Transit Signal Priority

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Transit Signal Priority – Help or Hype?

- Zurich: nearly zero traffic delay for trams, even with mixed traffic (and punctuality!!)
- San Diego trolley: green wave through downtown intersections
- Some US applications: < 3 s savings per intersection , or …
- No measurement at all

Transit Priority as a Societal Objective

- Transit use benefits society
  - Congestion
  - Air quality, climate impact, energy use
  - Vibrant communities
- Priority breaks the vicious cycle in which congestion drives people to switch from transit to car

Priority Makes Sense

- One extreme ($$$$): build a metro
- Other extreme: do nothing, buses become swamped in congestion
  - Traffic delay can represent 30% of a bus route's operating cost
  - Feeds vicious cycle of ever-lower transit use
- In between:
  - Priority in space: bus lanes, etc.
  - Priority in time: signal priority

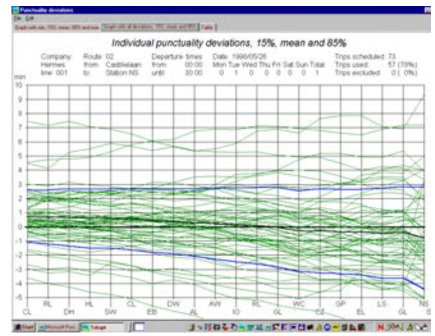
What Priority Means to a Transit Operation

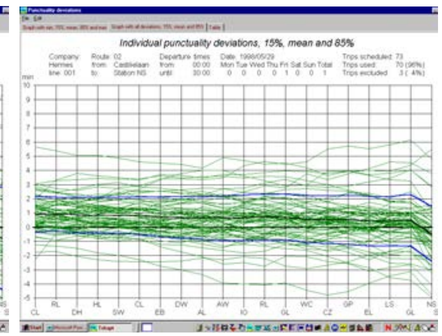
- Reduced mean running time
  - Lowers passenger travel time
  - Reduces operating cost
- Improved reliability (lower 95-percentile running time)
  - Less need for recovery time -> shorter cycle time -> lower operating cost
  - Tri-Met Line 12: priority reduced needed cycle length from 104 min to 93 min (11%) – saved a bus
  - Less waiting time, less crowding for passengers

Operational Control: Schedule Adherence, Crowding

Schedule deviation along the route, without priority, Eindhoven

With priority





Priority Makes Transit …

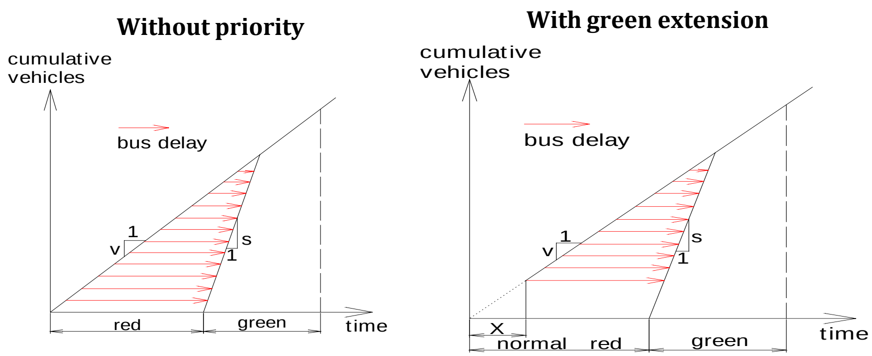
- More competitive
  - Bus has natural disadvantages due to *stops* and *walking / waiting*
  - Priority compensates, especially if cars suffer congestion
- More socially acceptable (red carpet)
  - my great aunt …

