Transit Priority in Urban Traffic: Real-time signal control and person-based evaluation

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Motivation

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Vehicle-based vs. **Person-based**

Vehicle-based
- *Minimize vehicle delay*
- *Evaluate transit preferential treatments using vehicle delay*

Person-based
- *Minimize person delay*
- *Evaluate transit preferential treatments using person delay, person discharge flow*

Transit Preferential Treatments (TPTs)

Space Preferential Treatments


Source: Viegas, et al (2007)

Source: www.ottawa.ca

www.mta.info

Time Preferential Treatments

Source: http://sustainabletransportationholland.org/

Exclusive Bus Lanes

commons.wikimedia.org

www.sustainablecities.com

www.mta.info

www.transportdeals.co.uk

www.streetsblog.org

Exclusive Bus Lanes

New York City, NY

- Reduction in travel time by:
  - 43% (express bus)
  - 34% (local bus)
- Increased travel time reliability by 57%

San Francisco, CA

- Reduction in travel time by:
  - 39% (local bus)

Intermittent Bus Lanes (IBL)

University Avenue, Lisbon, Portugal

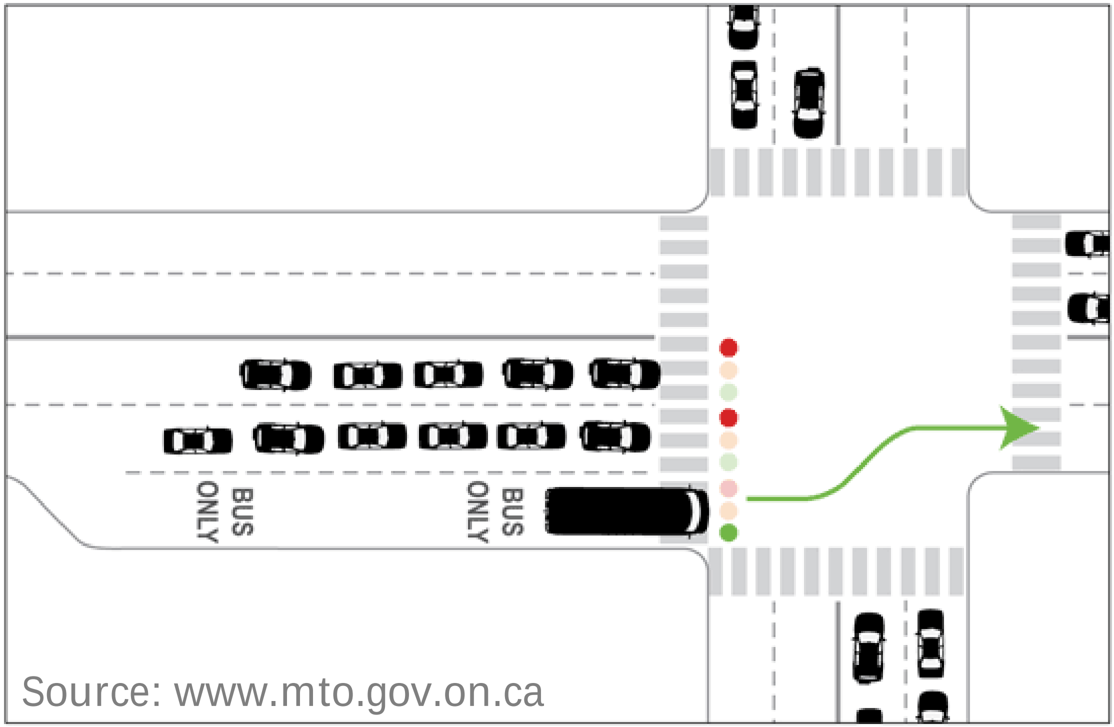
- Used for buses
- Increased bus speeds by 15%-25%
- No significant penalty to car traffic

Toorak Avenue, Melbourne, Australia

- Used for a streetcar
- Increased streetcar speeds by 1%-10%

Source: Viegas, et al (2007)

Queue Jumper Lanes



Source: www.mto.gov.on.ca

Source: www.ottawa.ca

Queue Jumper Lanes

Portland, OR

- Combination of queue jumper lane and Transit Signal Priority (TSP)
- Reduction in bus travel time by 5-8%
- Inconclusive impacts of TSP on traffic

Atlanta, GA

- On-time bus performance improved from 67% to 82%

Albany, NY

Source: Allen (2012)

Source: Allen (2012)

