Fundamentals of Traffic Operations and Control

Actuated Traffic Signal Design

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Outline

- Introduction
- Problem description / Terminology
- Classification of control strategies
  - Fixed-time control
  - Traffic actuated control
  - Traffic responsive control
  - Adaptive control
- Discussion

Acknowledgement: Some material was kindly provided by Dr. T. Kouvelas (EPFL) Prof. M. Papageorgiou (TU Crete) and Prof. A. Skabardonis (UC Berkeley).

Introduction

- Original reason for traffic lights:

  safe crossing of antagonistic streams of vehicles

  and pedestrians
- Once they exist, they can be set in different ways:

  optimization problem
- Difficulties:

  binary variables, large dimensions, many disturbances, available measurements, real-time constraints
- Many control strategies:

  both heuristic and systematic

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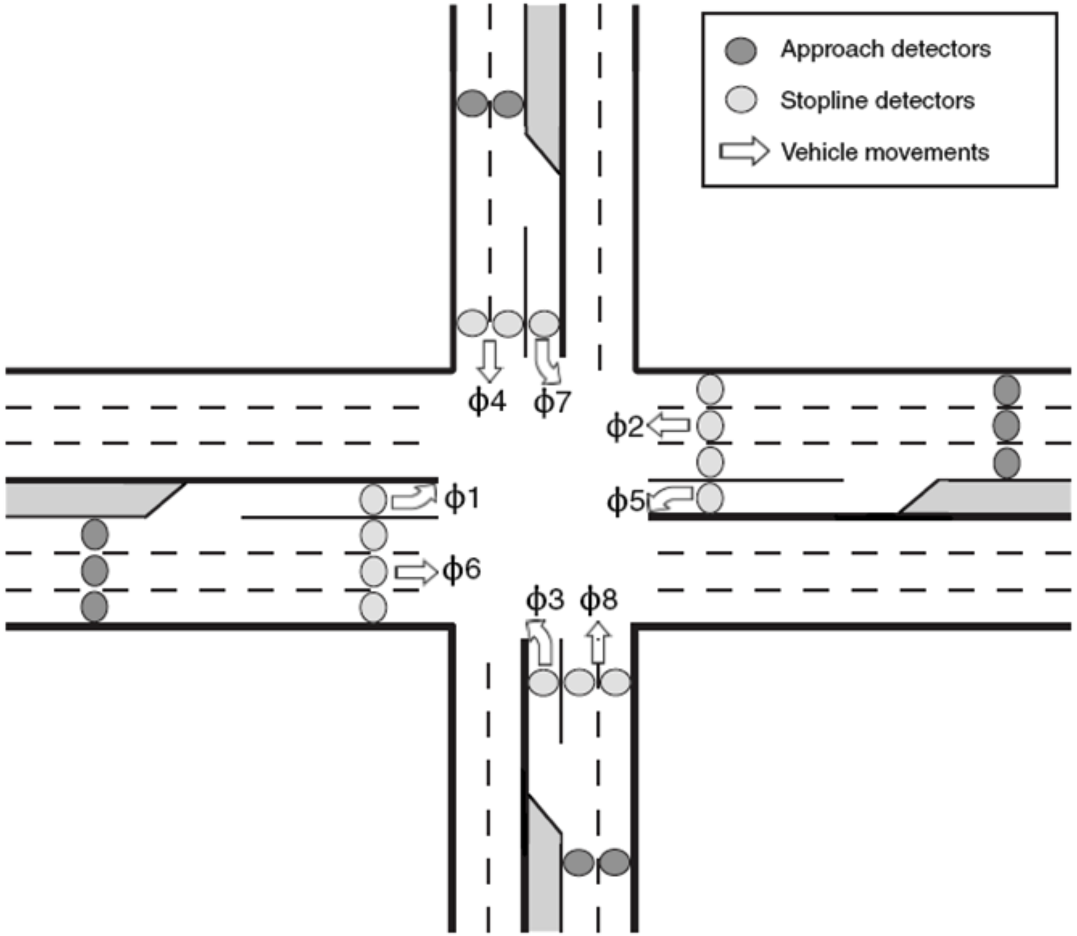
Terminology

junction (UK); intersection (US)



Each vehicle movement has an associated phase number.

Phases have approach detectors and/or stopline detectors.

Stage: set of compatible phases.

Signal cycle: one repetition of all signals.

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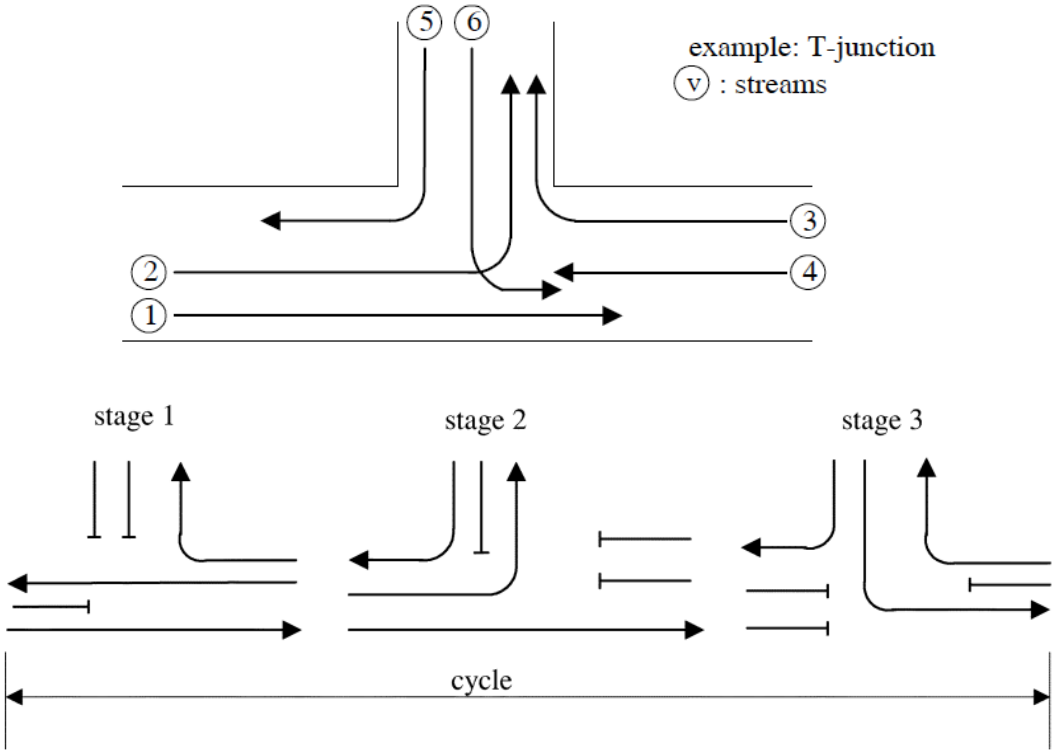
Example: T–junction



