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Signal Control Strategies for Improved Person Mobility and Air Quality in Multimodal Transportation Systems

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Outline

- Background
  - Transit Signal Priority (TSP) Strategies
  - Real-time signal control systems with TSP
  - Real-time signal control systems to reduce emissions
- Person-based signal control system
- Emission-based signal control system
- Other projects

Motivation

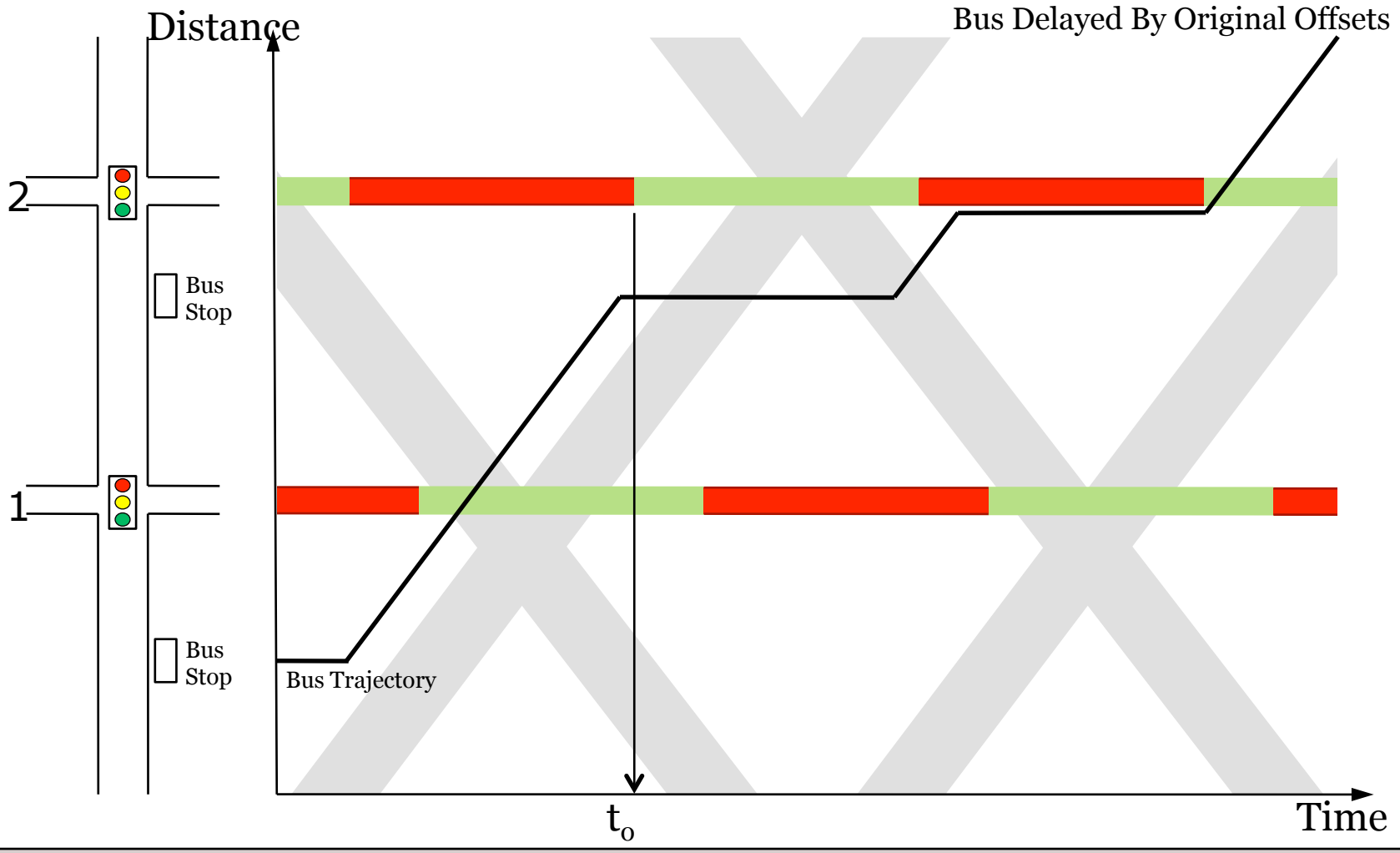
Motivation

Transit Signal Priority Strategies

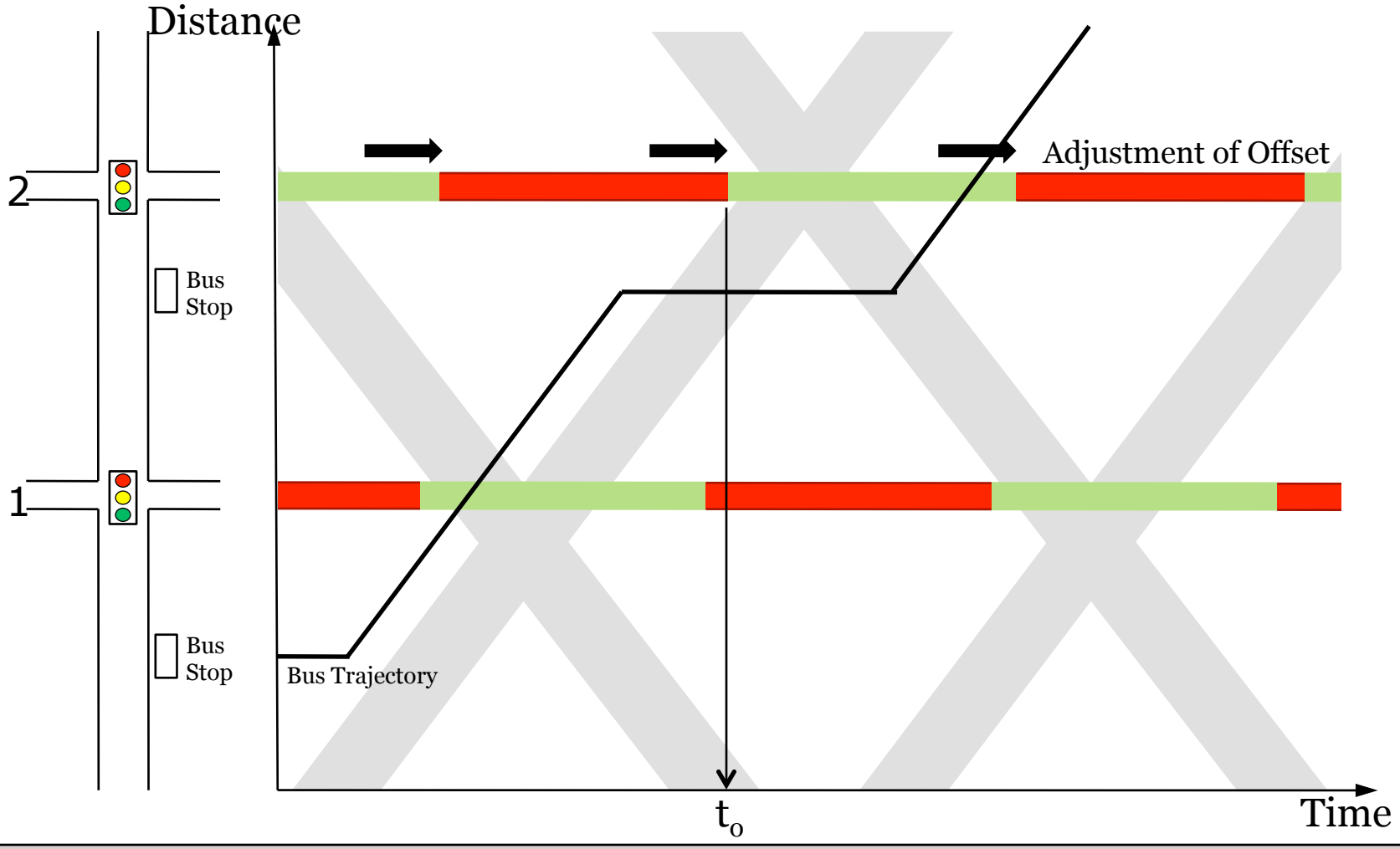
Passive Priority Strategies

- adjustment of offsets
- additional green time for transit phases
- reduction in cycle length

Adjustment of Offsets



Adjustment of Offsets



Transit Signal Priority Strategies

Passive Priority Strategies

- adjustment of offsets
- additional green time for transit phases
- reduction in cycle length

Issues:

- Fixed dwell times for transit vehicles
- Not traffic responsive

Transit Signal Priority Strategies

Active Priority Strategies

- phase extension (green extension)
- phase advance (red truncation)
- phase insertion
- phase rotation