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

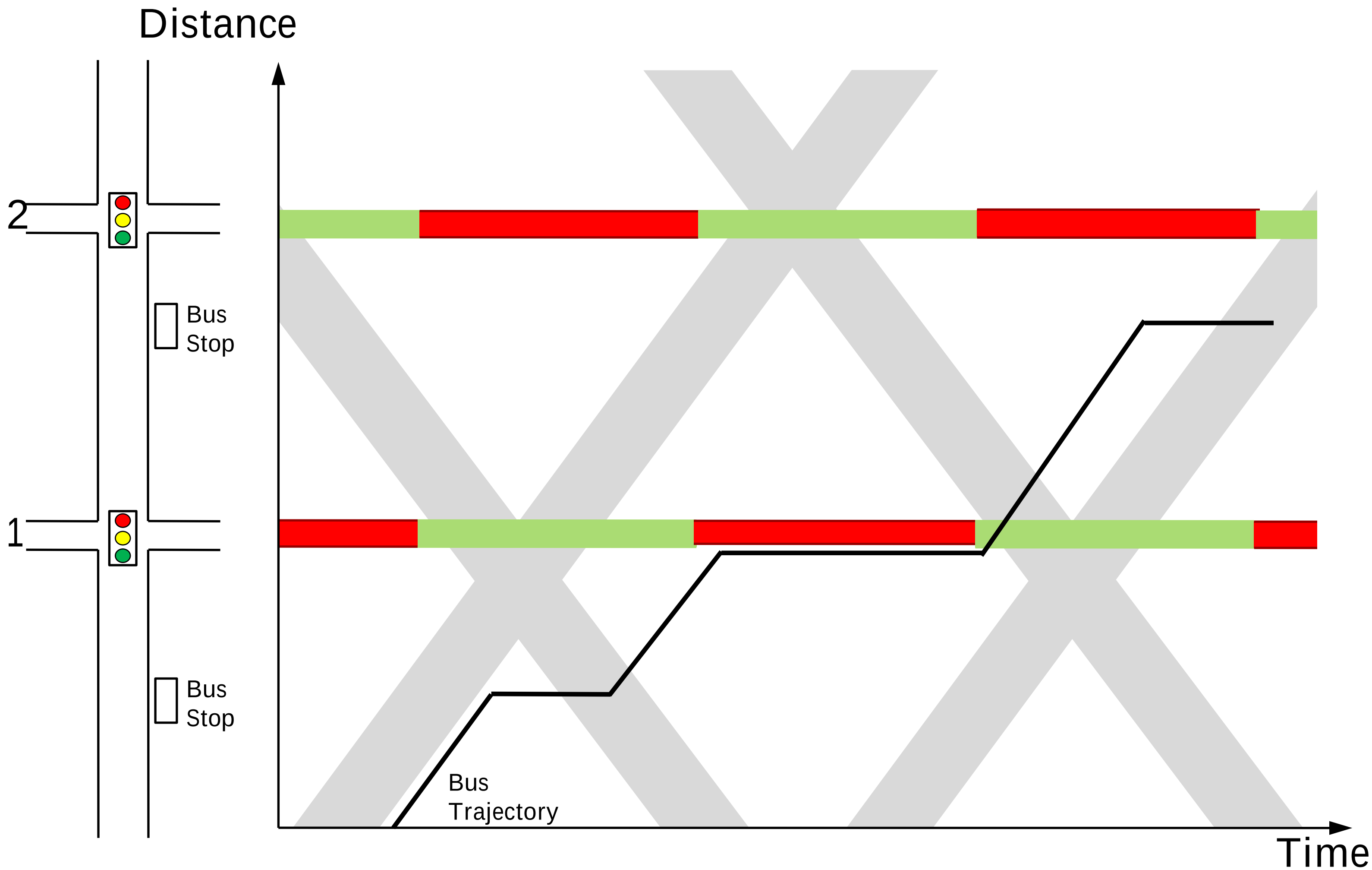
Active Priority Strategies

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

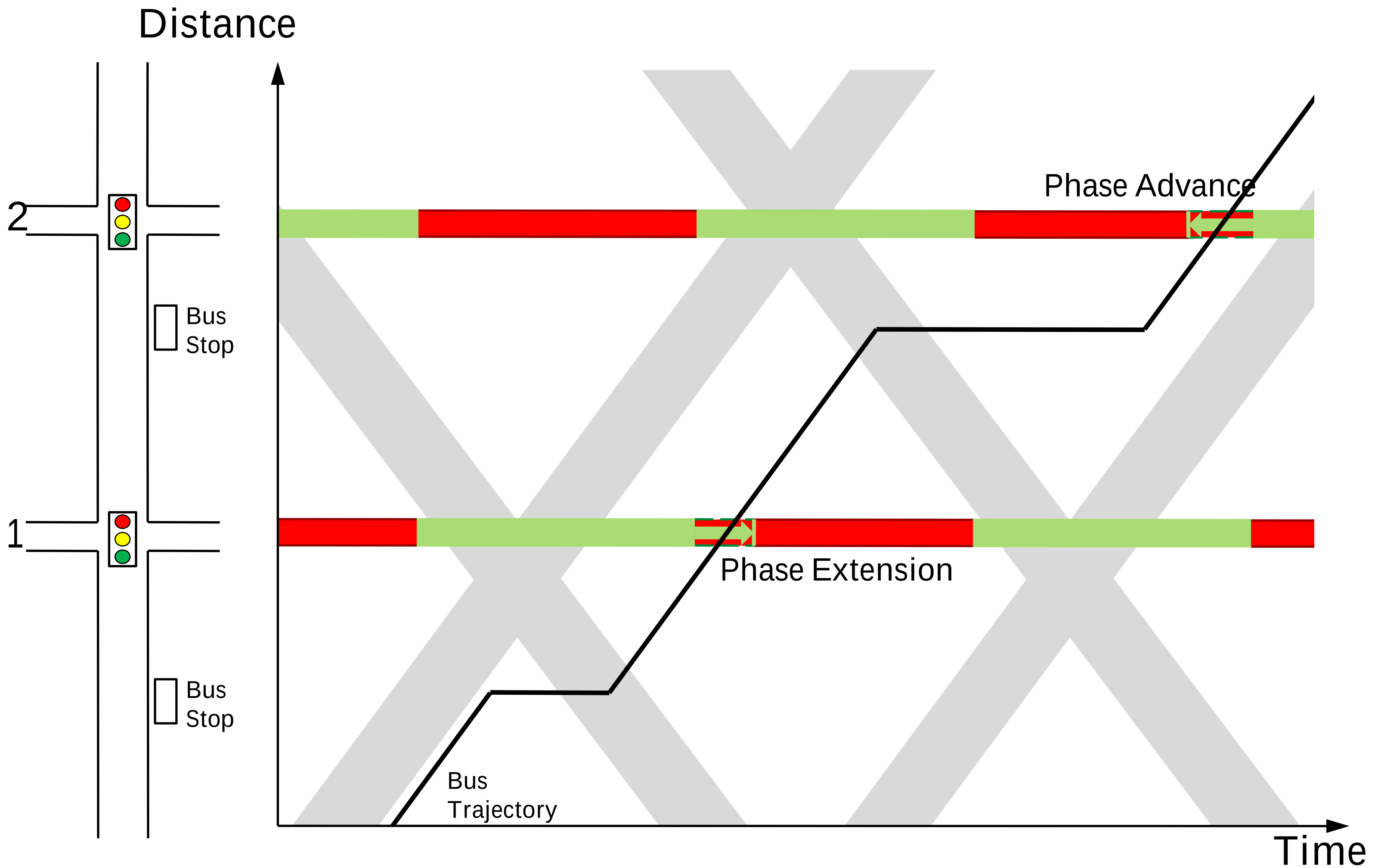
Source: www.umn.edu

Source: www.th.gov.bc.ca

Phase Extension – Phase Advance



Phase Extension – Phase Advance



Transit Signal Priority Strategies

Active Priority Strategies

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

Source: www.umn.edu

Issues:

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

Transit Signal Priority Strategies

Source: Kittelson et al. (2003)

Seattle, WA

- Phase advance
- Phase extension
- Reduction of travel time by 1-5%

Portland, OR

- Phase advance
- Phase extension
- Reduction of travel time by 8-10%
- Reduction in travel time reliability of 19% during am peak

Transit Signal Priority Strategies

Miami, FL

- Phase advance
- Phase extension
- Reduction of travel time by 1.5-12%
- On-time performance improved from 66.7% to 75%

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)

Literature Review Summary

1. Existing Real-time Signal Control Systems
   - No consideration of person delay
   - No efficient treatment of conflicting transit routes
   - No consideration of schedule delay
   - No utilization of deployable technologies
   - High computation times

2. Lack of comprehensive evaluation of TPTs:
   - When implemented individually and in combination
   - Based on person-related performance measures

Research Questions

- How should traffic signal control systems be designed so that they provide
  - priority to transit vehicles traveling in conflicting directions,
  - while minimizing the impact on auto traffic

  in signalized arterial networks?

Source: www.th.gov.bc.ca

- What is the impact of TPTs on:
  - the person delay of all users?

  when implemented individually and in combination?