Isolated intersection control

Fixed-time (pre-timed)

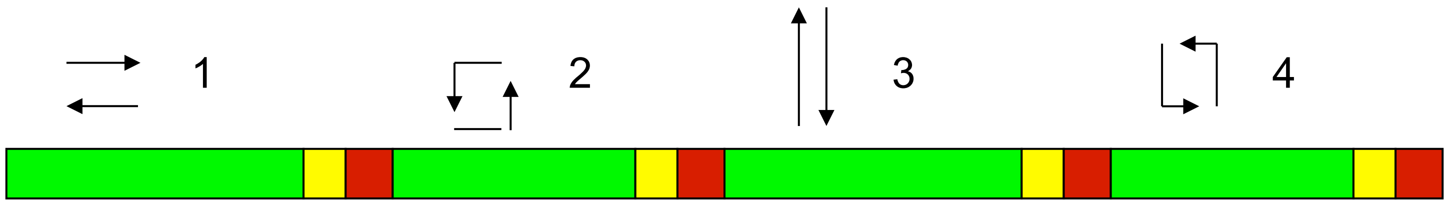
Time-of-Day

Actuated

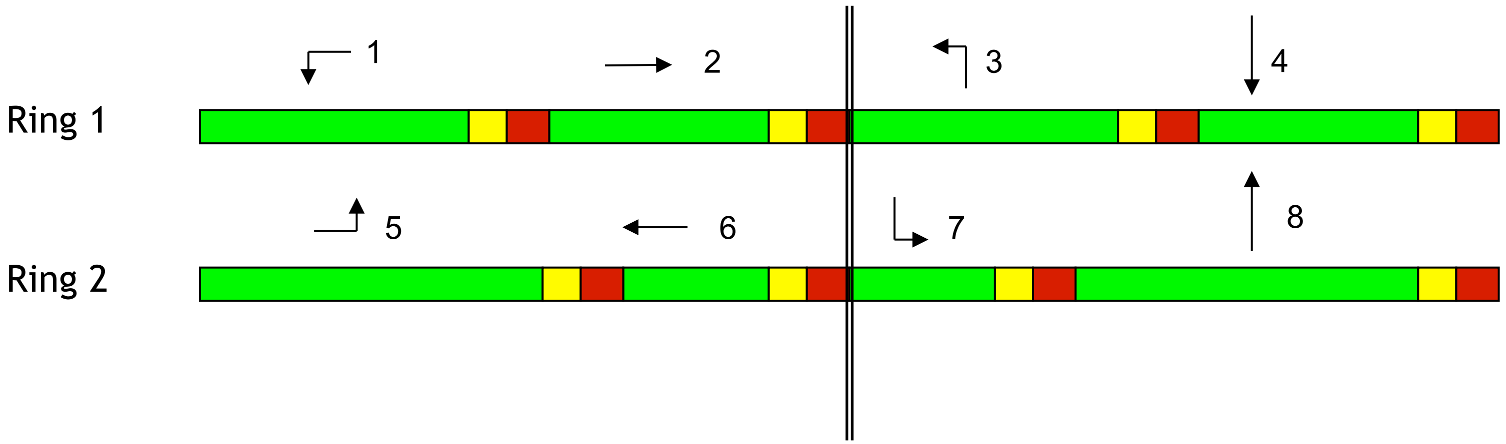
- Semi-actuated
- Fully-actuated

Modelling a plan with rings

- Single ring controller



- Dual ring controller



Permitted/Protected left turns.

