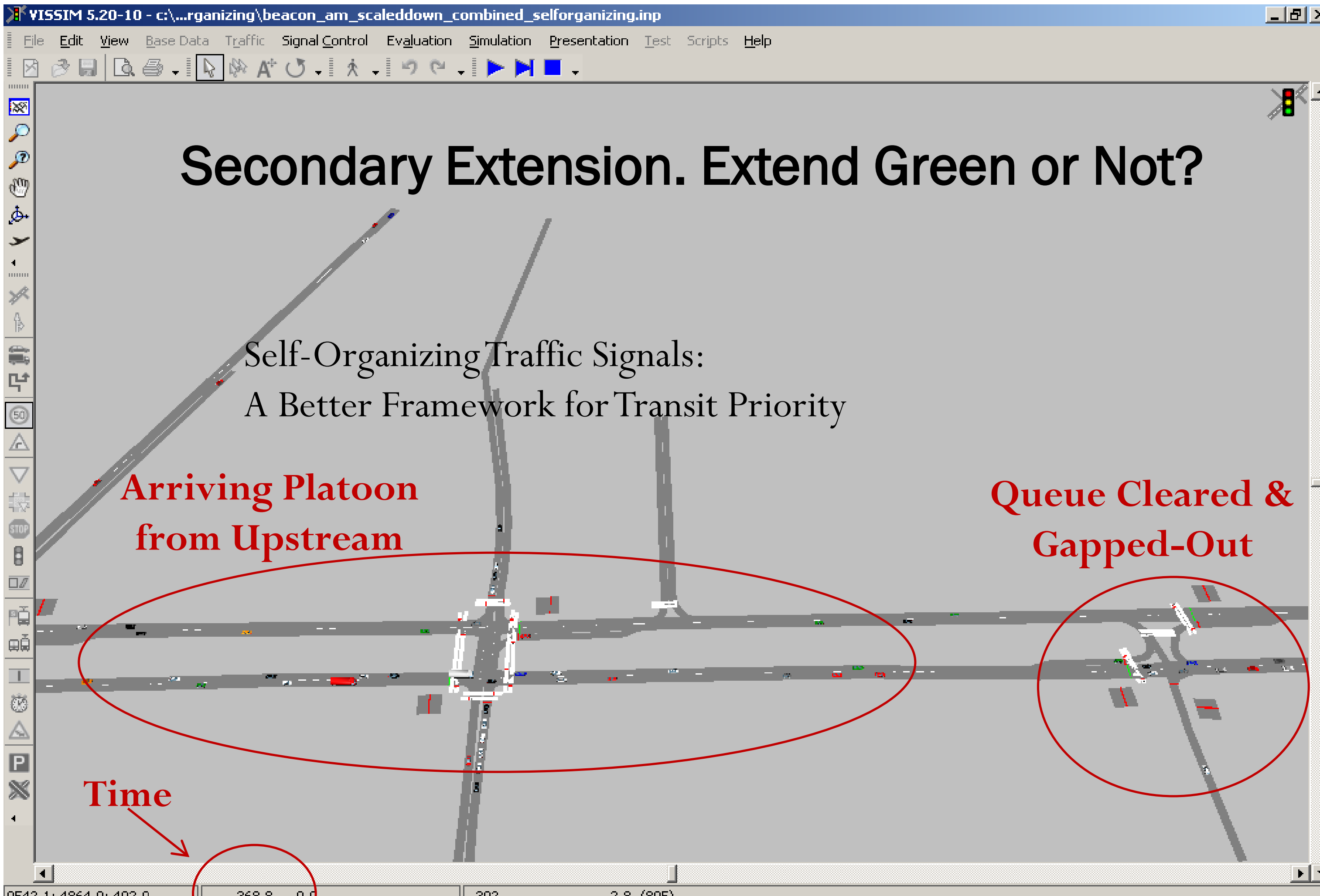
3-13-2015

Self-Organizing Signals: A Better Framework for Transit Signal Priority

Peter G. Furth
Northeastern University

Self-Organizing Traffic Signals: A Better Framework for Transit Priority



Northeastern University

NSF

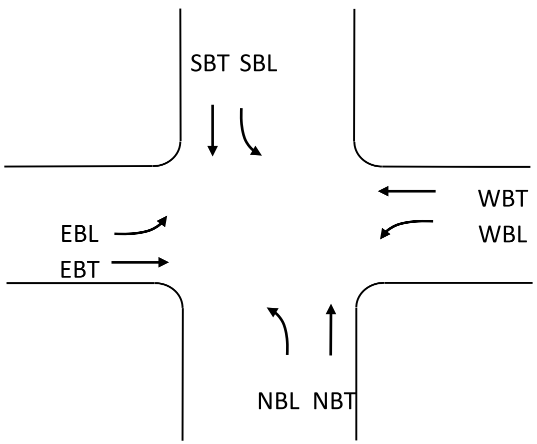
Self-Organizing Traffic Signals: A Better Framework for Transit Priority

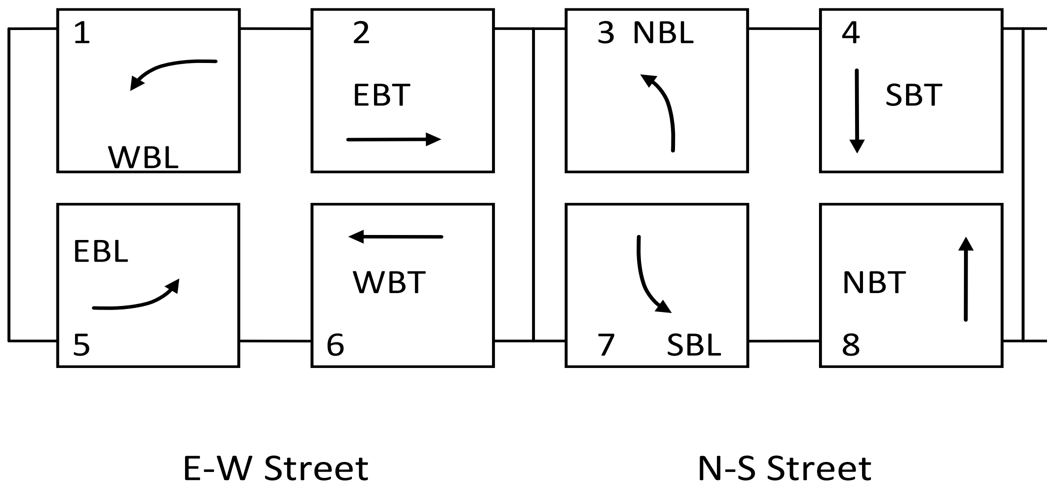
Peter G. Furth

Co-Researcher: Burak Cesme

Actuated "Free" Control

- Match supply to demand in real time ("Gap-out", "Skipping")

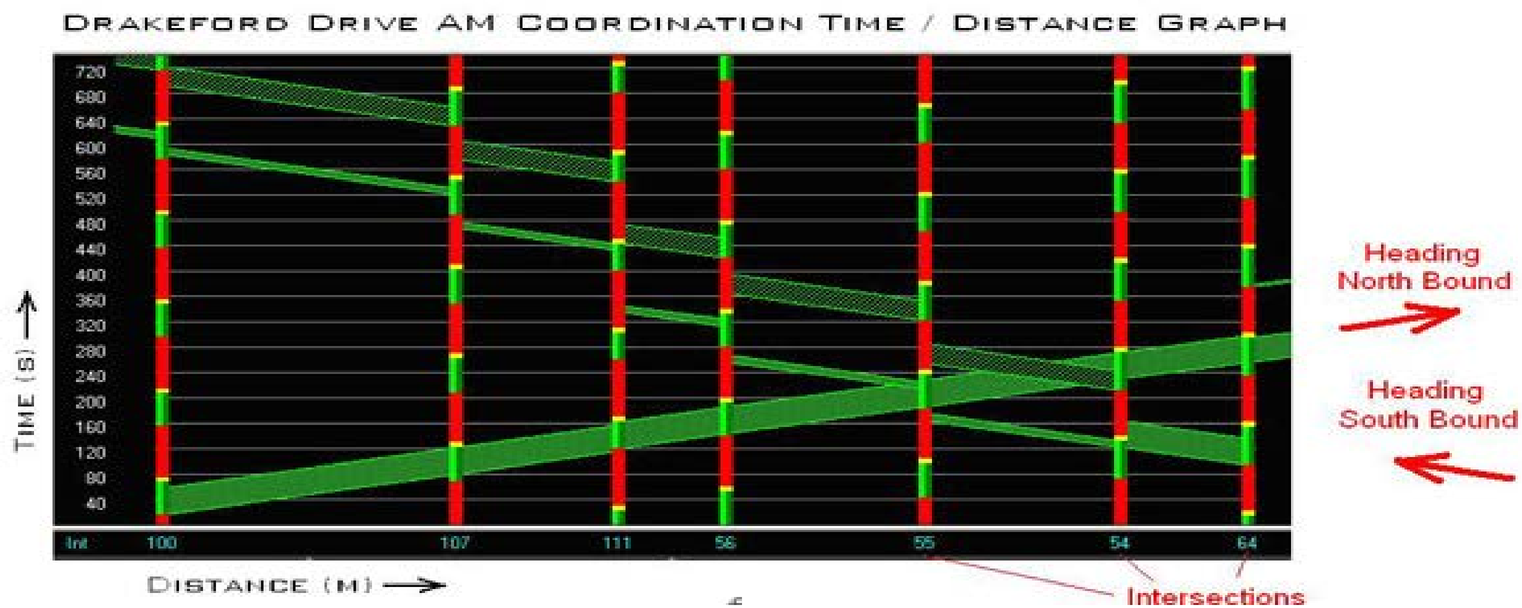




- Offer short cycles – good for transit, pedestrians, minor traffic
- Amenable to transit priority due to built-in *compensation*
- However, makes signal coordination impossible

Northeastern University

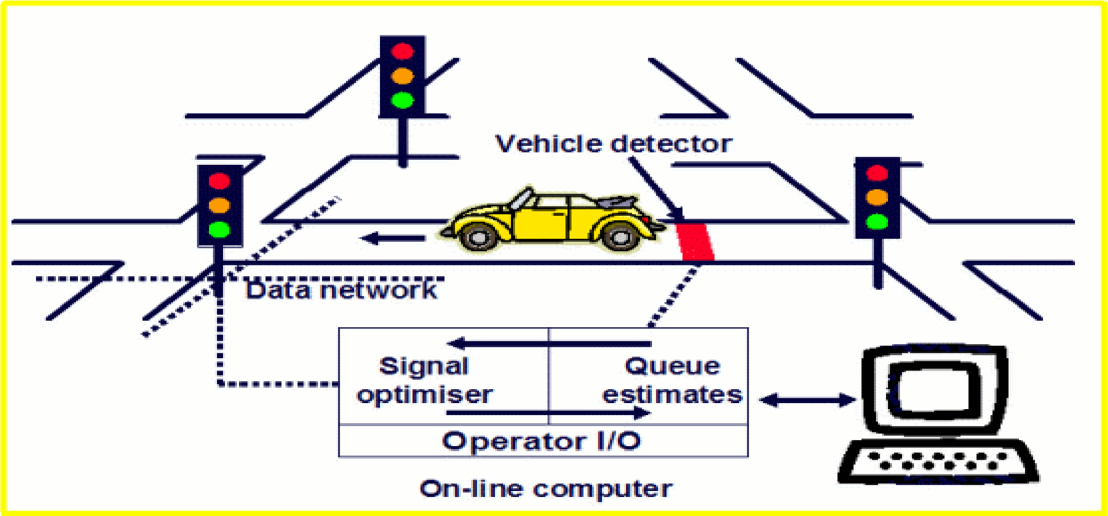
Fixed Cycle-Coordinated Control



- Parameters: Cycle length, splits, and offsets
- Performance: Longer cycle at non-critical intersections
  - ❖Less delay for arterial in the favored direction
  - ❖Longer cycle lengths – more delay for non-coordinated movements
  - ❖Long unsaturated green periods – less safe
  - ❖Lacks compensation mechanisms – Limits application of signal priority.

Adaptive Control (most)

- *Uses standard fixed-cycle coordination logic.*



- Adaptively updates cycle, split, and offsets every 5 or 10 minutes (e.g., SCOOT and SCATS).
- All the same problems as fixed time coordination

Cycle-Free Optimizing Control (e.g., RHODES, OPAC)

Not yet proven practical

- Computational complexity
- Inability to predict future arrivals

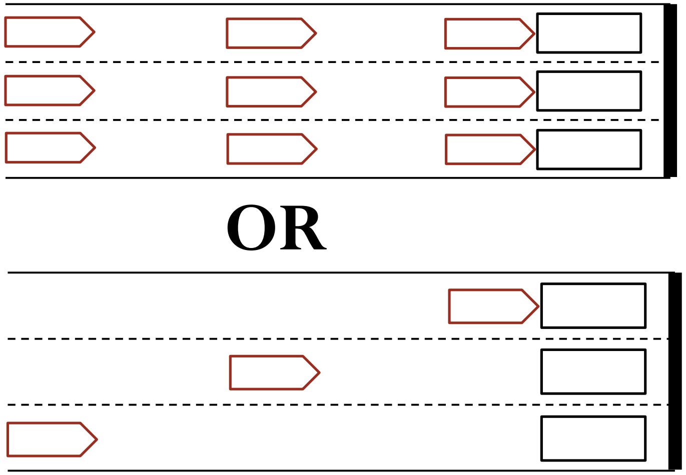
Direction of Improvement

- **Use basic actuated control logic as a base**
- Add coordination mechanisms
- Make signal control "Self-Organizing"

Actuated control already possesses some self-organizing mechanisms

- Finds the best cycle length
- Has compensation mechanisms that promote healing after a priority interruption
- Will hold green for a platoon that has arrived