Source: www.telegraph.co.uk

Outline

1. Person-based traffic responsive signal control system with transit priority
   - Mathematical program
   - Isolated Intersection (Test site & results)
   - Signalized Arterial (Results)

2. Person-based evaluation of TPTs
   - Analytical Model
   - Test Site
   - Results

Person-based traffic responsive signal control system with transit priority

Mathematical Program

$$\text{Min} \sum_{r=1}^{2} \left[\sum_{a=1}^{A^r_T} o_a d_a(g^r_{i,T}) + \sum_{b=1}^{B^r_T} o^r_{b,T}(1+\delta^r_{b,T}) d_b(g^r_{i,T}) \right]$$

(Person Delay)

subject to:

$$g^r_{i,T} \geq g^r_{min} \quad \text{for all } i,r$$

(Minimum Green)

$$\sum_{i=1}^{I^r} g^r_{i,T} + L^r = C \quad \text{for all } r$$

(Constant Cycle Length)

- o_α : *occupancy of auto α [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*
- $d_\alpha(g^r_{i,T})$: *control delay for auto α [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]*

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

Performance Measures:

- Total person delay, bus passenger delay, auto passenger delay
- Number of stops
- Speed
- CO emissions

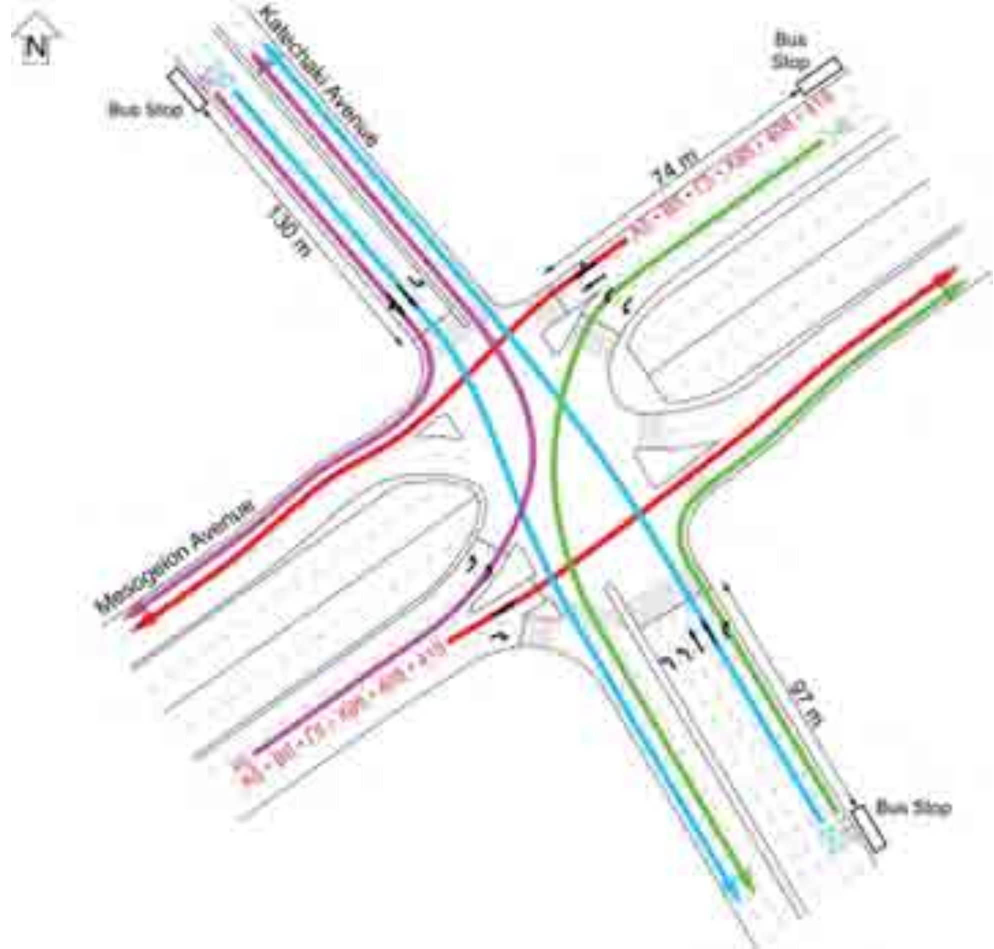
Test Sites

Isolated Intersection

Arterial

Isolated Intersection

Test Site – Mesogeion & Katechaki Avenues



Test Site – Mesogeion & Katechaki Avenues

9 bus routes

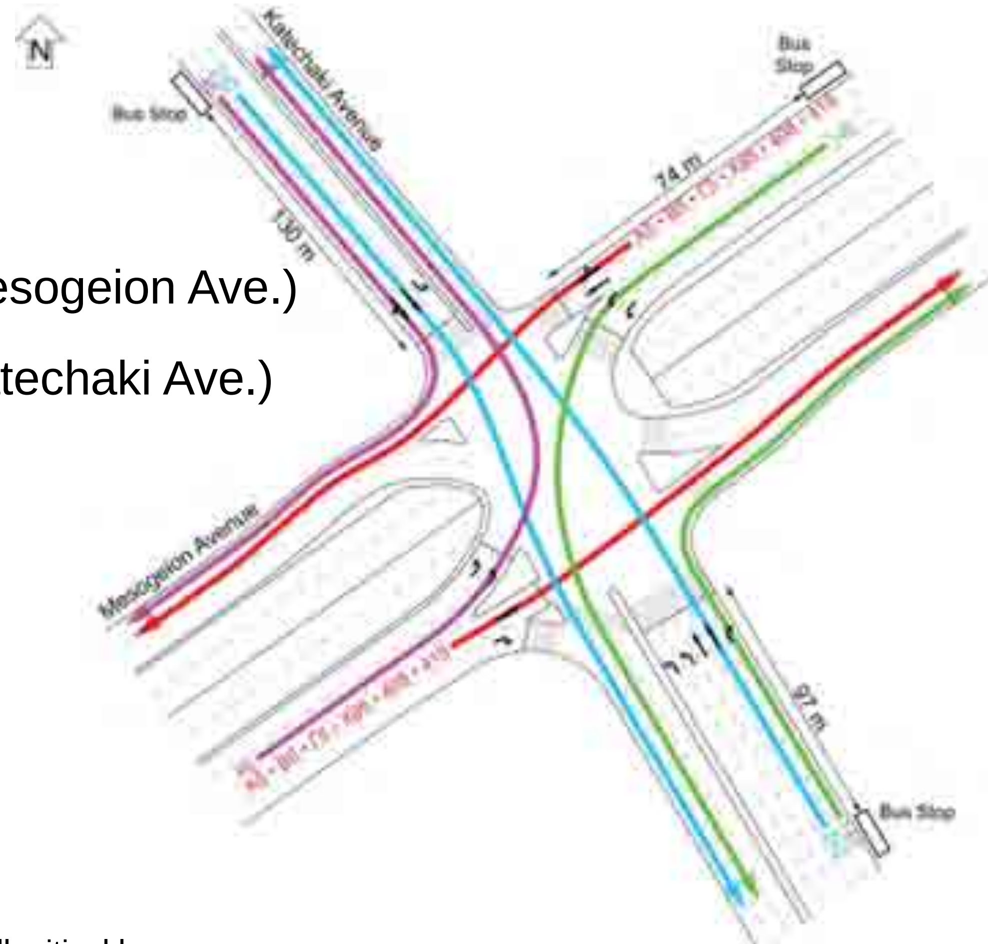
43 buses/hour

- *70%* on NE-SW approaches (Mesogeion Ave.)
- *30%* on NW-SE approaches (Katechaki Ave.)