Actuated control

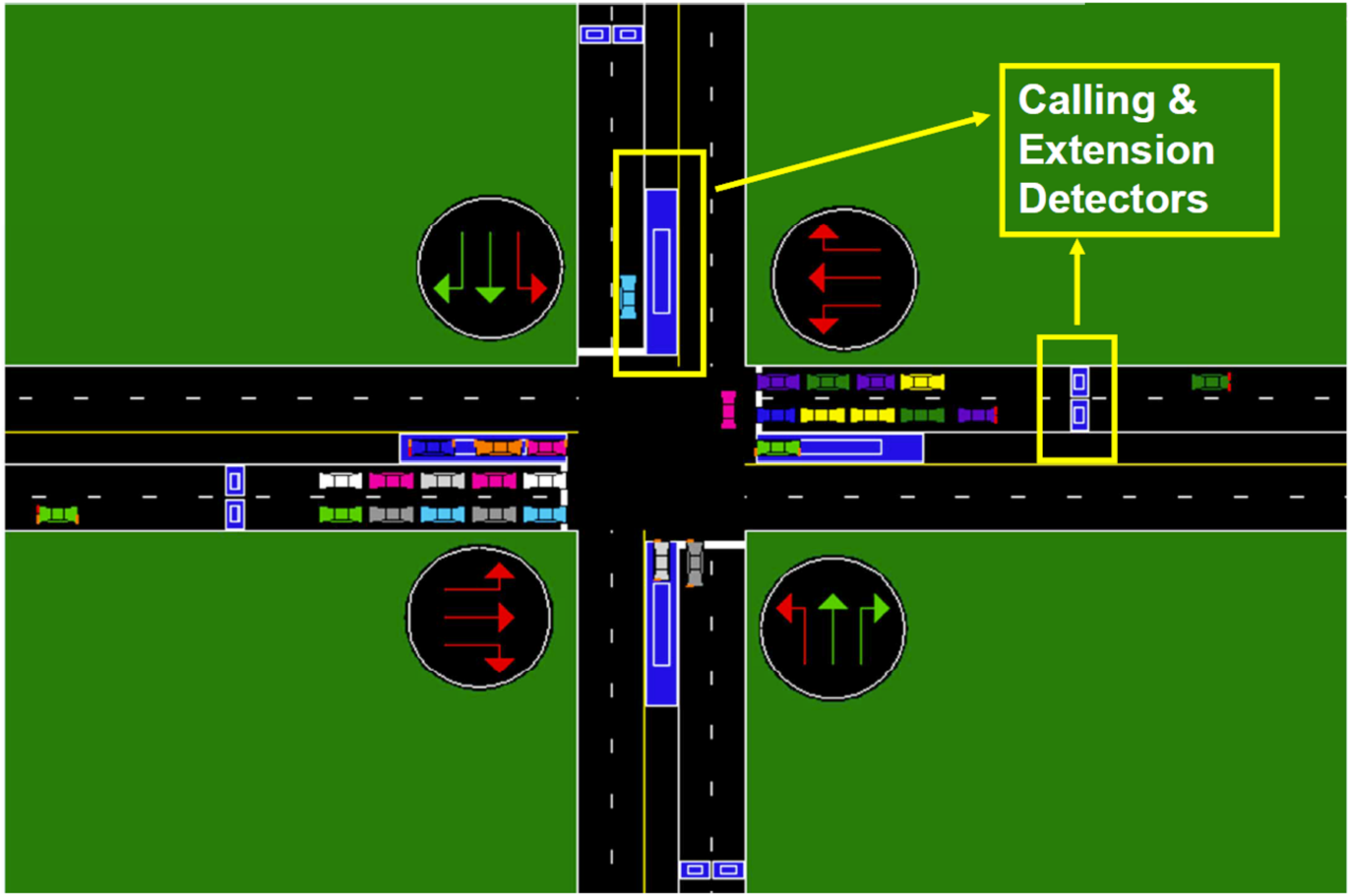
Vehicle actuations change the phases durations (and cycle length).

Min, max greens (pedestrians).

Phase skip; gap acceptance; recall.

- Semi-actuated (coordination)
- Fully-actuated (change cycles)

