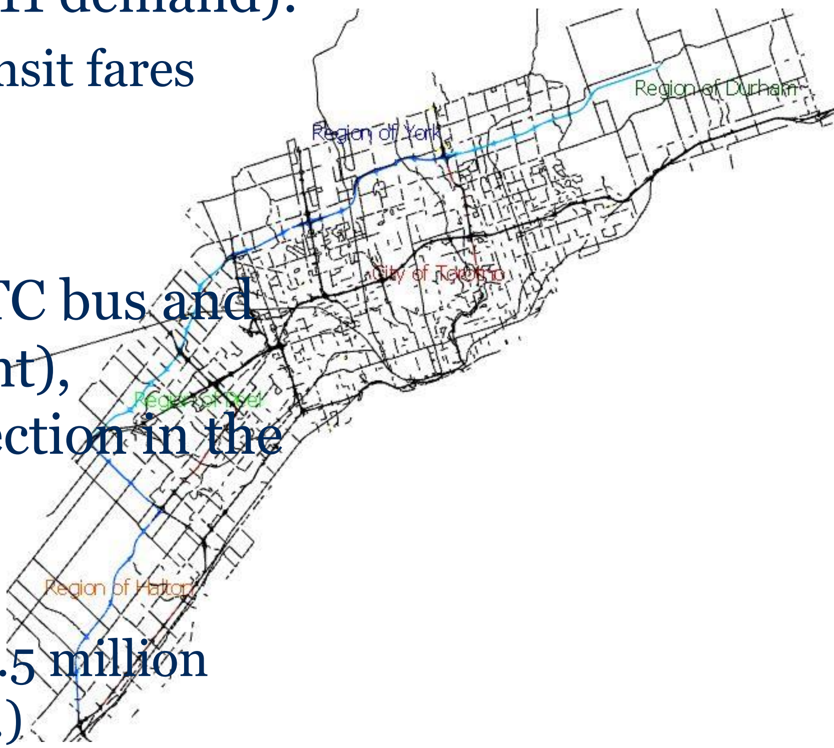
- Real data sets
- What needs adjustment

QEW Subnetwork – Size and Boundaries

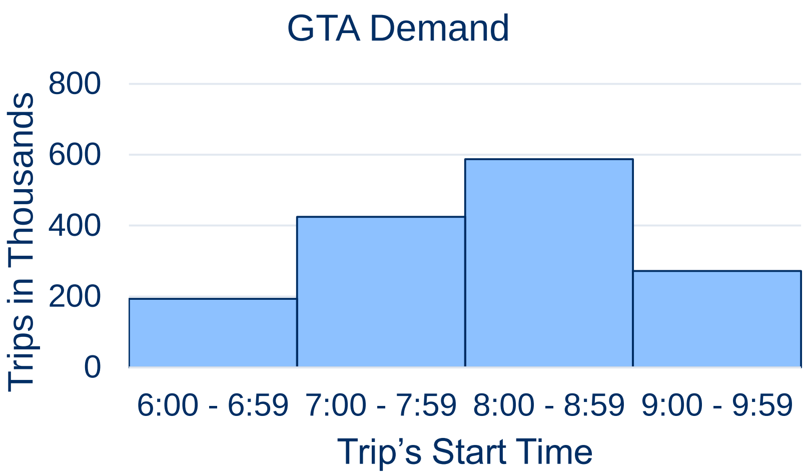
- Mainline sections and on/off ramps. Not sufficient!
  - Including some arterials for demand generation/attraction
- From the interchange at HWY 2 (North Shore Blvd) until the end of QEW at HWY 427 and the Gardiner

QEW Subnetwork of a larger GTA Mesoscopic Model

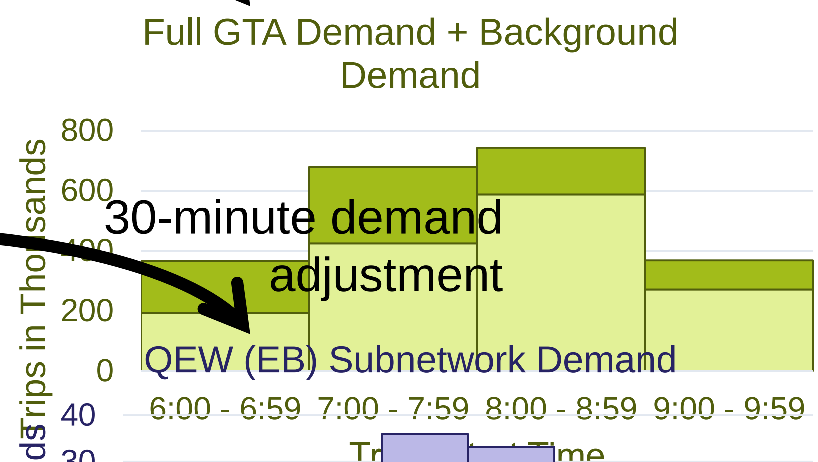
- Used in various applications (TTS 2011 demand):
  - Evaluating/optimizing time-based transit fares
  - Measuring emissions
- 1497 traffic zones
- Various features are available, e.g. TTC bus and streetcar routes (for traffic assignment), possibility to apply road toll to any section in the network, etc.
- Upgraded to TTS 2016 demand:
  - 2.16 million trips (1.6 million SOV + 0.5 million HOV) during morning peak (6-10 a.m.)



