ITE SEMINAR
UNIVERSITY OF TORONTO

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Real-time Safety and Mobility Optimization of Traffic Signals in a Connected-vehicle Environment

The following slides show part of Mohamed Essa's Ph.D. Research conducted between 2015 and 2020 at the Bureau of Intelligent Transportation Systems and Freight Security, University of British Columbia, Vancouver, under the supervision of Prof. Tarek Sayed.

Two main concerns for signalized intersections

1- Safety

2- Mobility

**Images' source: Vancouver Courier Website*

1- Safety of signalized intersections

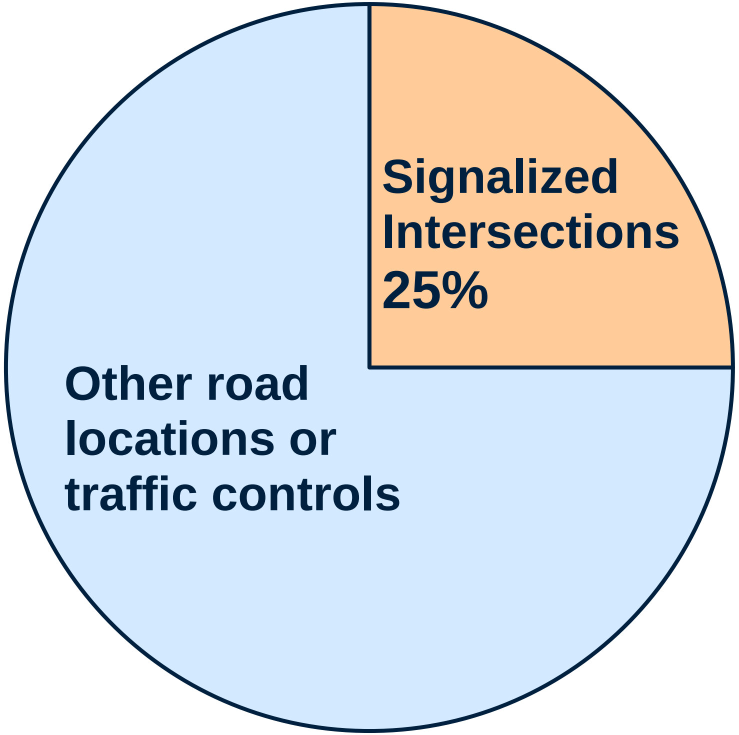
- ❑ **Stop and Go Conditions**
- ❑ **Vehicle Interactions**
- ❑ **Dilemma Zone**
- ❑ **Shock Waves**

❑ **Traffic collisions in Canada:**

- **≈ 1,900 fatalities annually**
- **≈ 165,000 injuries annually**

**Source: Transport Canada, "Motor Vehicle Safety, National Collision Database (NCDB)," Transport Canada, 2019. [Online]*

Traffic collisions in Canada



**Source: Transport Canada, "Motor Vehicle Safety, National Collision Database (NCDB)," Transport Canada, 2019. [Online]*

2- Mobility at signalized intersections

- ❑ Recurrent congestion
- ❑ Delays
- ❑ Poor signal design
- ❑ Inadequate capacity

❑ Traffic congestion affects:

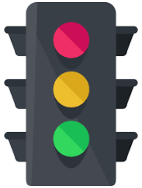
- the environment
- the economy
- the quality of life

CONNECTED VEHICLES is a promising solution

**Source: USDOT Connected-Vehicles : https://www.its.dot.gov/cv_basics/ [Online]*

Motivation

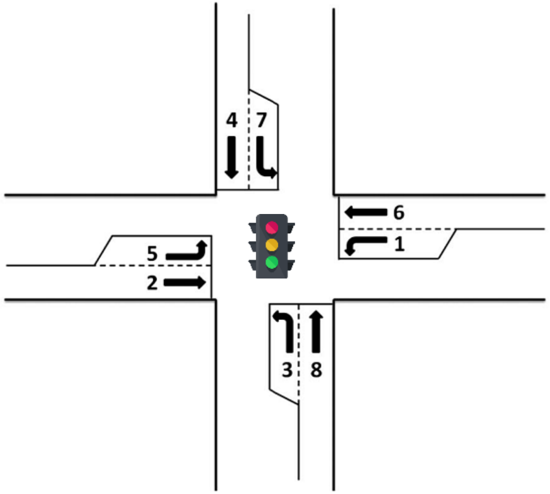
- ❑ **CVs → considerable amount of real-time data**



- ❑ **How can these data be used for real-time safety and mobility optimization of traffic signals?**

Previous research

- ❑ **Adapting traffic signals in real time to optimize traffic mobility:**



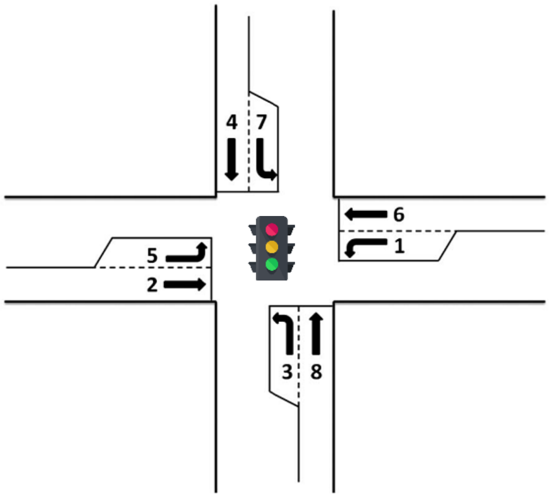
- Minimize travel/delay time
- Minimize queue length

Gaps in previous research

- ❑ **Safety is not considered in the real-time signal optimization process**

- ❑ **The main challenges are:**

- How to evaluate safety in real time?
- How do real-time changes in the signal controller affect safety?



Research objectives

a) To develop a new method to evaluate the safety of signalized intersections in real time

- Real-time safety models (traffic conflicts at the signal cycle level)
- Video analysis procedure (traffic database)
- Conflict heat maps (spatial and temporal distribution of traffic conflicts)
- Various traffic conflict indicators with multiple severity levels
- Full Bayesian models to account for unobserved heterogeneity and site effect
- Investigating the models’ transferability to new jurisdictions

Research objectives

b) To integrate the developed real-time safety models with traffic microsimulation

- A new procedure for evaluating the safety of signalized intersections from traffic simulation was proposed
- Validation using real-world data
- Compared with SSAM
- Case study: Evaluating of the safety impact of a CV-based application

Research objectives

c) To develop an Adaptive Traffic Signal Control (ATSC) algorithm to optimize safety in real time using CVs data

- A novel self-learning ATSC algorithm using real-time safety models
- Validation using real-world data
- Compared to the state-of-the-art actuated signal control system (ASC)
- Tested under various Market Penetration Rates of CVs

Research objectives

a) Real-time safety evaluation models

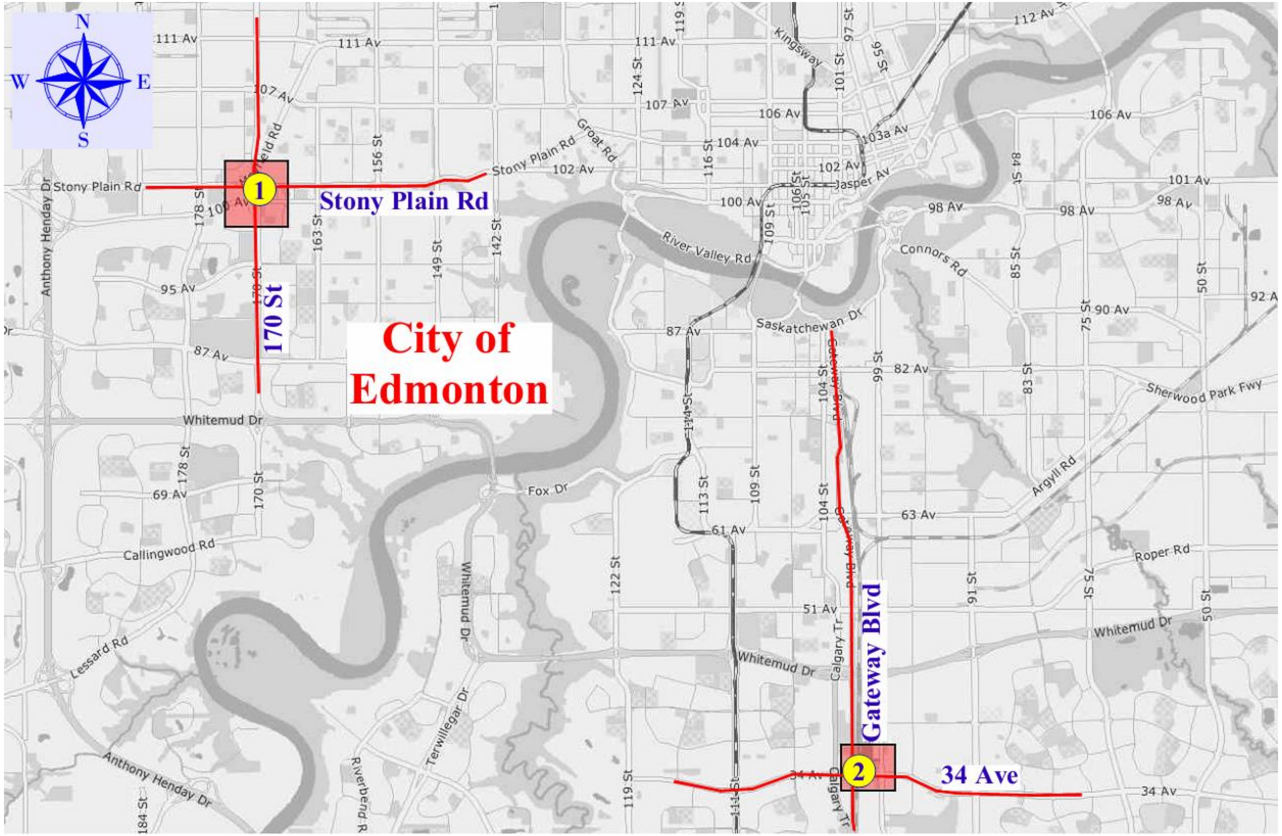
b) Integration with traffic microsimulation models