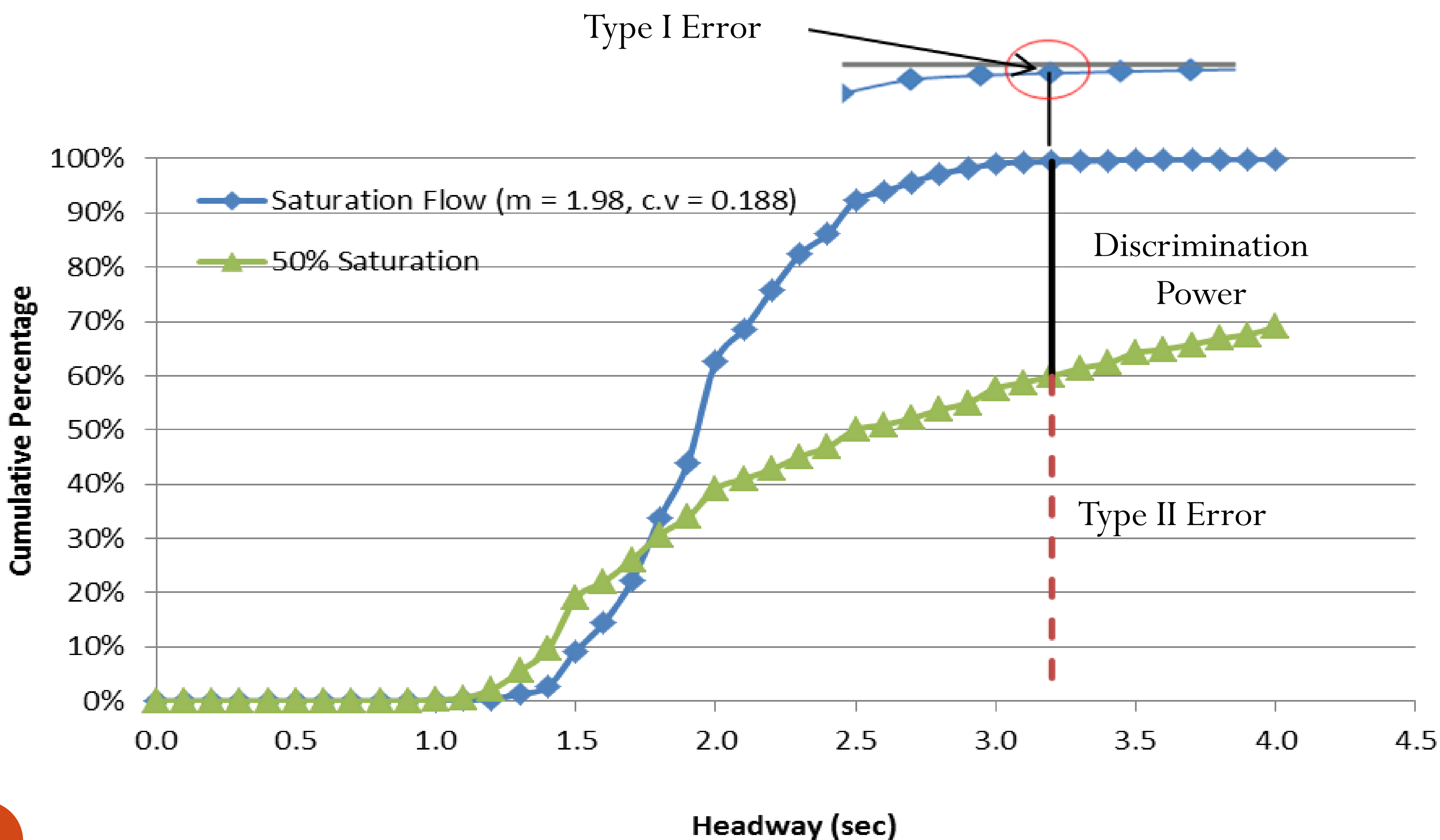
Incremental Improvement to Actuated Control: Better Gap-Out Logic for Multilane Approaches



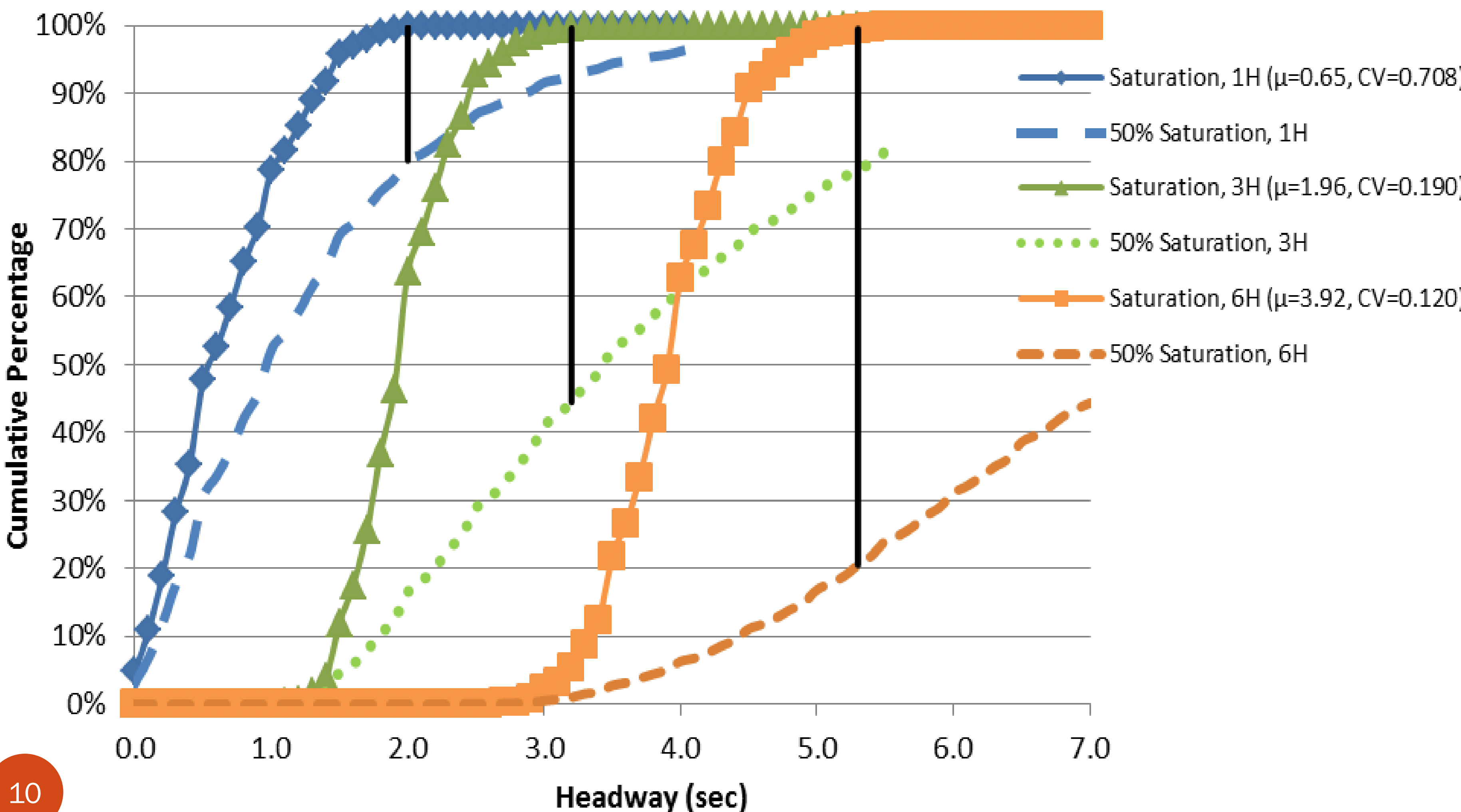
Flow = Saturation Flow
Decision:
Extend Green!

Flow = Saturation Flow / 3
Decision: ???

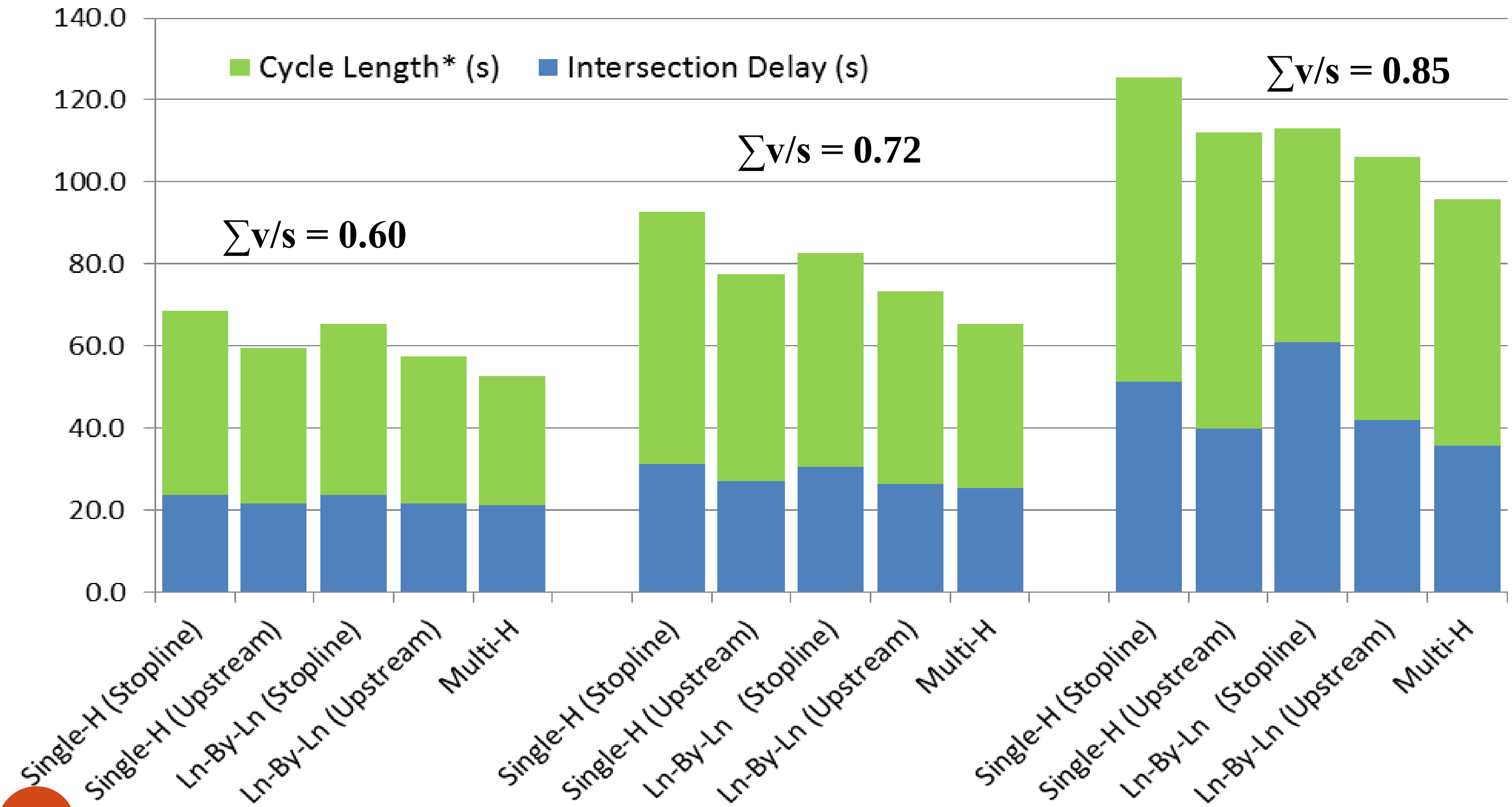
Headway Distribution: Single Lane



Headway Distribution: Multi-Lane

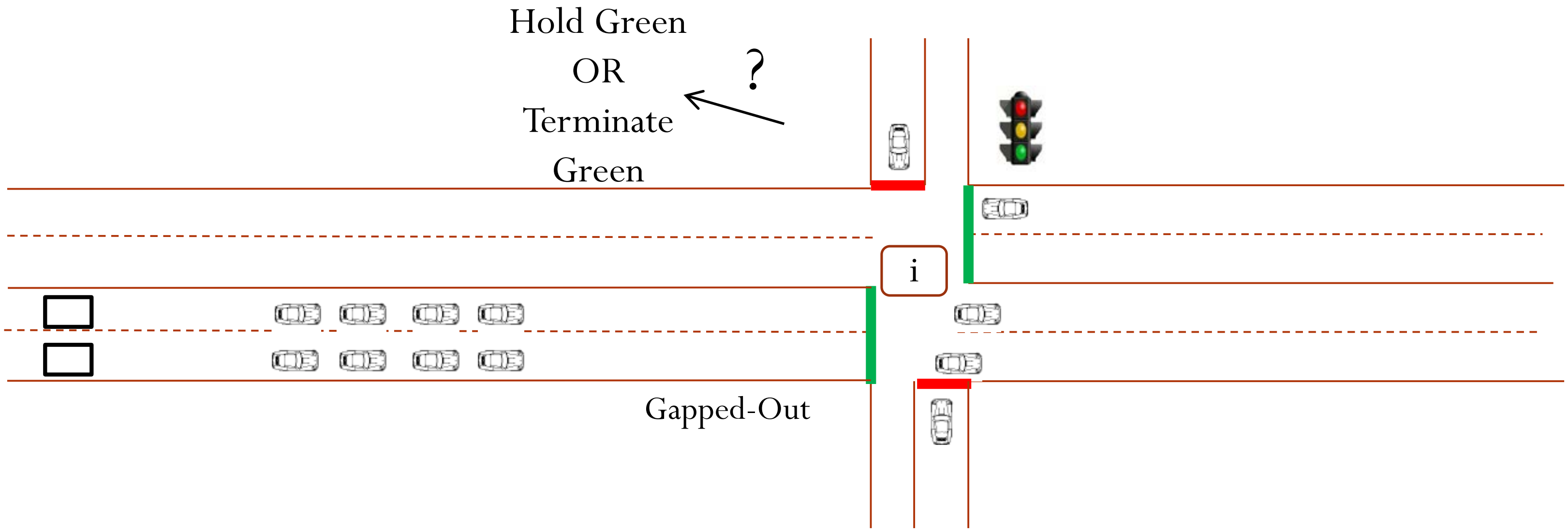


Multi-Headway Gap-Out Logic Results



Adding a Progression Mechanism: "Secondary Extension"