Intelligent Signal Priority

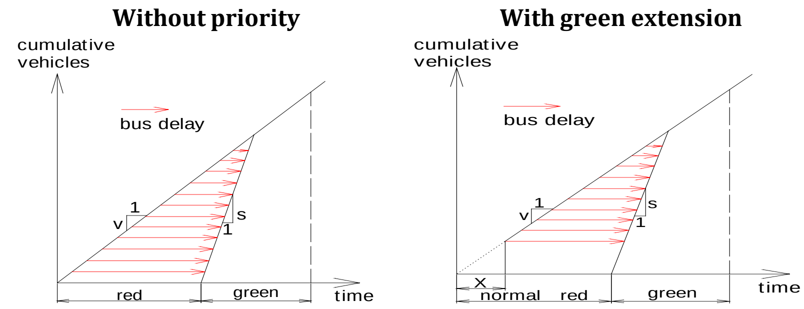
- Not “preemption” (too blunt)
- Not “cautious priority” (almost useless)
- Intelligent tactics, algorithms, detection to give transit near-zero-delay service, without undue impact on other traffic

Green Extension

- Built-in logic in modern controllers
- Large benefit to a few buses
  - Therefore little disruption to traffic
- Extension increment is a parameter (10 s? 15 s?)



"Priority Push" is not the same as Allowed Extension



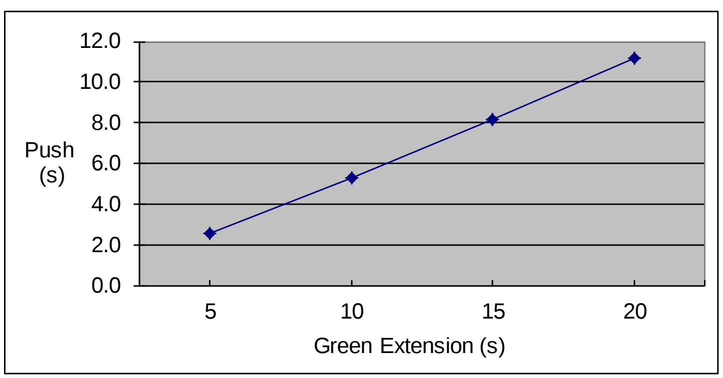
$$E[delay] = \frac{R^2}{2C} \frac{1}{1 - v/s}$$

$$E[delay] = \frac{R^2}{2C} \frac{1}{1 - v/s} - \boxed{\left[X \frac{R}{C} - \frac{X^2}{2C}(1 - v/s) \right]}$$

Priority push!

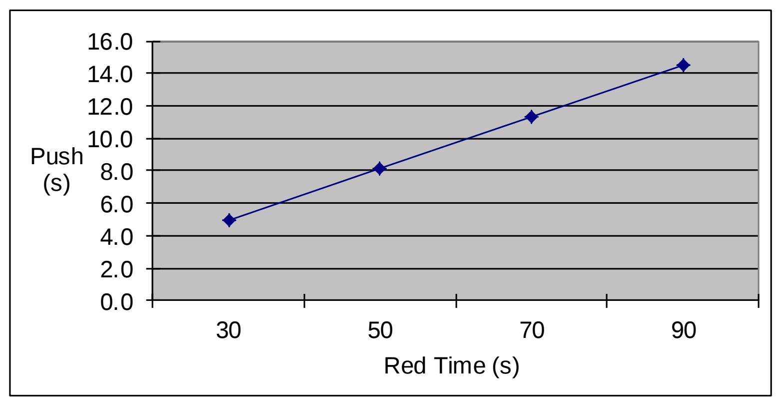
Priority Push vs. Green Extension

(cycle length = 100 s, red time = 50 s, degree of saturation = 85%)

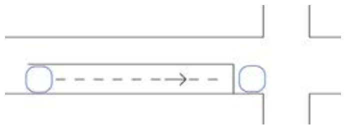


Priority Push vs. Red Time for allowed green extension of 15 s

(cycle length = 100 s, degree of saturation = 85%)

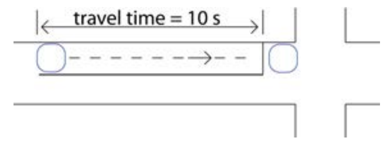


Detection



- Check-in detector location
  - Early enough to allow time to respond
  - Late enough to estimate bus arrival time
- Checkout detector to cancel request
  - Avoid wasted green
  - Performance measurement
- In-ground vs. overhead
- Optical signal with calibrated sensitivity
- GPS with continuous detection (short-range radio between bus and control box)