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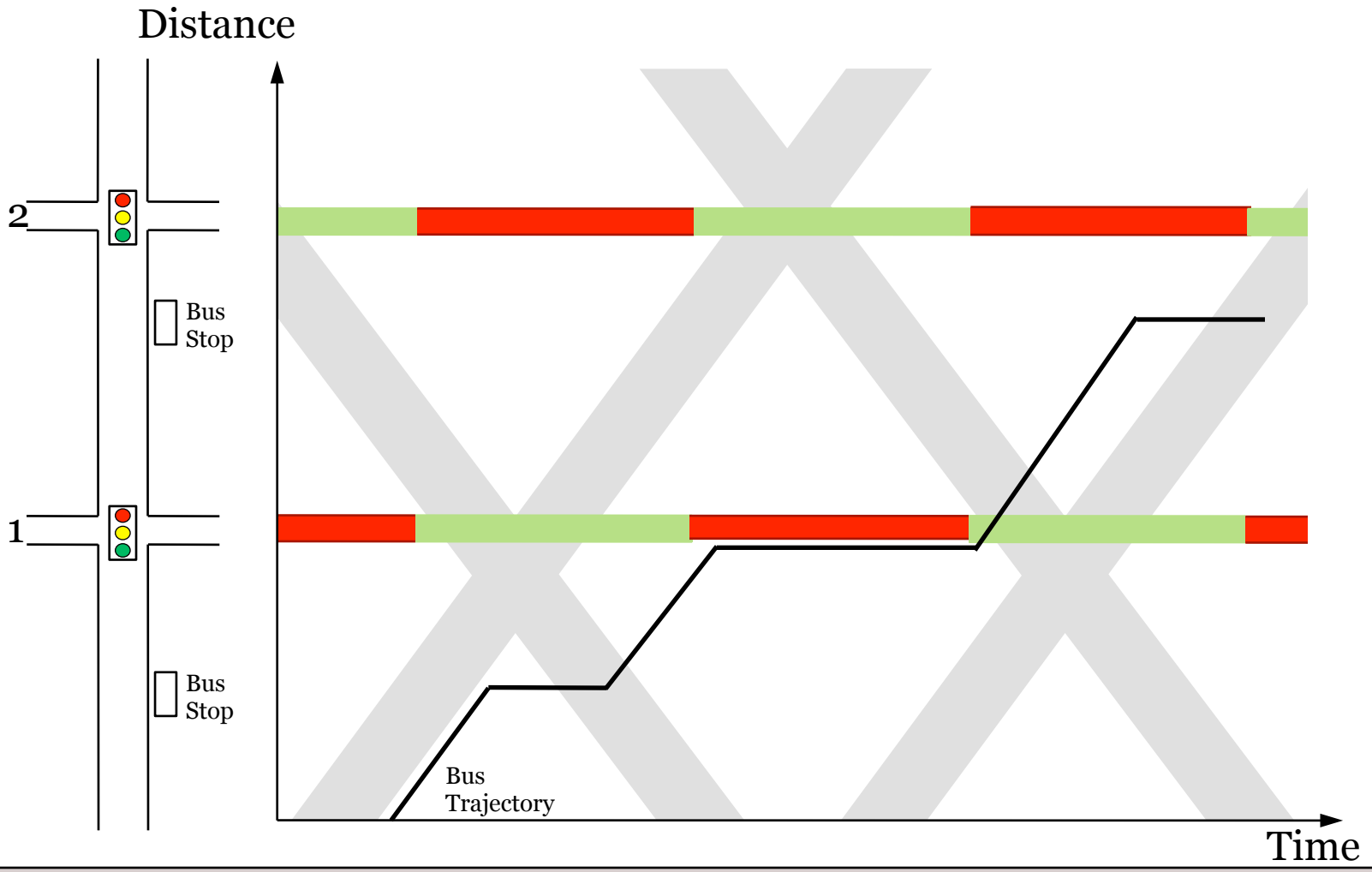
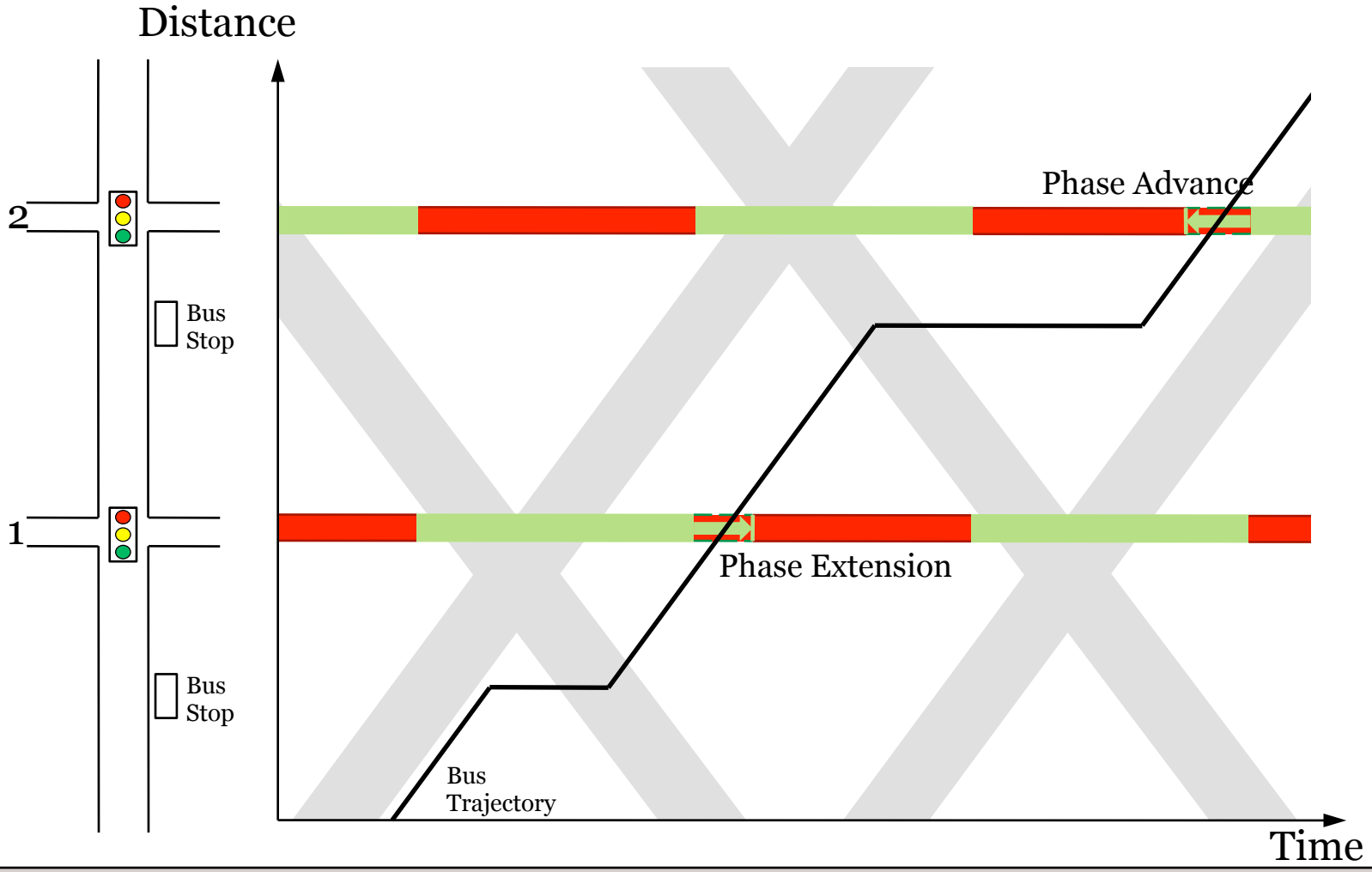
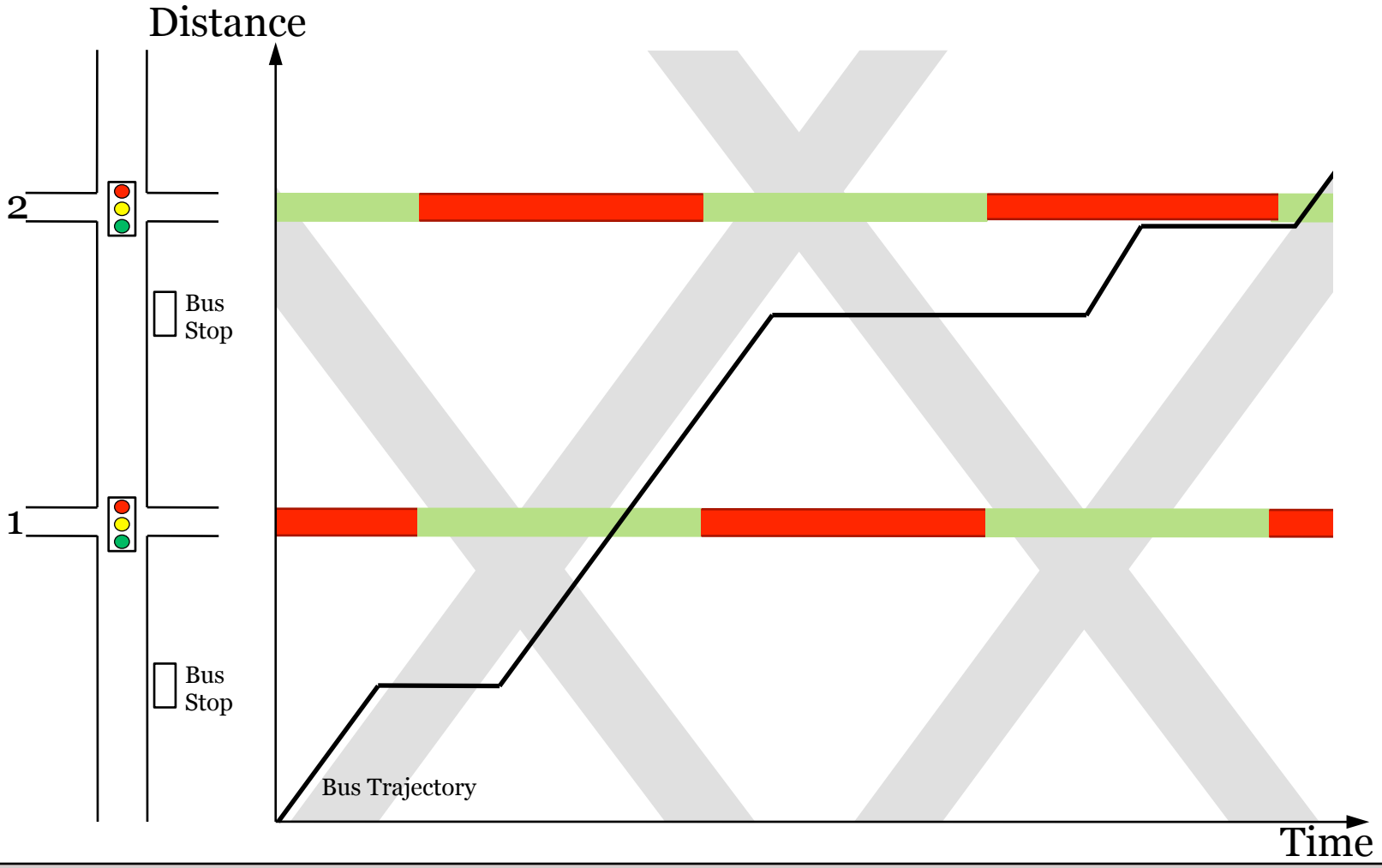
Phase Extension – Phase Advance