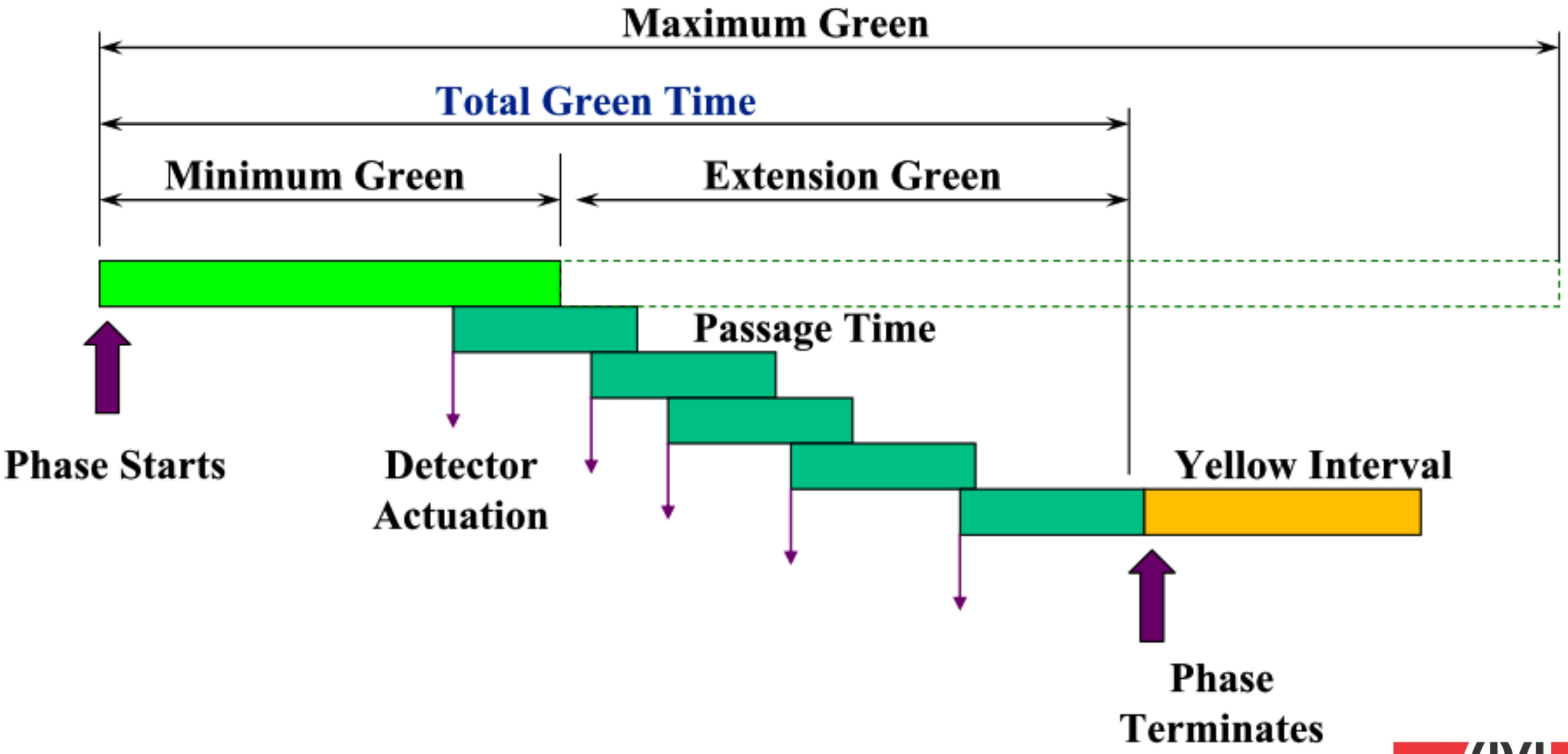
Traffic actuated signal control



Calling & Extension Detectors

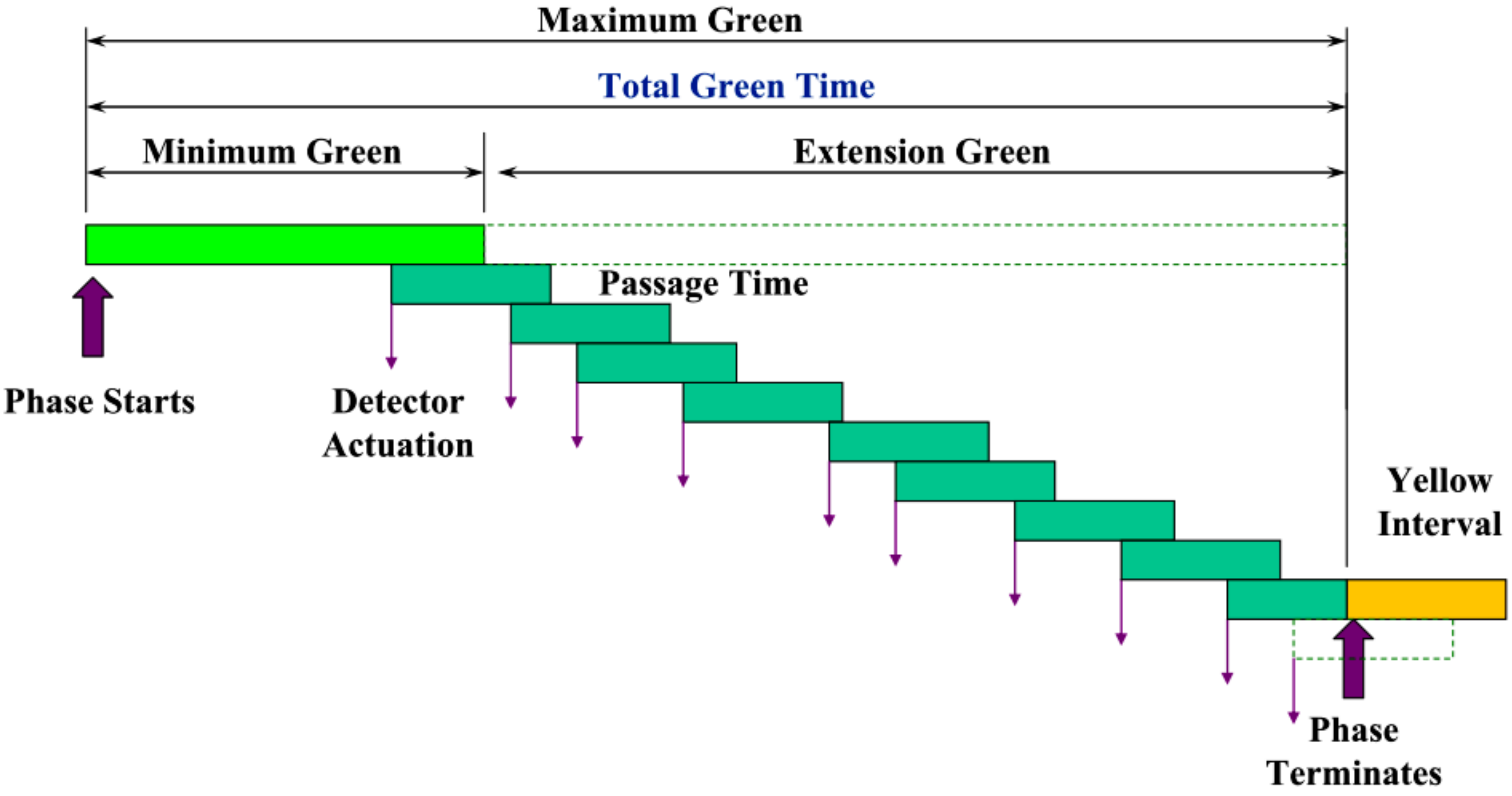
Operation of an actuated phase