Upstream Detector, with travel time = maximum green extension



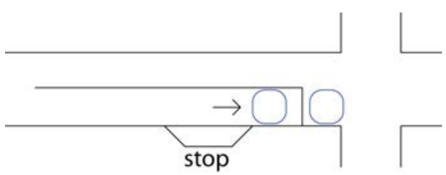
Simplicity:

- Request = detection
- No need for “priority request generator”

Weaknesses:

- assumes constant speed
- no flexibility for updates, time of day settings
- may not be suitable for other priority tactics

What if There’s a Near-Side Stop?

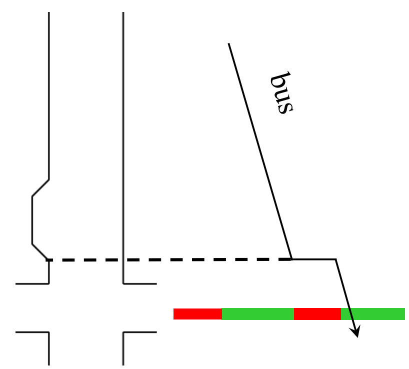


- Detector located just after stop
- Disable optical signal until door closes (Portland, OR)
- Does vehicle queue block entry to the bus stop?

Flush-and-Return

Early green tactic for Near-Side Stops
Tested using simulation on San Juan (PR) arterial

- Green extension to clear queue from bus stop
- Force signal to red during stop
  - *Minimizes bus’s impact on road capacity*
- Return to green as quickly as possible



Result: 8% reduction in transit time, saves 1 bus;
16% reduction in motorist delay because buses block intersections less

Common Weaknesses in Signal Priority Implementation

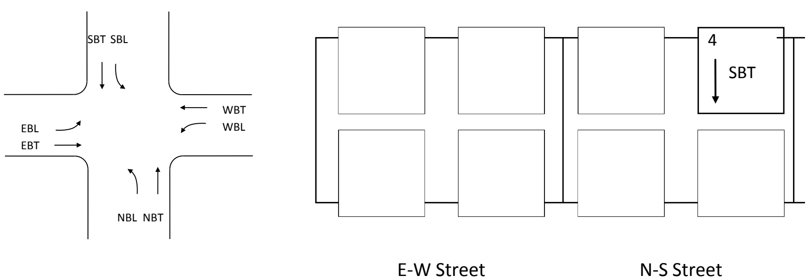
1. Lack of checkout detector = wasted green
2. Is extra time “borrowed” or “stolen”?
   - **Lack of compensation** creates large queuing impacts
3. “Cautious priority”
   - Inhibit priority for 5 minutes or 1 full cycle after a priority interruption
   - Inhibit priority if cross street occupancy exceeds threshold
4. Lack of data collection and analysis
   - Nobody ever gets it right the first time

Fully actuated (uncoordinated) signals have natural compensation

- Transit phase
  - Longer green in cycle with priority
  - Shorter green in next cycle, because some of its demand was served in previous cycle
- Competing phases
  - Longer red due to priority
  - Need more green, and get it, in next realization
- System quickly recovers

Lack of compensation in coordinated systems

- Fixed cycle length; fixed point = end of phase 2 (coordinated phase)
- Uncoordinated phases may run shorter than their allotted split, but not longer; coordinated phase gets the slack time (starts early)



- Green extension for 2 – no mechanism for compensation
- Green extension for 4 – slight compensation

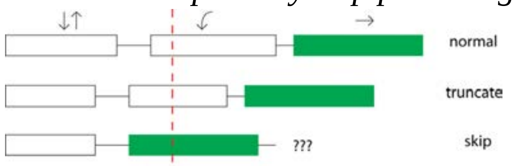
Returning to Coordination – a Problem with Clock-based Coordination

In coordinated systems, recovery means

- dissipating queues AND
- Returning to the background cycle
  - “Short way” = shorten phases following an extension
  - “Long way” = lengthen phases, skip a cycle
  - To smooth the impact, spread recovery over several cycles