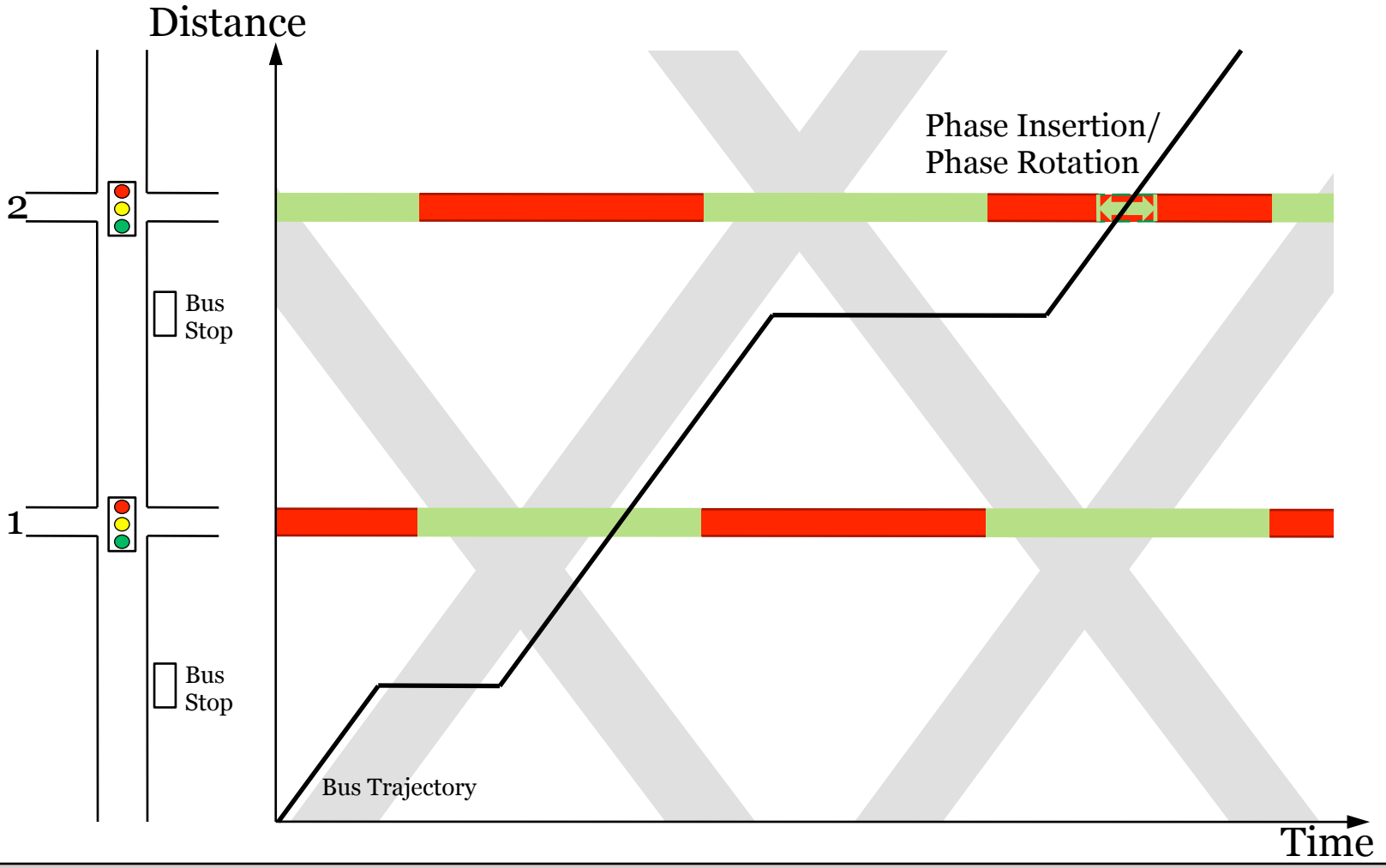
Phase Extension – Phase Advance



Phase Rotation– Phase Insertion



Phase Rotation – Phase Insertion



Transit Signal Priority Strategies

Active Priority Strategies

- phase extension (green extension)
- phase advance (red truncation)
- phase insertion
- phase rotation

Issues:

- Loss of signal coordination (potential)
- Oversaturation of vehicle movements (side-streets)
- Not conditional TSP

Transit Signal Priority Strategies

Real-Time (Traffic Responsive, Adaptive)

- Real-time signal settings adjustment
- Prediction of flows and arrival times from sensors

Real-time Signal Control Systems with TSP

Traffic Responsive

SCOOT
(Hunt et al., 1982; Bretherton, 1996; Bretherton et al., 2002)

SCATS
(Cornwell et al., 1986)

TUC
(Diakaki et al., 2003)

ATSPS—California, PATH
(Li, 2008)

Adaptive

UTOPIA
(Donati et al., 1984; Mauro and Di Taranto, 1989)

PRODYN
(Henry and Farges,1994)

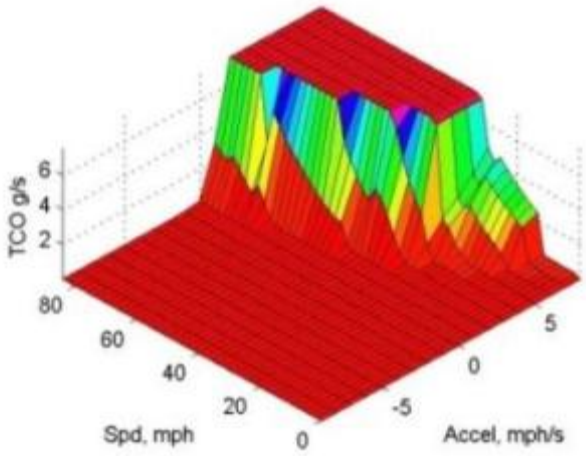
SPPORT
(Yagar and Han, 1994; Yagar and Dion, 1996; Conrad et al., 1998; Dion and Hellinga, 2002)

Centralized TSP—LADOT
(Li et al., 2008)

PAMSCOD
(He et al., 2011)

Emission-based signal control

- The majority of the studies have focused on evaluation of the signal control strategies' impacts on pollutant emissions
  - Field studies
  - Simulation studies
  - Analytical models
- Existing analytical models estimate emissions based on average speed
  - Effects of instantaneous speed changes are not captured
  - Vehicle movements with the same average speed and different speed changes and acceleration levels produce different emission levels
  - Non-smooth operations and stop-and-go traffic results to higher levels of emissions



Barth et al., 1999

Literature Review Summary

1. Existing Real-time Signal Control Systems with TSP

- No efficient treatment of conflicting transit routes
- No consideration of schedule delay
- No utilization of currently deployable technologies
- High computation times

2. Existing Emission-based Real-time Signal Control Systems

- No estimation using modal-based emission models

1. Person-based traffic responsive signal control system

Objectives

- Person-based traffic responsive signal control system with transit priority
  - Conditional priority based on occupancy & schedule delay
  - Transit vehicles traveling in conflicting directions
  - Impact on auto traffic is minimized
- Use of currently available technologies

Mathematical Program

$$\text{Min} \quad \sum_{r=1}^{2} \left[\sum_{a=1}^{A_T^r} o_a d_a(g_{i,T}^r) + \sum_{b=1}^{B_T^r} o_{b,T}^r \left(1 + \delta_{b,T}^r\right) d_b\left(g_{i,T}^r\right) \right]$$

(Person Delay)

subject to:

$$g_{i,T}^r \geq g_{i,\min}^r \quad \forall i, r$$

(Minimum Green)

$$\sum_{i=1}^{I^r} g_{i,T}^r + L^r = C \quad \forall r$$

(Constant Cycle Length)

o_a : *occupancy of auto a [pax/veh]*

$o^r_{b,T}$: *occupancy of transit vehicle b during cycle T at intersection r [pax/veh]*

A^r_T : *total number of autos present at intersection r during cycle T*

B^r_T : *total number of transit vehicles present at intersection r during cycle T*

$d_a(g^r_{i,T})$: *control delay for auto a [sec]*

$d_b(g^r_{i,T})$: *control delay for transit vehicle b [sec]*

$\delta^r_{b,T}$: *variable for schedule delay of transit vehicle b at intersection r during T*

$g^r_{i,T}$: *green time allocated to phase i during T at intersection r [sec]*

g^r_{imin} : *minimum green time allocated to phase i at intersection r [sec]*

C : *cycle length [sec]*

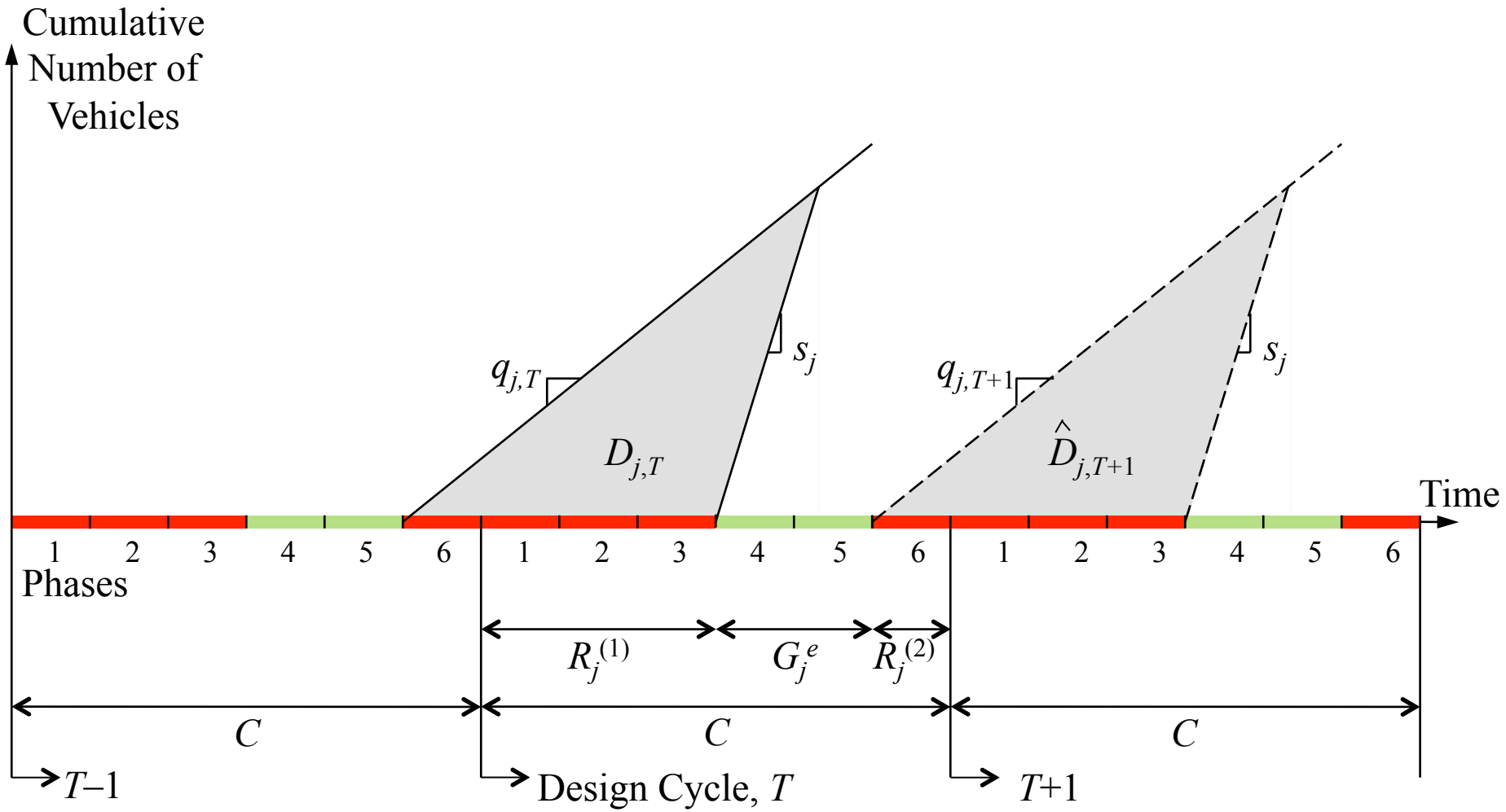
I^r : *number of phases in a cycle for intersection r*