- **Hold green for an arriving platoon???**



- **YES if:**

i. There's excess capacity

ii. Arriving platoon is dense, large, and imminent

Measure of Platoon Qualification

$$Lost\ Time\ Per\ Vehicle = \frac{Holding\ Time - n * h_{sat,approach}}{n}$$

n: vehicles that benefit from an anticipated extension of length *t*

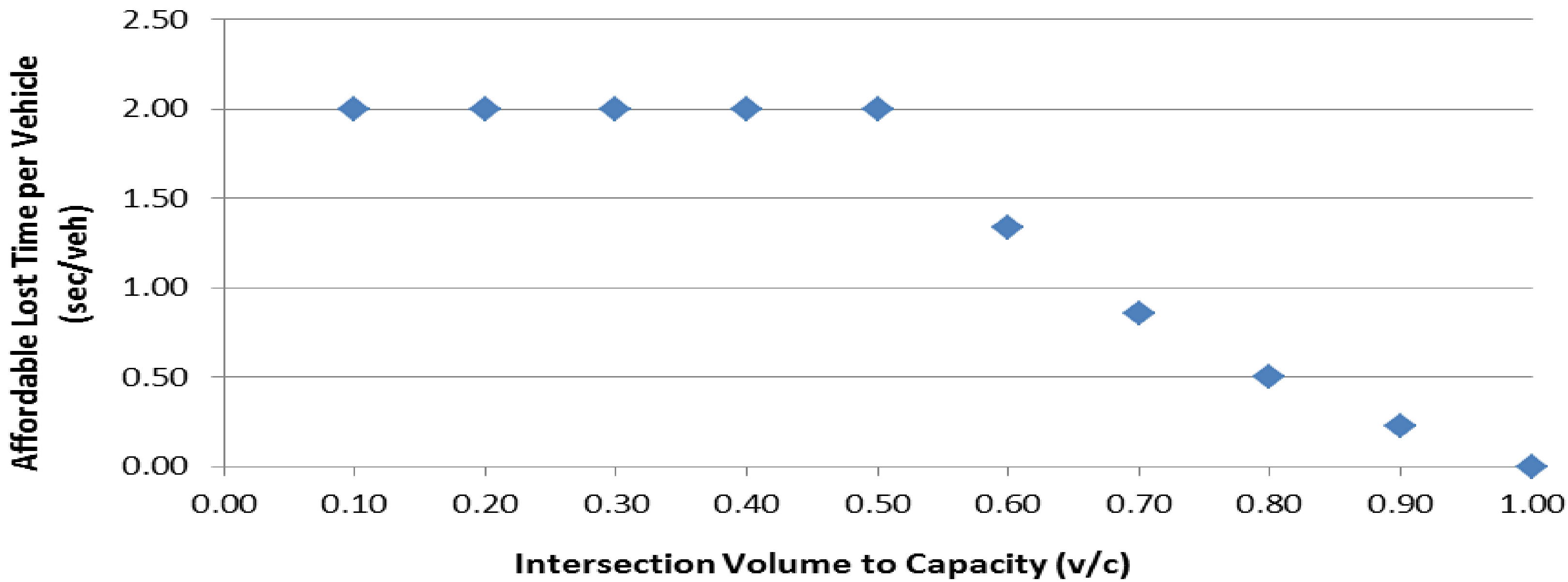
h_{sat}: saturation headway in seconds

maximized over values of $t = \{2, 4, 6, \ldots, 20s\}$

- Smaller if arriving platoon is *dense, large, and imminent*

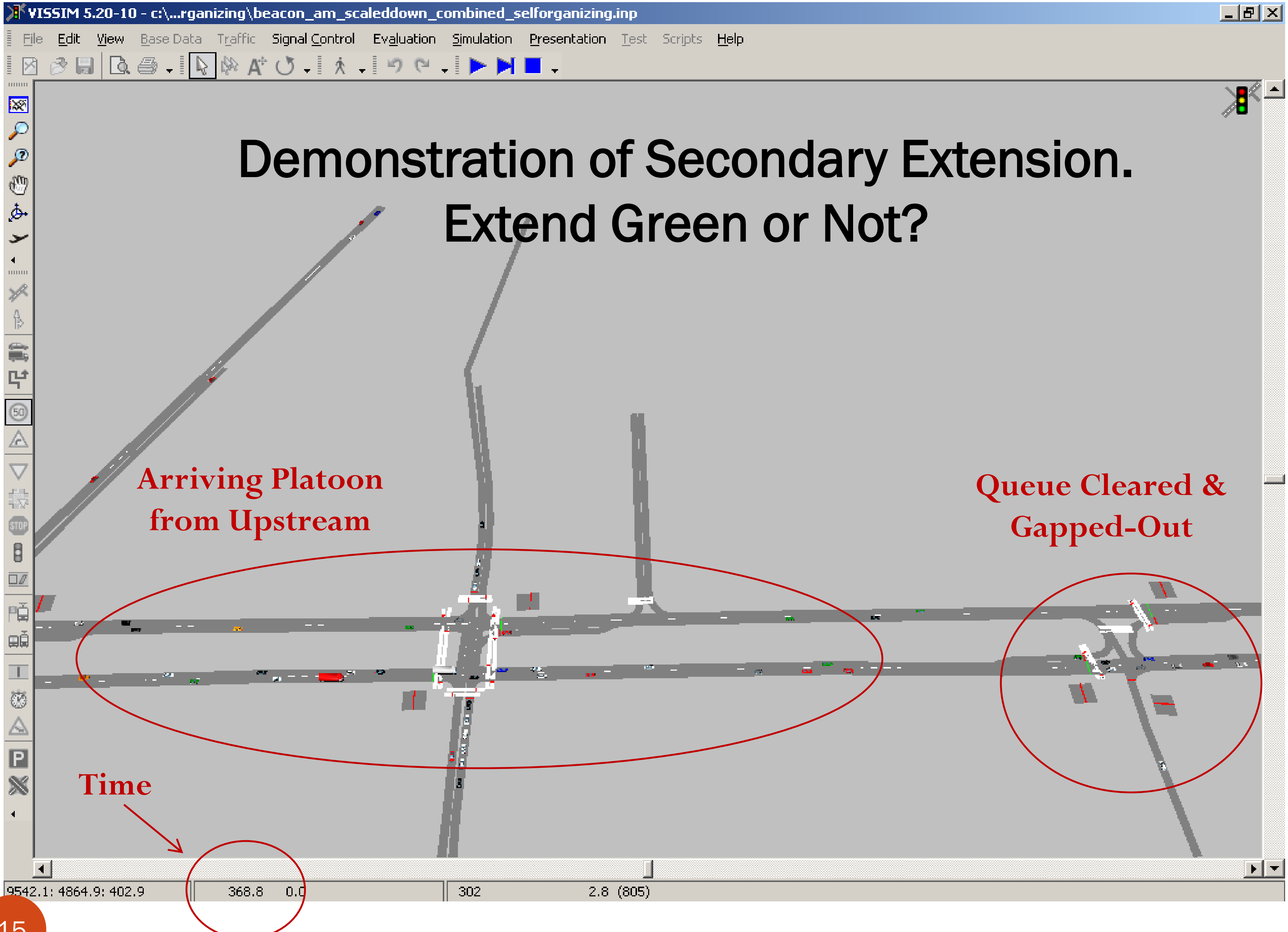
Secondary Extension Criterion for the Critical Direction

Extend **IF** Lost Time Per Vehicle ≤ Affordable Lost Time

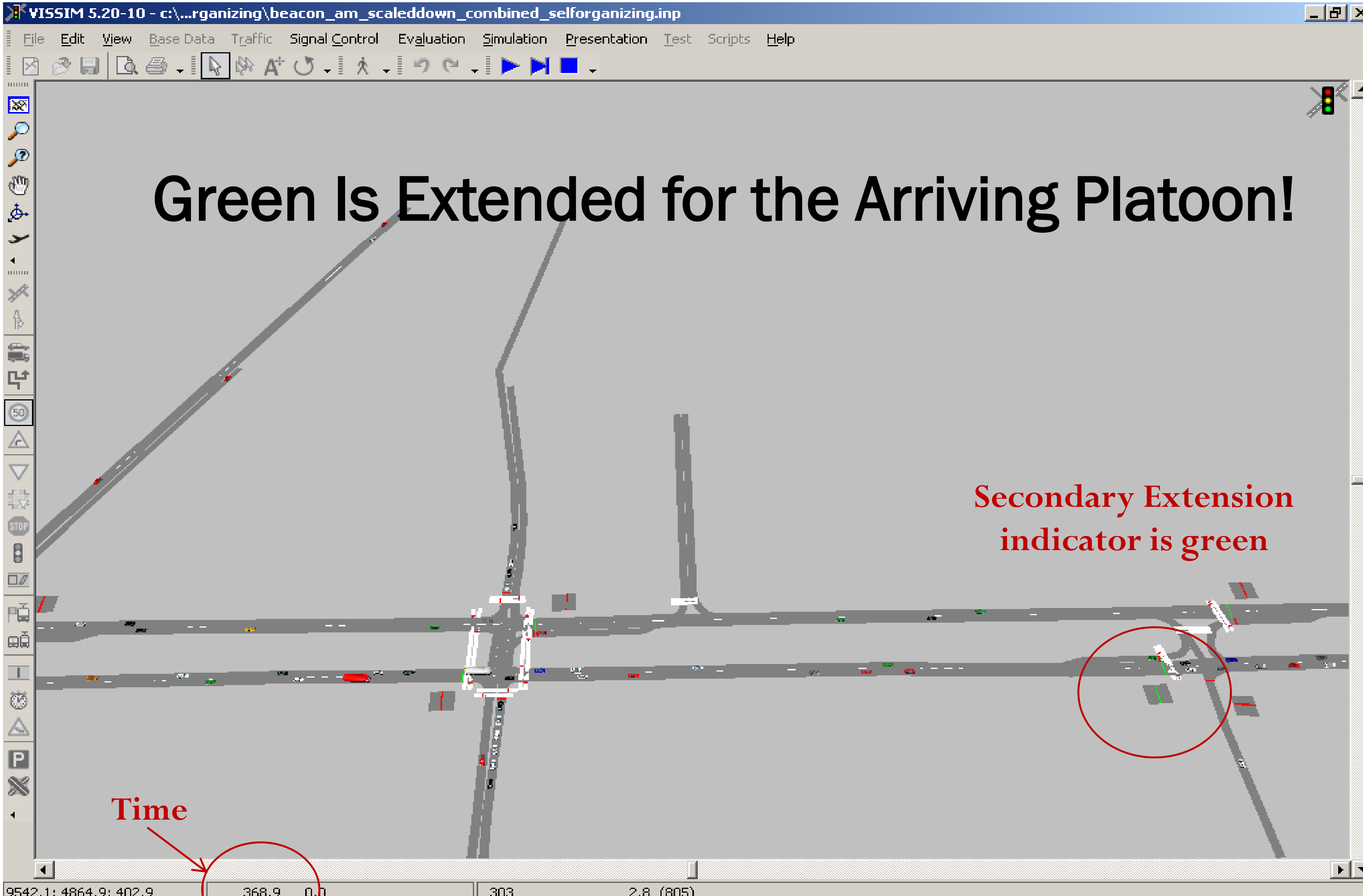


Limit of one secondary extension per cycle

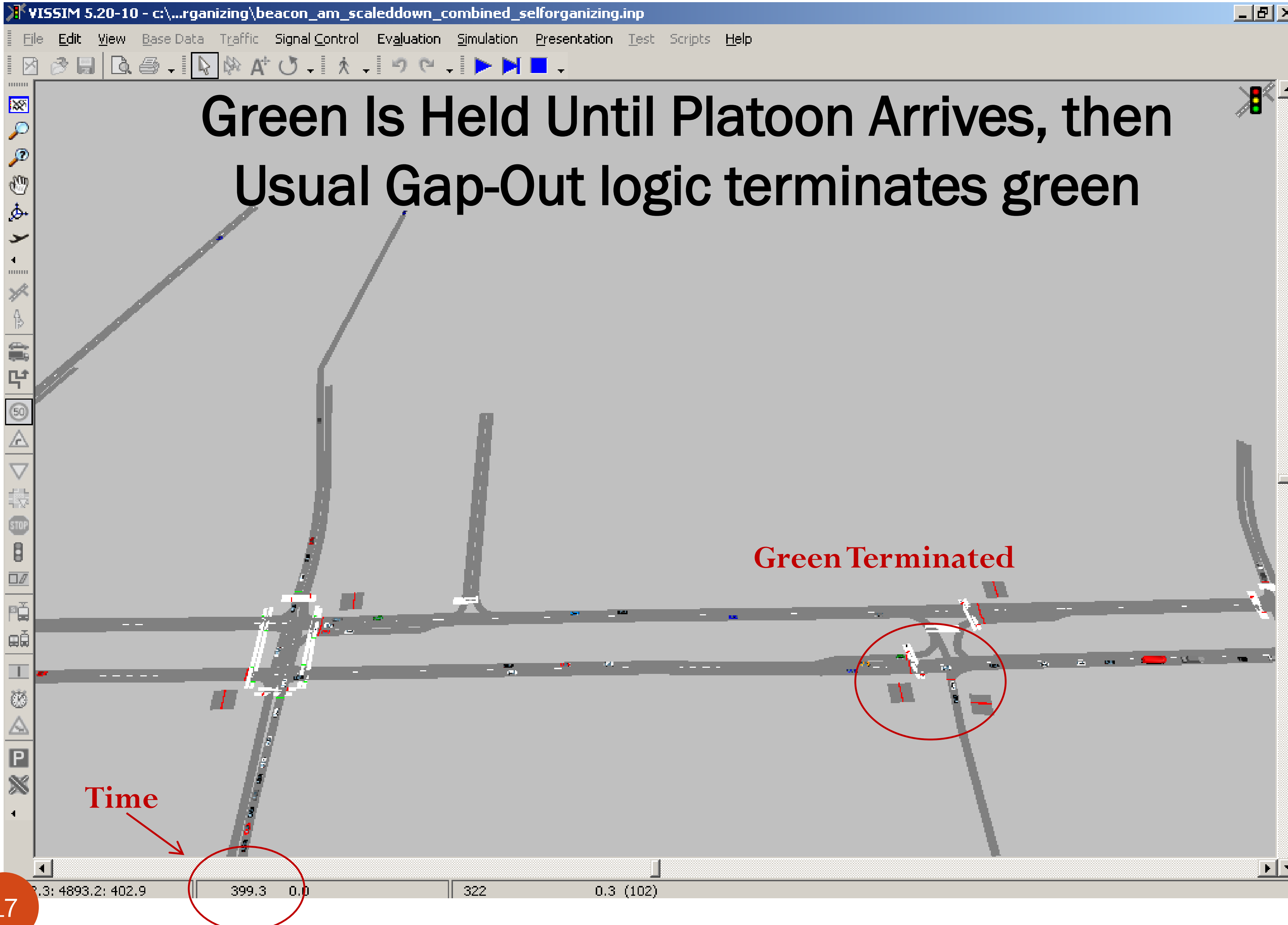
Demonstration of Secondary Extension. Extend Green or Not?