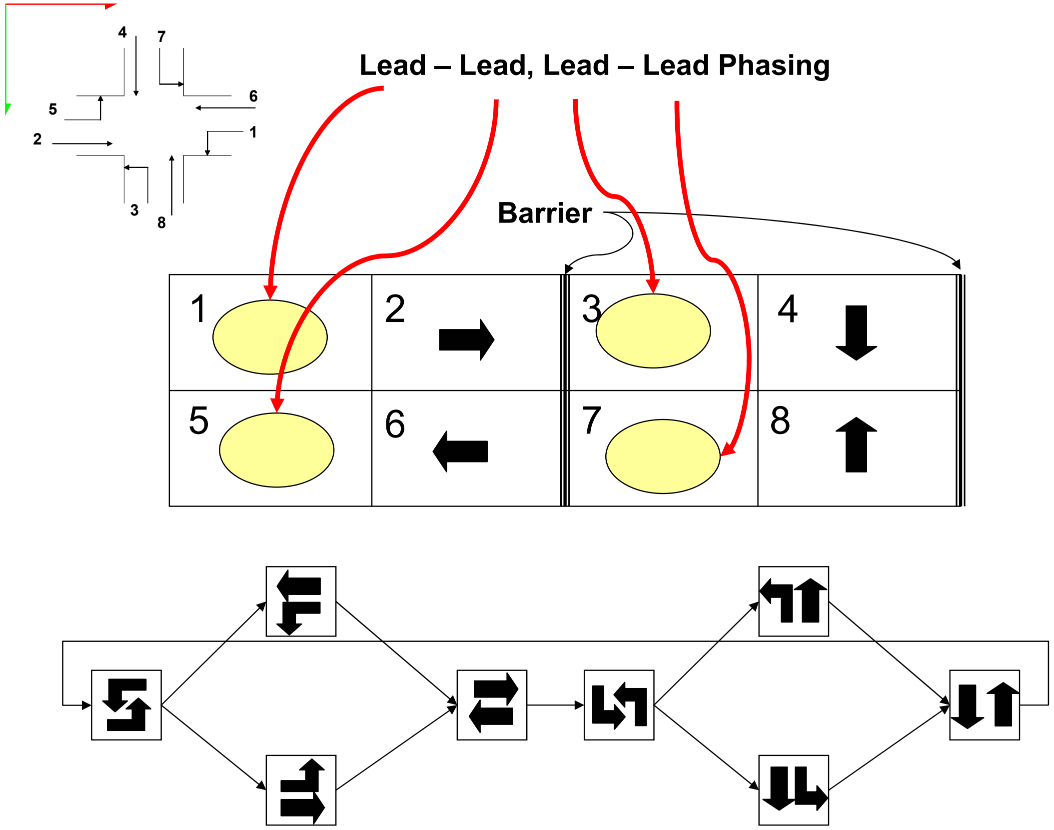
Case 1: Max green not reached (Gap out).



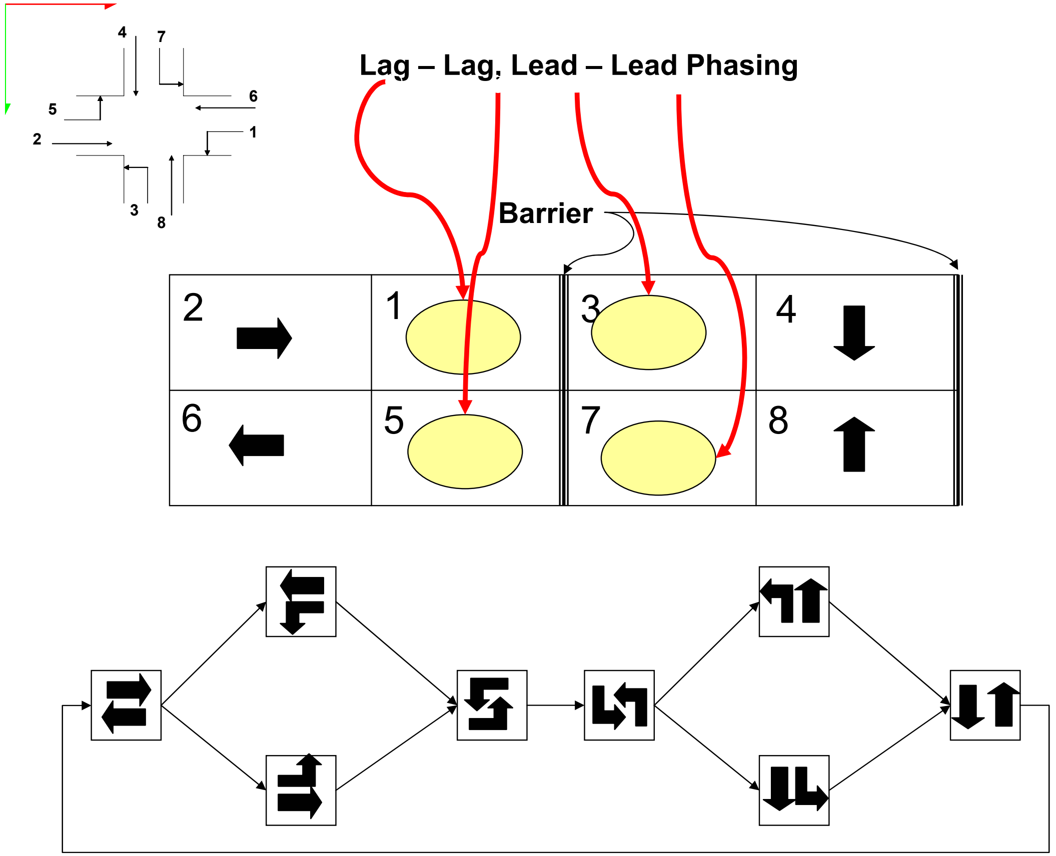
Operation of an actuated phase

Case 2: Max green reached (Max out).