Cycle length (C) = *120* sec

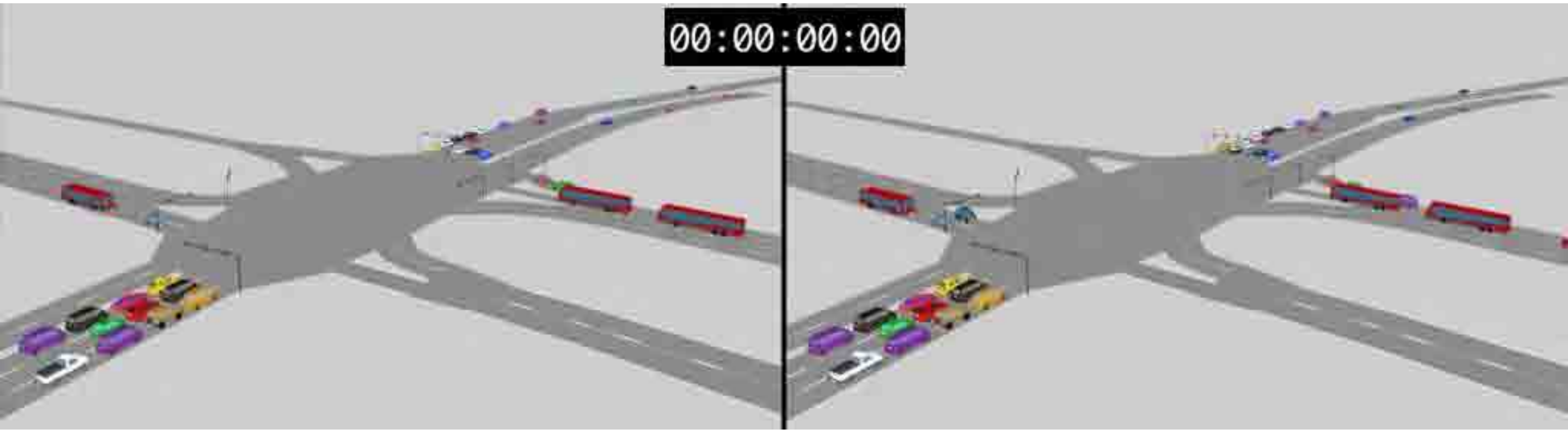
Lost time (L) = *14* sec

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

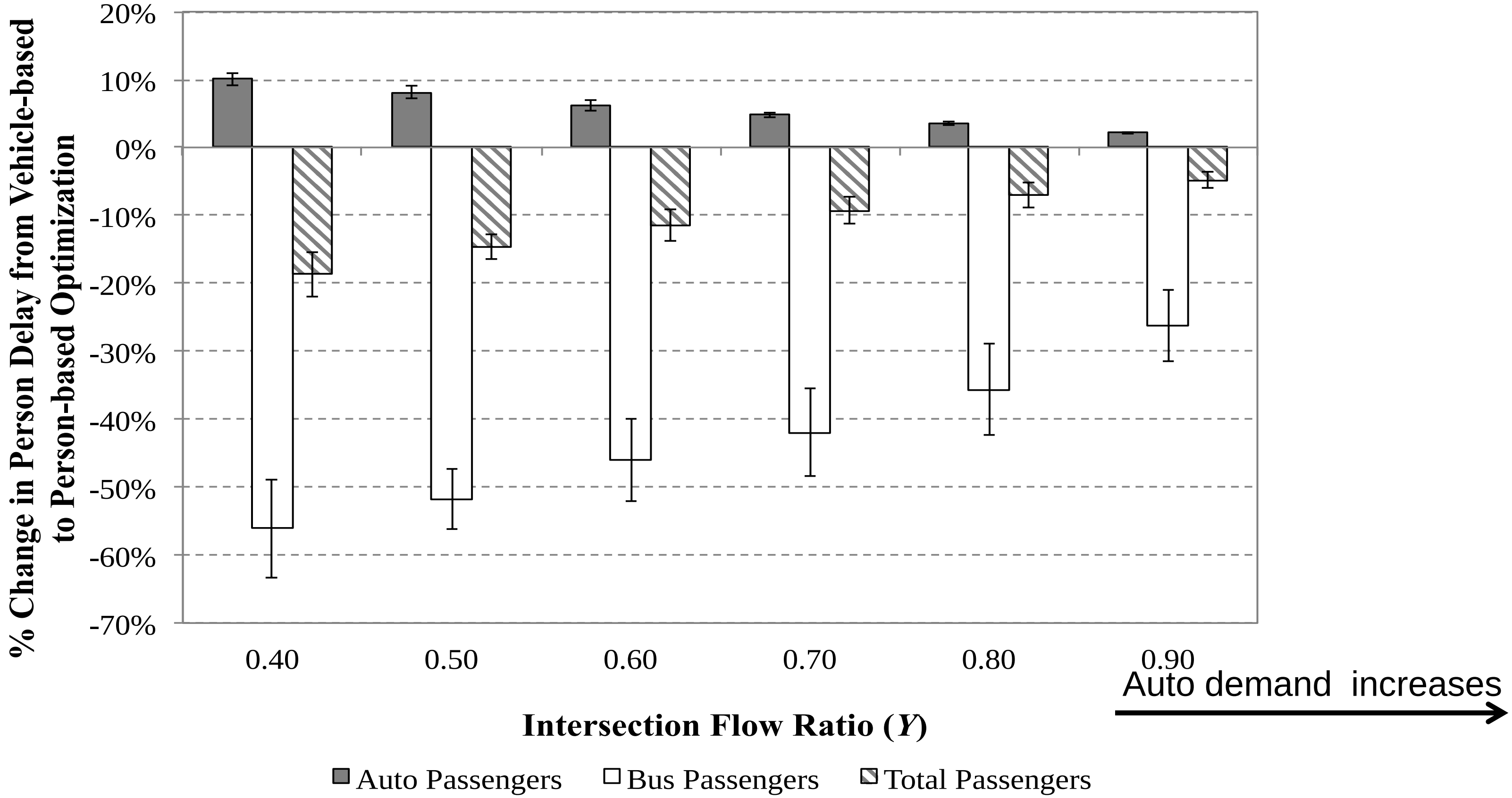
Person-based Optimization

Test I – Deterministic arrival tests

Effect of Auto Demand