c) Adaptive Traffic Signal Control (ATSC) algorithm

First objective: Real-time safety evaluation models

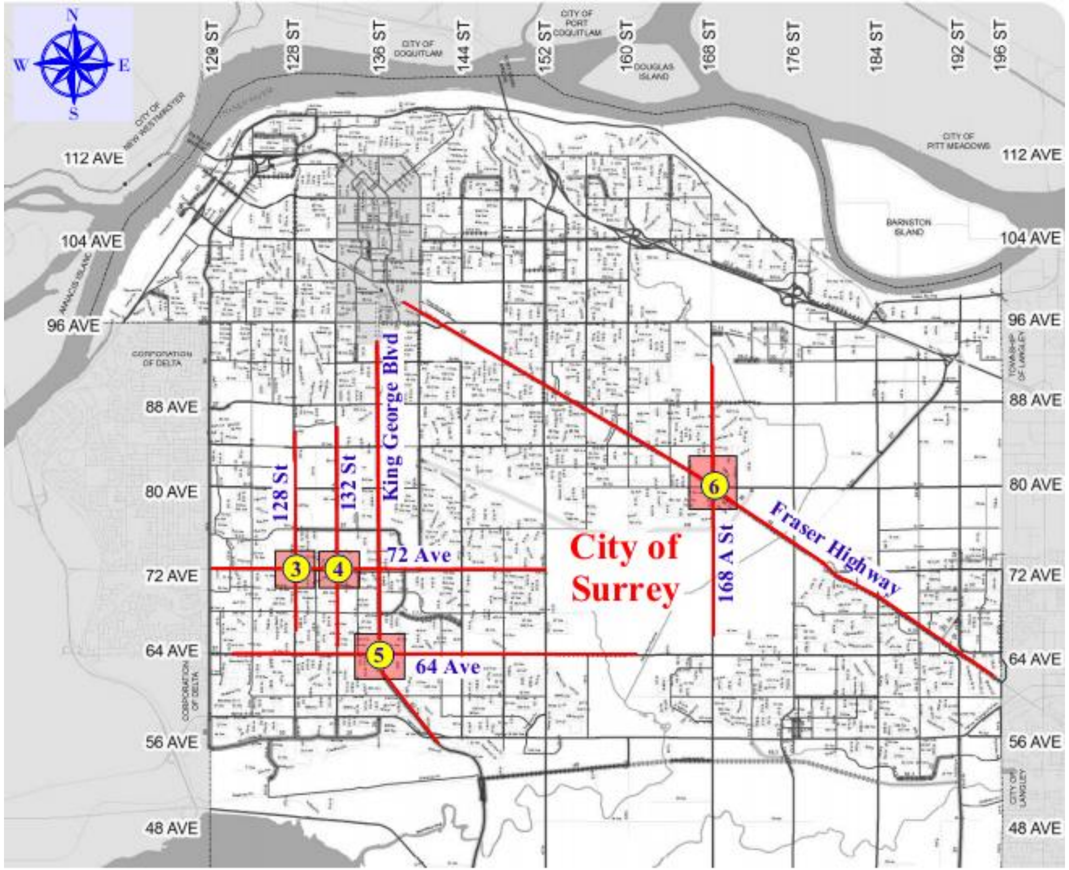
- Real-world traffic video data
- Video analysis
- Dynamic traffic parameters over a short time-period
- Develop models that relate the number of traffic conflicts to those dynamic parameters
- Transferability analysis

Traffic data and video analysis

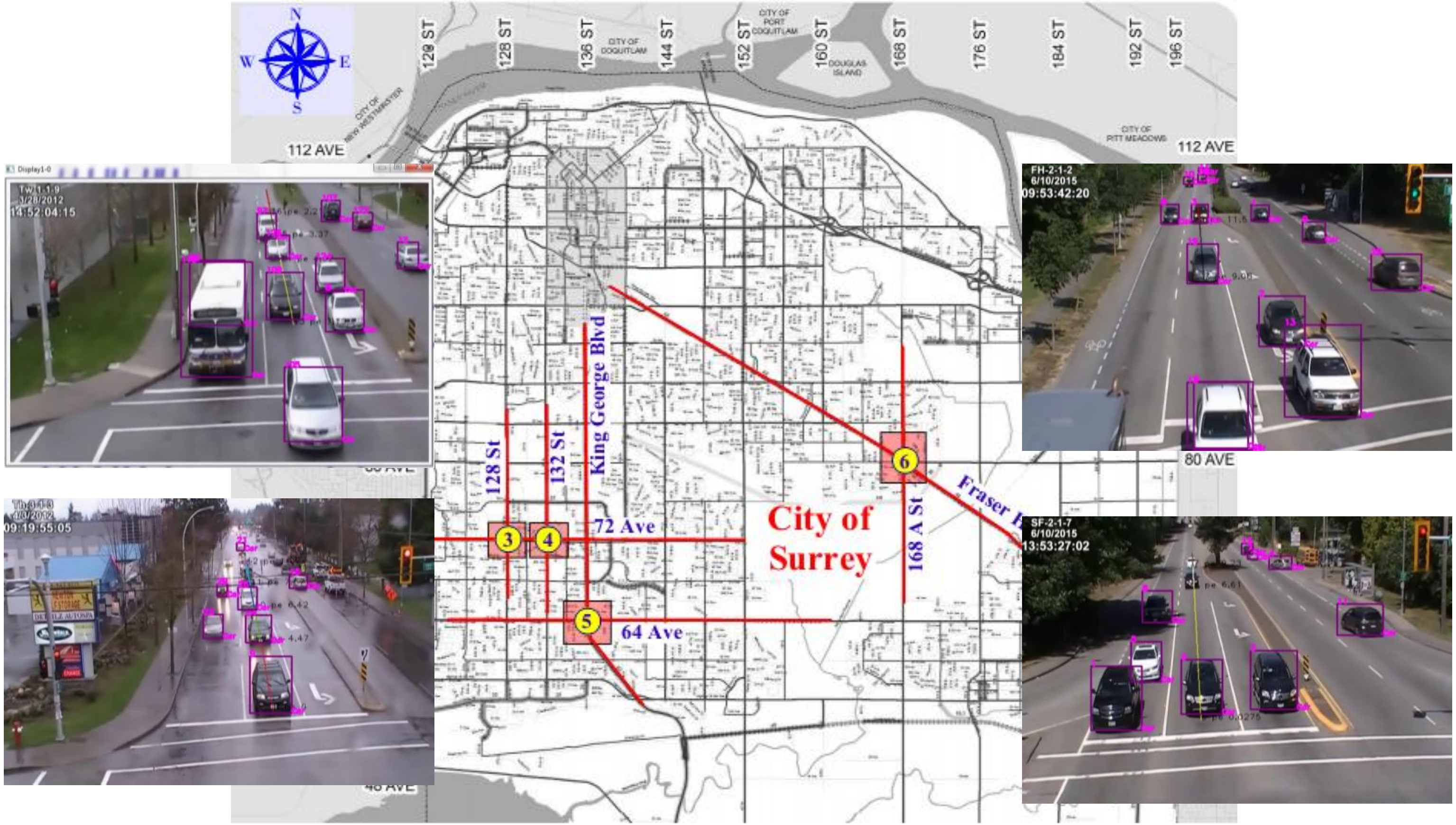


Traffic data and video analysis

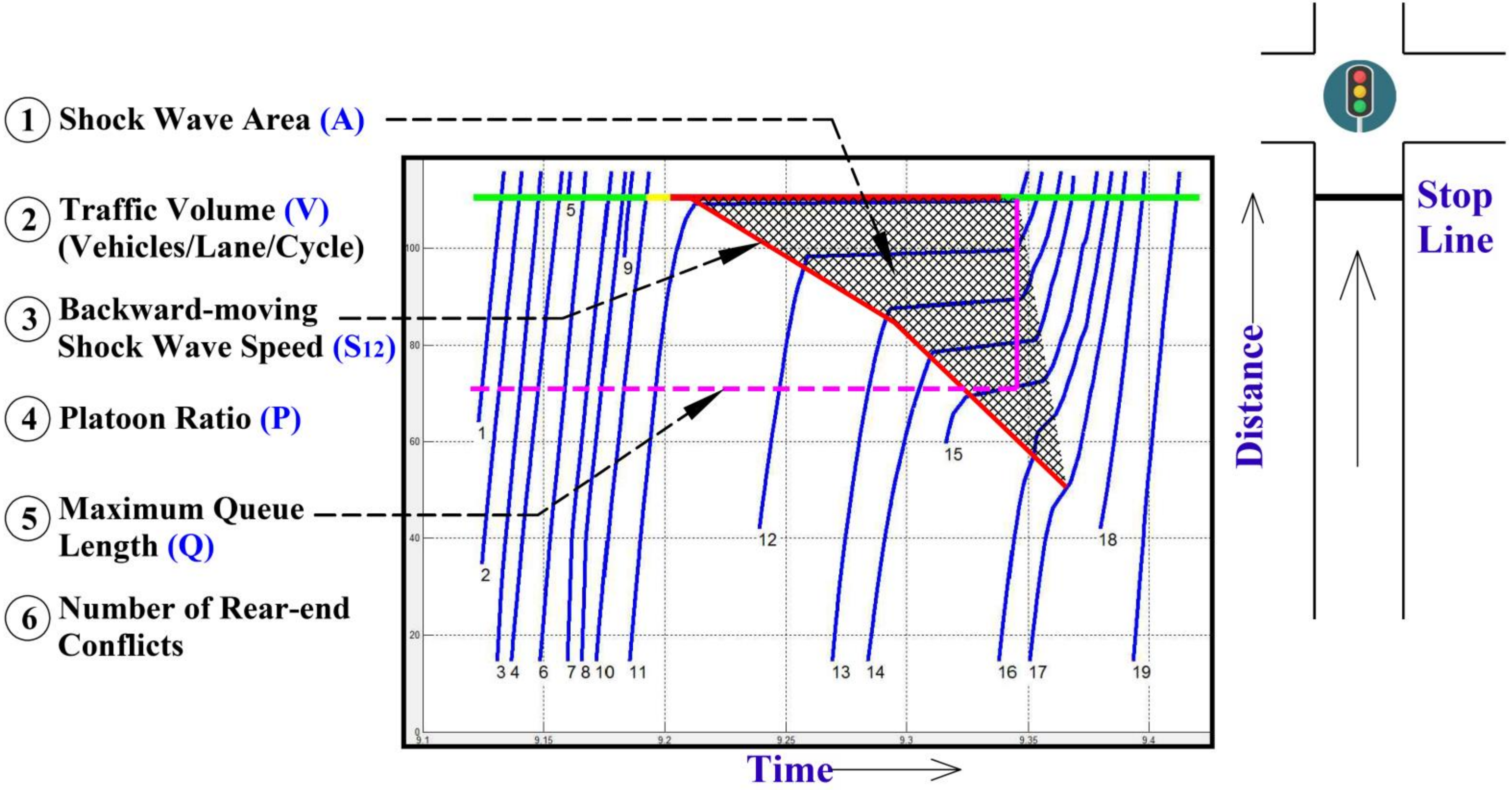
Traffic data and video analysis



Traffic data and video analysis



Dynamic traffic parameters



Real-time safety evaluation models

$$\mathbf{Y} = f\,(\textit{dynamic traffic parameters})$$

- ❑ **Y: the number of traffic conflicts**
- **Various traffic conflict indicators (TTC, MTTC, DRAC)**

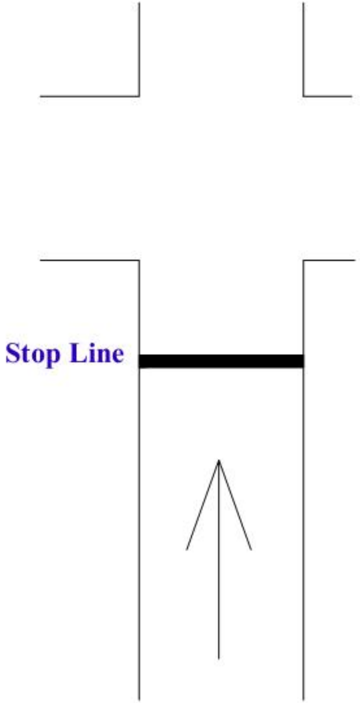
- ❑ **Various statistical analysis methods:**
- **Negative binomial models (GLM models)**
- **Full Bayesian models (Unobserved heterogeneity and random effect)**