Demand and Traffic Zones

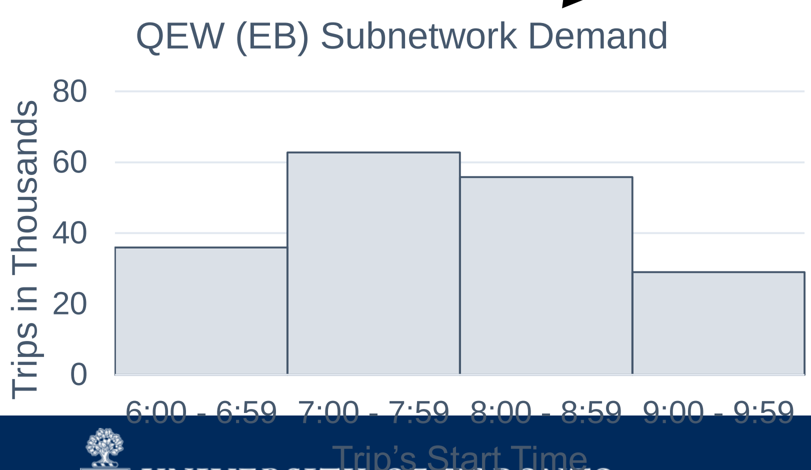


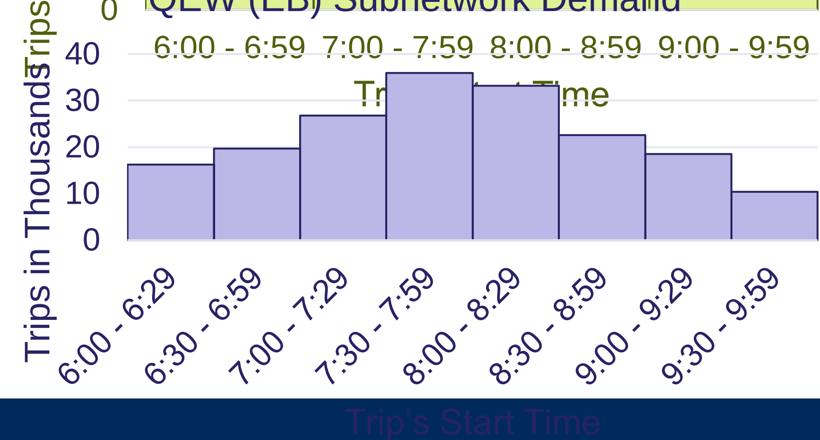
Adding background trips to the full model's demand