L^r : *lost time for intersection r [sec]*

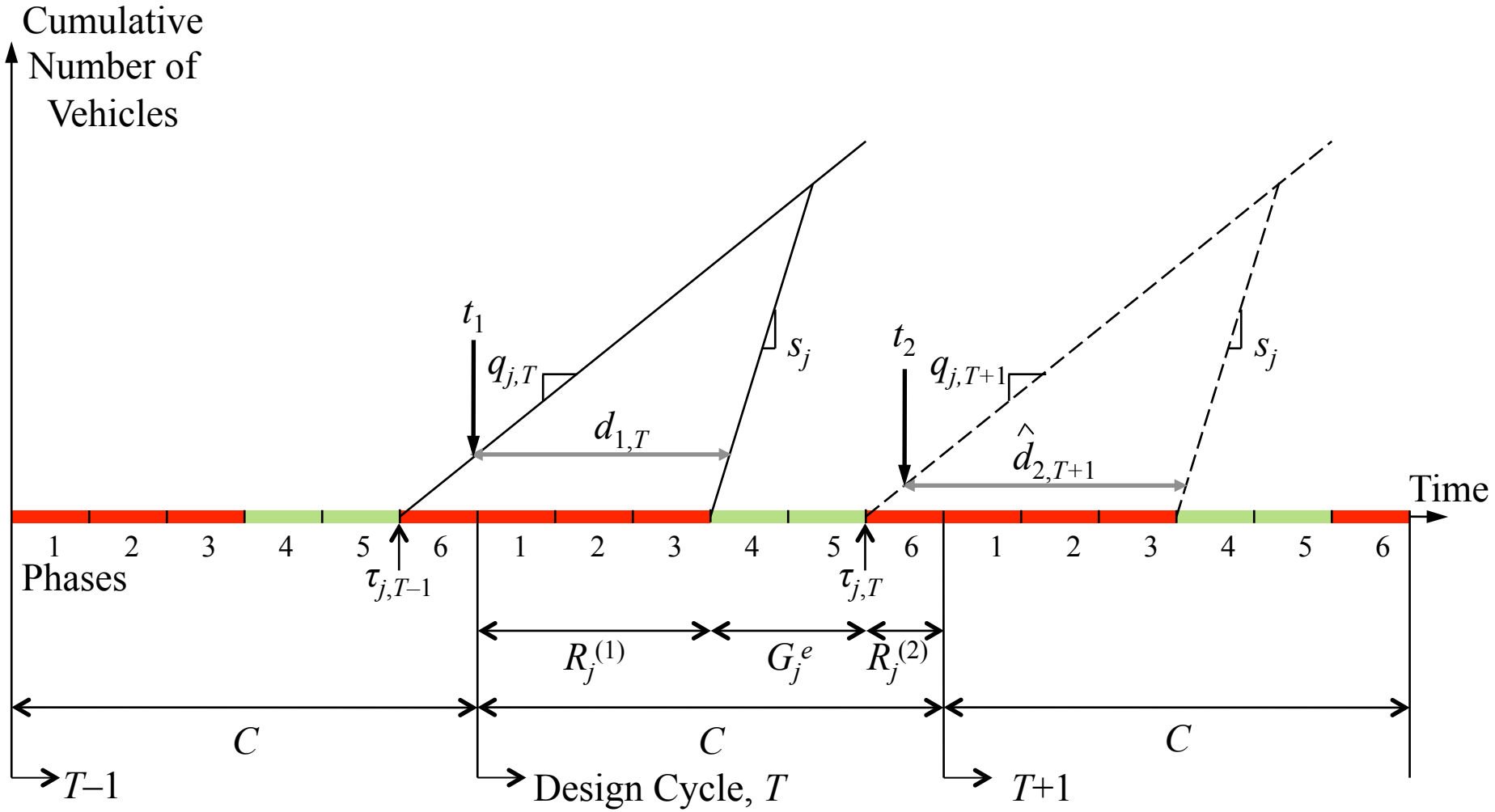
Assumptions

- Impact of bus stops on auto and transit operations are ignored
- Deterministic service times at the intersection
- Transit vehicles travel in mixed lanes along with autos
- On isolated intersections vehicles arrive at a constant rate
- On arterial signalized intersections vehicles arrive in platoons
  - no platoon dispersion is taken into account
- Analytical models developed:
  - account only for uniform delay
  - assume that auto and transit vehicle arrival times are known in real-time

Auto delay estimation



Transit vehicle delay estimation



Input

Sensing Systems (detectors)

- Vehicle platoon size/arrival rate
- Travel times

Automated Vehicle Location (AVL) Systems

- Bus dwell times at bus stops→ travel times→ arrival times
- Schedule delay

Automated Passenger Counter (APC) Systems

- Bus passenger occupancy

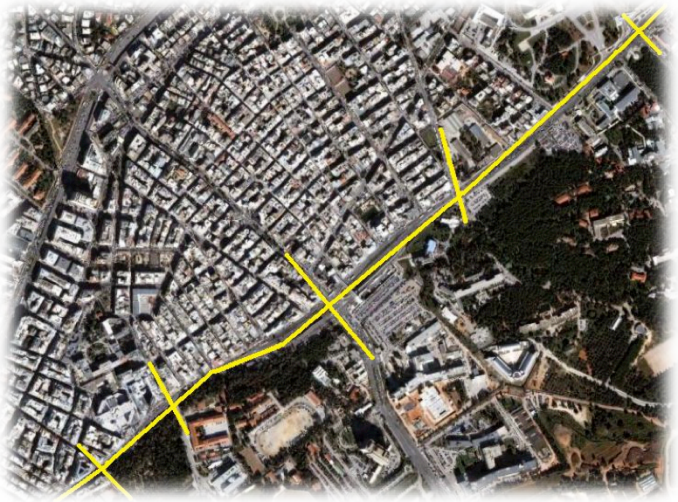
Evaluation

Types of Tests:

1. Test I: Deterministic arrival tests
   - Perfect information about the input
2. Test II: Stochastic arrival tests
   - Simulation

Test Sites

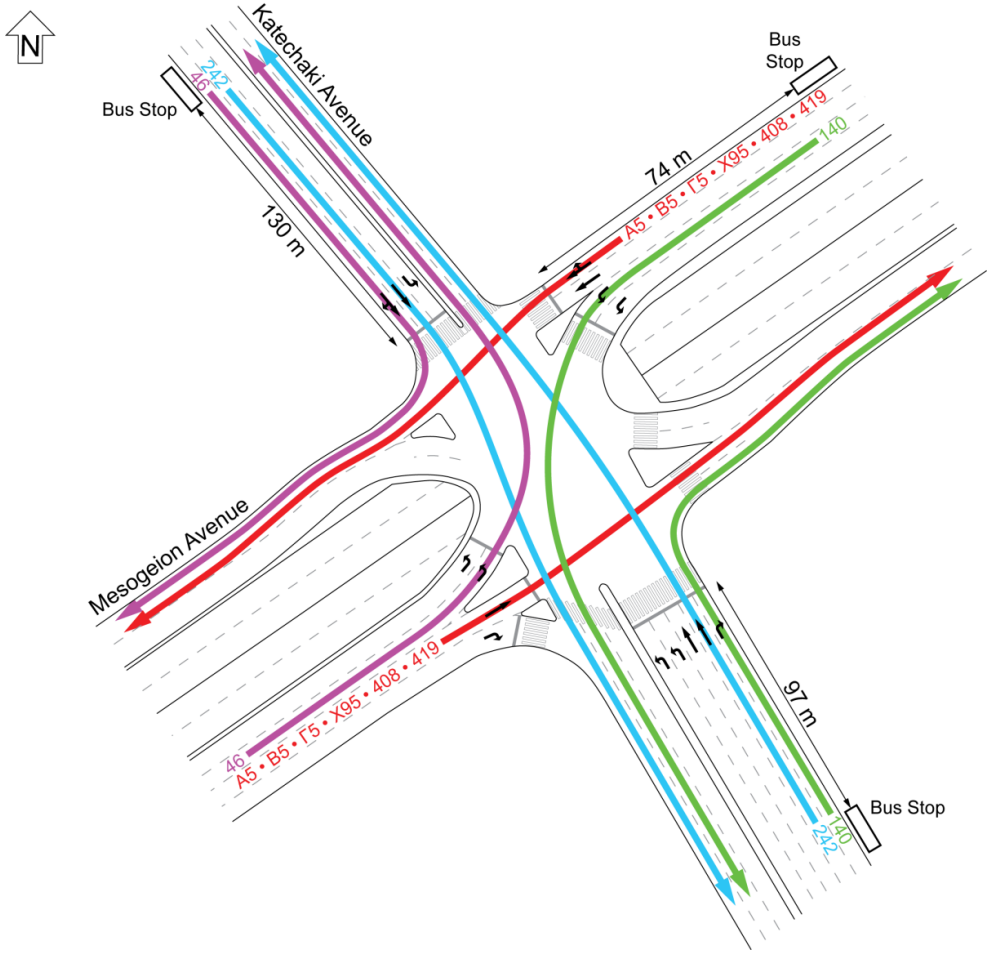
Isolated Intersection



Arterial

Isolated Intersection

Test Site – Mesogeion & Katechaki Avenues



Test Site – Mesogeion & Katechaki Avenues

9 bus routes

43 buses/hour

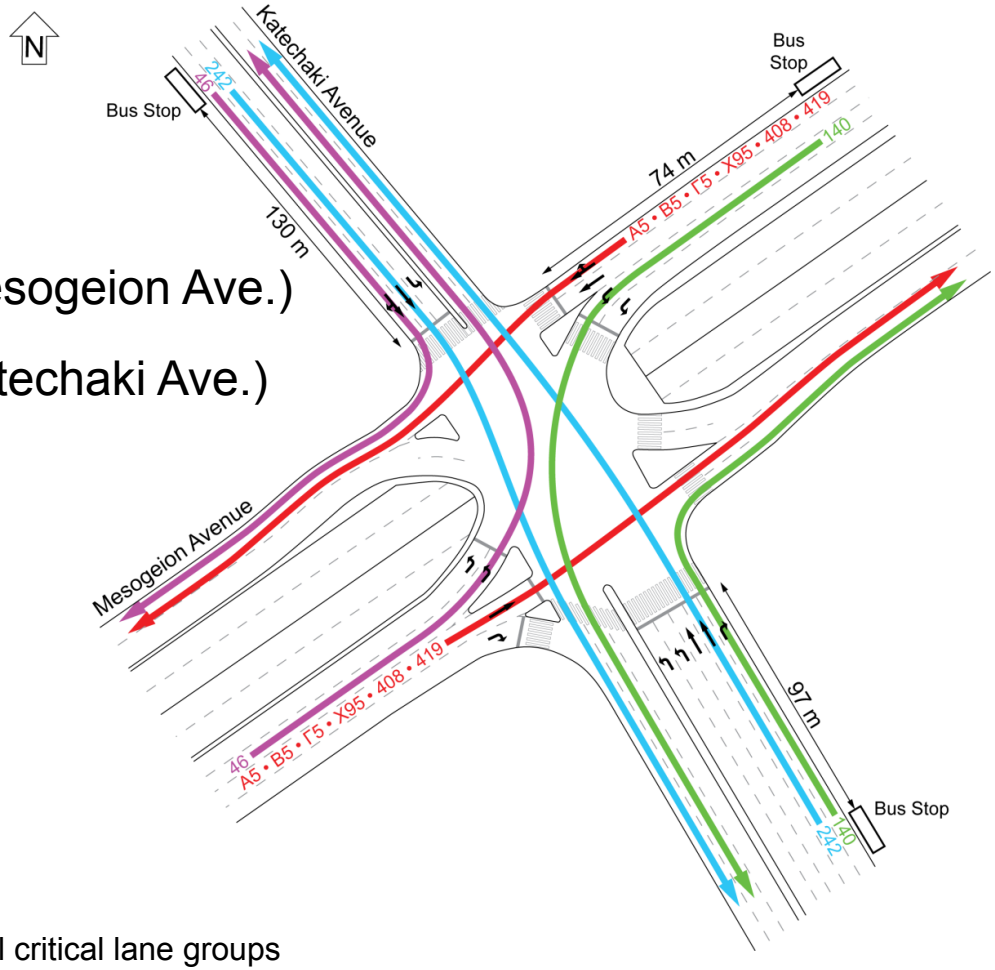
70% on NE-SW approaches (Mesogeion Ave.)