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

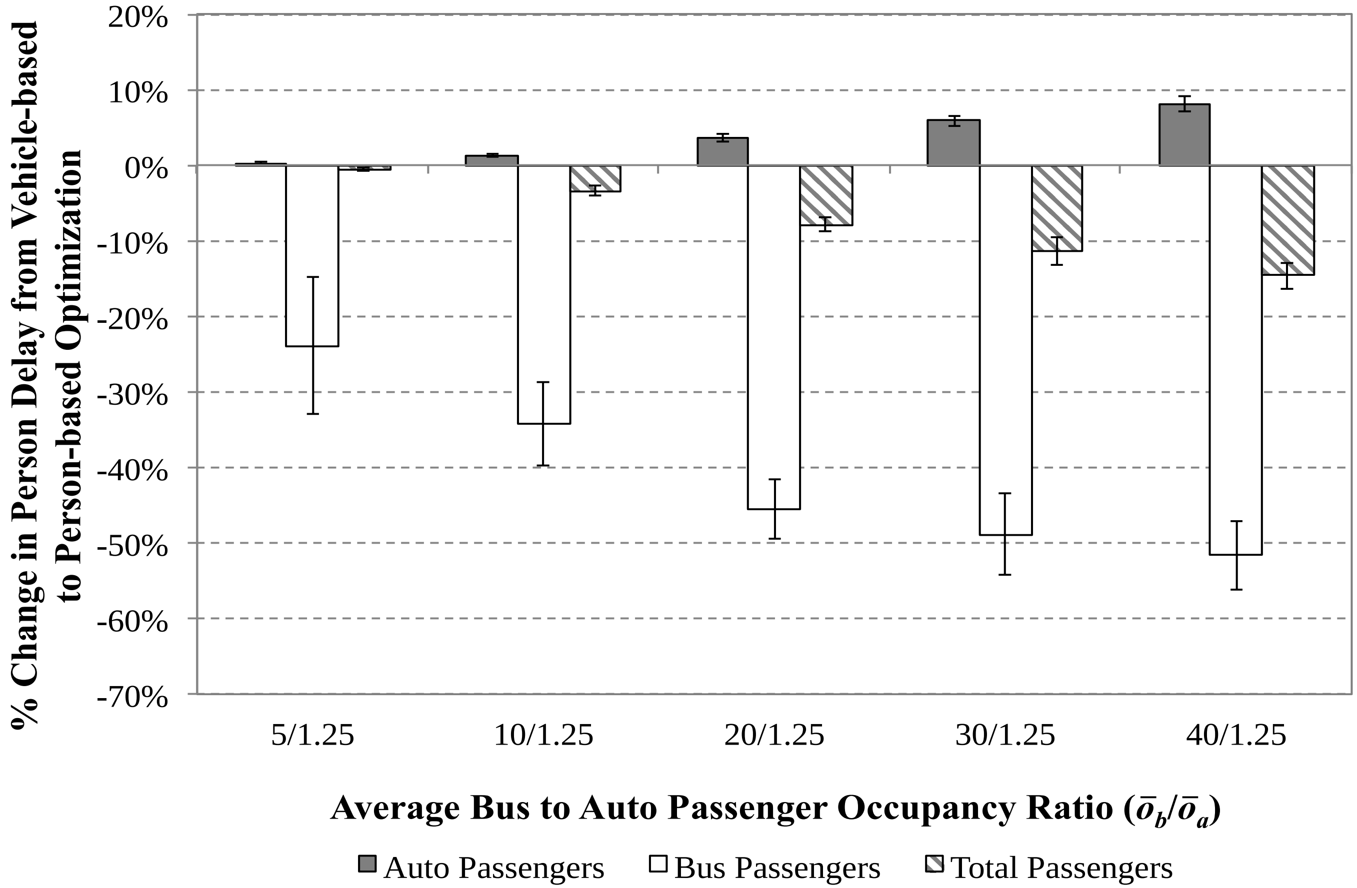
$\bar{o}_b = 40$ [pax/veh]



Test I – Deterministic arrival tests

Effect of Bus Passenger Occupancy

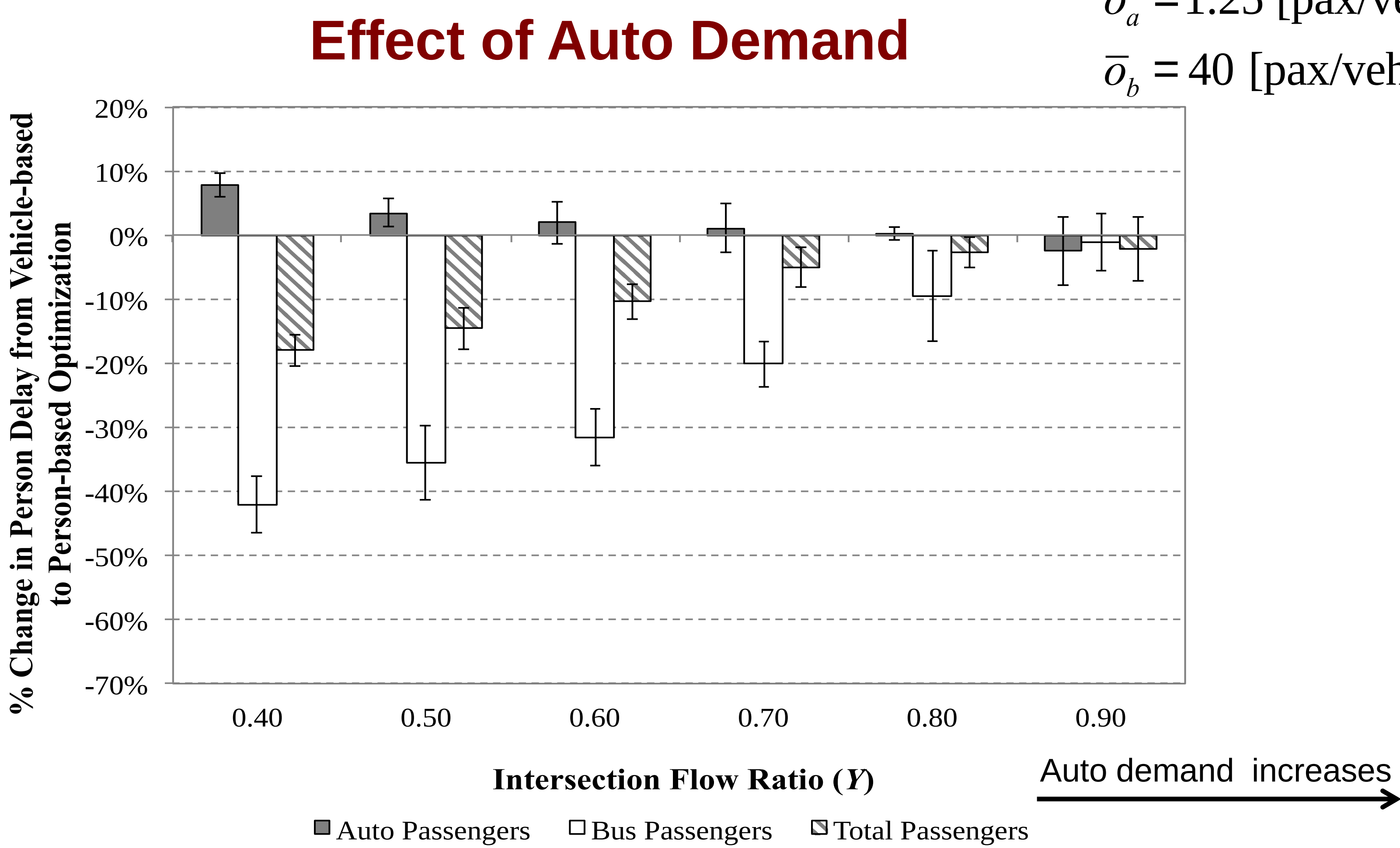
Y=0.5



Test II – Stochastic arrival tests (simulation)