Early Green

Truncate and possibly skip preceding phases

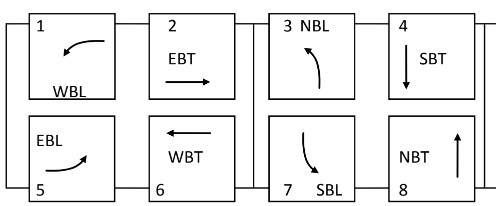


- What's the truncation rule?
  - How much to shorten competing phases? Can they be skipped?
- Smaller benefit to large number of buses
  - More traffic impact; hard to implement when bus frequency is high

Early Green Issues

- Exclusive lane for bus? (No queue, easier arrival time prediction)
- Mixed traffic: Eindhoven's "electronic bulldozer"
- Arrival time prediction
  - How far upstream? (Bus stop and intersection spacing …)
  - Tracking queue length to know how long is needed to flush out the queue (Zurich's trap logic)

Early green (truncating competing phases) under coordination



E-W Street N-S Street

Assume phase 2 is coordinated

- Early green for 2 is possible, but without compensation to shortened phases
- Early green for 3 – not possible under standard logic
- Early green for 4: Phase 3 could be shortened, but not Phase 2

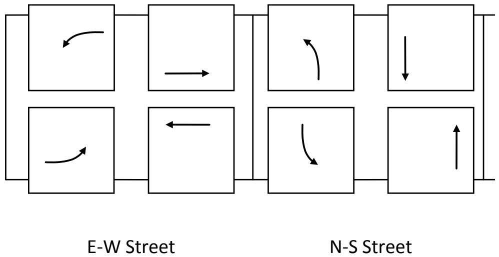
Eindhoven Experiment

Coordinated phase (ring road, no buses)

Buses every 10 min NB and SB

Existing Priority Scheme

- Coordinated phase is 6
- Buses on phases 4 and 8 (every 10 minutes)
- Priority only if bus is more than 20 s late (about half the buses)

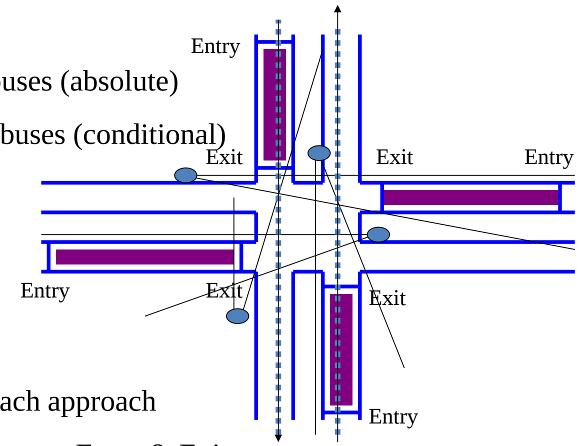


- Green extension if bus arrives on green
- Aggressive early green otherwise: reduce intervening phases to minimum green
- “Short way” minimum green to return to background cycle

Intersection Experiment and Site Description

One day each of

- priority to all buses (absolute)
- priority to late buses (conditional)
- no priority