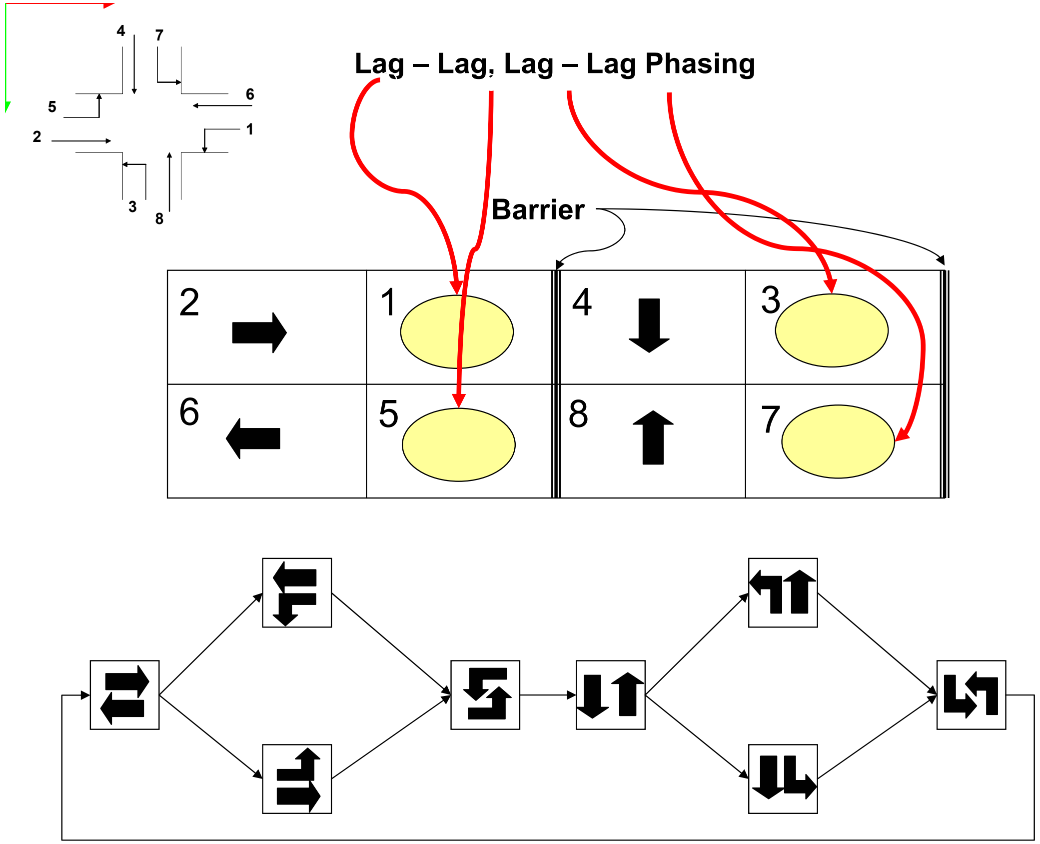


Lead – Lead, Lead – Lead Phasing



Lag – Lag, Lead – Lead Phasing

Lag – Lag, Lag – Lag Phasing



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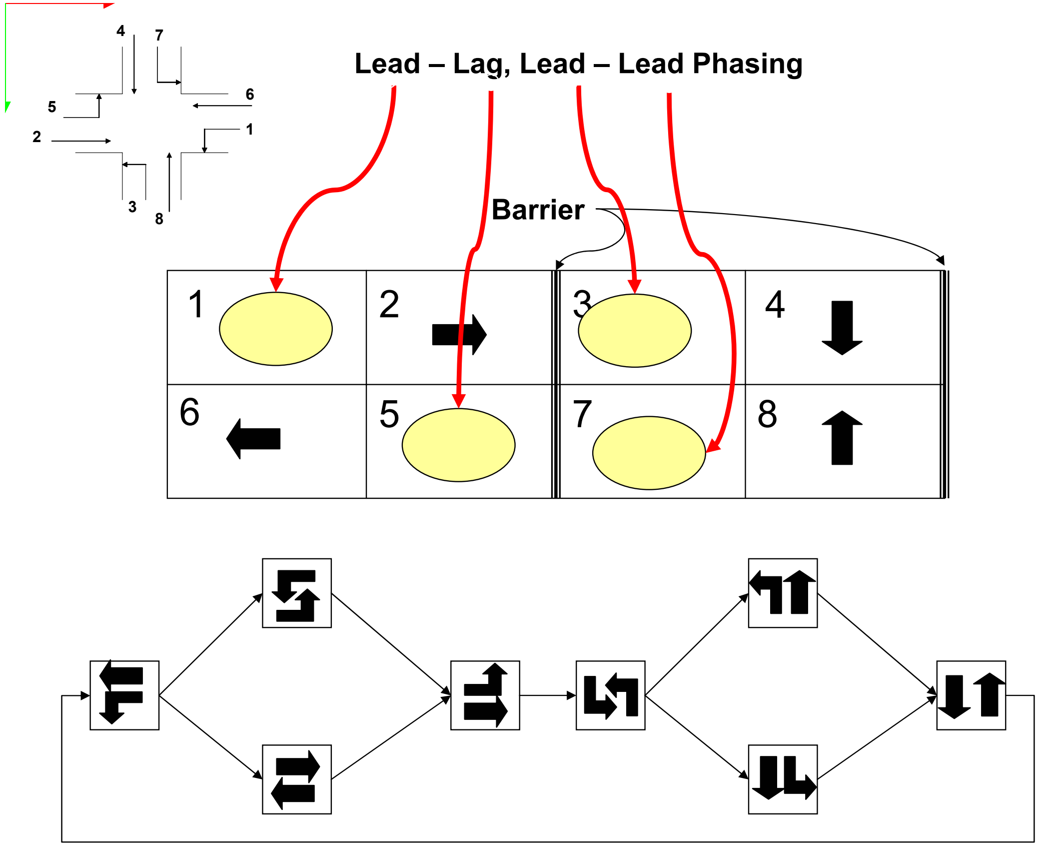