30% on NW-SE approaches (Katechaki Ave.)

Cycle length (*C*) = *120* sec

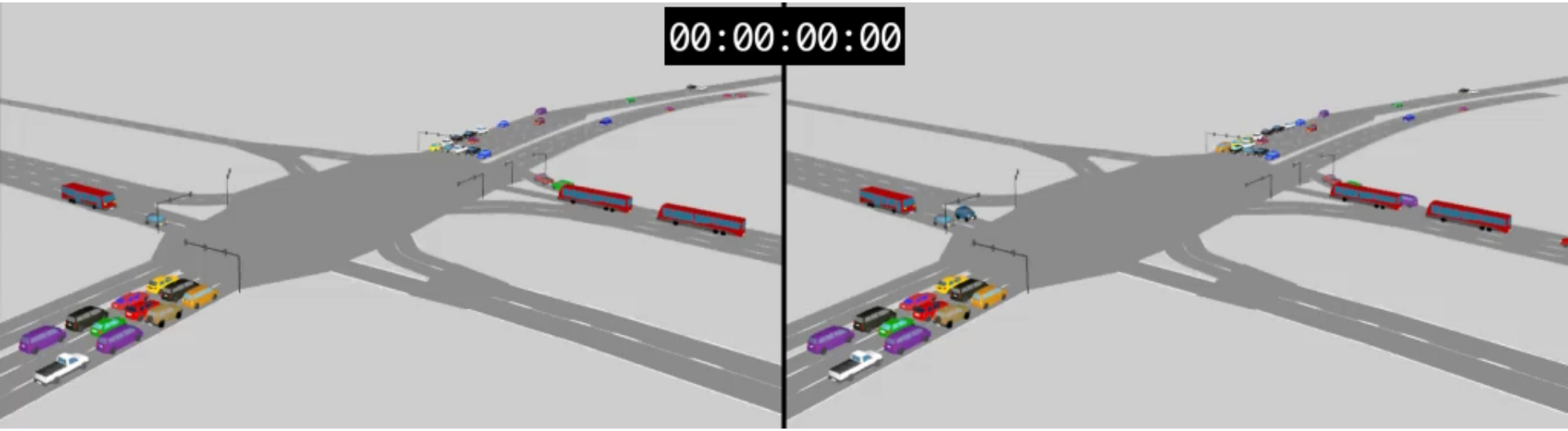
Lost time (*L*) = *14* sec

Intersection flow ratio* (*Y*) = *0.90*



* *Intersection flow ratio*: the sum of flow ratios (v/s) for all critical lane groups

Isolated Intersection—Simulation



Vehicle-based Optimization

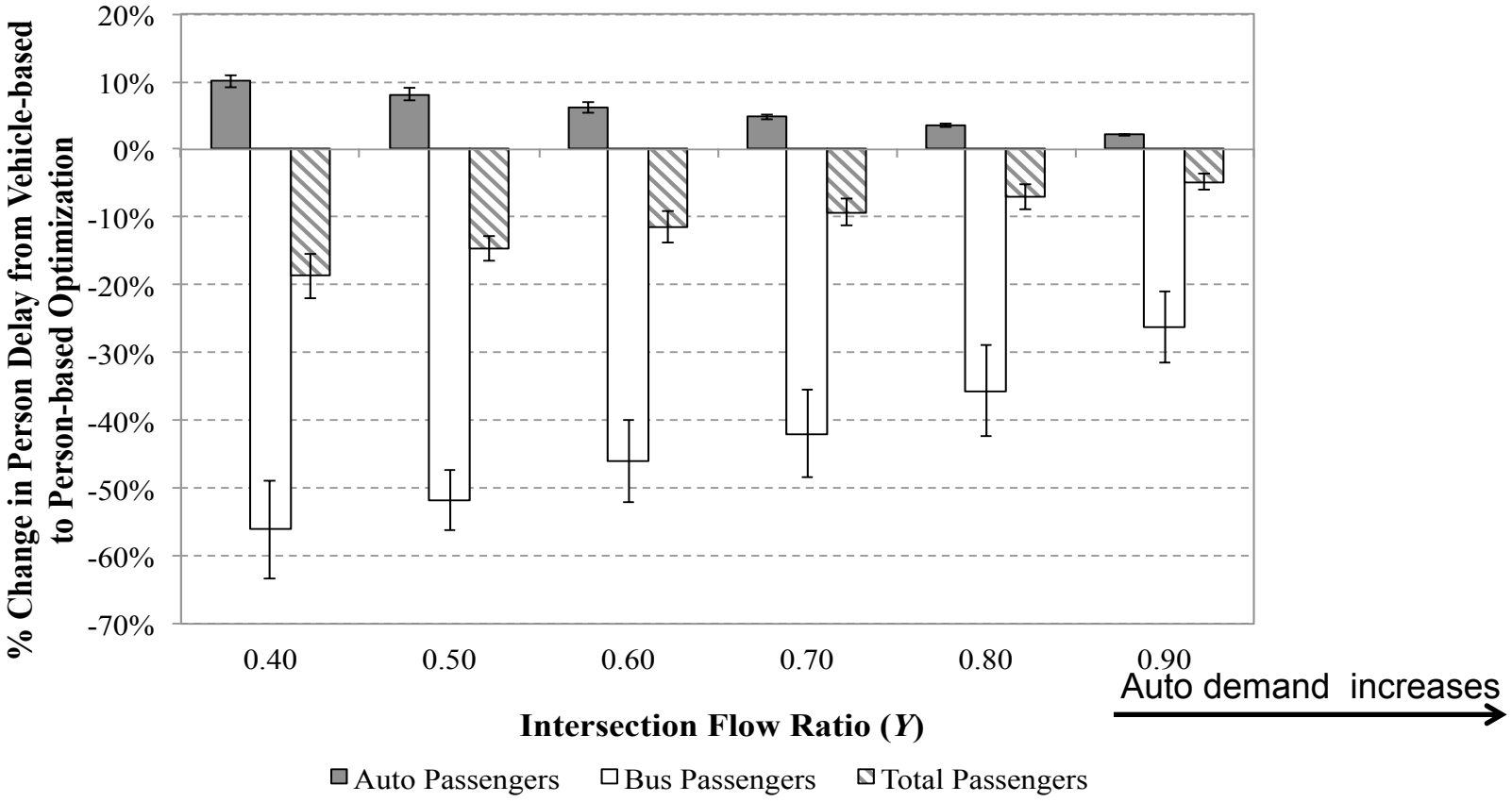
Person-based Optimization

Test I – Deterministic arrival tests

Effect of Auto Demand

$\bar{o}_a = 1.25$ [pax/veh]

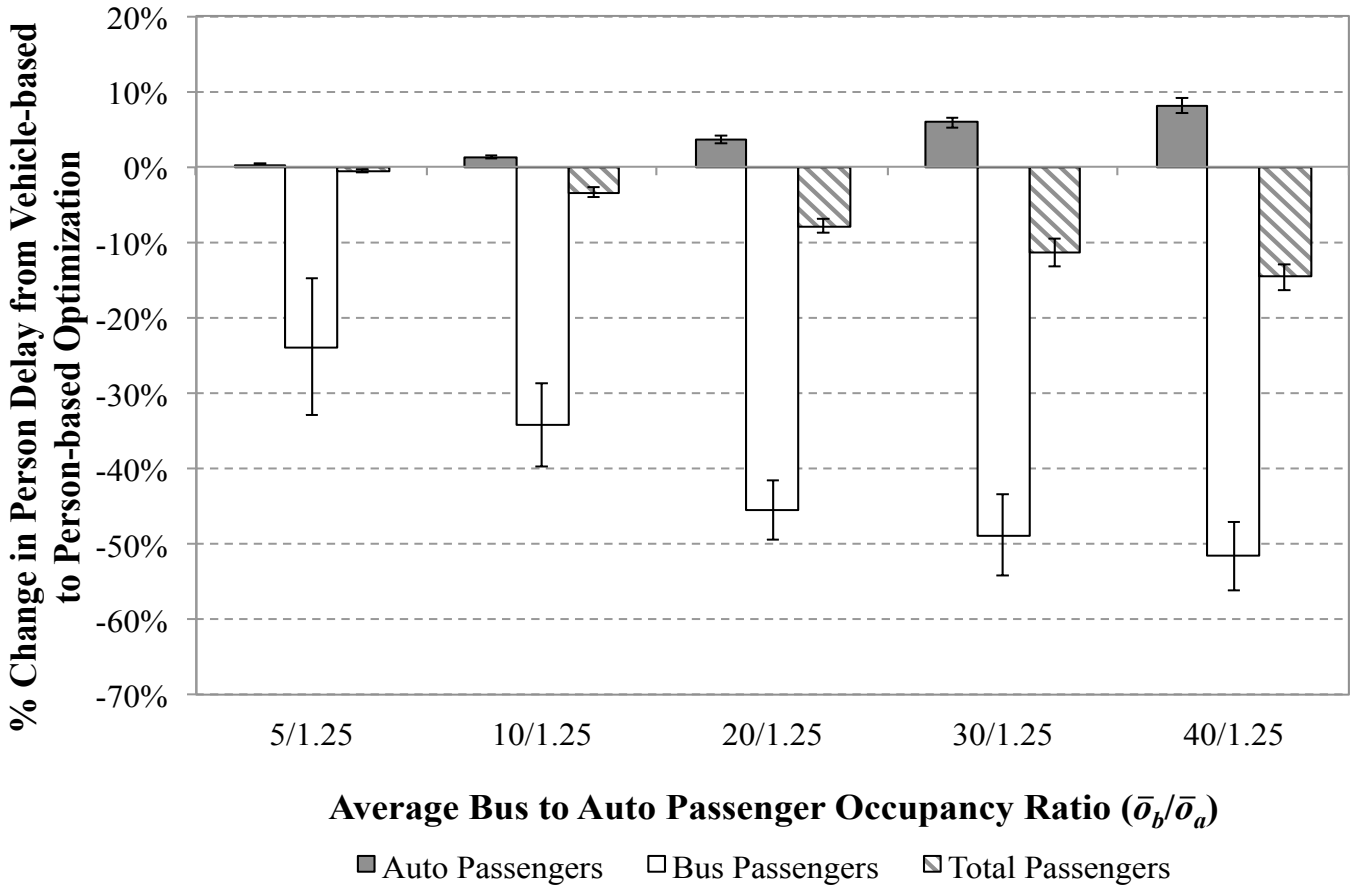
$\bar{o}_b = 40$ [pax/veh]