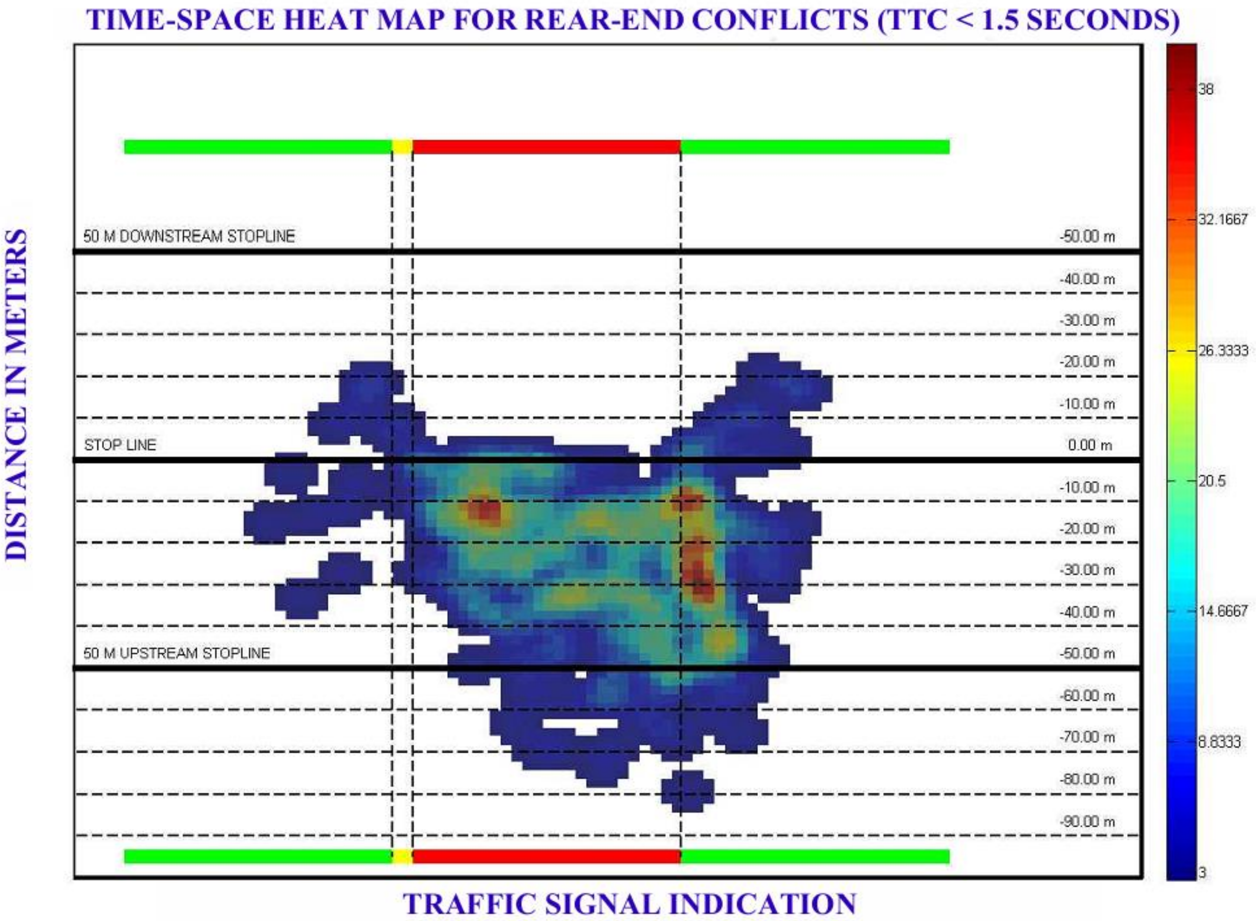
Model# $\boldsymbol{E(Y)} =$	**Variables**	**Error Structure**	**K**	**SD**	**df**	**χ^2**	**AIC**
One Variable (Exposure only):							
Model 1: $V^{1.563}exp(-3.231)$	V	NB	3.05	249	220	356	775
(Exposure + One Variable):							
Model 2: $V^{0.706}exp(-1.797 + 0.501\ A)$	V, A	NB	14.9	244	219	241	702
Model 3: $V^{0.65}exp(-2.046 + 0.0122\ Q)$	V, Q	NB	8.73	243	219	253	716
Model 4: $V^{1.637}exp(-3.316 + 0.05\ S_{12})$	V, S_{12}*	NB	3.10	248	219	347	775
Model 5: $V^{1.571}exp(-1.768 - 1.266\ P)$	V, P	Poisson	---	276	219	281	706
Combined Model:							
Model 6: $V^{1.239}exp(-1.624 + 0.294\ A - 0.828\ P + 0.119\ S_{12})$	V, A, P, S_{12}	Poisson	---	240	217	215	674

K: Dispersion parameter for Negative binomial family

All variables are significantly different from zero at 95% confidence level

*Significantly different from zero at 90% confidence level


Stop Line


TIME-SPACE HEAT MAP FOR REAR-END CONFLICTS (TTC < 1.5 SECONDS)
DISTANCE IN METERS
50 M DOWNSTREAM STOPLINE
-50.00 m
-40.00 m
-30.00 m
-20.00 m
-10.00 m
STOP LINE
0.00 m
-10.00 m
-20.00 m
-30.00 m
-40.00 m
50 M UPSTREAM STOPLINE
-50.00 m
-60.00 m
-70.00 m
-80.00 m
-90.00 m
38
32.1667
26.3333
20.5
14.6667
8.8333
3
TRAFFIC SIGNAL INDICATION

Model Format: $\ln(Y) = \beta_0 + \beta_1 \ln(V) + \beta_2 A + \beta_3 P + \beta_4 S_{12} + u_i$; where: $u_i \sim N(0, \sigma_u^2)$

Conflict Indicator	Y: Number of rear-end conflicts per cycle where	β_0 Estimate (2.5%, 97.5% Bayesian C.I)	β_1 Estimate (2.5%, 97.5% Bayesian C.I)	β_2 Estimate (2.5%, 97.5% Bayesian C.I)	β_3 Estimate (2.5%, 97.5% Bayesian C.I)	β_4 Estimate (2.5%, 97.5% Bayesian C.I)	σ_u^2 Estimate** (2.5%, 97.5% Bayesian C.I)	DIC
TTC	TTC ≤ 1.0 sec	-0.503 (-0.734, -0.302)	1.503 (0.872, 2.144)	0.353 (0.168, 0.541)	-1.145 (-1.636, -0.655)	0.313 (0.183, 0.455)	0.030 (0.0003, 0.270)	521
	TTC ≤ 1.5 sec	0.349 (0.224, 0.469)	1.250 (0.827, 1.686)	0.296 (0.166, 0.422)	-0.83 (-1.182, -0.484)	0.122 (0.055, 0.197)	0.003 (0.0003, 0.019)	674
	TTC ≤ 2.0 sec	0.884 (0.790, 0.975)	1.178 (0.850, 1.511)	0.205 (0.101, 0.307)	-0.765 (-1.038, -0.493)	0.088 (0.040, 0.141)	0.002 (0.0003, 0.008)	770
	TTC ≤ 2.5 sec	1.184 (1.105, 1.261)	0.993 (0.712, 1.276)	0.162 (0.070, 0.253)	-0.749 (-0.989, -0.510)	0.051 (0.014, 0.091)	0.002 (0.0003, +0.0006)	838
	TTC ≤ 3.0 sec	1.302 (1.228, 1.375)	0.998 (0.737, 1.266)	0.150 (0.063, 0.236)	-0.713 (-0.939, -0.489)	0.040 (0.008, 0.076)	0.002 (0.0002, 0.007)	860
MTTC	MTTC ≤ 1.0 sec	0.722 (0.620, 0.821)	1.239 (0.900, 1.583)	0.220 (0.111, 0.329)	-0.790 (-1.082, -0.498)	---*	0.003 (0.0003, 0.012)	755
	MTTC ≤ 1.5 sec	1.376 (1.305, 1.447)	1.073 (0.824, 1.326)	0.142 (0.059, 0.225)	-0.677 (-0.891, -0.463)	---*	0.002 (0.0003, 0.007)	907
	MTTC ≤ 2.0 sec	1.559 (1.494, 1.623)	1.024 (0.792, 1.257)	0.128 (0.050, 0.207)	-0.553 (-0.750, -0.354)	---*	0.002 (0.0002, 0.010)	959
	MTTC ≤ 2.5 sec	1.663 (1.602, 1.722)	0.975 (0.754, 1.197)	0.139 (0.062, 0.213)	-0.413 (-0.601, -0.227)	---*	0.002 (0.0003, 0.012)	1000
	MTTC ≤ 3.0 sec	1.687 (1.627, 1.746)	0.984 (0.768, 1.203)	0.144 (0.070, 0.218)	-0.366 (-0.552, -0.179)	---*	0.002 (0.0003, 0.013)	1016
DRAC	DRAC ≥ 6.0 m/s²	-1.556 (-1.911, -1.231)	1.884 (0.893, 2.904)	0.391 (0.119, 0.658)	-1.518 (-2.290, -0.762)	0.287 (0.101, 0.501)	0.007 (0.0003, 0.053)	305
	DRAC ≥ 4.5 m/s²	-1.134 (-1.419, -0.870)	2.110 (1.278, 2.963)	0.297 (0.065, 0.528)	-1.412 (-2.069, -0.748)	0.257 (0.105, 0.430)	0.003 (0.0003, 0.016)	375
	DRAC ≥ 3.0 m/s²	-0.368 (-0.555, -0.19)	1.522 (0.920, 2.137)	0.336 (0.162, 0.508)	-0.870 (-1.353, -0.398)	0.172 (0.071, 0.285)	0.005 (0.0003, 0.037)	522
	DRAC ≥ 1.5 m/s²	0.909 (0.818, 0.998)	1.097 (0.774, 1.426)	0.119 (0.013, 0.224)	-0.858 (-1.135, -0.584)	0.054 (0.013, 0.100)	0.002 (0.0003, 0.010)	794

* The explanatory variable S_{12} was removed from this model as its coefficient was not found to be significant at 95% confidence level