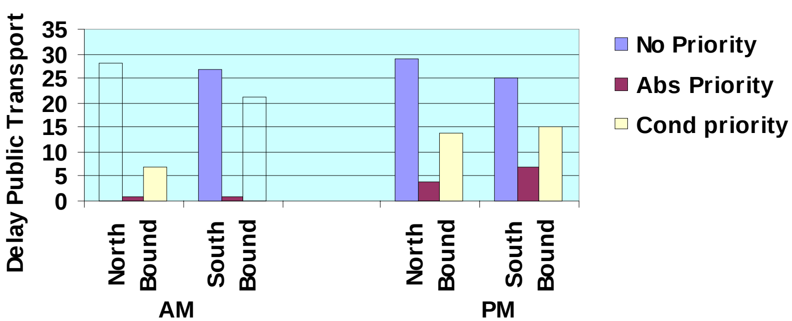
Camera facing each approach

filmed “trap” between Entry & Exit

Playback in lab to count queue lengths, measure delay

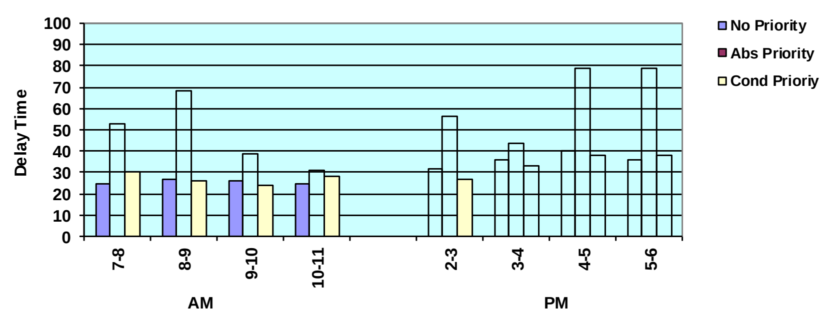
Experiment Eindhoven

Average Transit Delay [sec]



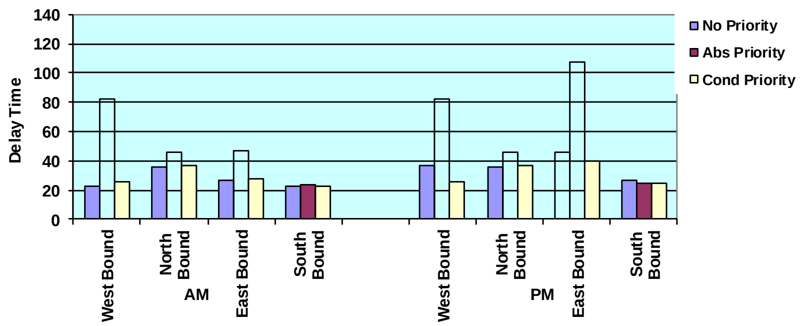
Experiment Eindhoven: Traffic Impact

Average Vehicle Delay [sec]



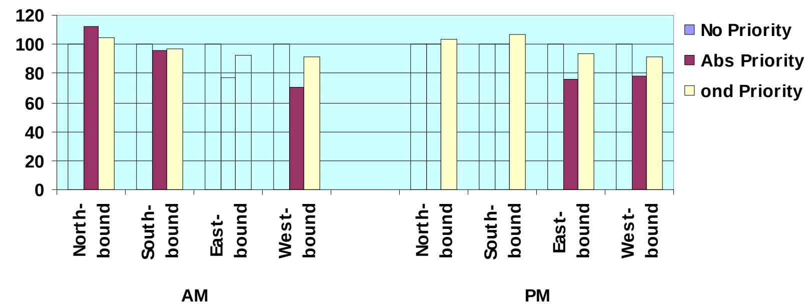
Experiment Eindhoven

Average Vehicle Delay per Approach [sec]



Experiment Eindhoven

Relative Capacity per Approach (no priority = 100%)

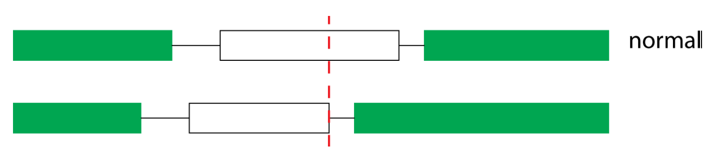


Lessons from Eindhoven

- Aggressive early green resulted in near-zero delay for buses
- Conditional priority needs finely-tuned schedule
  - Schedule too tight – bus always late – absolute priority
  - Schedule too loose – bus always early – no priority
- Lack of compensation: OK for 6 interruptions per hour, but not 12
- Capacity loss due to
  - Early green truncations, but more from …
  - "short way" recovery to background cycle

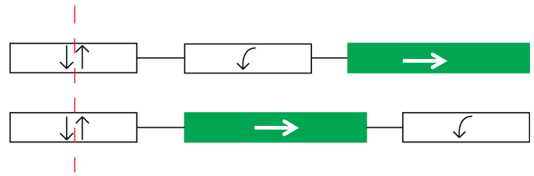
Early Red

Shorten bus street's current green to get faster return to green in the next cycle