Green Is Extended for the Arriving Platoon!



Green Is Held Until Platoon Arrives, then Usual Gap-Out logic terminates green



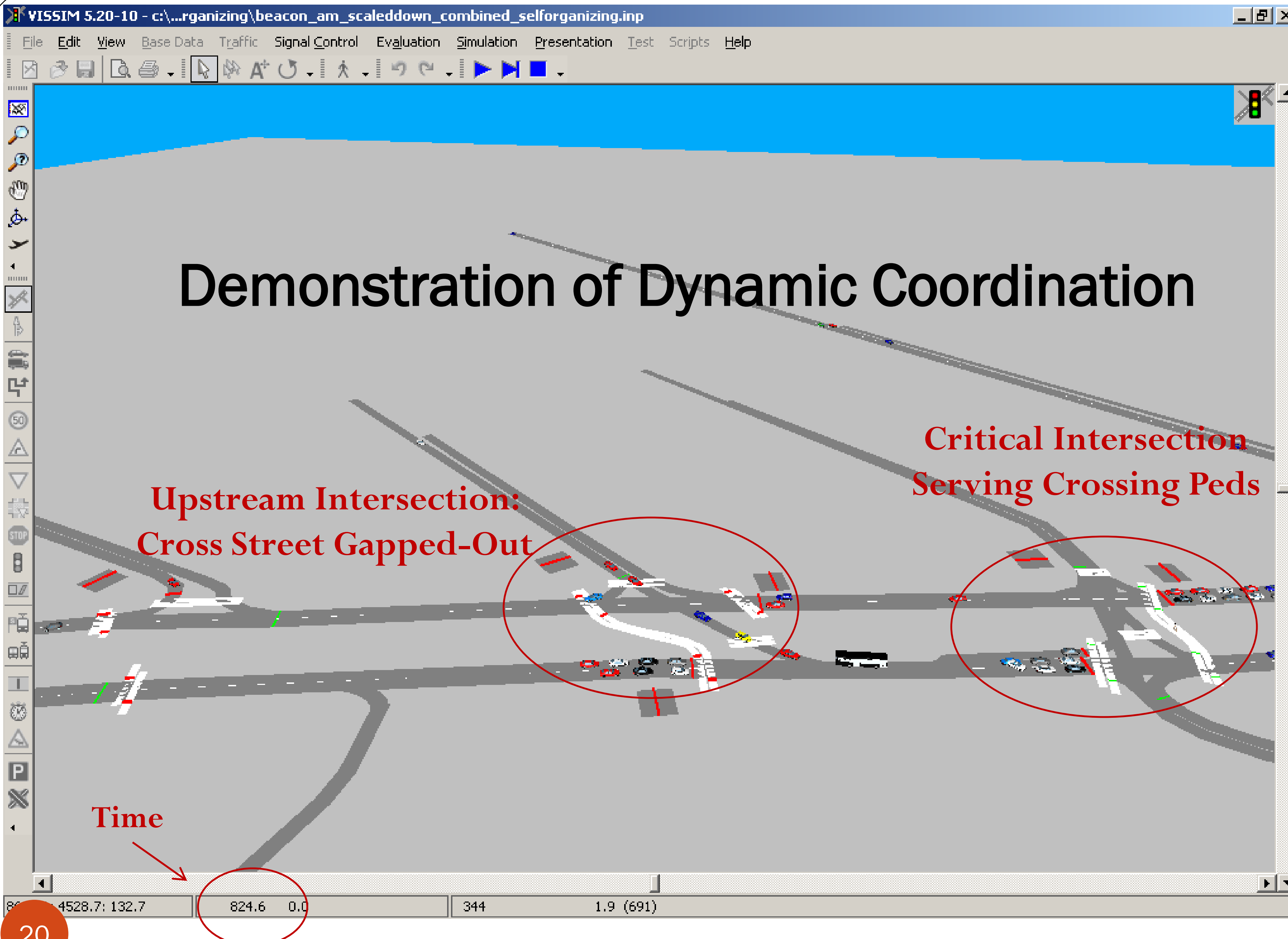
Secondary Extension for Non-Critical Direction

- Similar criterion, except that maximum anticipated extension is smaller

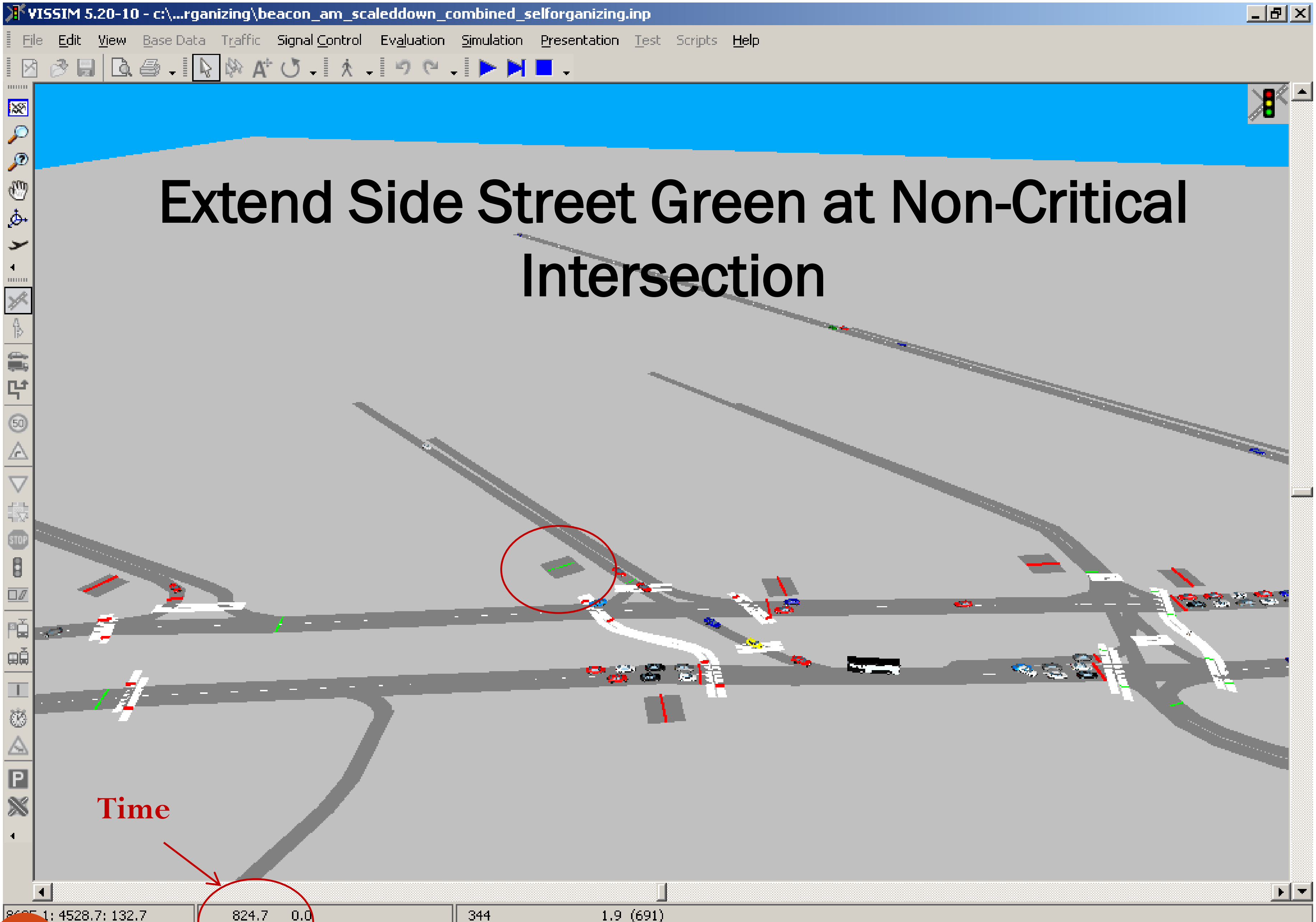
Coordination Logic for at Closely-Spaced Intersections (i.e., Limited Queue Storage Capacity – about 150 m)

- Dynamic coordination for small zones (2 or 3 intersections)
- Within a zone, critical intersection is the "leader"
  - Non-critical int'ns adjust their green start times based on predicted earliest green start of the critical intersection
  - Cycle length is not pre-determined
- Control tactics aim to avoid spillback or starvation at the critical intersection – maximize *throughput* during periods of oversaturation

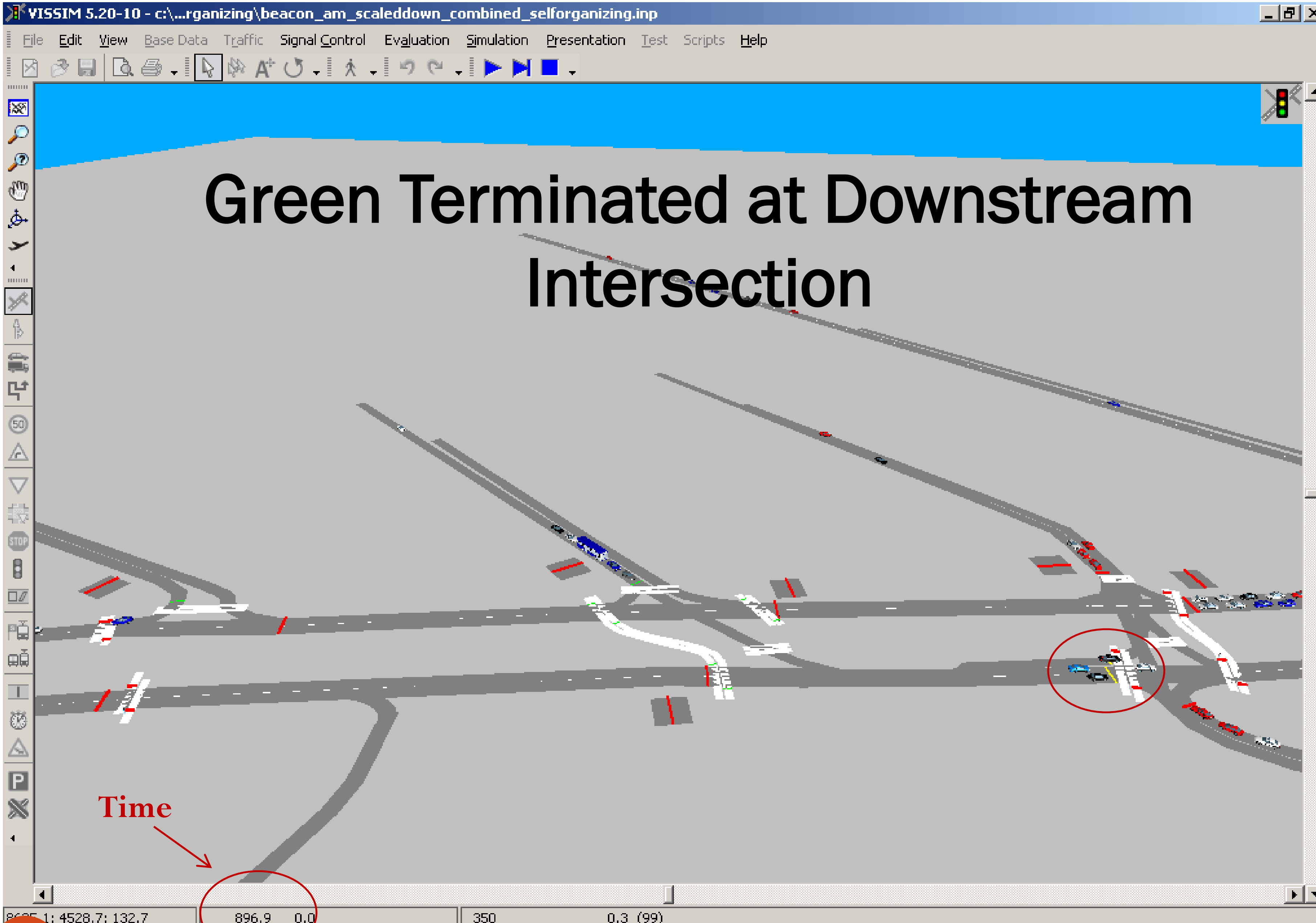
Demonstration of Dynamic Coordination



Extend Side Street Green at Non-Critical Intersection

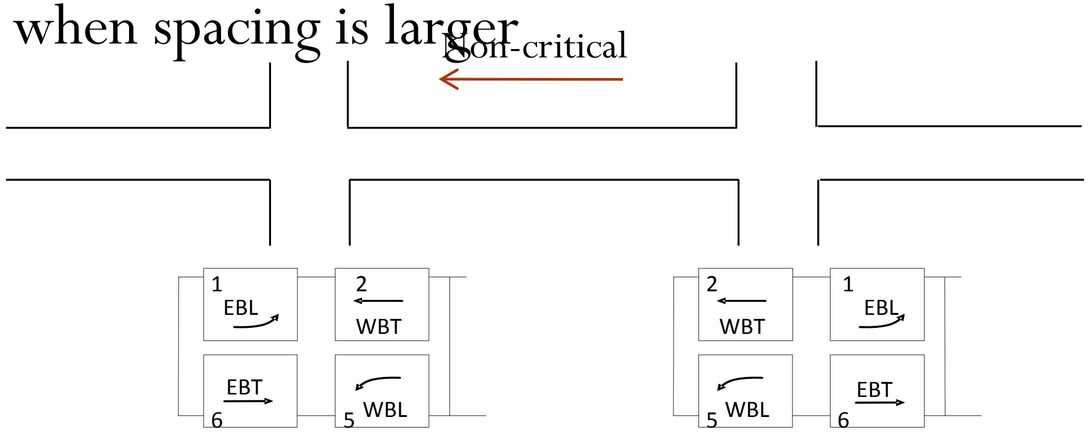


Green Terminated at Downstream Intersection



Coordinate for One Direction or Two?