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

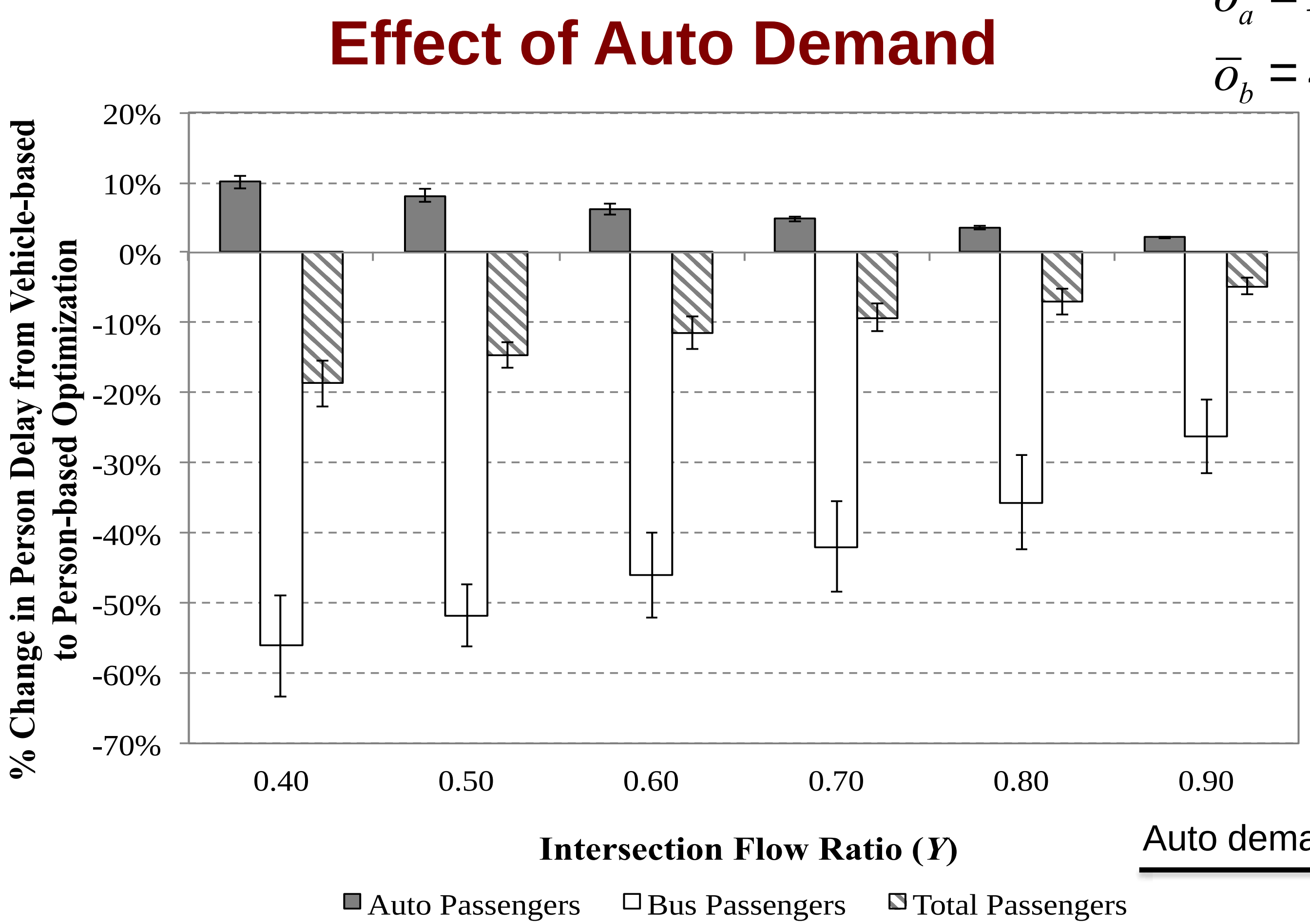
$\bar{o}_b = 40$ [pax/veh]