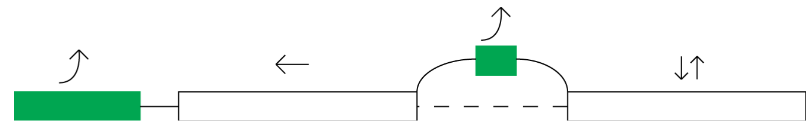
- Needs advanced detection (almost a full cycle)
- Incompatible with typical coordination logic

Phase Rotation

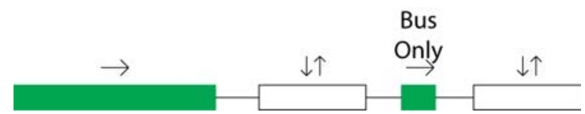


- Example: change leading bus phase to lagging
  - Lagging bus phase becomes leading – like early green
  - Leading bus phase becomes lagging – like green extension (more effective)
- Used extensively in Germany
- Zurich's pre-application safety campaign: random phase sequencing for 6 months!

Phase Insertion / Reservice



- Second realization on bus detection only
  - Shorter red period for bus – big reduction in delay
- Zurich's "insert and return"



Dynamic Coordination
(Zurich)

- Small zones (1-3 intersections)
- No fixed clock
- Shape green waves through the zone around bus
- Zone boundaries are segments that offer storage buffer

Passive Priority

Treatments that favor buses, but don't rely on bus detections

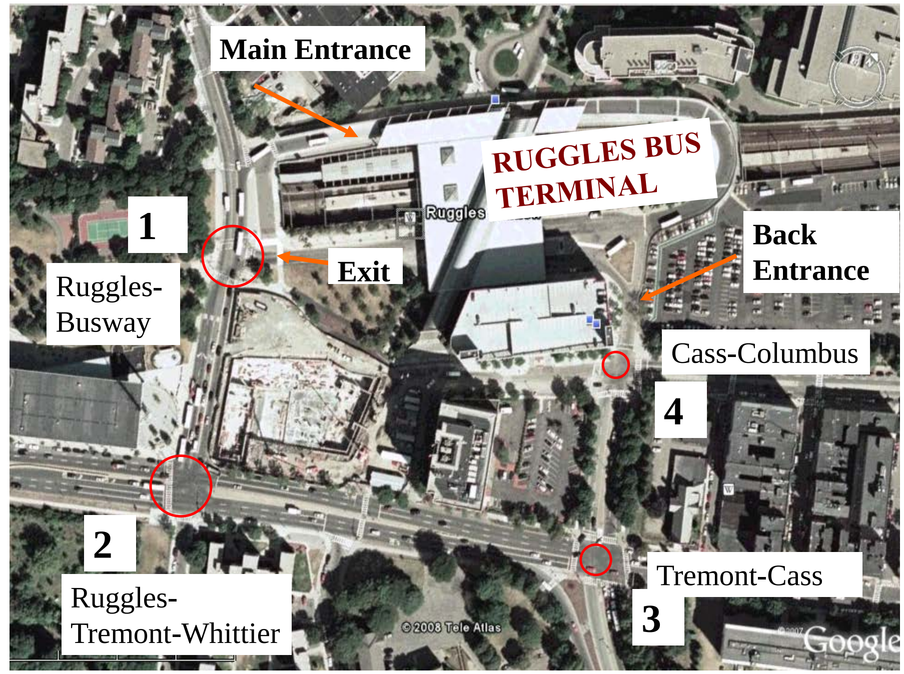
- Favorable splits for bus phase
- Favorable offsets (progression) for bus
  - Hard to do over more than a few intersections due to uncertain dwell time
- Short cycles or double realizations (short red is the key)