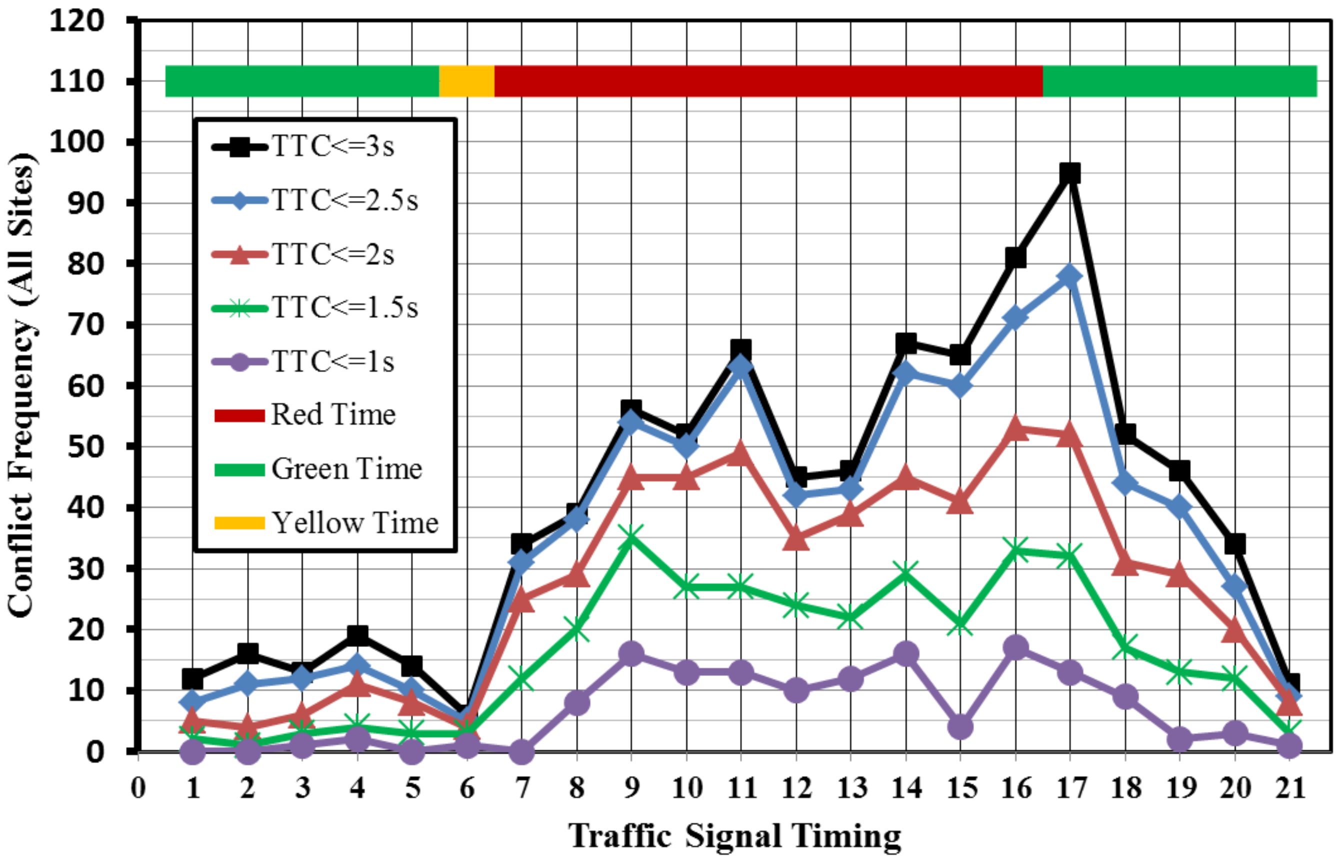
** σ_u^2 is the extra Poisson variance that addressing unmeasured or unobserved heterogeneity in the Full Bayes models

Model Format: $\ln(Y) = \beta_0 + \beta_1 \ln(V) + \beta_2 A + \beta_3 P + \beta_4 S_{12} + u_i + w_{s(i)}$; where: $u_i \sim N(0, \sigma_u^2)$ & $w_{s(i)} \sim N(0, \sigma_s^2)$

Conflict Indicator	Y: Number of rear-end conflicts per cycle where	β_0 Estimate (2.5%, 97.5% Bayesian C.I)	β_1 Estimate (2.5%, 97.5% Bayesian C.I)	β_2 Estimate (2.5%, 97.5% Bayesian C.I)	β_3 Estimate (2.5%, 97.5% Bayesian C.I)	β_4 Estimate (2.5%, 97.5% Bayesian C.I)	σ_u^2 Estimate** (2.5%, 97.5% Bayesian C.I)	σ_s^2 Estimate*** (2.5%, 97.5% Bayesian C.I)	DIC
TTC	TTC ≤ 1.0 sec	-0.484 (-1.135, 0.116)	1.749 (1.063, 2.457)	0.315 (0.101, 0.529)	-0.861 (-1.374, -0.343)	0.180 (0.054, 0.325)	0.005 (0.0003, 0.037)	0.560 (0.128, 1.795)	463
	TTC ≤ 1.5 sec	0.376 (0.076, 0.669)	1.449 (0.981, 1.929)	0.268 (0.121, 0.411)	-0.789 (-1.156, -0.424)	0.072 (0.007, 0.145)	0.003 (0.0003, 0.015)	0.111 (0.020, 0.376)	643
	TTC ≤ 2.0 sec	0.886 (0.757, 1.013)	1.227 (0.883, 1.579)	0.190 (0.078, 0.298)	-0.760 (-1.044, -0.482)	0.083 (0.033, 0.137)	0.002 (0.0003, 0.007)	0.011 (0.0004, 0.057)	767
	TTC ≤ 2.5 sec	1.175 (1.065, 1.276)	1.022 (0.730, 1.316)	0.150 (0.052, 0.244)	-0.744 (-0.990, -0.498)	0.052 (0.015, 0.093)	0.002 (0.0003, 0.007)	0.006 (0.0003, 0.031)	835
	TTC ≤ 3.0 sec	1.291 (1.188, 1.386)	1.032 (0.758, 1.319)	0.136 (0.042, 0.226)	-0.716 (-0.951, -0.486)	0.041 (0.007, 0.078)	0.001 (0.0003, 0.006)	0.006 (0.0004, 0.028)	857
MTTC	MTTC ≤ 1.0 sec	0.728 (0.567, 0.894)	1.355 (0.974, 1.757)	0.189 (0.066, 0.308)	-0.805 (-1.110, -0.502)	---*	0.0023 (0.0003, 0.011)	0.023 (0.0005, 0.105)	748
	MTTC ≤ 1.5 sec	1.331 (1.182, 1.456)	1.126 (0.856, 1.401)	0.111 (0.019, 0.202)	-0.698 (-0.933, -0.466)	---*	0.002 (0.0003, 0.009)	0.018 (0.001, 0.069)	893
	MTTC ≤ 2.0 sec	1.484 (1.313, 1.636)	1.093 (0.840, 1.350)	0.091 (0.005, 0.176)	-0.603 (-0.824, -0.385)	---*	0.002 (0.0002, 0.007)	0.032 (0.005, 0.112)	931
	MTTC ≤ 2.5 sec	1.574 (1.384, 1.742)	1.062 (0.819, 1.307)	0.097 (0.014, 0.178)	-0.483 (-0.698, -0.274)	---*	0.002 (0.0002, 0.006)	0.041 (0.007, 0.140)	966
	MTTC ≤ 3.0 sec	1.594 (1.399, 1.773)	1.079 (0.840, 1.322)	0.096 (0.016, 0.177)	-0.429 (-0.641, -0.220)	---*	0.002 (0.0003, 0.0065)	0.047 (0.010, 0.156)	974
DRAC	DRAC ≥ 6.0 m/s²	-1.547 (-1.921, -1.199)	1.855 (0.841, 2.888)	0.405 (0.132, 0.688)	-1.474 (-2.271, -0.680)	0.282 (0.094, 0.496)	0.007 (0.0003, 0.057)	0.022 (0.0003, 0.191)	304
	DRAC ≥ 4.5 m/s²	-1.101 (-1.484, -0.704)	2.043 (1.180, 2.921)	0.324 (0.078, 0.574)	-1.259 (-1.975, -0.523)	0.244 (0.086, 0.422)	0.003 (0.0003, 0.015)	0.100 (0.0004, 0.583)	370
	DRAC ≥ 3.0 m/s²	-0.332 (-0.569, -0.060)	1.527 (0.905, 2.152)	0.337 (0.153, 0.518)	-0.784 (-1.300, -0.262)	0.158 (0.053, 0.273)	0.003 (0.0002, 0.015)	0.037 (0.0004, 0.222)	518
	DRAC ≥ 1.5 m/s²	0.906 (0.785, 1.024)	1.109 (0.780, 1.446)	0.105**** (-0.008, 0.214)	-0.820 (-1.108, -0.529)	0.057 (0.014, 0.105)	0.002 (0.0003, 0.011)	0.008 (0.0004, 0.045)	791

* Not significant at 95% confidence level ** σ_u^2 is the extra Poisson variance that addressing unobserved heterogeneity in the Full Bayes models

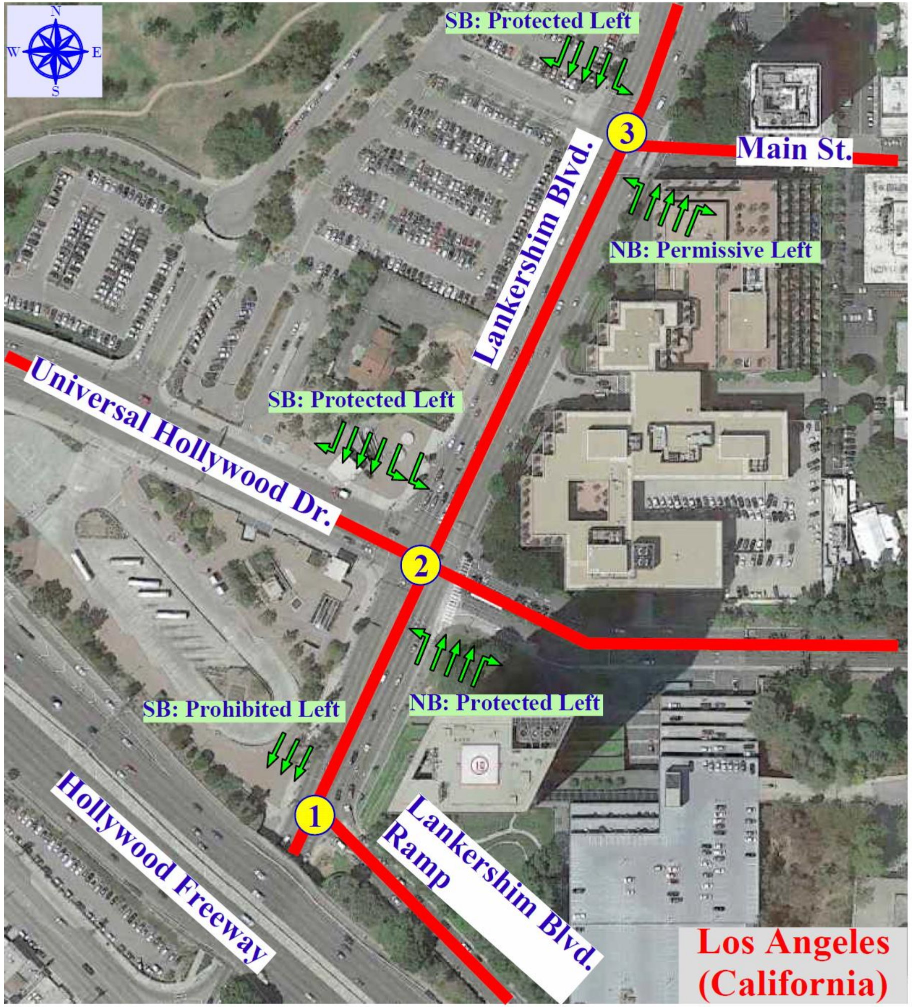
*** σ_s^2 is the additional variance component that addressing the variation among different sites