Test I – Deterministic arrival tests

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

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

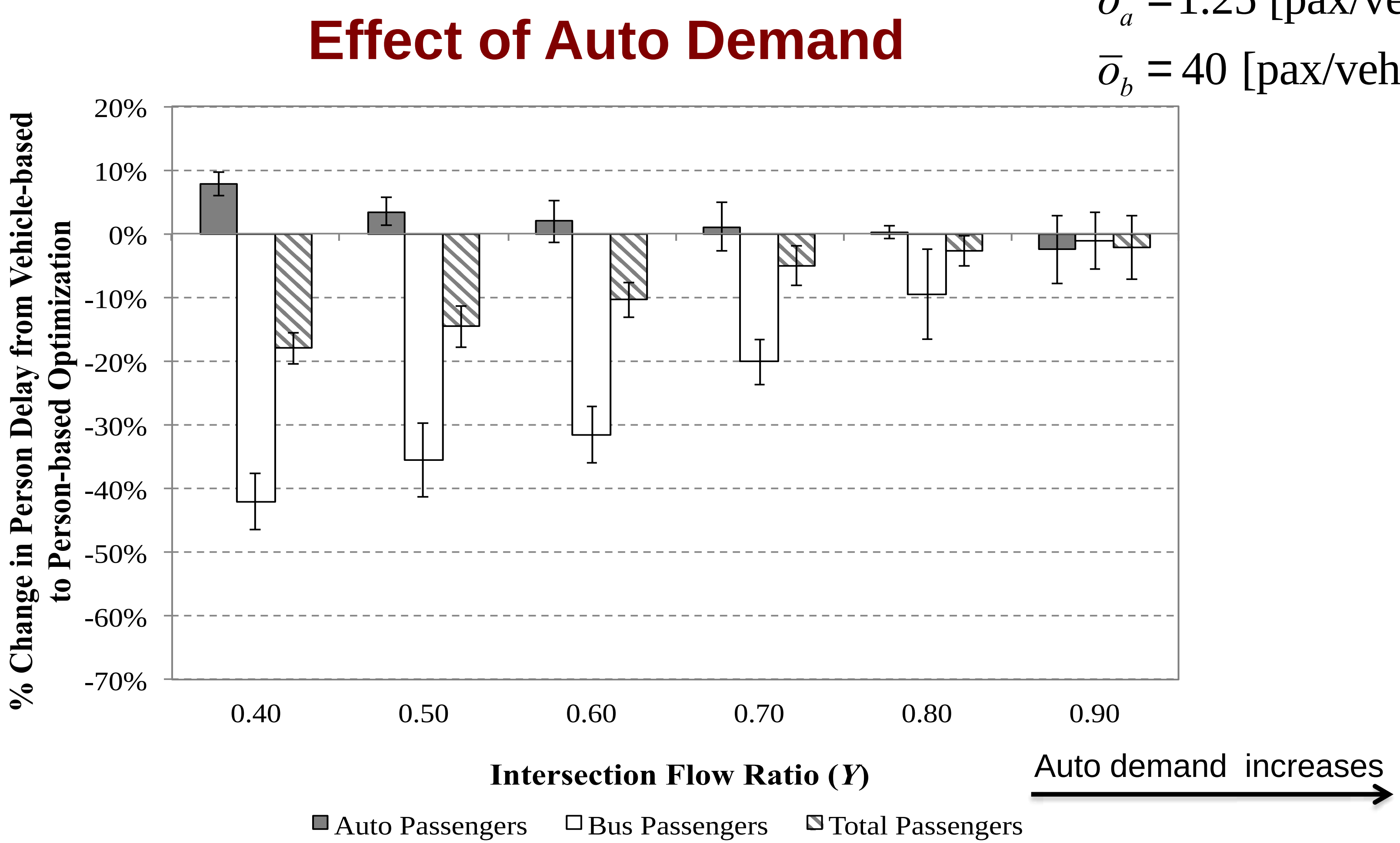


Auto demand increases →

Test II – Stochastic arrival tests (simulation)

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

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



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

Signalized Arterial

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

Summary

Person-based Traffic Responsive Signal Control with Transit Priority

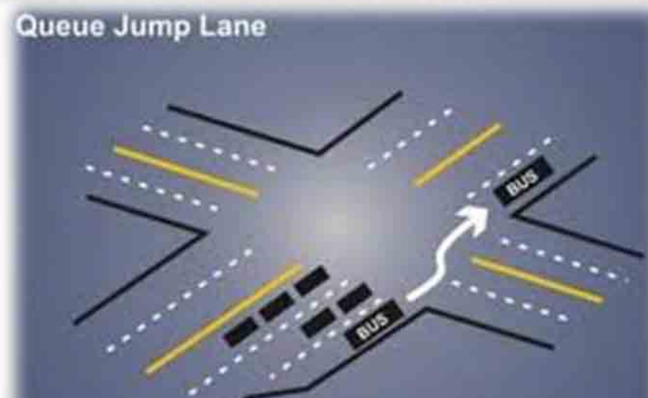
- Systematically provides priority to conflicting transit routes
- Accounts for passenger occupancy and schedule delay
- Maintains coordination
- Input from available sensing and communication technologies
- Can be solved in real-time
- Generic and flexible

2. Person-based evaluation of TPTs

TPT Alternatives

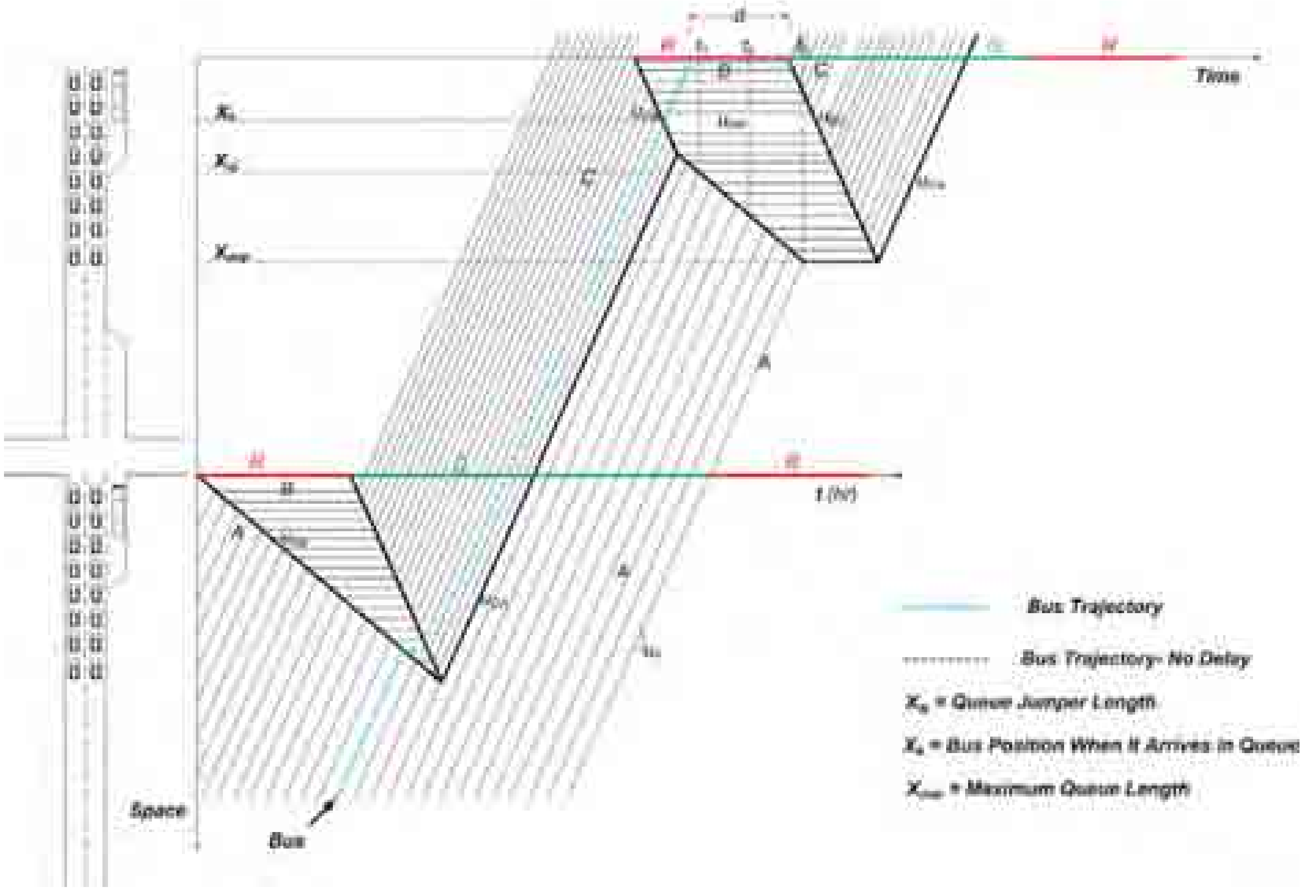
- Bus lanes
- Queue Jumper Lanes
- TSP (Green extension)
- Combinations of the above 3