- May specify lead-lag phasing (through movement leads on entry, lags on exit) when spacing is larger

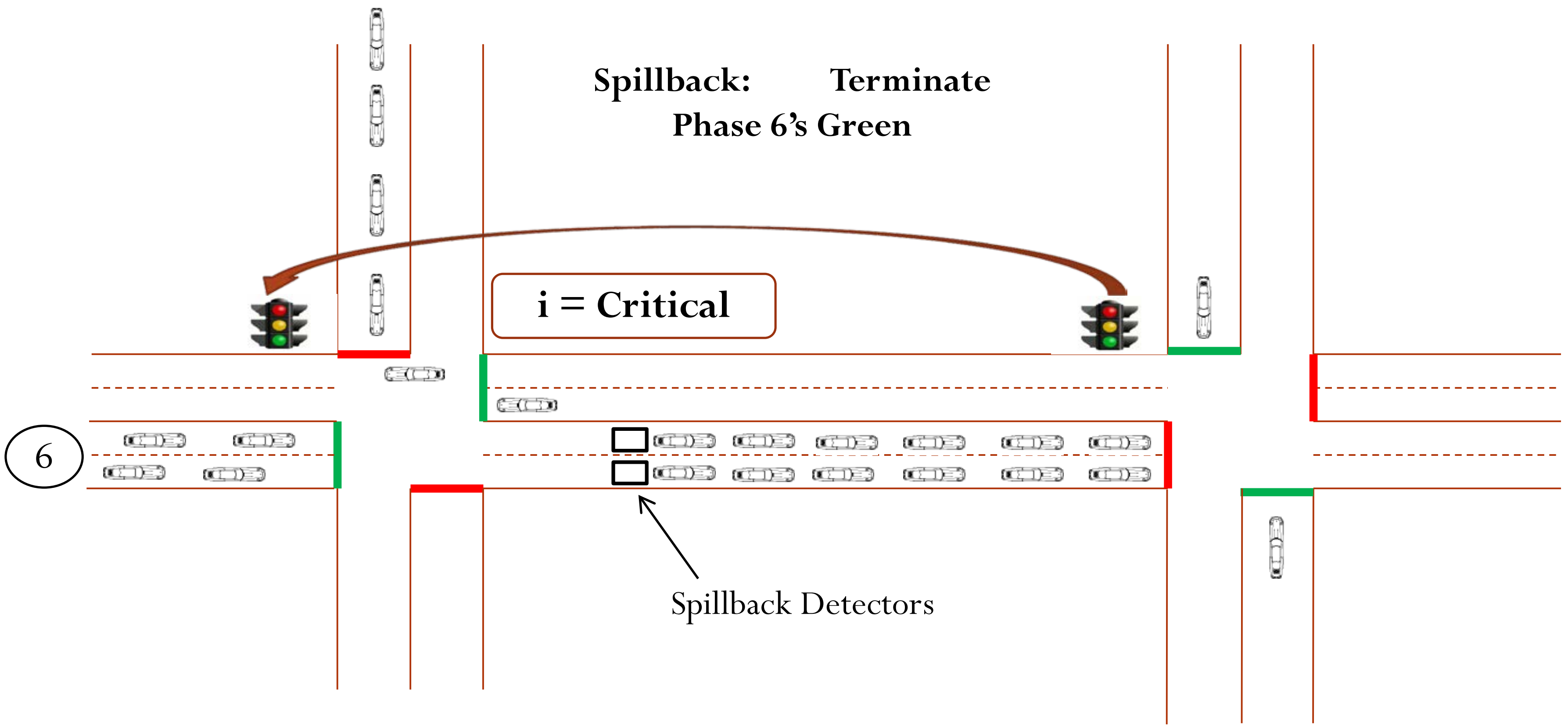


- For good bi-directional progression when intersections have excess capacity, start both directions simultaneously
- If degree of saturation > 0.90, progression strictly follows critical direction

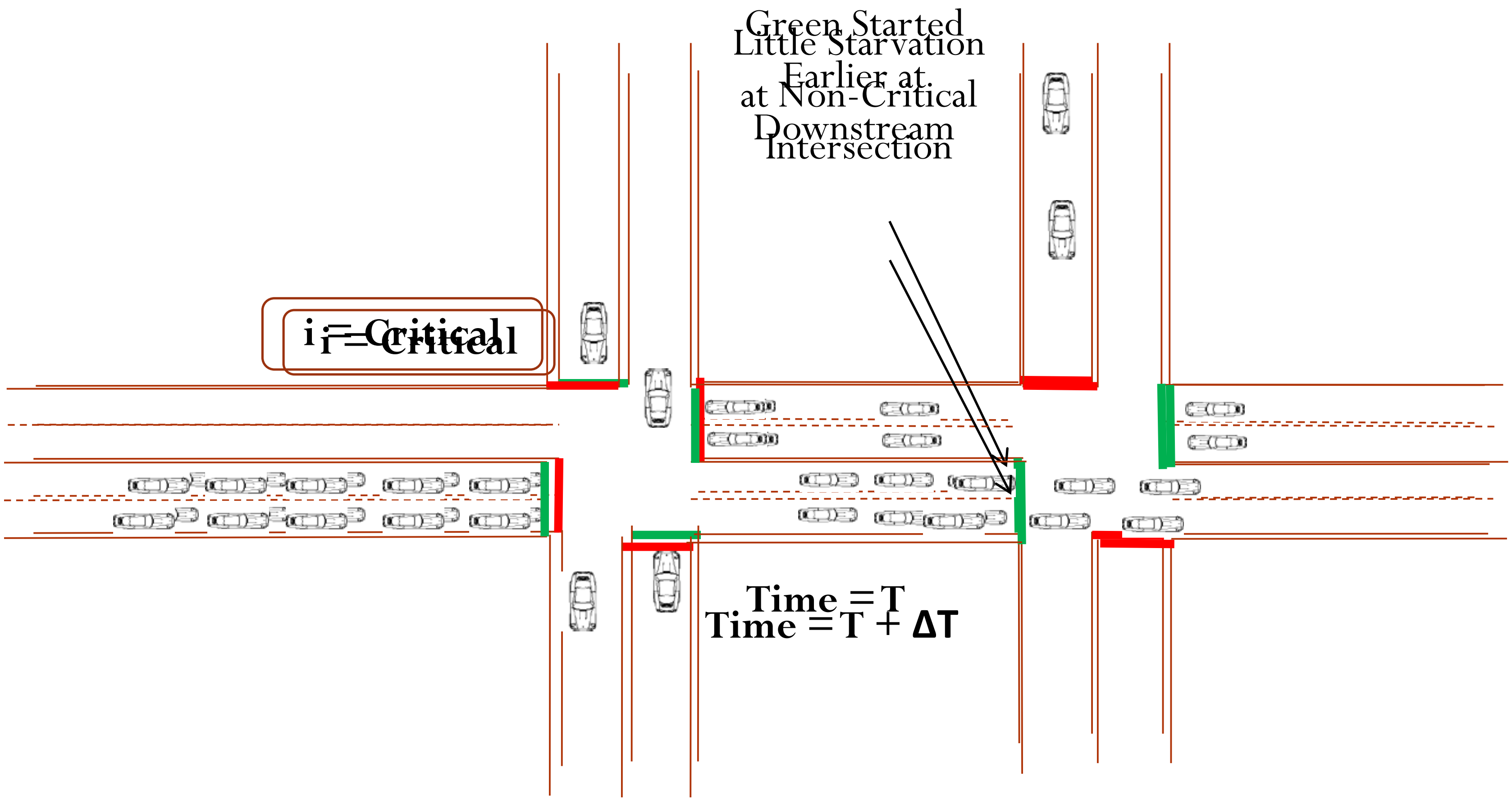
Throughput Maximization for Oversaturated Arterials in Coupled Zones

1. Prevent spillback from downstream intersection to critical intersection
2. Prevent starvation from upstream intersection
3. Eliminate spillback from turning-bay lane onto through lane.

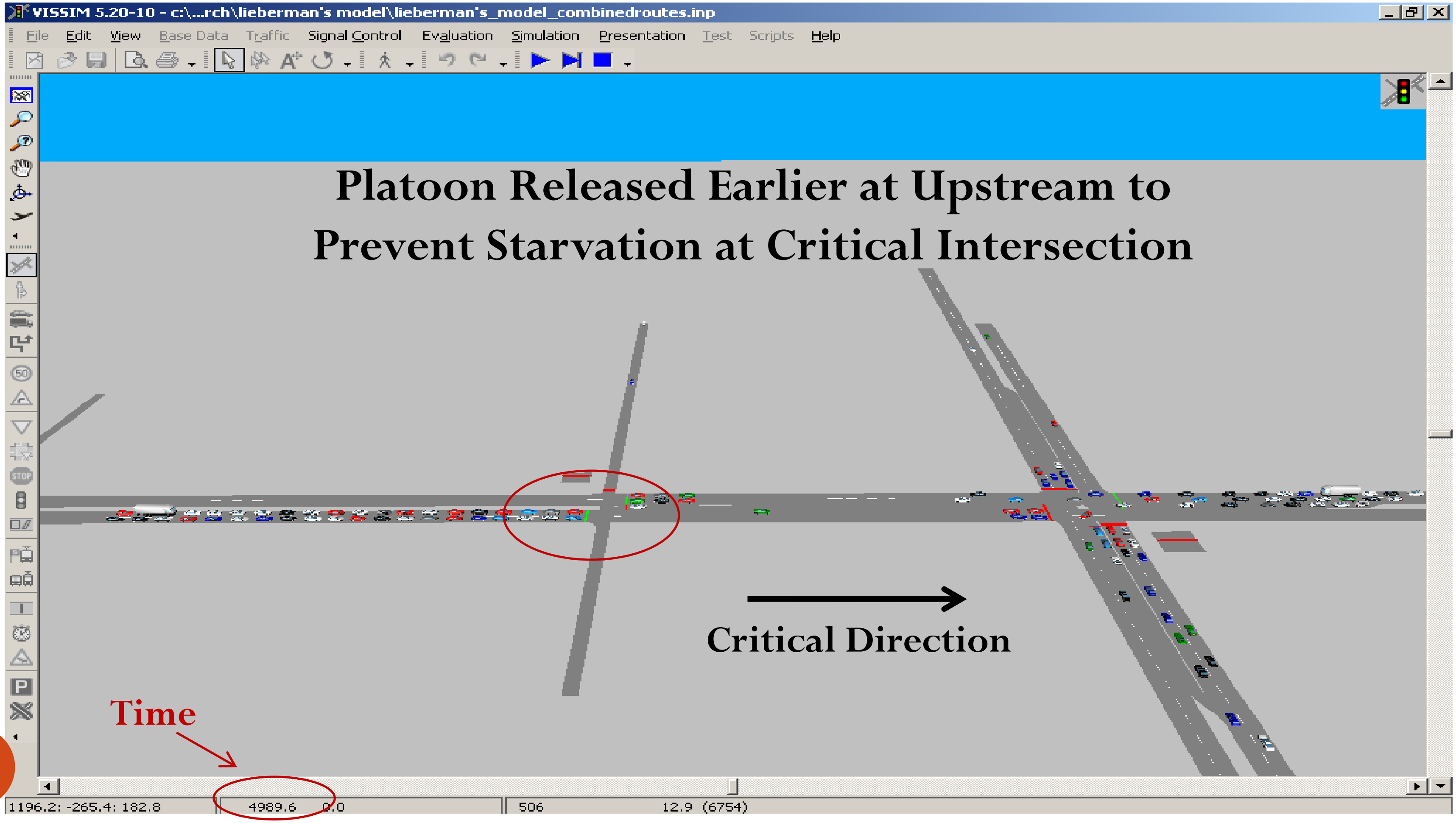
1a & b. Use spillback detector to truncate green and to inhibit start of green.

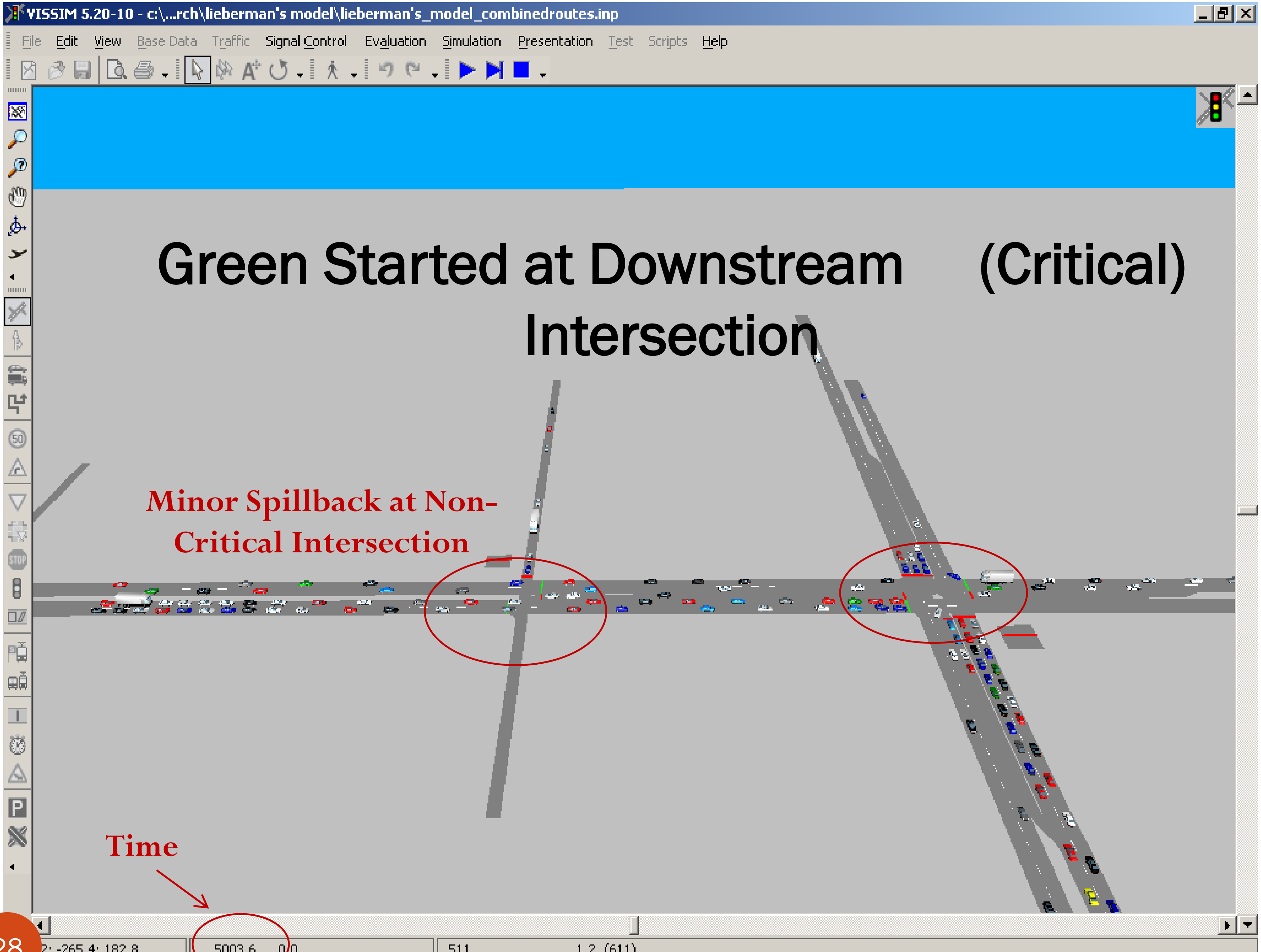


1c. Allow a little starvation at downstream intersection to protect against spillback at critical intersection.