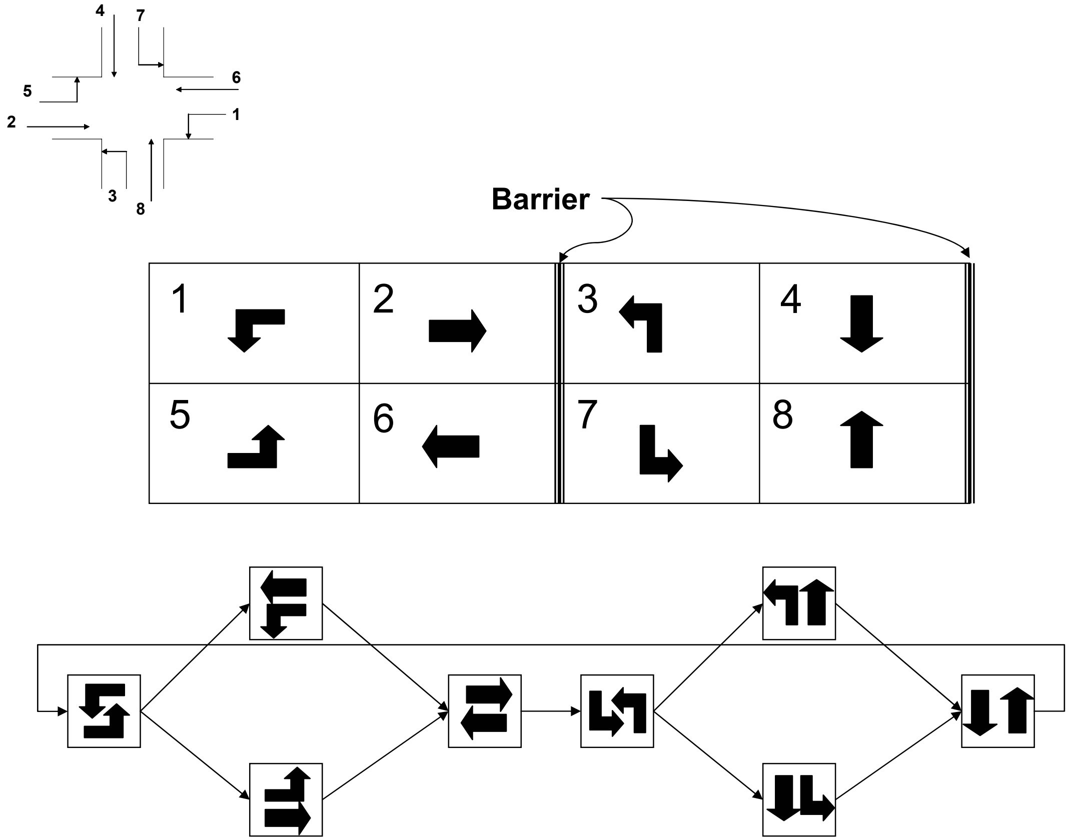
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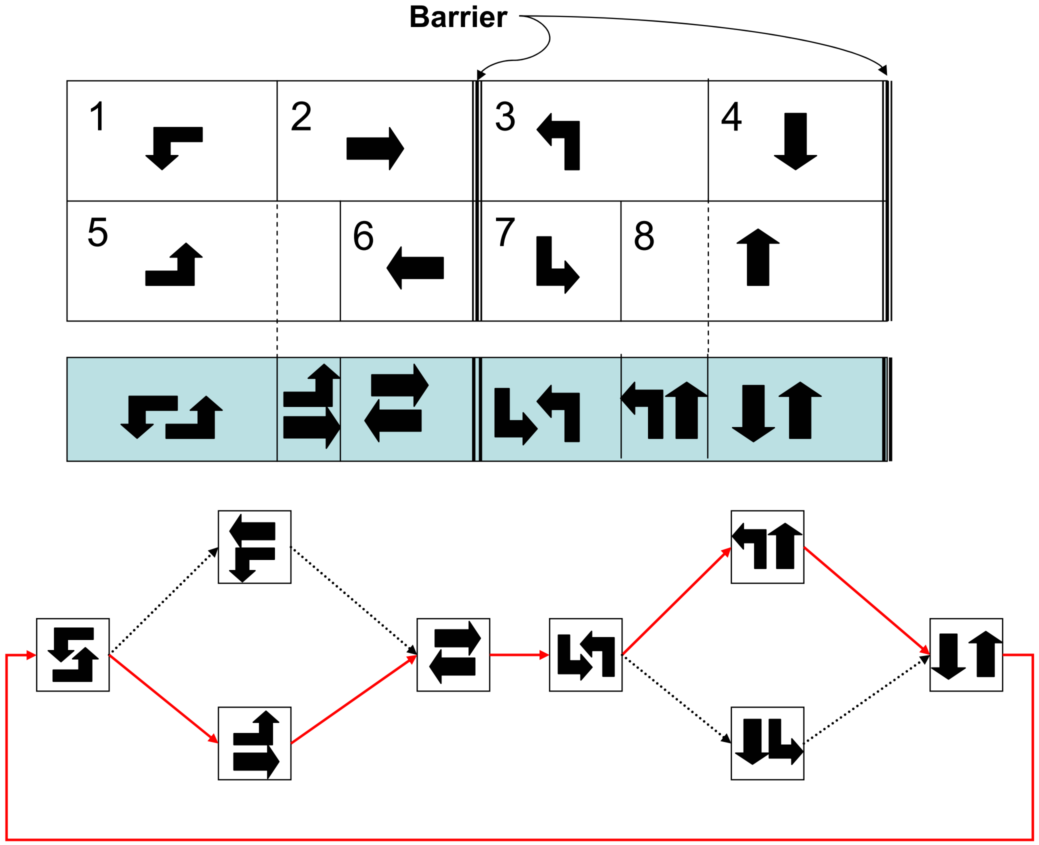
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