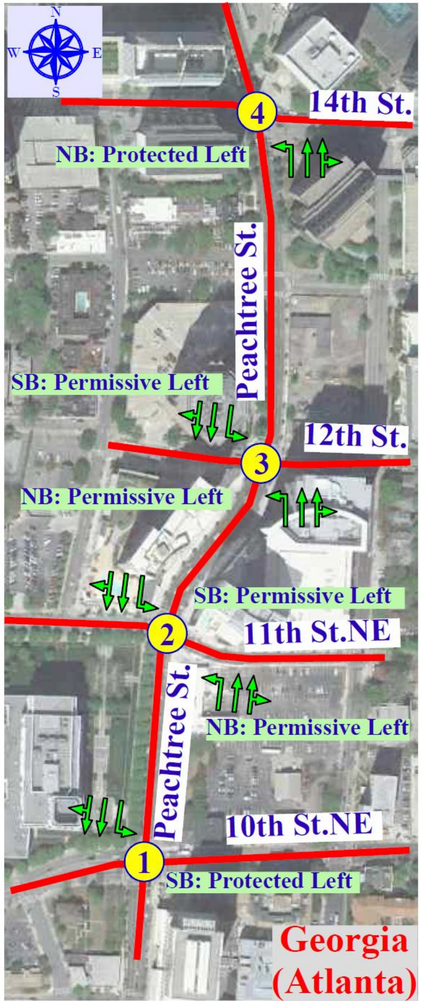

Conflict Frequency (All Sites)
Traffic Signal Timing
0
10
20
30
40
50
60
70
80
90
100
110
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
TTC<=3s
TTC<=2.5s
TTC<=2s
TTC<=1.5s
TTC<=1s
Red Time
Green Time
Yellow Time

Investigate the models' transferability

- ❑ **New jurisdictions**

- ❑ **NGSIM Data: data of two corridors of signalized intersections in USA**


N
W
E
S
SB: Protected Left
3
Main St.
NB: Permissive Left
Lankershim Blvd.
Universal Hollywood Dr.
SB: Protected Left
2
NB: Protected Left
SB: Prohibited Left
1
Hollywood Freeway
Lankershim Blvd.
Ramp
Los Angeles
(California)


N
W
E
S
4
14th St.
NB: Protected Left
Peachtree St.
SB: Permissive Left
3
12th St.
NB: Permissive Left
SB: Permissive Left
2
11th St.NE
Peachtree St.
NB: Permissive Left
10th St.NE
1
SB: Protected Left
Georgia
(Atlanta)

Transferability Analysis

- **1- Application-based approach**
- **2- Estimation-based approach**
  - **a) Intercept and shape parameter calibration**
  - **b) Full model calibration**

Summary of the first objective

- ❑ **Models to evaluate safety in real time**
- ❑ **Predict the safety level using dynamic traffic parameters**
- ❑ **Enable real-time safety evaluation using CVs data**
- ❑ **Transferable**
- ❑ **Potential applications**

- **Safety evaluation using field data**
- **Calibration of traffic simulation models**
- **Real-time safety optimization**

Second objective: Integration with traffic microsimulation

- A new procedure to evaluate safety from traffic simulation
- The procedure combines simulated vehicle trajectories with real-time safety models
- Validation using real-world traffic conflict data from 2 intersections
- Compared with SSAM

1- Traffic microsimulation model matching the field conditions

Traffic volumes, speeds, priority rules, signal timing, geometry

2- Record detailed traffic data continuously (every second)

Signal heads, vehicle positions, speeds, vehicle types

3- Determine signal cycles for each approach

Using signal head recordings

4- Specify vehicle trajectories for each cycle for each lane

Filter vehicle trajectories by time and position

5- Calculate traffic parameters for each cycle

Traffic volume, shock wave area, platoon ratio, etc

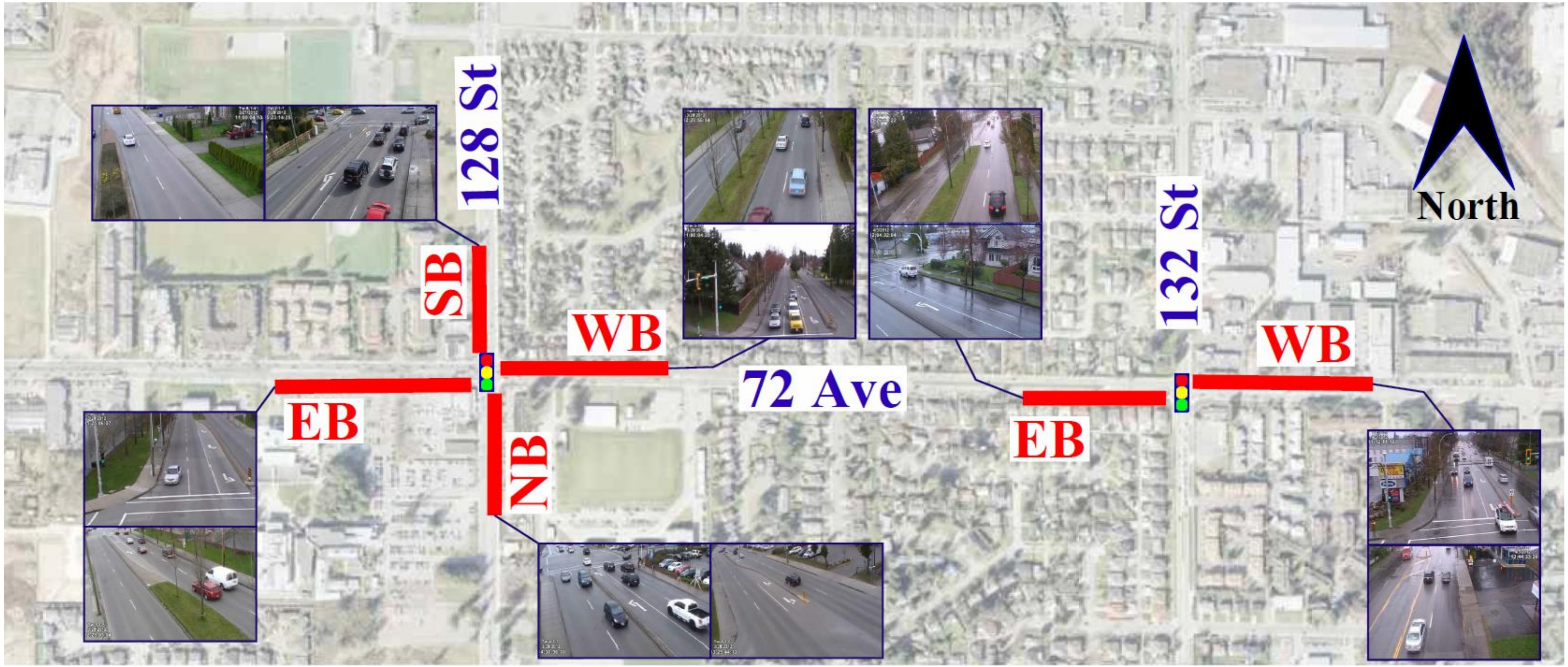
6- Apply real-time safety models to predict rear-end conflicts

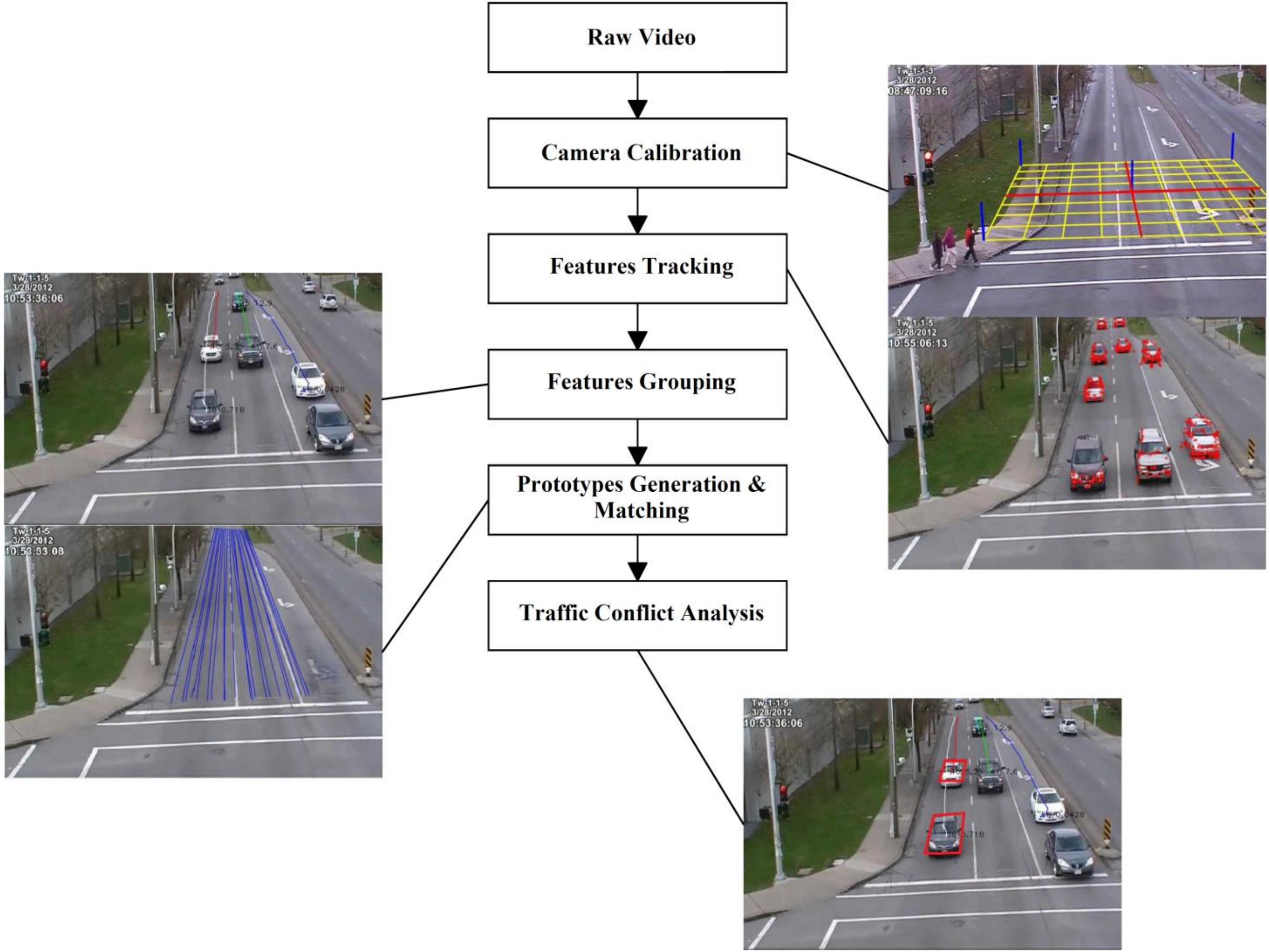
Number of rear-end conflicts per cycle per lane