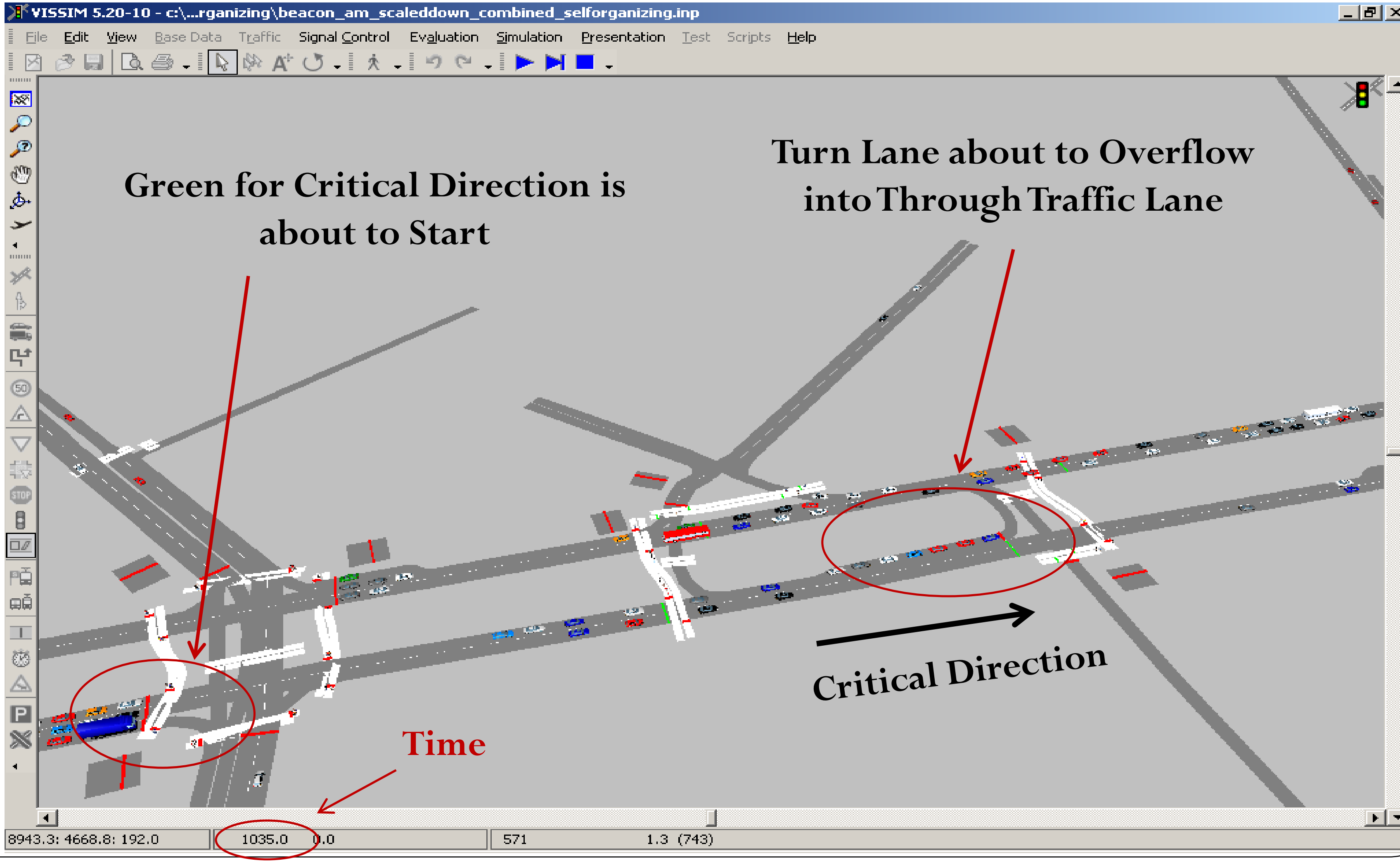


2a. Allow temporary spillback into upstream intersection to protect against starvation at critical intersection.

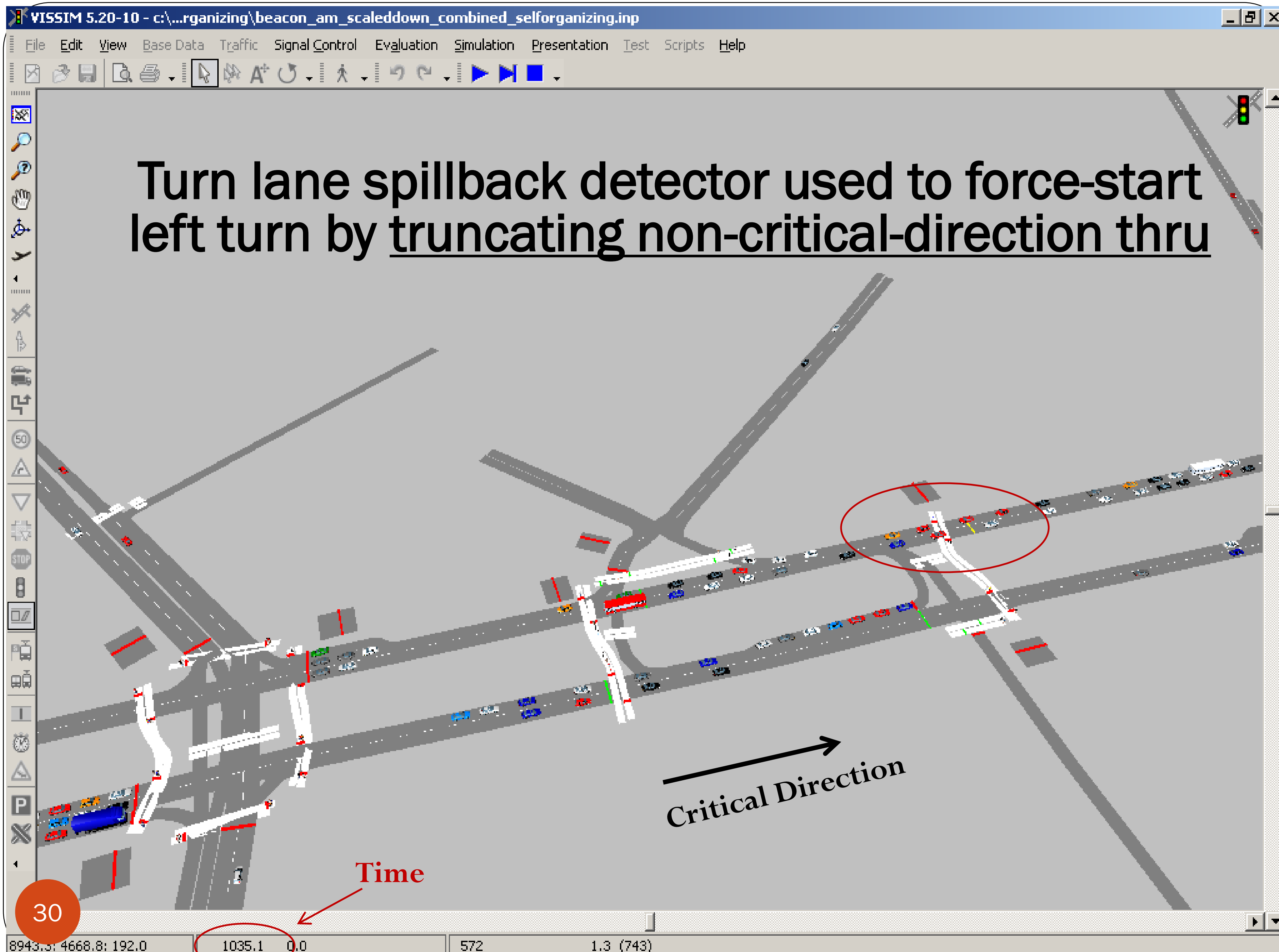


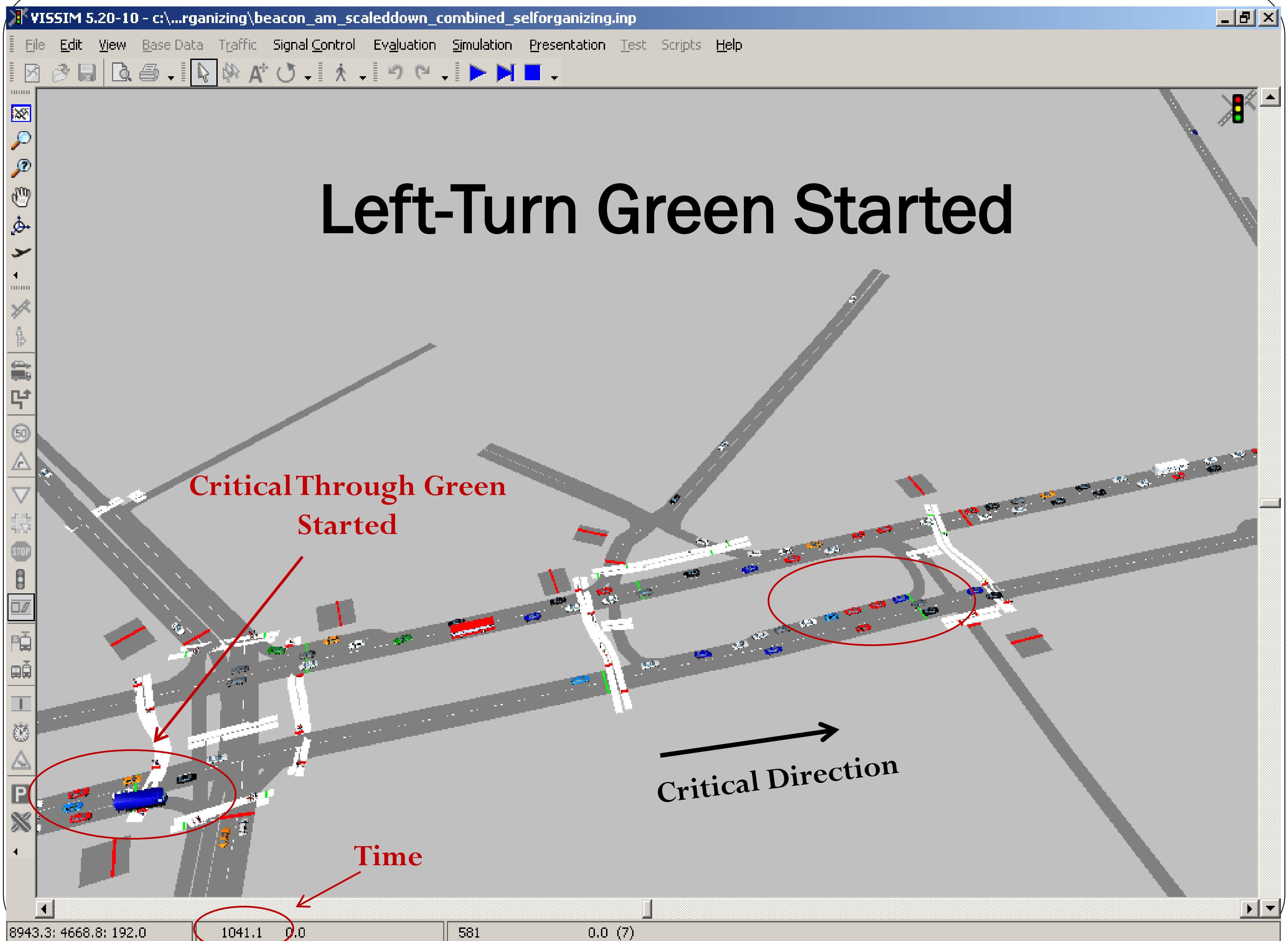

VISSIM 5.20-10 - c:\...rch\lieberman's model\lieberman's_model_combinedroutes.inp
File Edit View Base Data Traffic Signal Control Evaluation Simulation Presentation Test Scripts Help
Green Started at Downstream (Critical) Intersection
Minor Spillback at Non-Critical Intersection
Time
2: -265.4: 182.8
5003.6 0.0
511
1.2 (611)