Source: www.th.gov.bc.ca



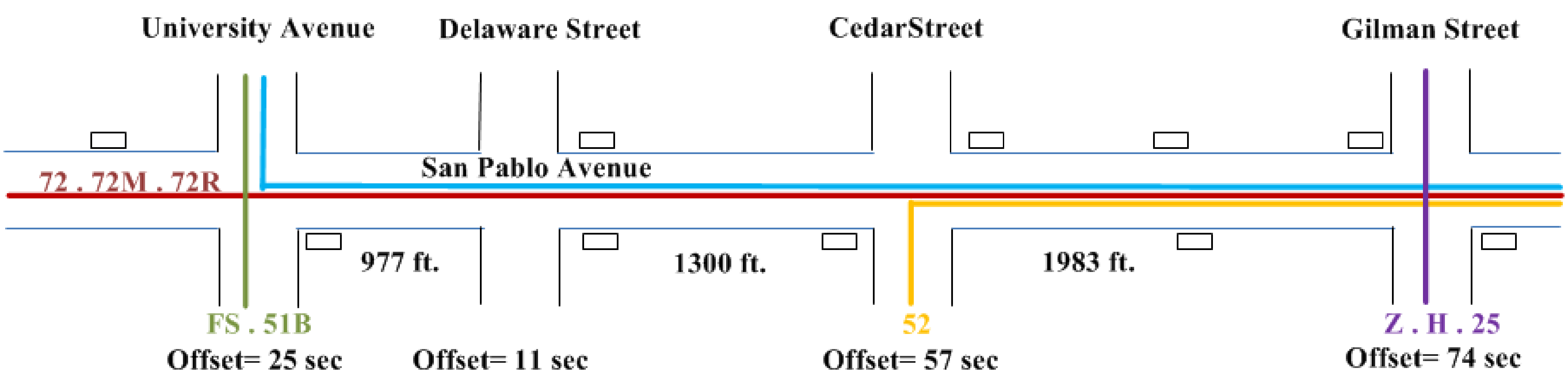
Source: www.tc.gc.ca

Analytical Delay Model

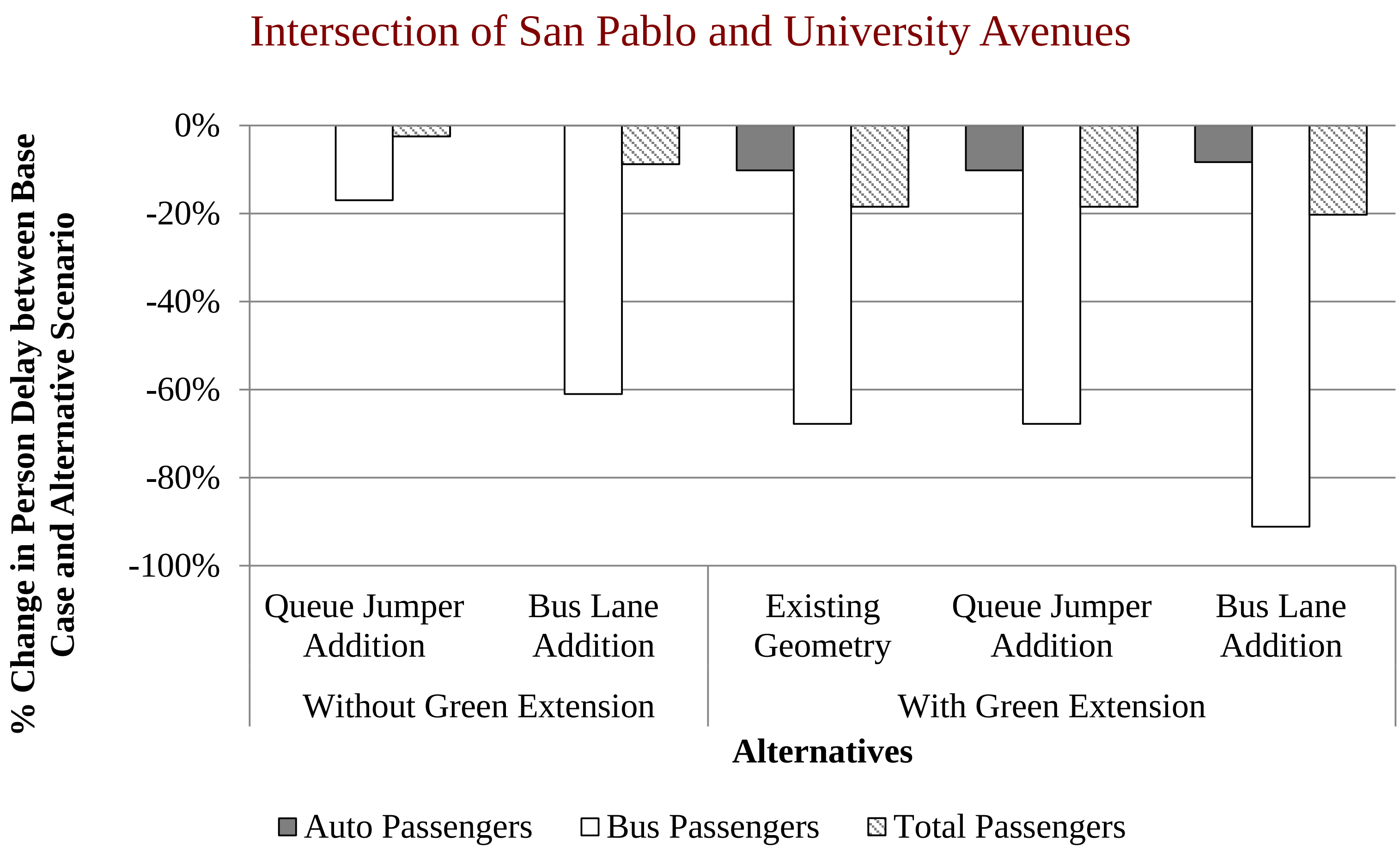


Test Site – San Pablo Avenue, Berkeley

- 4 signalized intersections (University Ave. to Gilman Street)
- Corridor length: 0.8 miles
- Signal Control: Fixed-time coordinated
- Cycle length: 80 sec (common for all intersections)
- Ten bus lines travel through the corridor
- Focus is on the NB direction



Test Results–Person Delay



Bus Occupancy= 30 (Pax/veh), Car Occupancy= 1.25 (Pax/veh), Existing auto demand and bus frequency

Summary of Results

- Queue jumper lane reduces bus person delay by 10-20%
- Bus lane addition reduces bus person delay by 70-77%
- Small positive impact of queue jumper and bus lane addition on auto person delay
- Green extension when implemented in combination with queue jumper lanes improves bus person delay by an additional 60% to 80% (when bus frequency doubles)
- When green extension is implemented in combination with bus lanes it improves bus person delay by 70%

Future Work

- Inclusion of pedestrian delays
- Inclusion of bus stop impact
- Prediction algorithms for vehicle arrivals (to account for stochasticity)
- Extension of real-time signal control to networks
- Evaluation of additional space and time priority treatments:
  - Intermittent bus lanes
  - Phase advance
  - Phase rotation

Conclusions

- Person mobility is important
- More person-based performance measures should be used in any evaluation of treatments
- Non-motorized modes of transportation should also be taken into account

Questions?

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