Extracting QEW (eastbound) demand

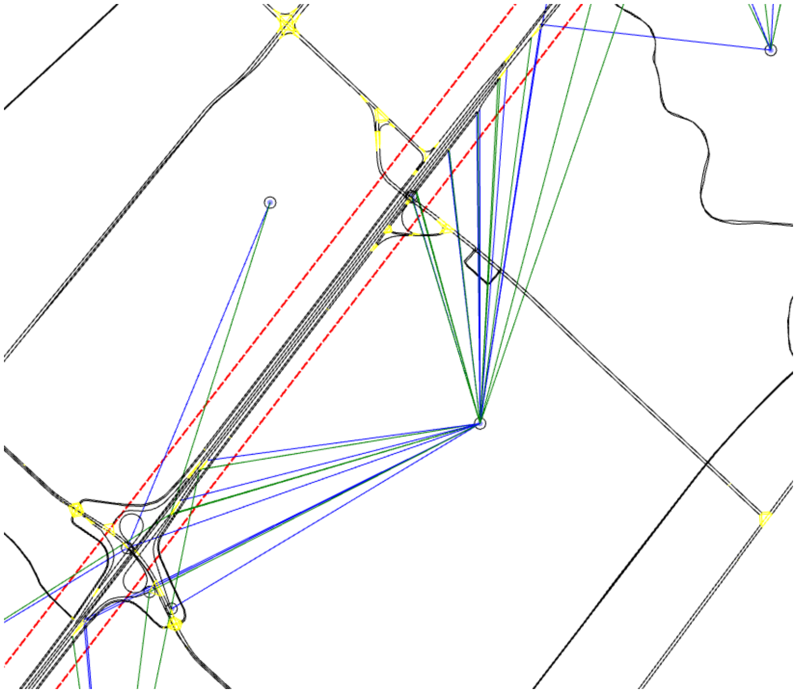
30-minute demand adjustment





Demand and Traffic Zones

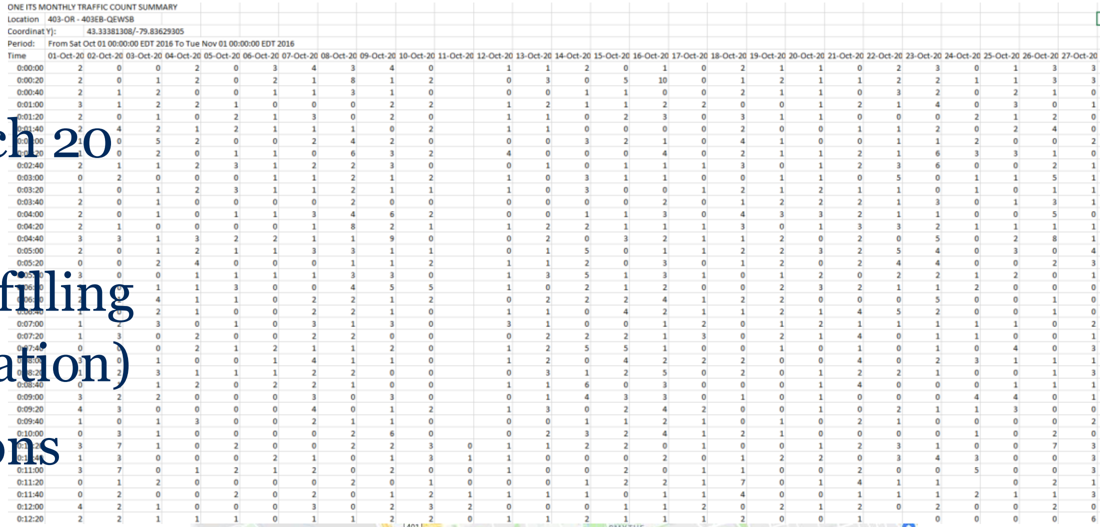
- 16 multiclass OD matrices
- 142 traffic zones (centroids)
- Centroid connections to arterials and ramps (not freeways)



Calibration – Real Data Set

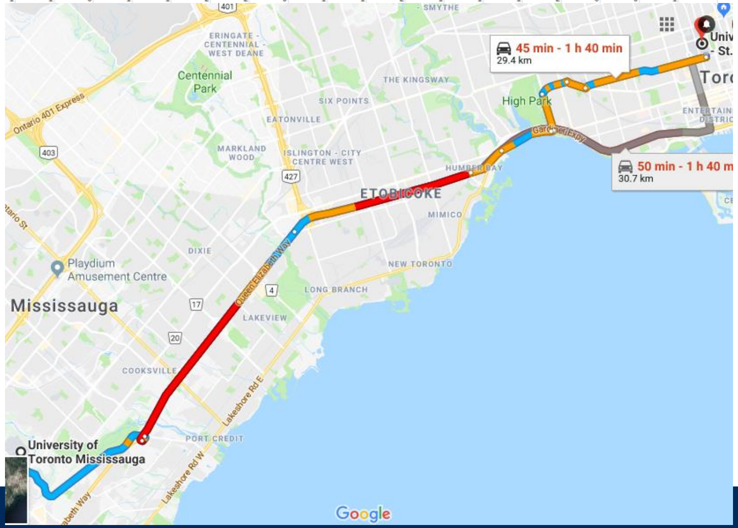
Loop detectors:

- Speed and counts (flow) each 20 seconds
- Data processing (filtration, filling gaps, averaging, and verification)
- Locating detectors on sections



Google Maps:

- Speeds and travel times using Google Directions API



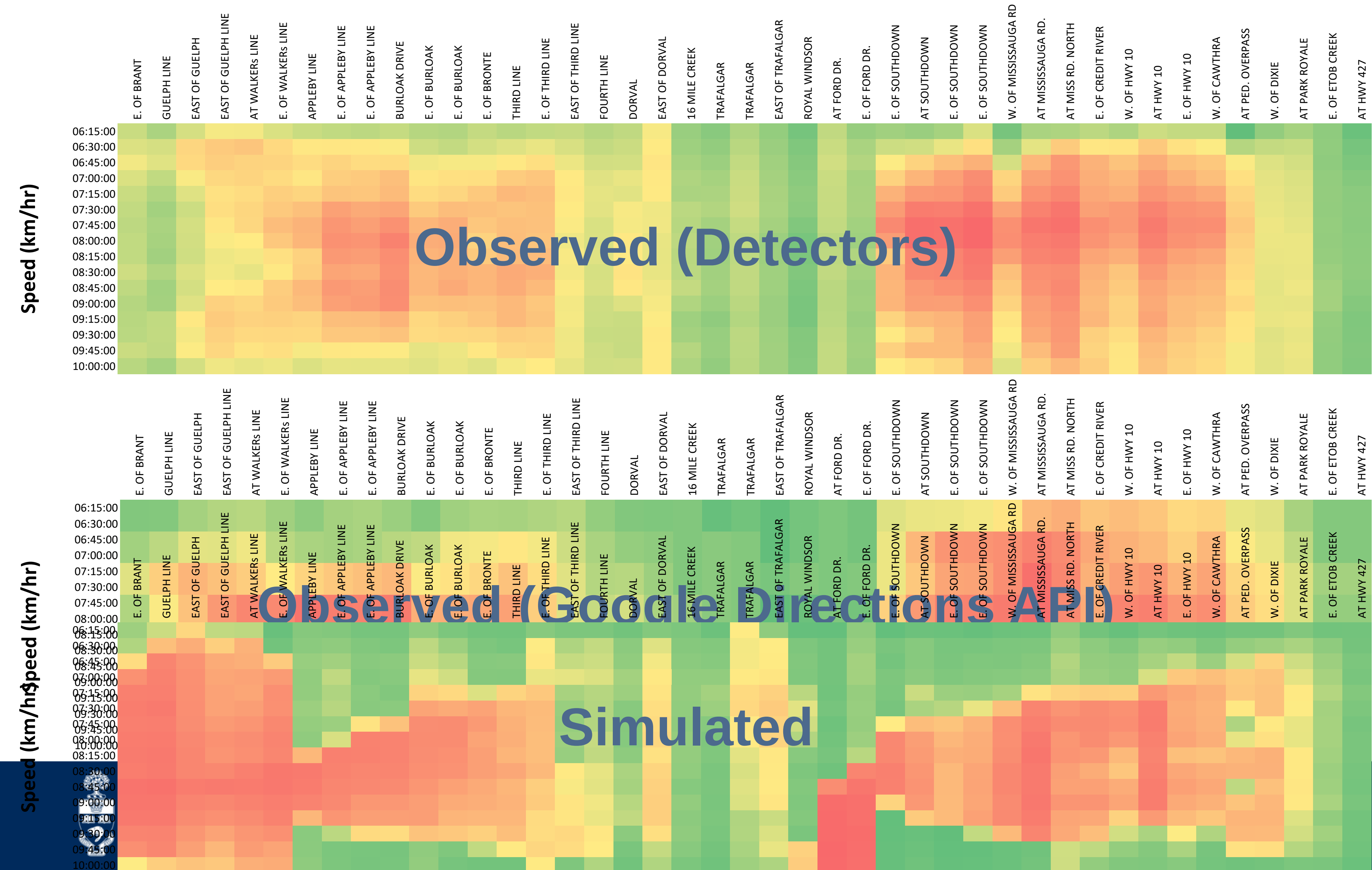
Microscopic Calibration – Parameters

- Global vs. local
- Behaviour vs. assignment
- Manually vs. GA optimization
- What to adjust
  - Reaction time
  - Merging behaviour
  - Changing lanes zones
  - Drivers' cooperation and aggressiveness
  - Stop lines
  - Road attractiveness
  - Attractiveness weight
  - Warm-up period
  - Experienced vs. instantaneous

Validation – Comparing with Real Data

- GEH Statistic
- Relative difference
- R^2
- Heatmaps

Microscopic Calibration – Latest Results



Next Steps

- Finalize the model calibration
- Implement the IDM in the QEW network

Discussion

References

- Rajamani, R. (2012). Vehicle dynamics and control. Second Edition. Springer.
- Kesting, A., et al., (2007). Extending Adaptive Cruise Control to Adaptive Driving Strategies. Transp. Res. Rec. 2000, 16–24.
- Kesting, A., 2008. Microscopic Modeling of Human and Automated Driving: Towards Traffic-Adaptive Cruise Control. Doctoral Thesis. Technical University of Dresden. Germany.
- Ntousakis, I. A., et al,. (2015): On microscopic modeling of adaptive cruise control systems. Transp. Res. Proc.
- Treiber, M., and A. Kesting. (2013). "Chapter 11: Car-Following Models Based on Driving Strategies." In Traffic Flow Dynamics, edited by S. B. Heidelberg, 181–204. Berlin Heidelberg: Springer.
- Stratidis, P. (2016), "Modelling Cooperative Lane Changing in Highways", Diploma Thesis, TechnicalUniversity of Crete, Chaina, Greece.