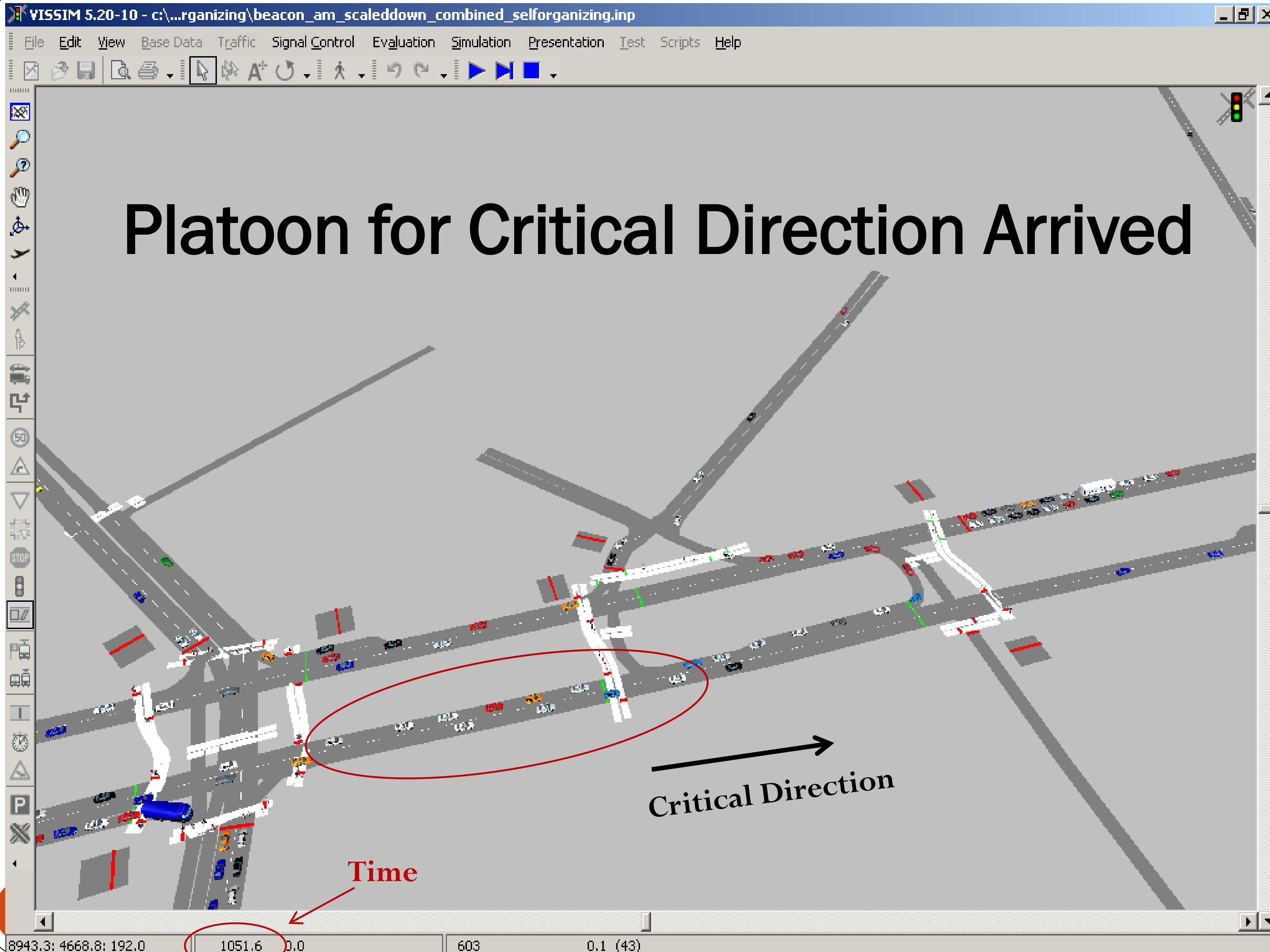
3. Prevent spillback from turning lane into a critical direction lane



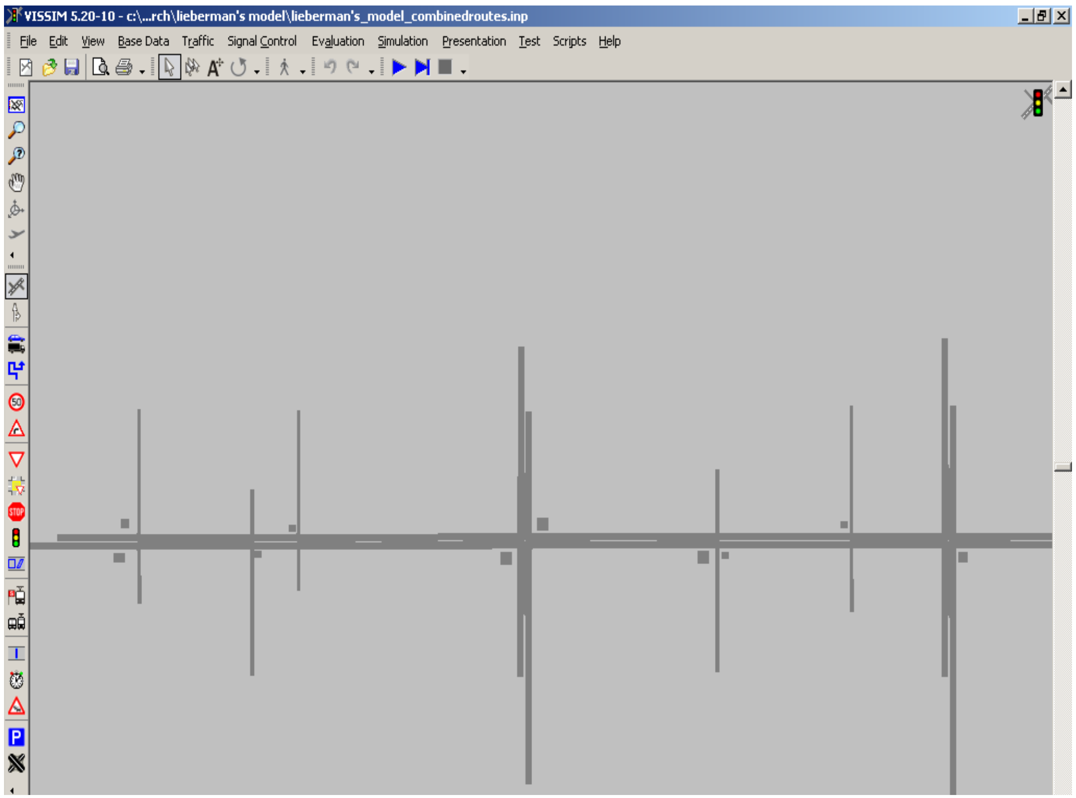
Turn lane spillback detector used to force-start left turn by truncating non-critical-direction thru



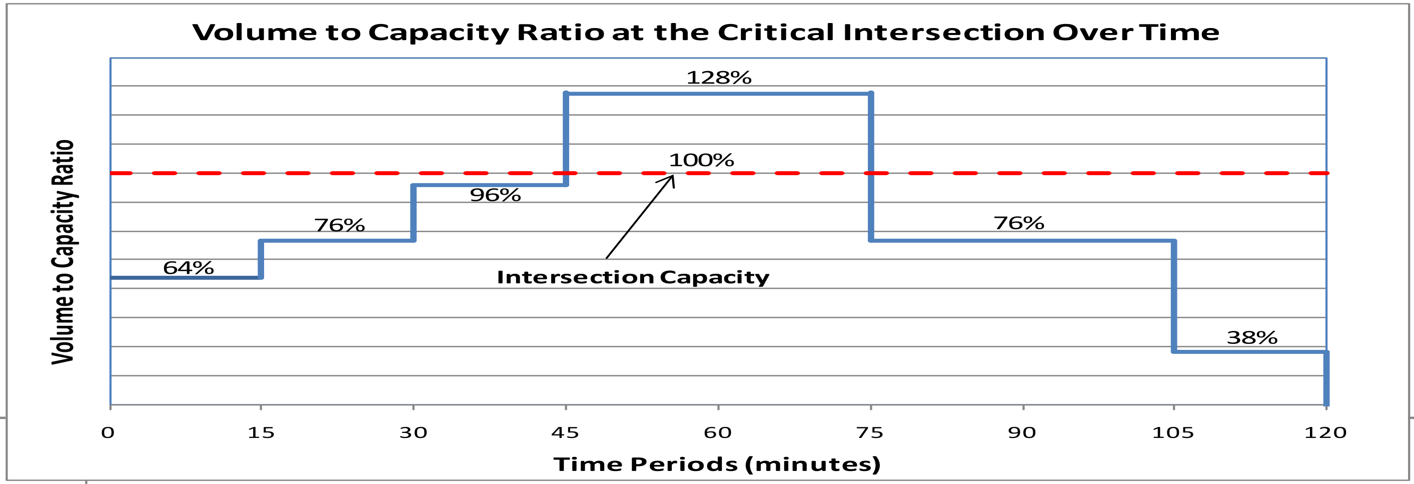

VISSIM 5.20-10 - c:\...rganizing\beacon_am_scaleddown_combined_selforganizing.inp
File Edit View Base Data Traffic Signal Control Evaluation Simulation Presentation Test Scripts Help
Left-Turn Green Started
Critical Through Green Started
Critical Direction
Time
8943.3: 4668.8: 192.0
1041.1 0.0
581
0.0 (7)

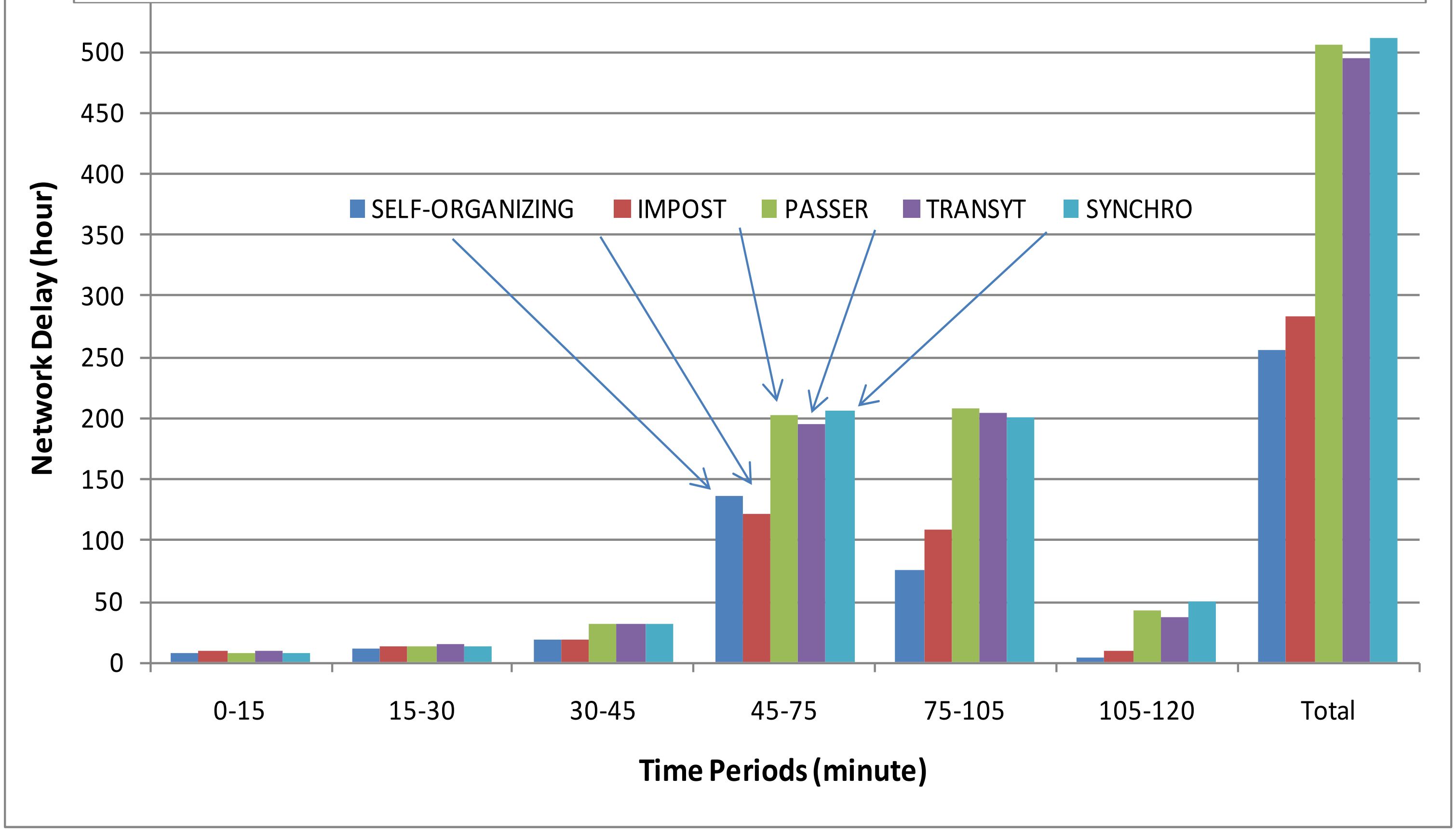

VISSIM 5.20-10 - c:\...rganizing\beacon_am_scaleddown_combined_selforganizing.inp
File Edit View Base Data Traffic Signal Control Evaluation Simulation Presentation Test Scripts Help
Platoon for Critical Direction Arrived
Critical Direction
Time
8943.3: 4668.8: 192.0
1051.6
0.0
603
0.1 (43)

Testing of Developed Algorithms for Oversaturated Arterials

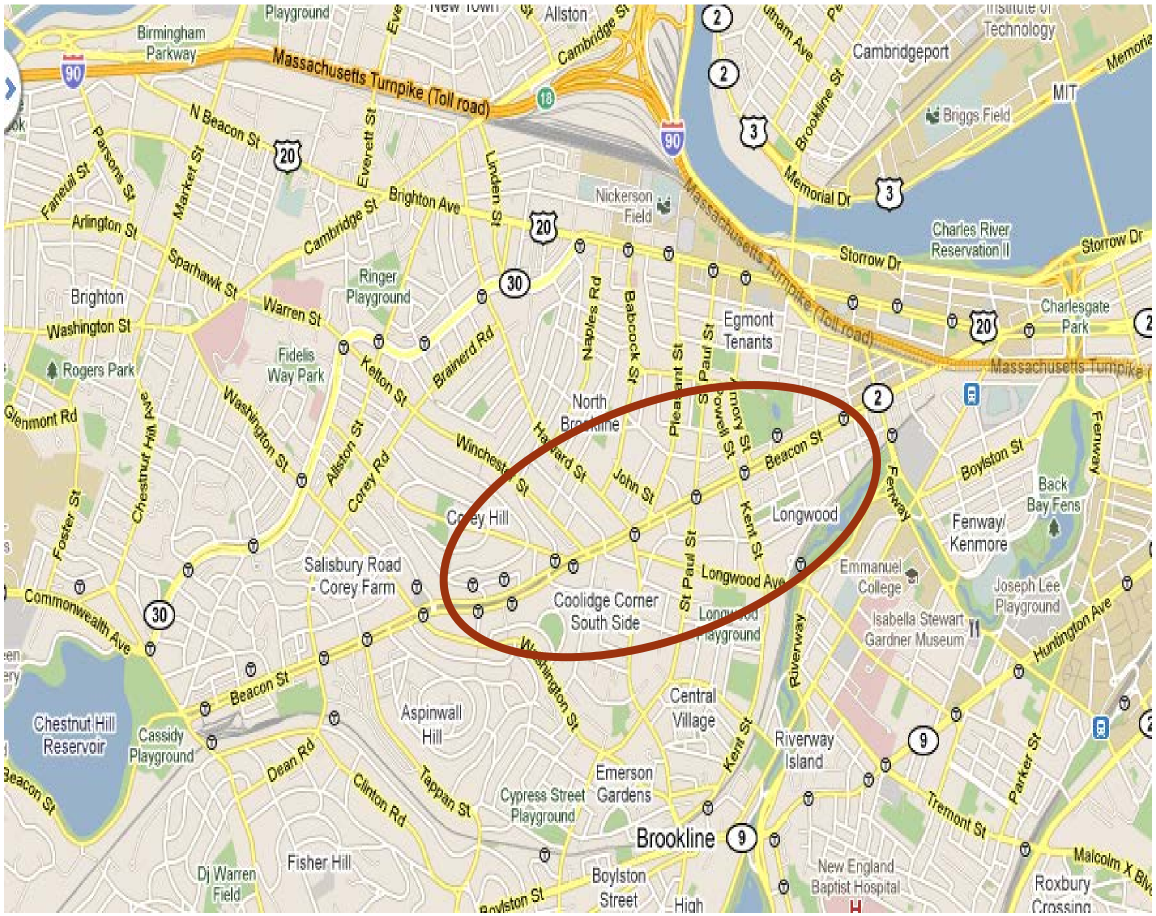


- 7- intersection arterial in VISSIM
- Various intersection spacing (75 to 350m)
- Control logic written in C++ and interfaced to VISSIM through API
- Calibration to match saturation flow rate
- Comparison with Lieberman's IMPOST and standard software packages for arterial traffic