7- Estimate the total number of conflicts per hour per approach

Aggregate cycles and lanes to get the total number of conflicts

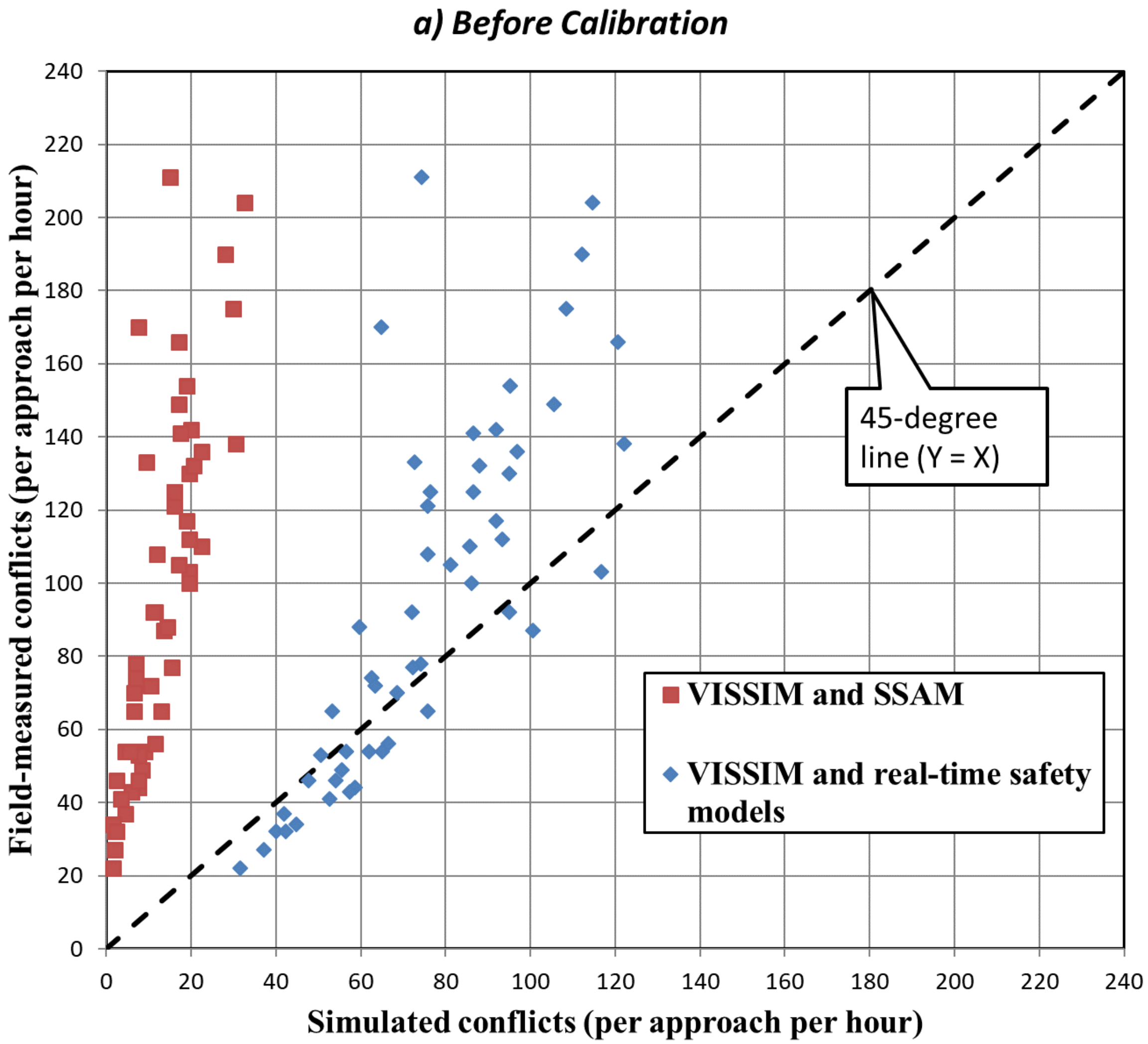
Validation using field-measured traffic data



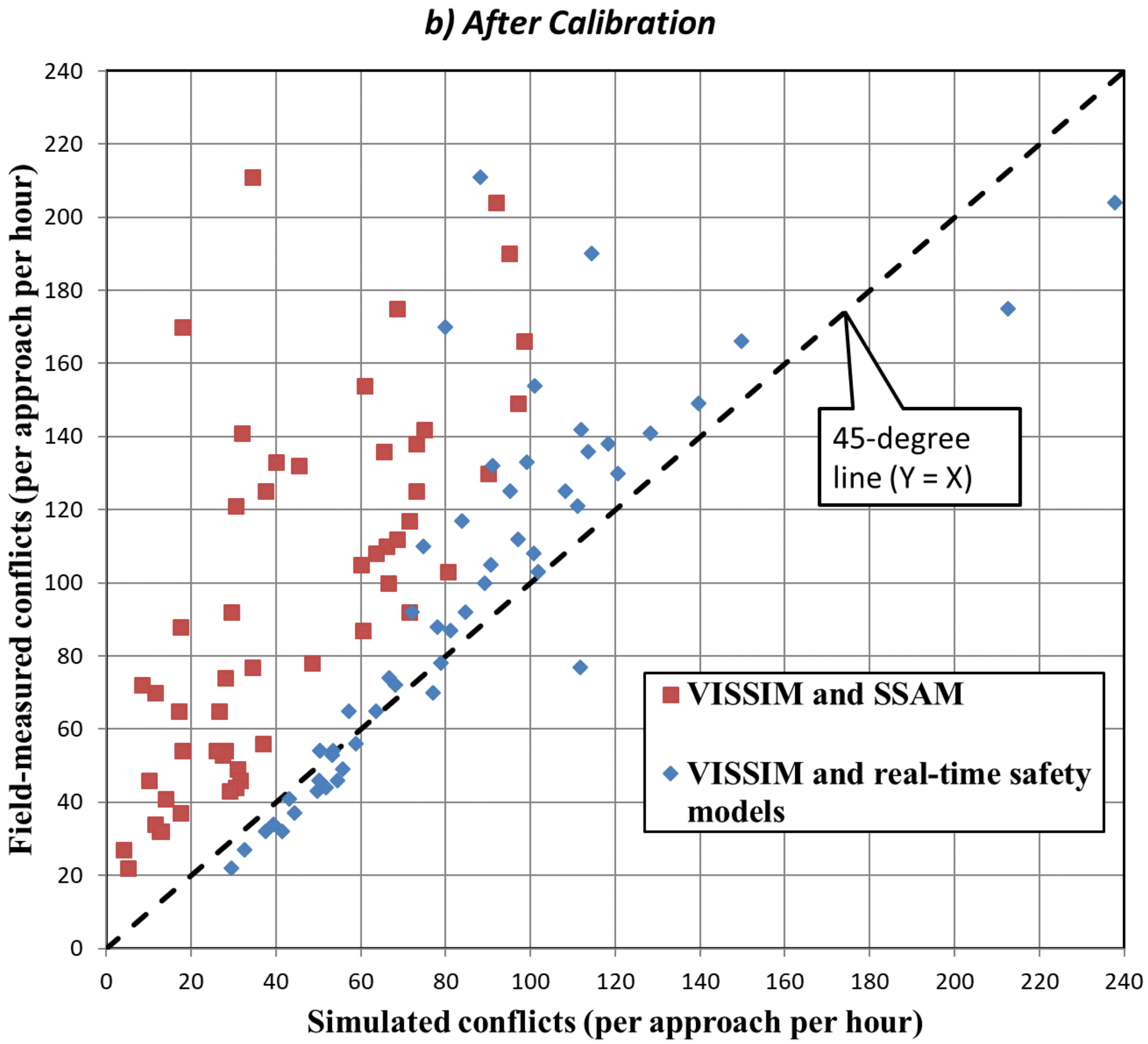

Raw Video
Camera Calibration
Features Tracking
Features Grouping
Prototypes Generation & Matching
Traffic Conflict Analysis

Compared to SSAM

- SSAM: Surrogate Safety Assessment Model (SSAM)
- SSAM estimates traffic conflicts from four commonly-used microscopic simulation models: VISSIM, AIMSUN, PARAMICS, and TEXAS.
- Several traffic conflict indicators as surrogate measures of safety, such as TTC, PET, deceleration rate, and speed differential.



a) Before Calibration
240
220
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Field-measured conflicts (per approach per hour)
Simulated conflicts (per approach per hour)
45-degree line (Y = X)
VISSIM and SSAM
VISSIM and real-time safety models


b) After Calibration
Field-measured conflicts (per approach per hour)
Simulated conflicts (per approach per hour)
0
20
40
60
80
100
120
140
160
180
200
220
240
45-degree line (Y = X)
VISSIM and SSAM
VISSIM and real-time safety models

	VISSIM + SSAM	VISSIM + Real-time safety models [Proposed Procedure]
54 Video hours from 6 approaches		
%Error (MAPE before calibration)	86.50%	28.90%
%Error (MAPE after calibration)	54.70%	19.10%

Summary of the second objective

- **The proposed procedure predicts traffic conflicts using dynamic traffic characteristics, such as traffic volume and shock waves**

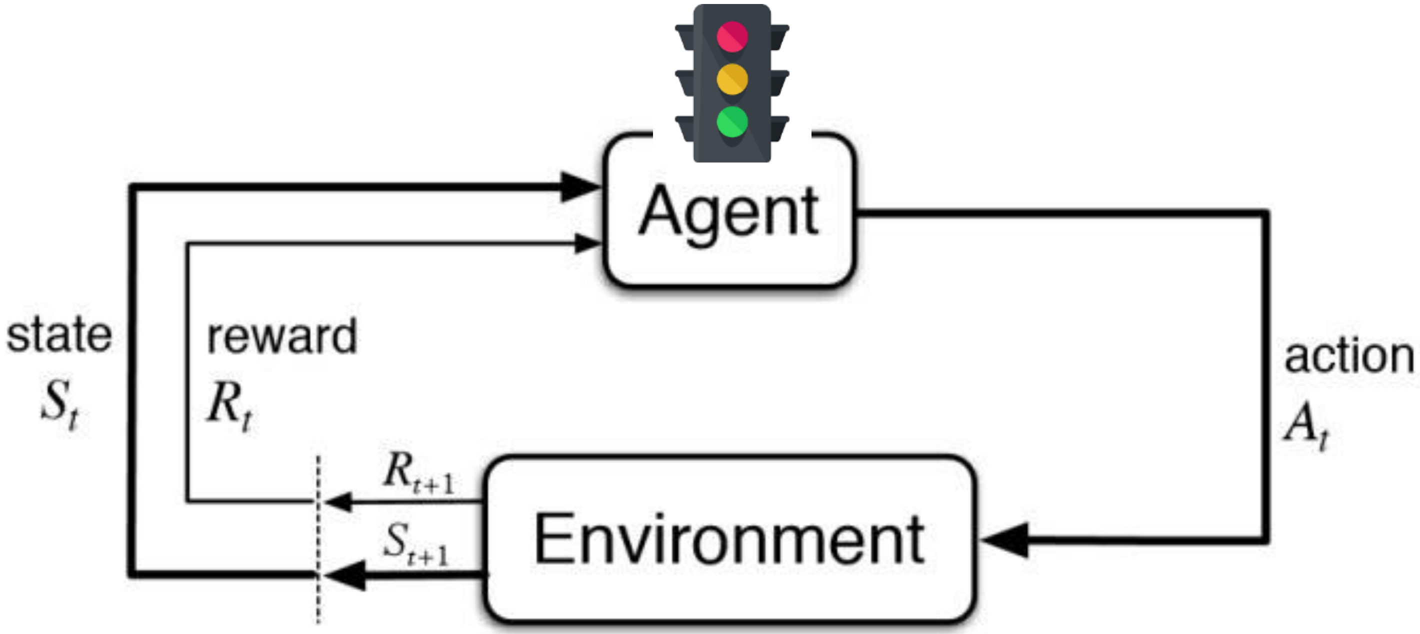
- **In most cases, these dynamic characteristics can be generated from traffic simulation with reasonable accuracy**

- **The procedure outperforms SSAM in predicting rear-end conflicts from traffic simulation**