Test I – Deterministic arrival tests

Effect of Bus Passenger Occupancy

Y=0.5

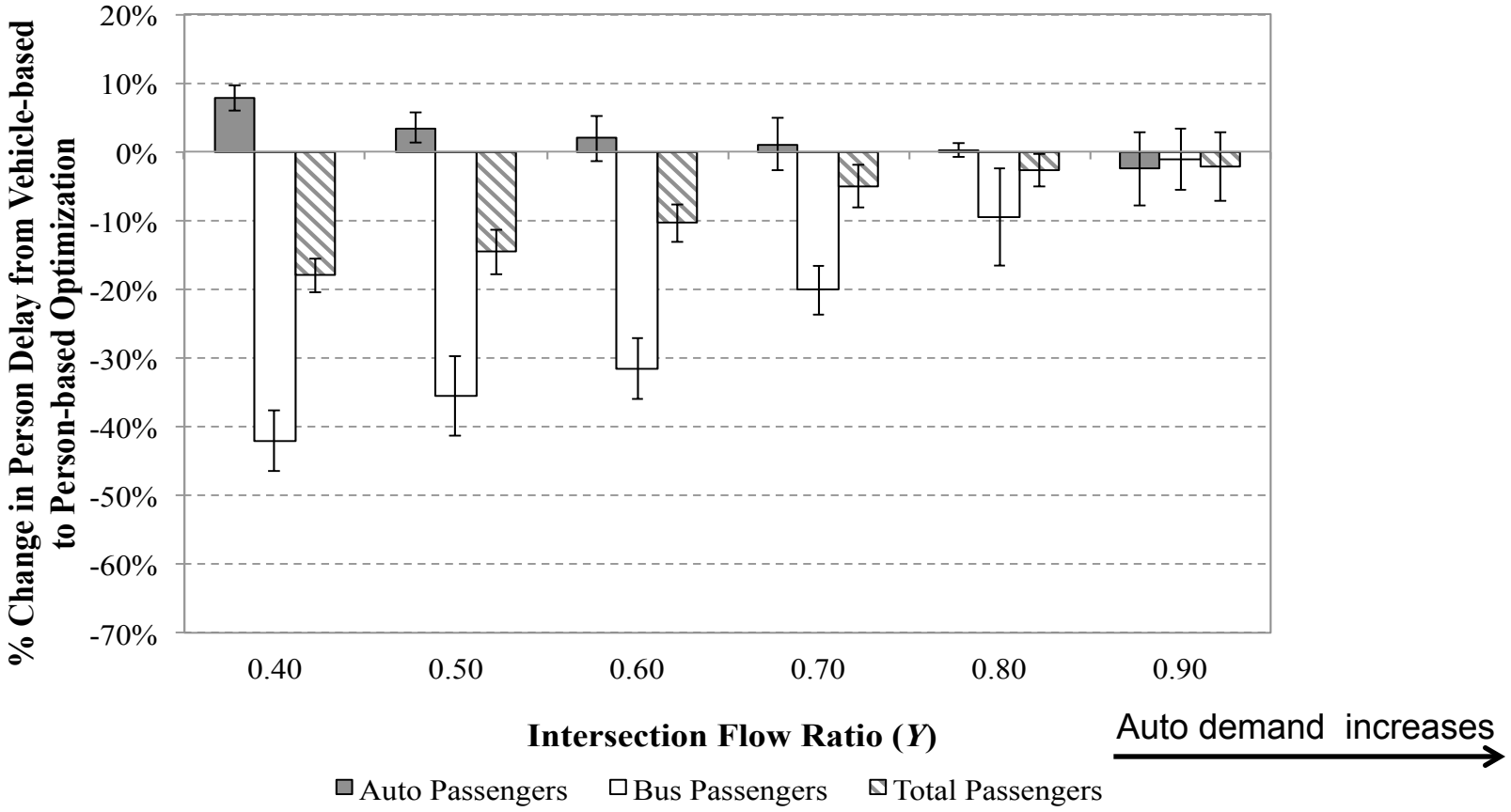


Test II – Stochastic arrival tests (simulation)

$\bar{o}_a = 1.25$ [pax/veh]

$\bar{o}_b = 40$ [pax/veh]

Effect of Auto Demand



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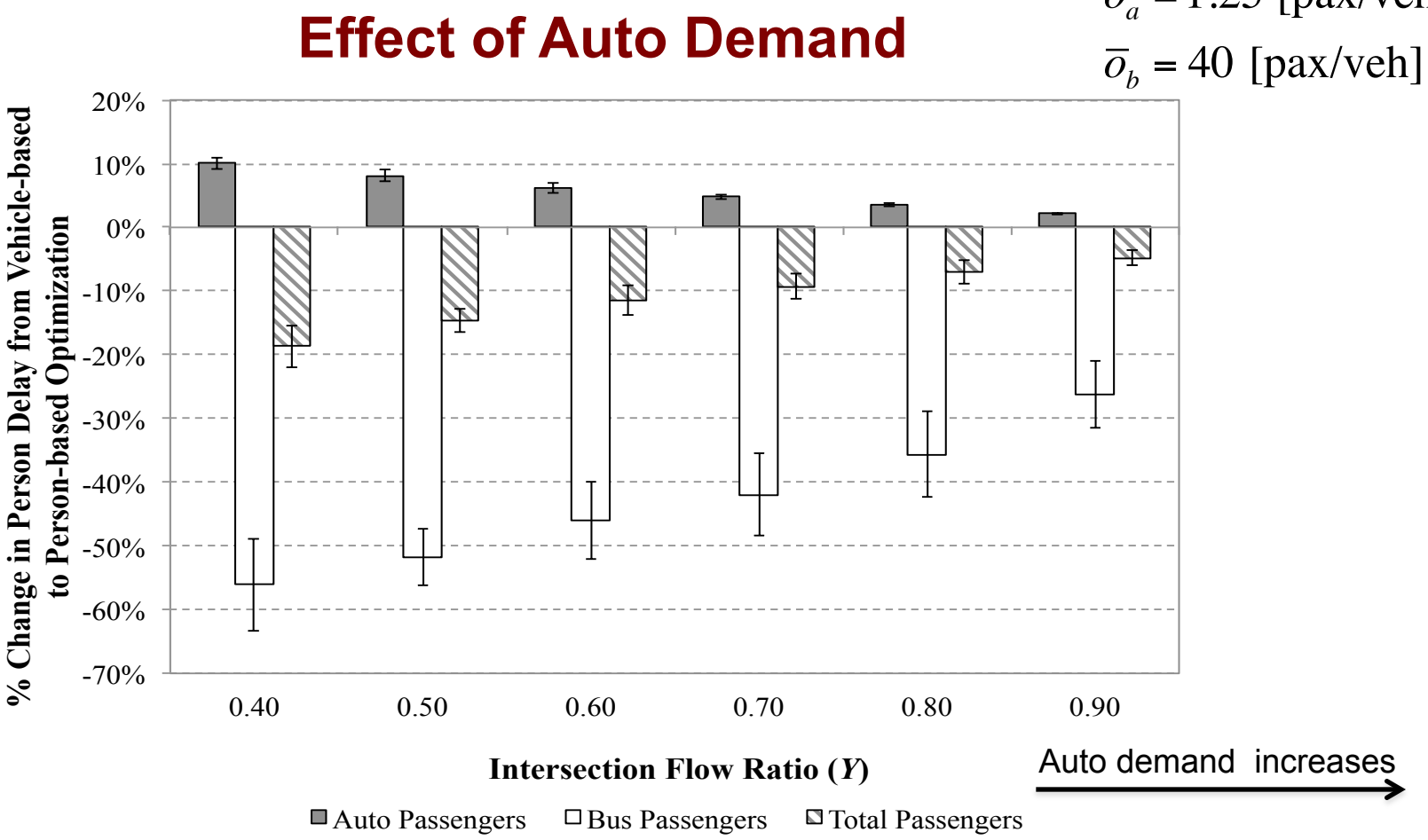

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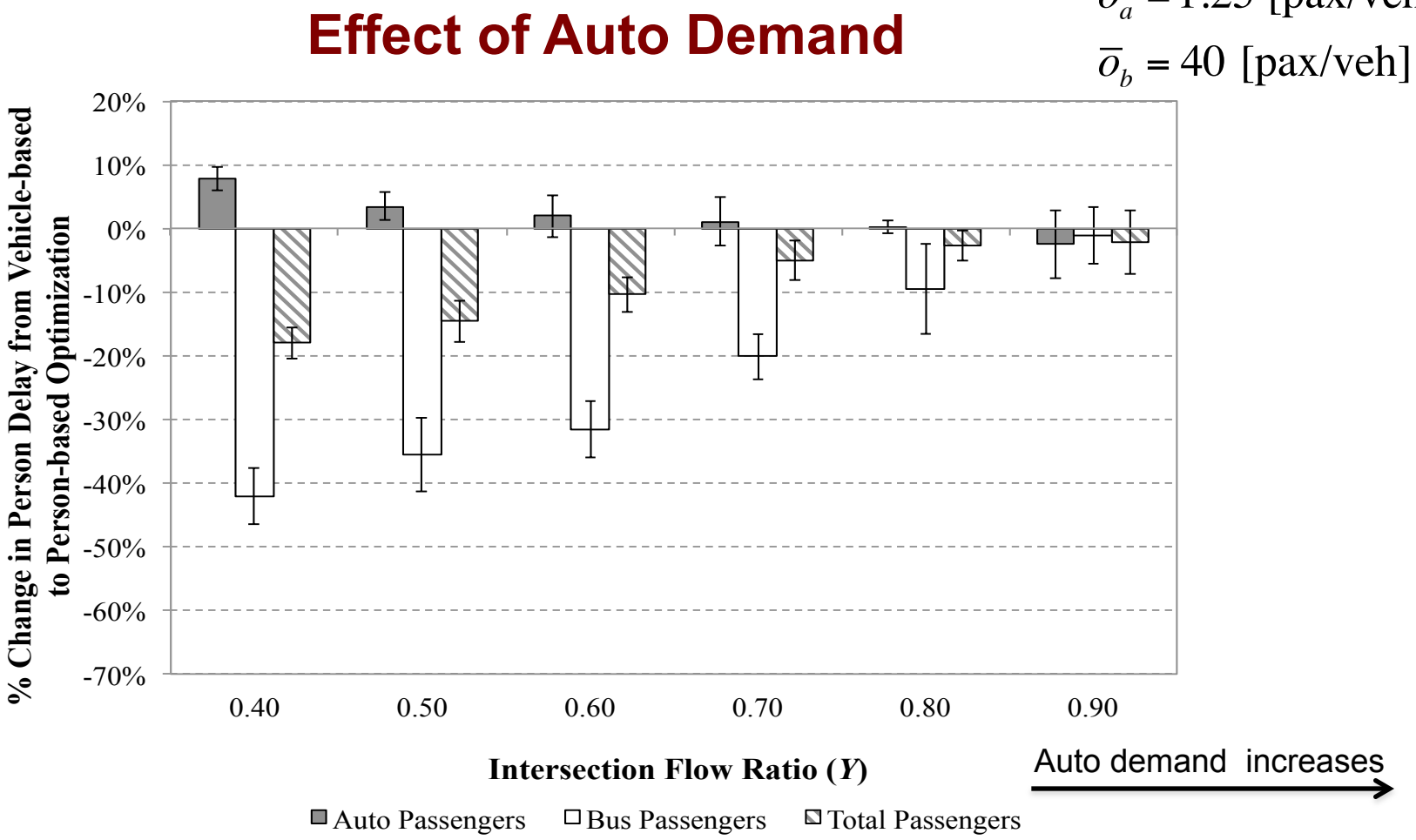


Findings – Isolated Intersection

- Reduction in overall person delay and transit user delay
- Small increases in auto user delay
- Negative impact on autos diminishes with higher auto demand
- Higher transit occupancies lead to higher total person delay reductions