Ruggles Bus Terminal Study

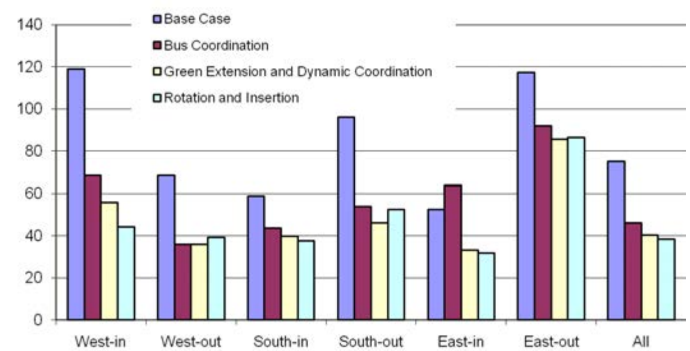
with Burak Cesme, recent PhD graduate

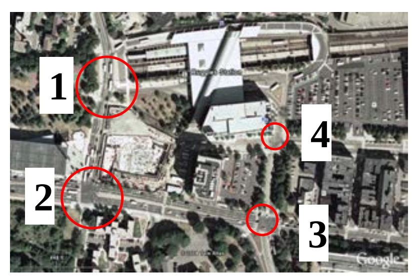
Using VISSIM simulation and VAP signal control programming

- 90 buses/h
  - 55 / h turn left from Tremont onto Ruggles
  - 2% of the traffic, but 30% of the people at that intersection



Poor Coordination for Buses

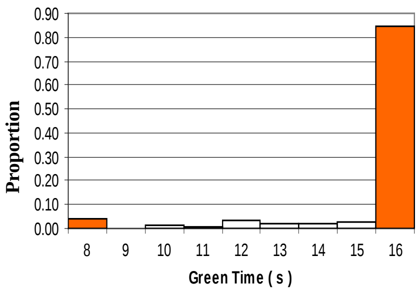




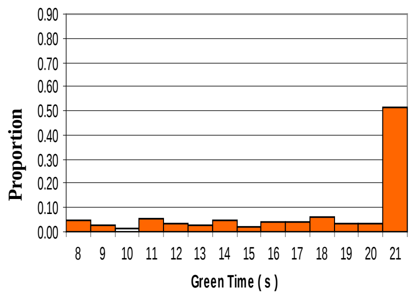
Bus Delays with Incremental Priority Treatments, by Route

Passive priority: Increase Max Green for bus left turn. Note: 5 s increase in split consumes only 2.5 s!

Max Green = 16 seconds



Max Green = 21 seconds

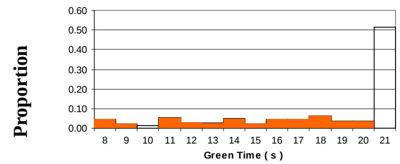


Avg Green (EBL) = 15.3s
p (max-out) = 84.6%
Avg bus delay = 98 s

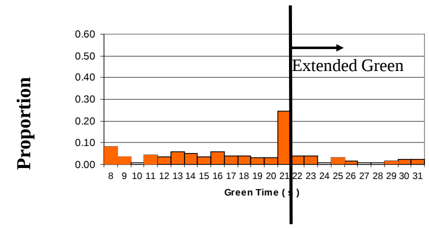
Avg Green (EBL) = 17.8s
p (max-out) = 51.2%
Avg bus delay = 67 s