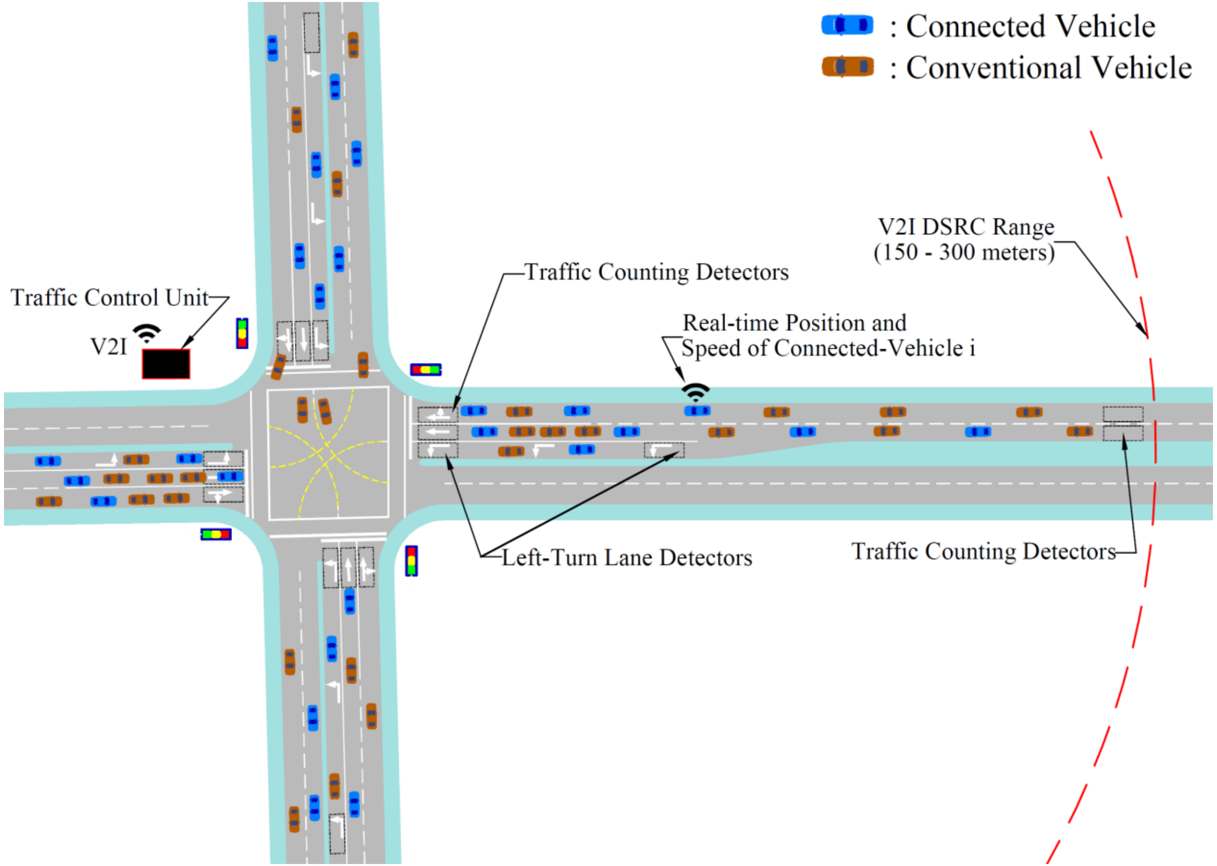
Third objective: ATSC algorithm

- A novel Real-time Safety-optimized ATSC (RS-ATSC) algorithm
- Improve safety using CVs data
- Traffic microsimulation
- RS-ATSC Versus ASC (actuated traffic signal controller)

Reinforcement Learning (RL)

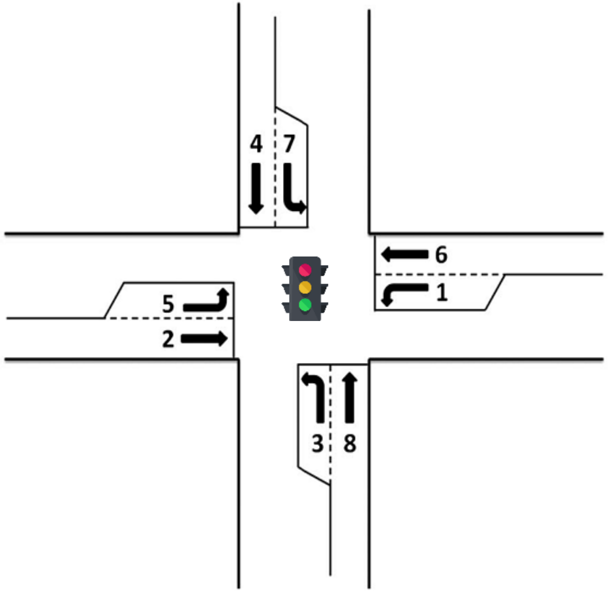


RL: Environment



RL: Action

- ❑ **Which signal phase will be green?**



- **Extend current green phase; OR**
- **Switch green light to another phase**

RL: Reward

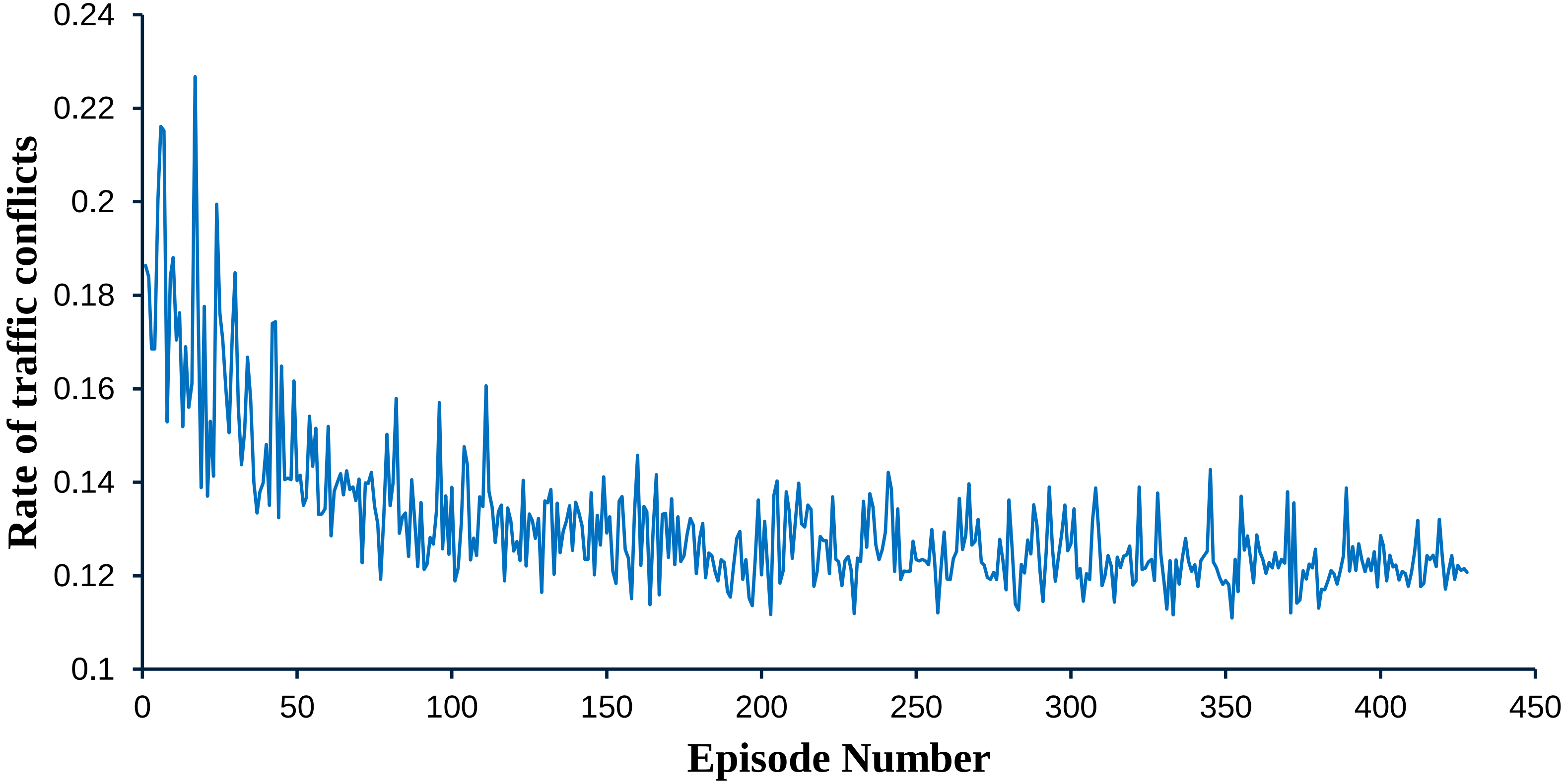
- Traffic conflicts/conflict rate as **a penalty**

- Using the developed real-time safety models:

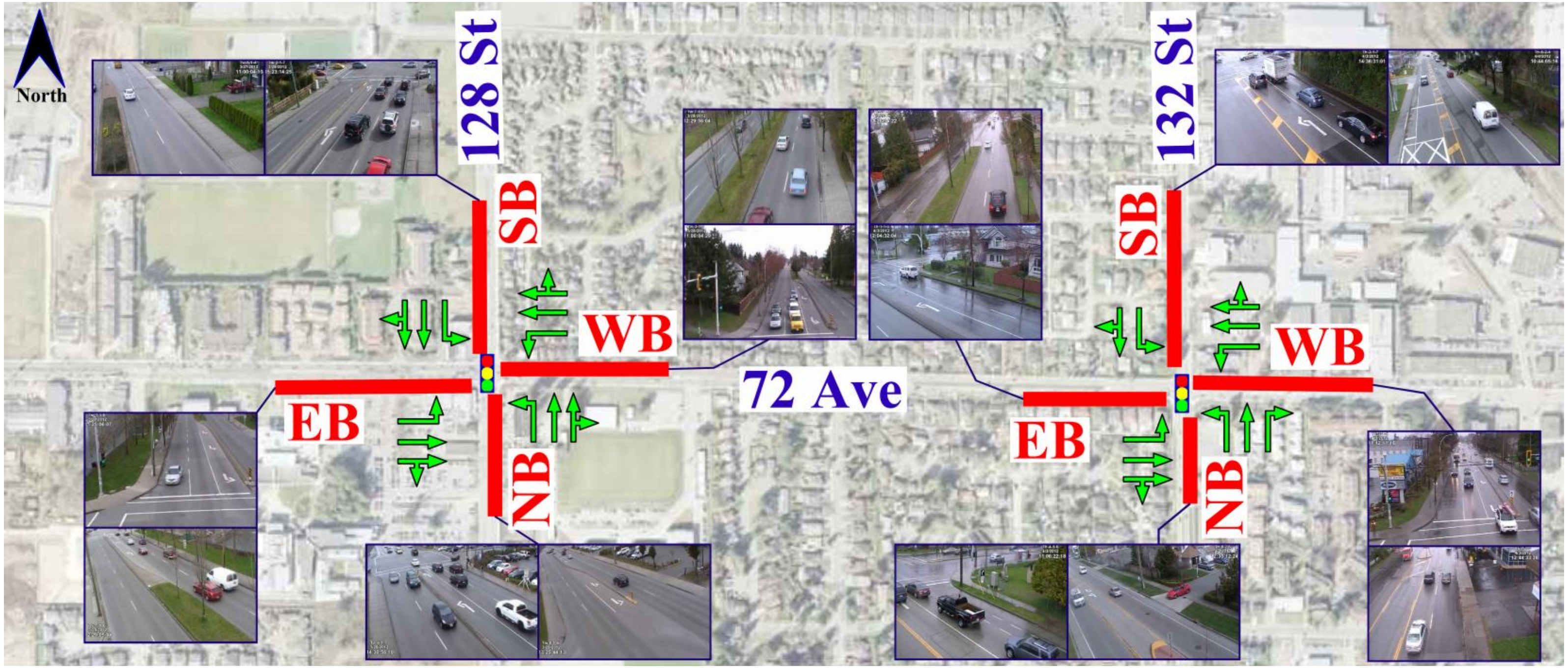
$$r^{t+1} = -\sum_{i=1}^{M}\sum_{j=1}^{N} Y_{ij}$$