Findings – Signalized Arterial

- Input accuracy is critical to the performance of the system
- Buses traveling on cross-streets with low auto demand experience very high benefits when priority is provided
- Higher benefit for transit users when schedule delay is accounted for without negatively affecting auto users

2. Emission-based traffic responsive signal control system

Mathematical Program

$$\text{Min} \sum_{a=1}^{A_T} \sum_{m} e_m^a t_{a,m}(g_{i,T}) + \sum_{b=1}^{B_T} \sum_{m} e_m^b t_{b,m}(g_{i,T})$$

(Emissions)

subject to:

$$g_{i,T} \geq g_{i,\min} \quad \forall i$$

(Minimum Green)

$$\sum_{i=1}^{I} g_{i,T} + L = C$$

(Constant Cycle Length)

e_a : *emission factor for auto a in mode m [g CO_2/sec]*

e_b : *emission factor for transit veh. b in mode m [g CO_2/sec]*

$t_{a,m}(g_{i,T})$: *travel time of auto a in mode m [sec]*

$t_{b,m}(g_{i,T})$: *travel time of transit vehicle b in mode m [sec]*

A_T : *total number of autos present at intersection r during cycle T*

B_T : *total number of transit vehicles present at intersection r during cycle T*

m : *driving mode (i.e., acceleration, deceleration, cruising, or idling)*

$g_{i,T}$: *green time allocated to phase i during T [sec]*

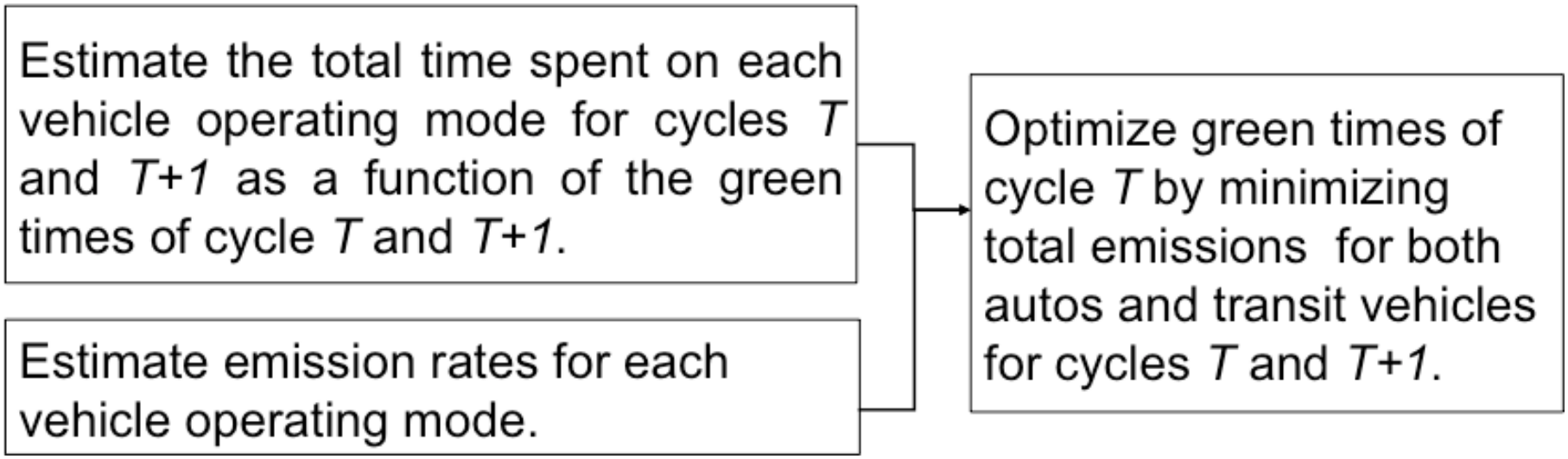
g_{imin} : *minimum green time allocated to phase I [sec]*

C : *cycle length [sec]*

I : *number of phases in a cycle for intersection r*

L : *lost time for intersection r [sec]*

Methodology



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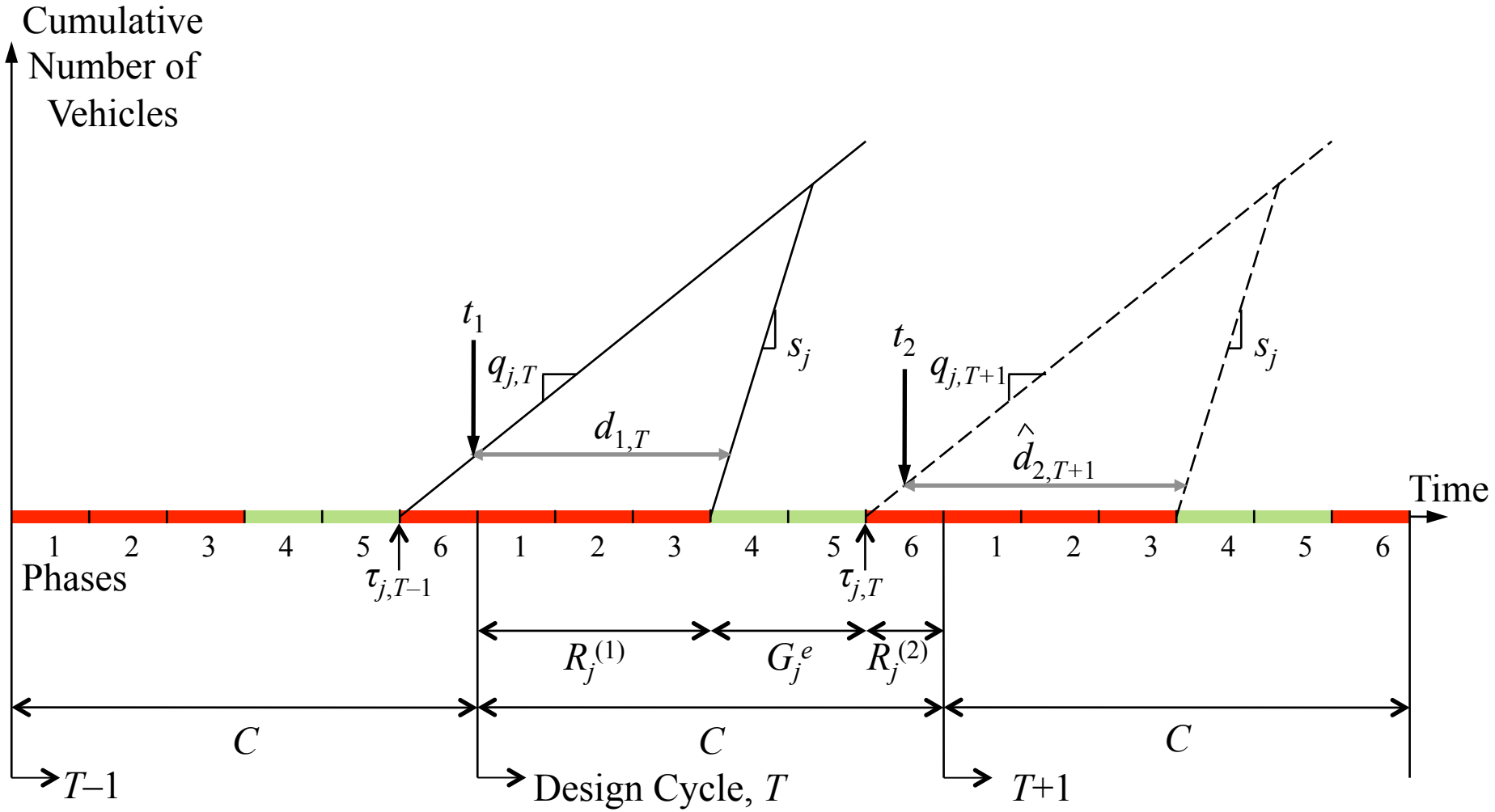

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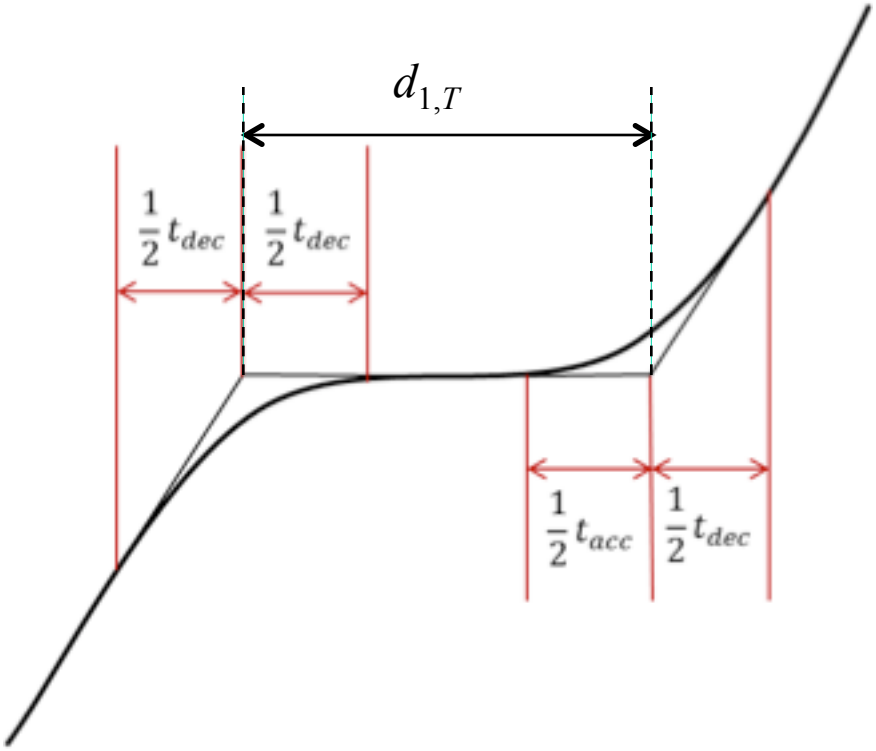
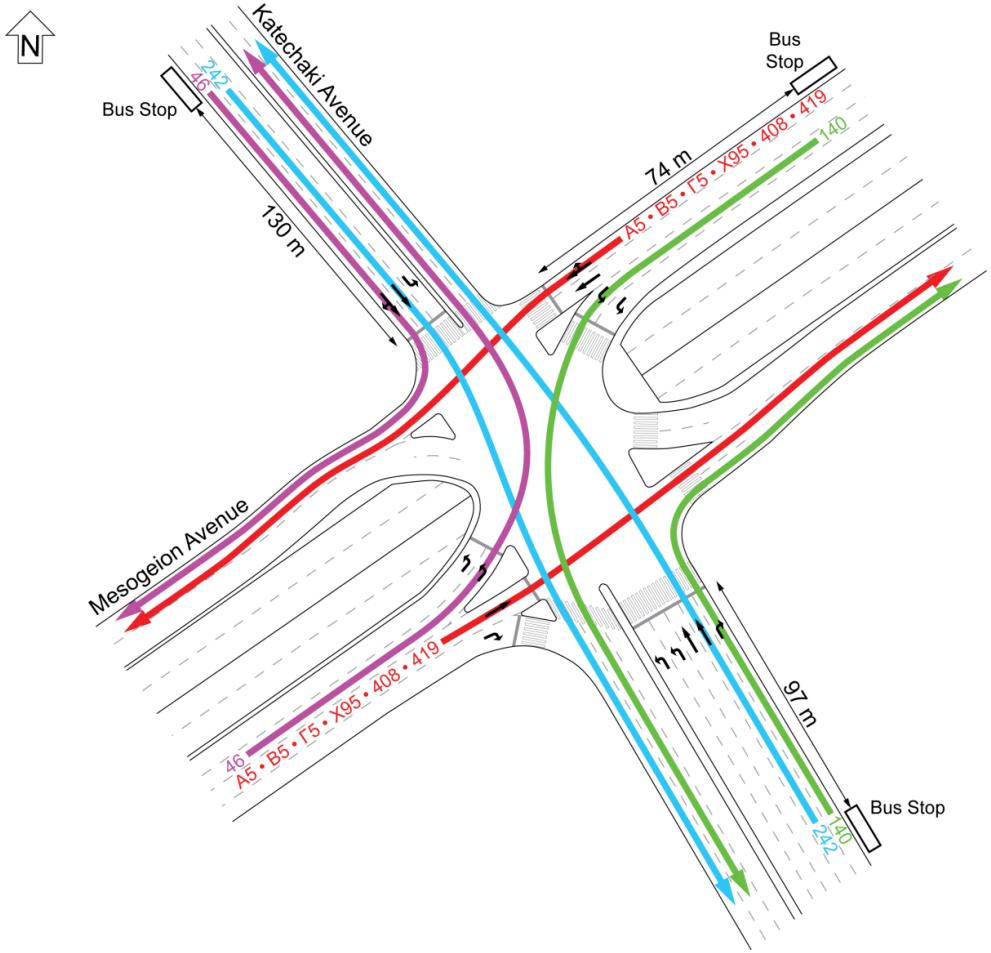