Intelligent Green Extension: 10 s extension at "cost" of 0.5 s

No Priority



With Green Extension



Avg Green (EBL) = 17.8s
p (max-out) = 0.512

Avg Green (EBL) = 18.1s
p (max-out) = 0.247
p (extended) = 0.213

Avg Green (WBT) = 30.3s

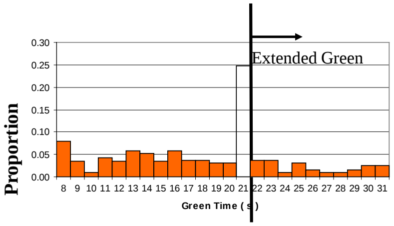
Avg Green (WBT) = 29.8s

Green Extension

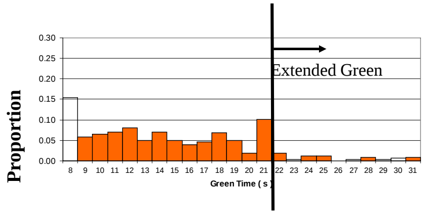
Green Insertion

Inserting 10 s phase: only consumes 2.5 s

Green Extension Only



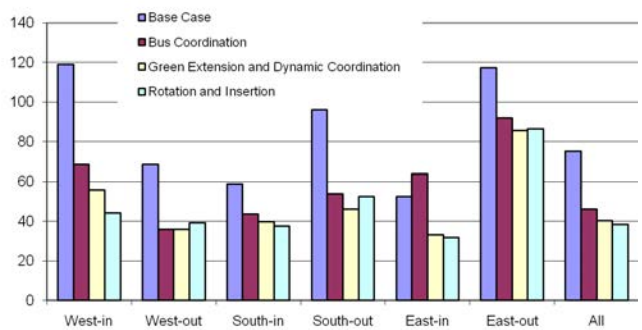
Primary Phase , when Phase Insertion is Programmed

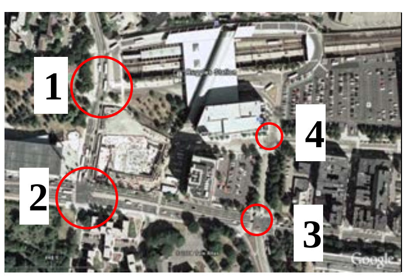


Green Extension Only	Primary Phase, when Phase Insertion is Programmed
Avg Green (EBL) = 18.1s	p (insertion) = 0.386 Avg Green (primary) = 14.7s Avg Green (insertion) = 4.4s Avg Green (total) = 19.1s
Bus delay = 55 s	Bus delay = 33 s
Avg Green (WBT) = 29.8s	Avg Green (WBT) = 27.3s

Priority Dynamic Coordination

Bus Delays with Incremental Priority Treatments, by Route





Conditional Priority

Priority to Late Buses

- Less interference with traffic (Eindhoven)
- Push-pull means of operational control (Einhoven)
- What is “Late:” 15 s or 3 minutes?
- Demands fine-tuned schedule
- Headway-based priority for short-headway service

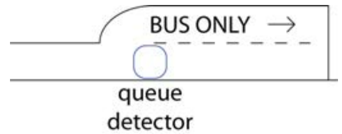
Multi-Level Priority

(South Tangent = Haarlem – Airport – Amsterdam South)

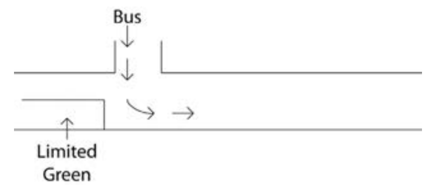
- Bus is early: green extension only
- 0 to3 min late: “normal” early green
- More than 3 min late: aggressive early green (skip competing phases)

Priority Queue Management

- Detectors & logic for queue management
  - Stopped cars, not moving cars, hinder buses



(Zurich)



(Eindhoven)

Zurich’s Custom Programming

- 5 full-time programmers work on signal control programs
- Logic runs in central computers; field controllers merely implement & communicate
- Experience has taught them:
  - Delay tram green until trams start to slow down
  - Evaporated traffic
  - Early red for the safety of last-moment crossing peds

Predictive Priority

Remote, upstream detection: simulated on Huntington Ave, used in Salt Lake City

- Detector 1 used to predict bus arrival at 4 (~2 minutes advance)
- Adjust cycle lengths so that bus will arrive on green
- Last-minute priority as backup
- Adaptive (learning) algorithm for predicting bus arrival

Self-Organizing Coordination

Simulated for San Juan, Puerto Rico

- Each signal's start of green becomes a request to downstream signal
  - Peer-to-peer communication between signals
  - upstream signal's request has lower priority that bus request
- Result: spontaneous green wave
- Inherently interruptible

Six Keys to Performance

1. Aim for near-zero delay
2. Multiple intelligent and aggressive tactics, with compensation
3. Coordinate with scheduling (cond'l priority)
4. Alternatives to rigid coordination
5. Advanced prediction with gradual cycle adjustments
6. Custom programming, performance measurement, & continual improvement