- M: number of approaches at the intersection
- N: number of lanes per approach

RL: Training the algorithm

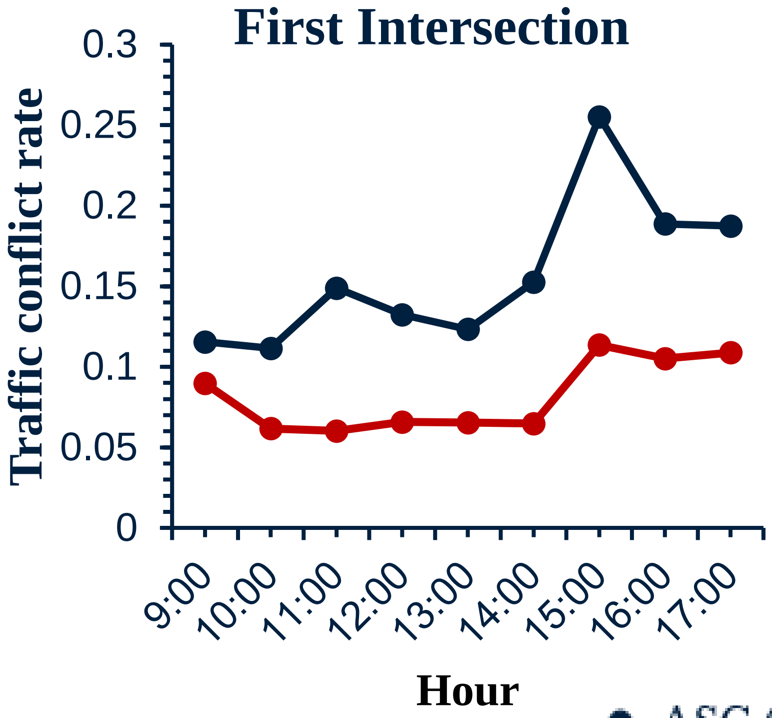


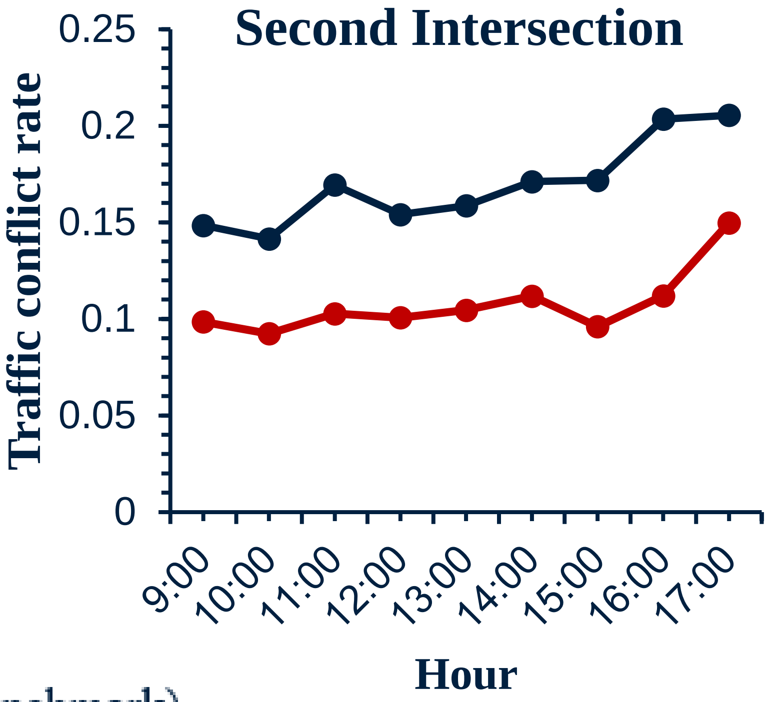
Validating the algorithm



- ❑ **Two signalized intersections**
- ❑ **Actuated Signal Controller (ASC)**

RS-ATSC Versus ASC

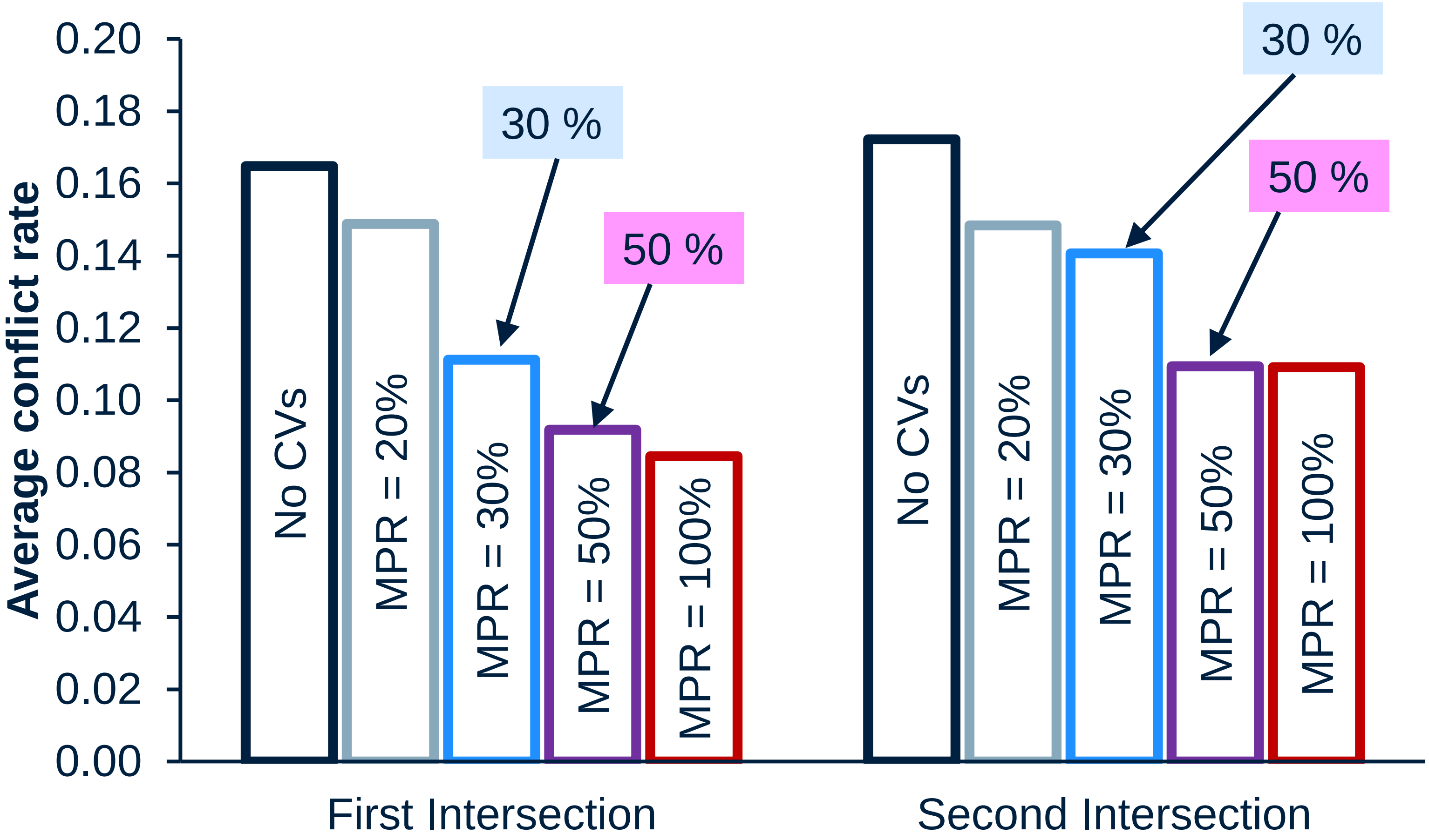




ASC (Benchmark)
Proposed RS-ATSC

	First Intersection	Second Intersection
Total traffic volume (9:00 am - 6:00 pm)	29,600	25,200
RS-ATSC compared to ASC		
Traffic Conflicts	-49%	-37%
Total Delays	-12%	-23%
Number of Stops	-47%	-27%
Max. Queue Length	-23%	-17%
95% Queue Length	-51%	-28%

Market Penetration Rate of CVs



Summary of the third objective

- RS-ATSC algorithm to optimize traffic safety using CVs data
- Reinforcement Learning approach
- Safety and mobility benefits
- Effective under low MPR values of CVs

Research Significance

- Three main contributions toward improving safety and mobility of signalized intersections under the CVs environment

- A new real-time safety evaluation method
- A new procedure to integrate real-time safety models with traffic microsimulation
- A new safety-oriented ATSC algorithm

Limitations and Future Research

- ❑ Sample size
- ❑ Other types of conflicts
- ❑ Other road facilities/ other road-users
- ❑ Safety index
- ❑ Convert conflicts to predicted number of crashes
- ❑ Undersaturated signal cycles

Limitations and Future Research

- ❑ **Signal coordination effect**
- ❑ **Multi-objective optimization (safety, mobility, environmental sustainability)**
- ❑ **Non-ideal V2X communication systems**
- ❑ **Multiple intersections (corridor/network)**
- ❑ **Sensitivity analysis (discount factor, DSRC, Δt, learning rate)**
- ❑ **Deep reinforcement learning**

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List of Publications

- Essa, M. and Sayed, T. 2018 “Traffic conflict models to evaluate the safety of signalized intersections at the cycle level.” Transportation Research Part C: emerging technologies, 89, pp.289-302.
- Essa, M. and Sayed, T. 2019 “Full Bayesian conflict-based models for real time safety evaluation of signalized intersections.” Accident Analysis and Prevention, 129, pp.367-381.
- Essa, M., Sayed, T. and Reyad, P. 2019 “Transferability of real-time safety performance functions for signalized intersections.” Accident Analysis and Prevention, 129, pp.263-276.
- Essa, M. and Sayed, T. 2020 “A comparison between SSAM and real-time safety models in predicting field-measured conflicts at signalized intersections.” Transportation Research Record, 2674(3), pp.100-112.
- Essa, M. and Sayed, T. “Self-learning adaptive traffic signal control for real-time safety optimization.” Accident Analysis and Prevention 146, 105713.

Other Publications

- Zheng, L., Sayed, T. and Essa, M. 2019 “Bayesian hierarchical modeling of the non-stationary traffic conflict extremes for crash estimation.” Analytic Methods in Accident Research, 23, p.100100.
- Zheng, L., Sayed, T. and Essa, M. 2019 “Validating the bivariate extreme value modeling approach for road safety estimation with different traffic conflict indicators.” Accident Analysis and Prevention, 123, pp.314-323.
- Zheng, L., Sayed, T. and Essa, M., 2020. Investigating the transferability of Bayesian hierarchical extreme value model for traffic conflict-based crash estimation. Canadian Journal of Civil Engineering.
- Guo, Y., Sayed, T. and Essa, M., 2020. Real-time conflict-based Bayesian Tobit models for safety evaluation of signalized intersections. Accident Analysis & Prevention, 144, p.105660.

Thank You

For Your Attention

Questions?