Test Site – Mesogeion & Katechaki Avenues

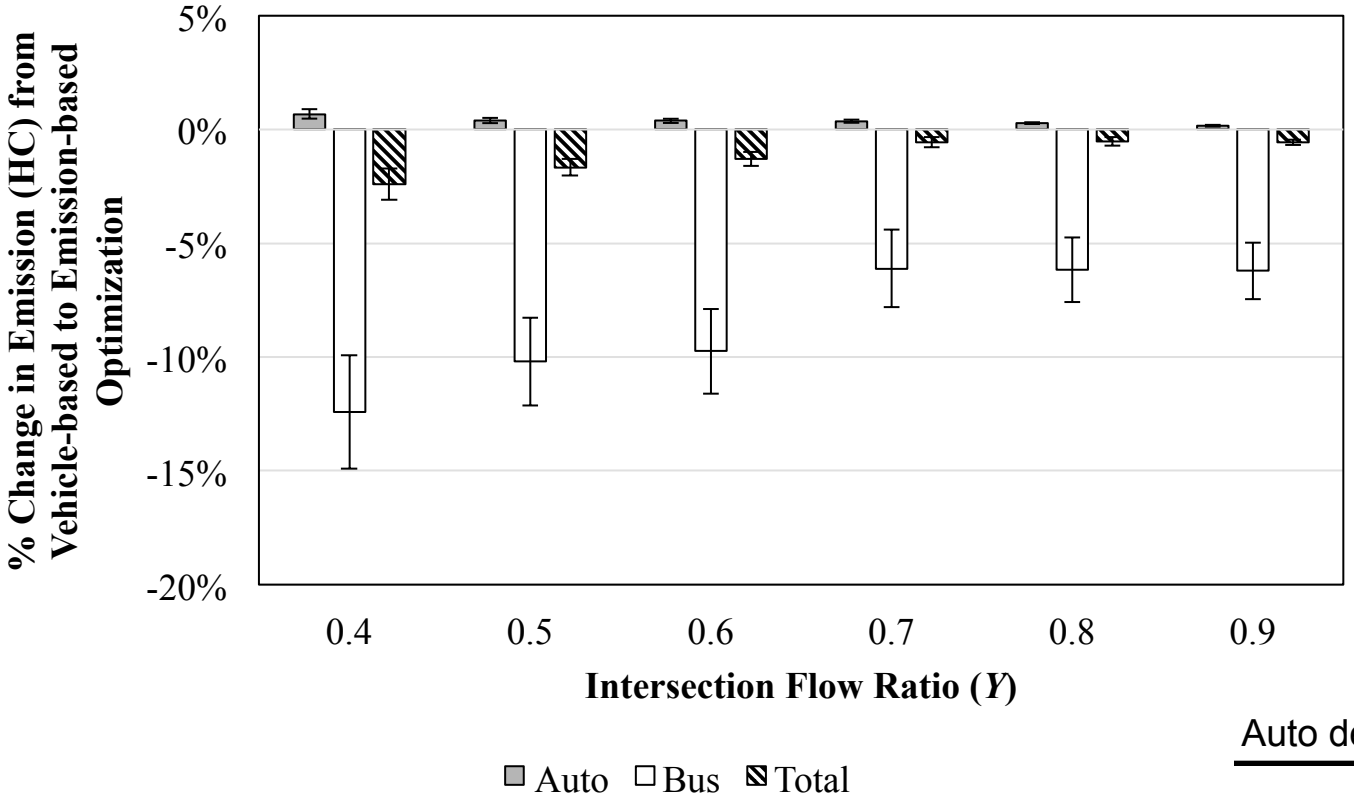


Emission Rates

Vehicle Type	Operating Mode	NO_x (mg/s)	HC (mg/s)
Gasoline Autos	Acceleration	7.7	2.5
	Deceleration	0.9	0.5
	Cruising	1.2	0.4
	Idling	0.3	0.4
Diesel Buses	Acceleration	263.5	2.1
	Deceleration	45.0	1.3
	Cruising	133.3	1.7
	Idling	45.0	1.3

Test I – Deterministic arrival tests

Effect of Auto Demand



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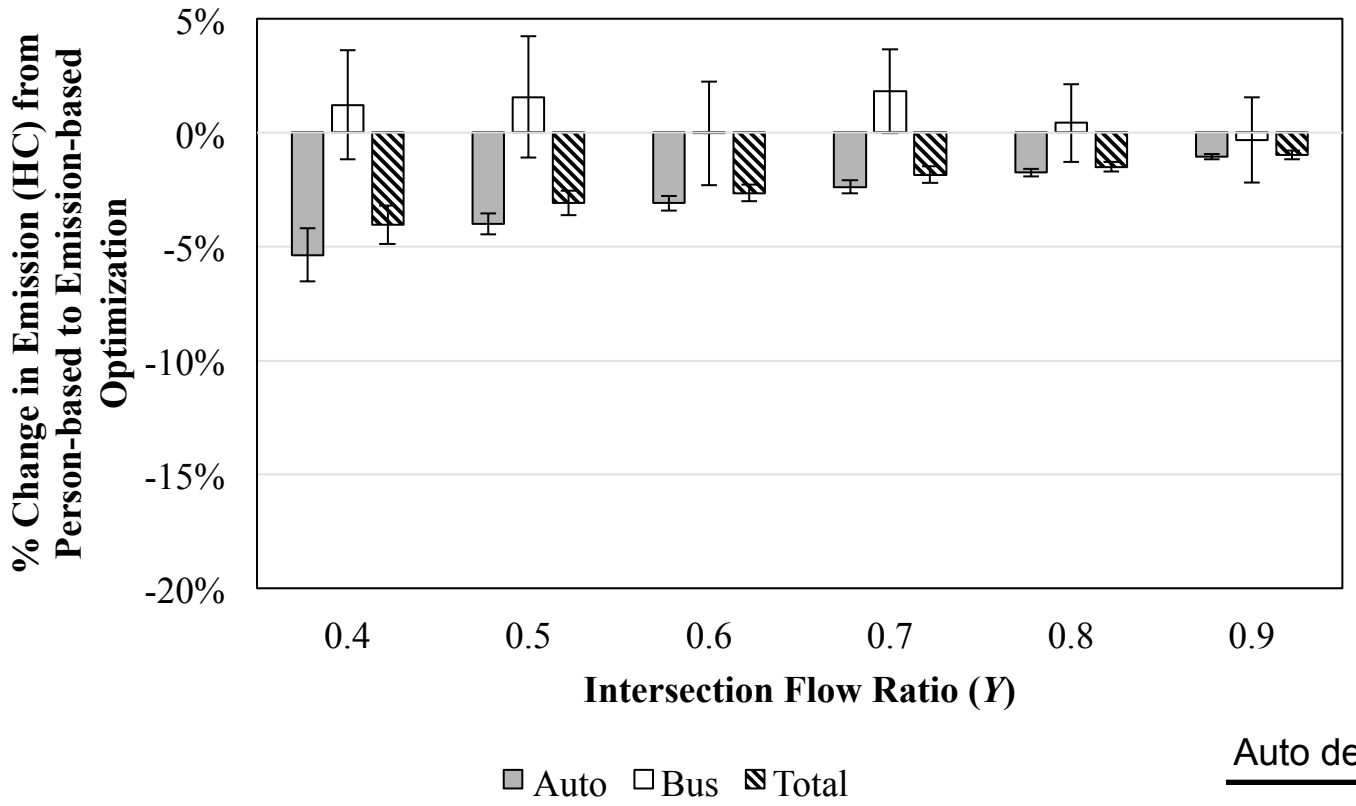

Findings – Isolated Intersection

- Reduction in overall emissions and transit emissions
- The higher the auto demand, the higher the overall reduction in emissions
- Results depend on the vehicle technology and emission factors

Current and Future Work

- Real-time signal control system with TSP that accounts for stochasticity in transit vehicle arrivals
- Real-time signal control system to minimize person delay and emissions
- Prediction algorithms for vehicle arrivals to account for stochasticity
- Inclusion of bus stop impact
- Extension of real-time signal control systems to networks

Relevant Publications

1. Khalighi, F., and Christofa, E. 2015. Emission-based Signal Timing Optimization for Isolated Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, 2487:1-14, doi: 10.3141/2487-01.
2. Christofa, E., Ampountolas, K., and Skabardonis, A. 2015. Arterial Traffic Signal Optimization: A Person-based Approach. *Transportation Research Part C: Emerging Technologies* [accepted]
3. Christofa, E., Papamichail, I., and Skabardonis, A. 2013. Person-based Traffic Responsive Signal Control Optimization. *IEEE Transactions on Intelligent Transportation Systems*, 14(3):1278–1289.
4. Christofa, E., and Skabardonis, A. 2011. Traffic Signal Optimization with Application of Transit Signal Priority to an Isolated Intersection. *Transportation Research Record: Journal of the Transportation Research Board*, 2259:192-201.

Other projects

- Bicycle demand prediction models
- Bus Stop Impact on Intersection Capacity and Arrival Prediction
- Driver behavior at innovative bicycle infrastructure treatments
- Operational, Safety, and Emissions Evaluation of Roundabouts
- Traffic Estimation and Signal Control with Connected Vehicles

Looking for graduate students!

- Traveler Response Architecture using Novel Signaling for Network Efficiency in Transportation (TRANSNET)
- Funded by the U.S. Department of Energy
- Mobility market and information system to incentivize travelers towards decisions that reduce network energy use
- Looking for PhD students

Thank you

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