Volume to Capacity Ratio at the Critical Intersection Over Time
Volume to Capacity Ratio
128%
100%
96%
76%
64%
76%
38%
Intersection Capacity
0
15
30
45
60
75
90
105
120
Time Periods (minutes)


Network Delay (hour)
500
450
400
350
300
250
200
150
100
50
0
SELF-ORGANIZING
IMPOST
PASSER
TRANSYT
SYNCHRO
0-15
15-30
30-45
45-75
75-105
105-120
Total
Time Periods (minute)

Case Study of Beacon Street, Brookline, Massachusetts

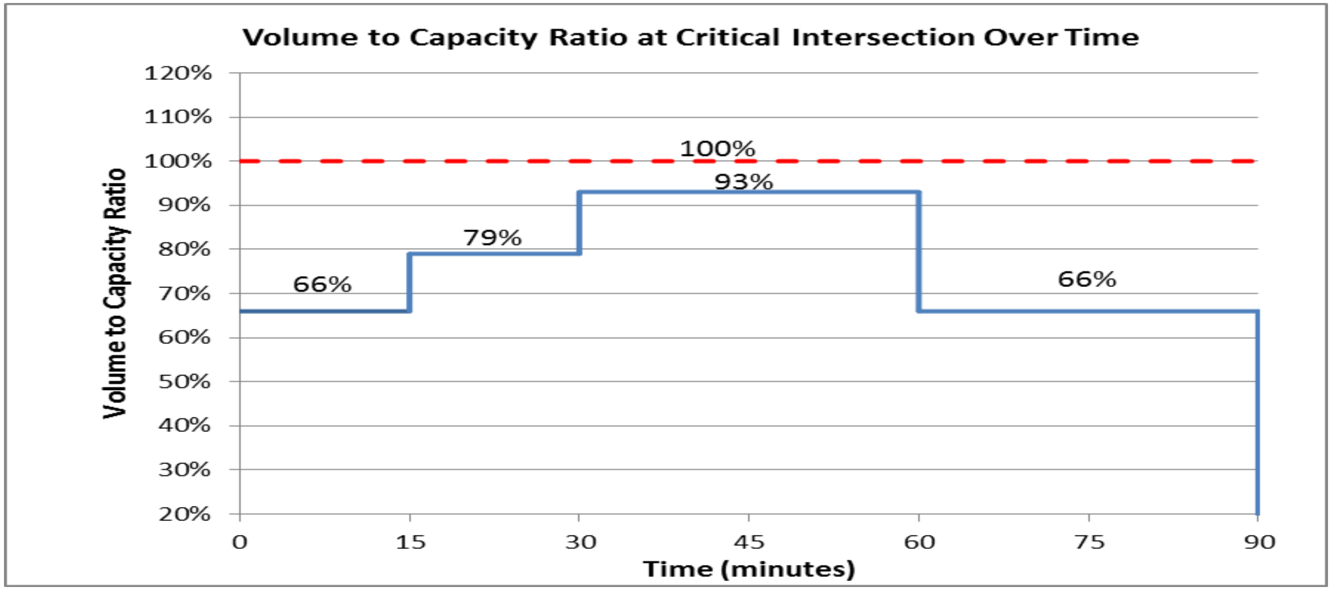


- 12- signalized intersection arterial in VISSIM
- Various intersection spacing (80 to 450m)
- Very high pedestrian activity
- Frequent transit service

Light Rail C line:
Headway = 7 mins

Bus Route 66:
Headway = 8 mins

Simulated Volume Profile



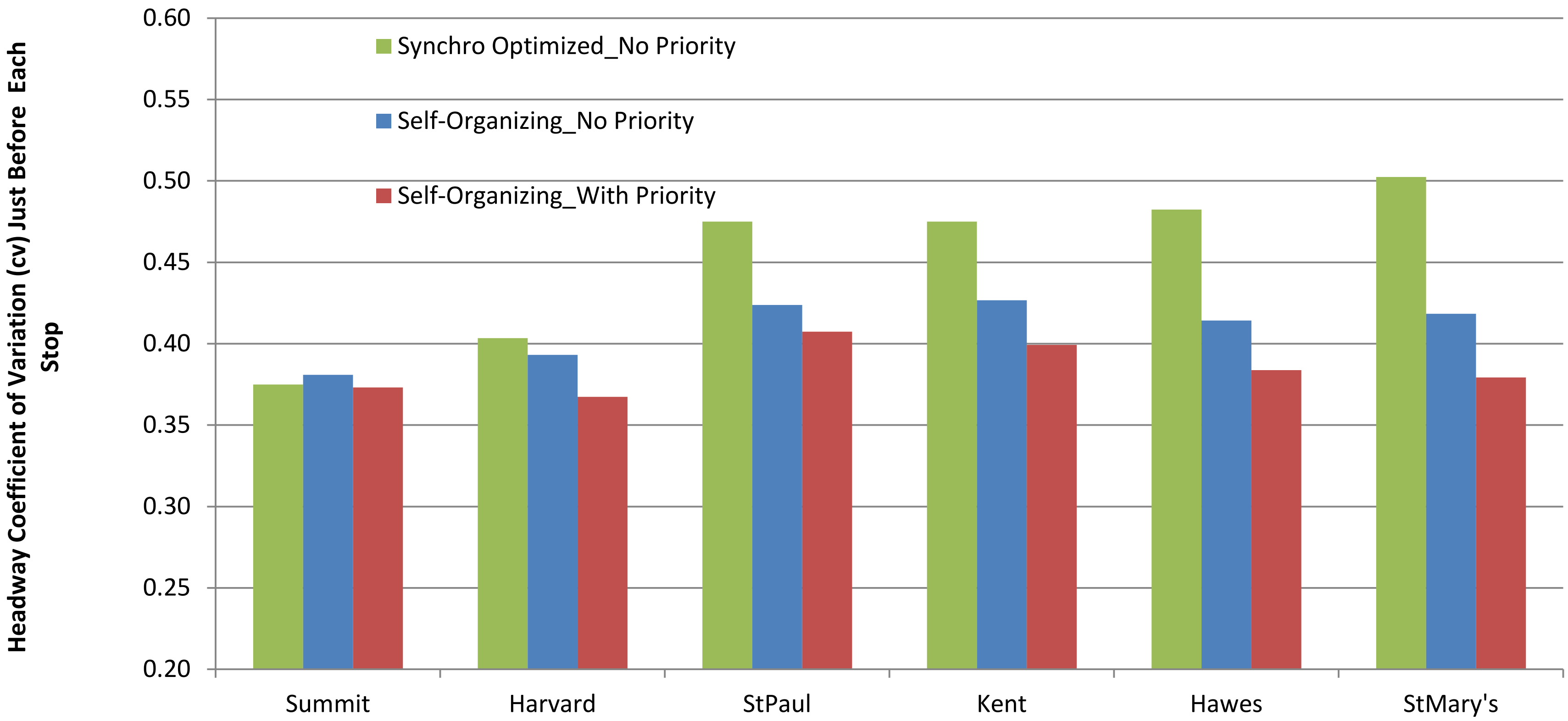
Transit Signal Priority (H = 7mins, 420s)

- Conditional Priority to Late Trams:
  - For peak direction: H > 315s (Impact on Crowding)
  - For non-peak direction: H > 180s (Crowding Is Not an Issue)
- Applied Transit Priority Strategies:
  - Green Extension (Extension as long as 15 seconds)
  - Early Green
- No Priority for crossing Bus Route 66

	Coordinated - Actuated[1]		Self-Organizing		
	No TSP	TSP	No TSP	TSP	Conditional TSP[2]
Average Network Delay (s/vehicle) and (change)	68.4[3] (0%)	74.0 (8%)	58.6 (-14%)	67.1 (-2%)	70.5 (3%)
Train Delay per intersection (s) and (change)	20.2[3] (-)	13.7 (-6.5 s)	21.2 (1.0 s)	7.1 (-13.1 s)	9.9 (-10.3 s)
Percent of Trains Requesting Priority (only late trains request priority)	0%	100%	0%	100%	69%
Average Cycle Length during Base Period (v/c = 0.81)	80 s	80 s	69 s	Not measured	Not measured

Northeastern University

Improvement in Headway Regularity



Conclusions

- Self-Organizing Traffic Signals outperform the performance of existing signal controllers.
- Actuated control combined with heuristic rules can produce the coordination mechanisms needed through advanced detection and communication.
- Self-Organizing Logic is flexible and highly interruptible, allowing one to apply aggressive TSP with almost no impact to non-transit traffic.

Future Work

- More efficient use of lagging lefts
  - Start lagging left so that its queue discharge ends when its parallel phase gaps-out
  - That way, slack time goes to the leading through phase (with typically higher arrival rate)

- Try to incorporate "look-ahead" or "Predictive priority" logic

ANY QUESTIONS??

"Self-Organizing Traffic Signals"

- **Efficient traffic signal control is a key to**

- Lessen traffic congestion, fuel consumption and air pollution.
- Promote public transportation, walking, and reduce auto-dependency

  Sustainable Transportation!!!

  ⟶

- **However, existing signal controllers are**

- Auto oriented: Large delay to transit and pedestrians.
- Not able to respond to variations in traffic demand.
- Not able to recover from interruptions such as transit signal priority (TSP).

Overview of Existing Signal Controllers

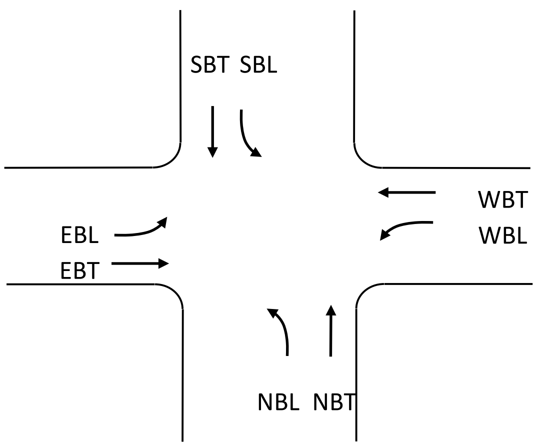
- Actuated Control

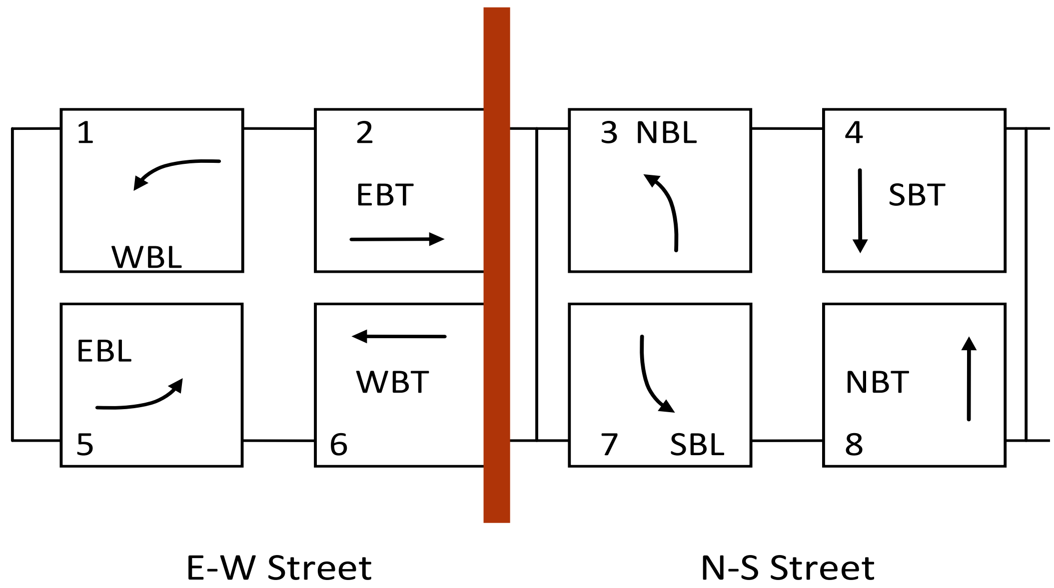
- Fixed Cycle Coordinated Control
  1. Pre-Timed
  2. Coordinated-Actuated
  3. Adaptive Control

- Cycle-Free Optimizing Control

Coordinated-Actuated Control

- Fixed cycle length.
- Fixed point = End of coordinated phase.
- Uncoordinated phases may run shorter, but not longer.
- Coordinated phases may start earlier.





- Offers relatively low flexibility.

Carlos Gershenson's Self-Organizing Traffic Lights (SOTL)

- Only local rules: Global solution is obtained dynamically with the intersection of local elements.
- Applies fundamentals of actuated control supplemented with spillback control logic.
- No communication between neighboring intersections.
- http://turing.iimas.unam.mx/~cgg/sos/SOTL/SOTL.html

SOTL, continuing…

- The model outperforms fixed-cycle coordination under different traffic flow rates, Gershenson et. al. (2009).

- However, the model was applied to a very limited network:

i. One-way streets.
ii. Perfect intersection spacing.
iii. No turning traffic.
iv. Equal traffic demand.
v. No lost time associated with change interval.