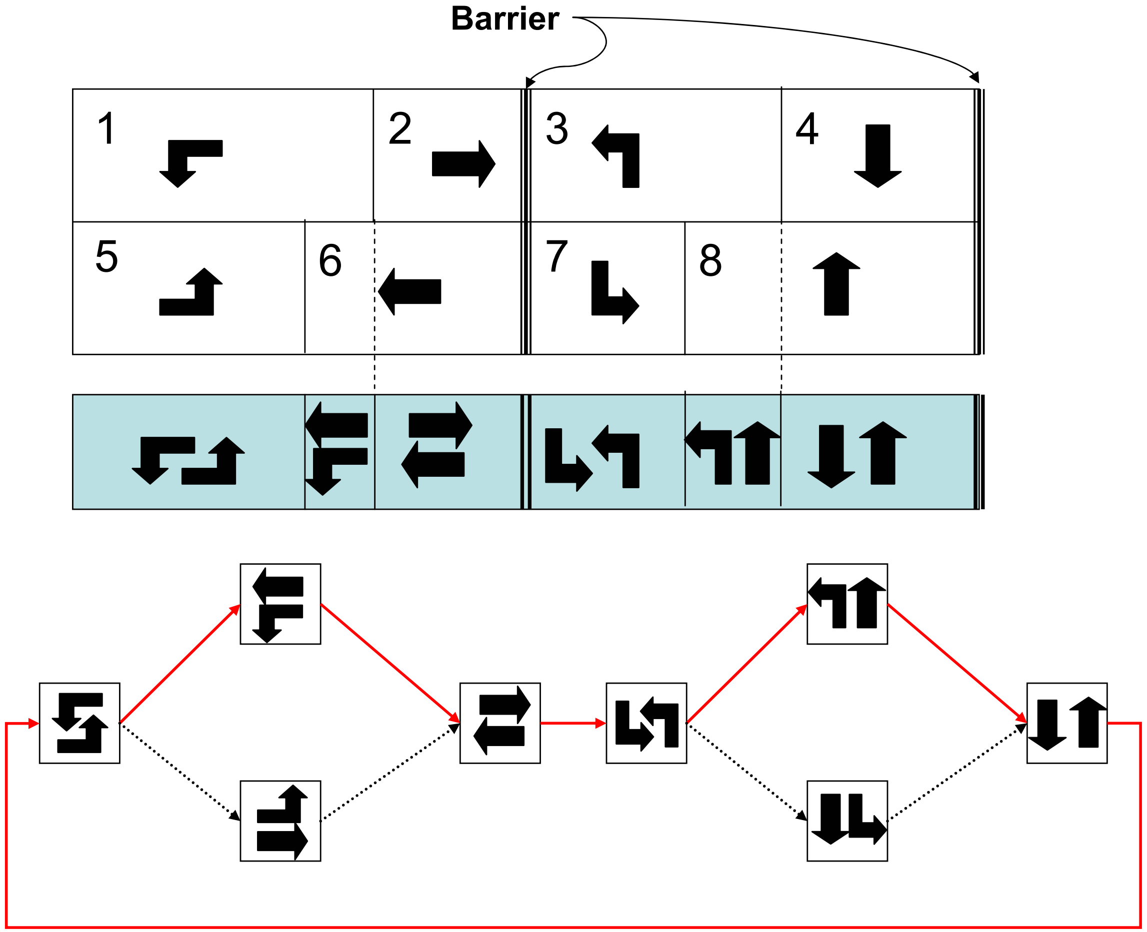
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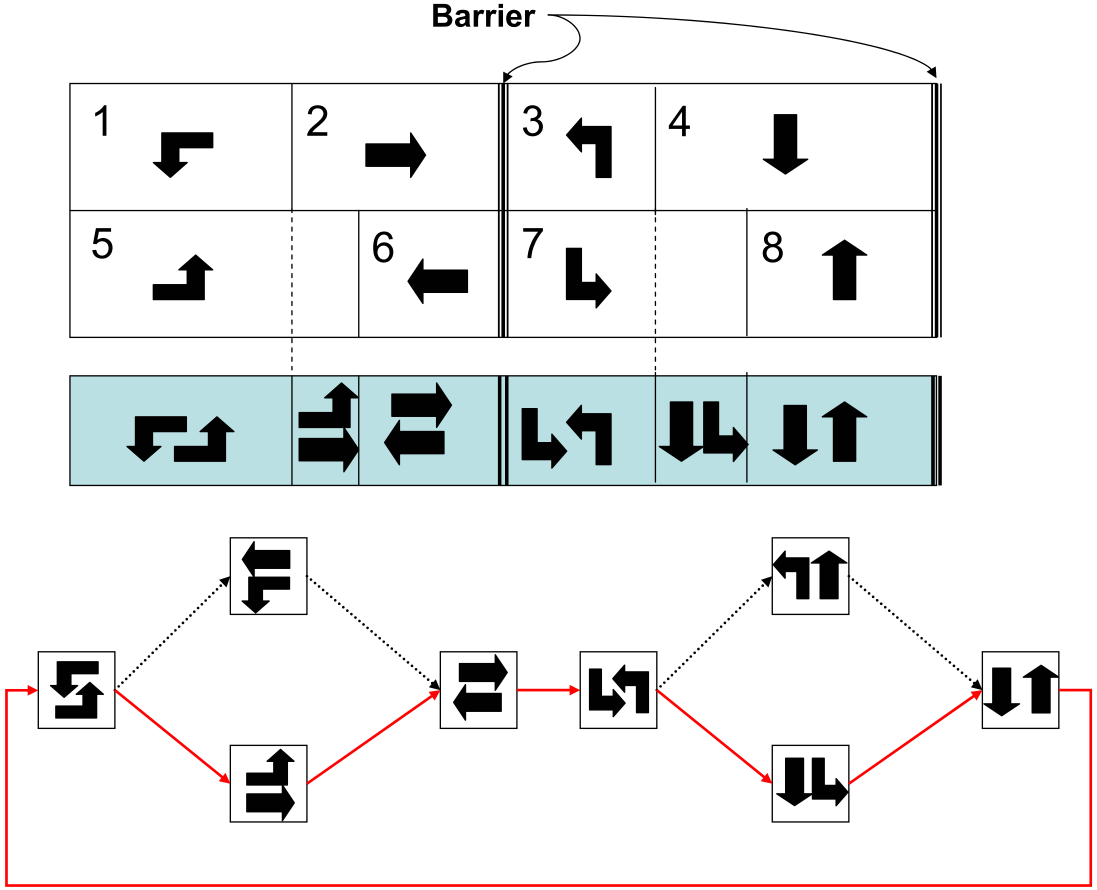
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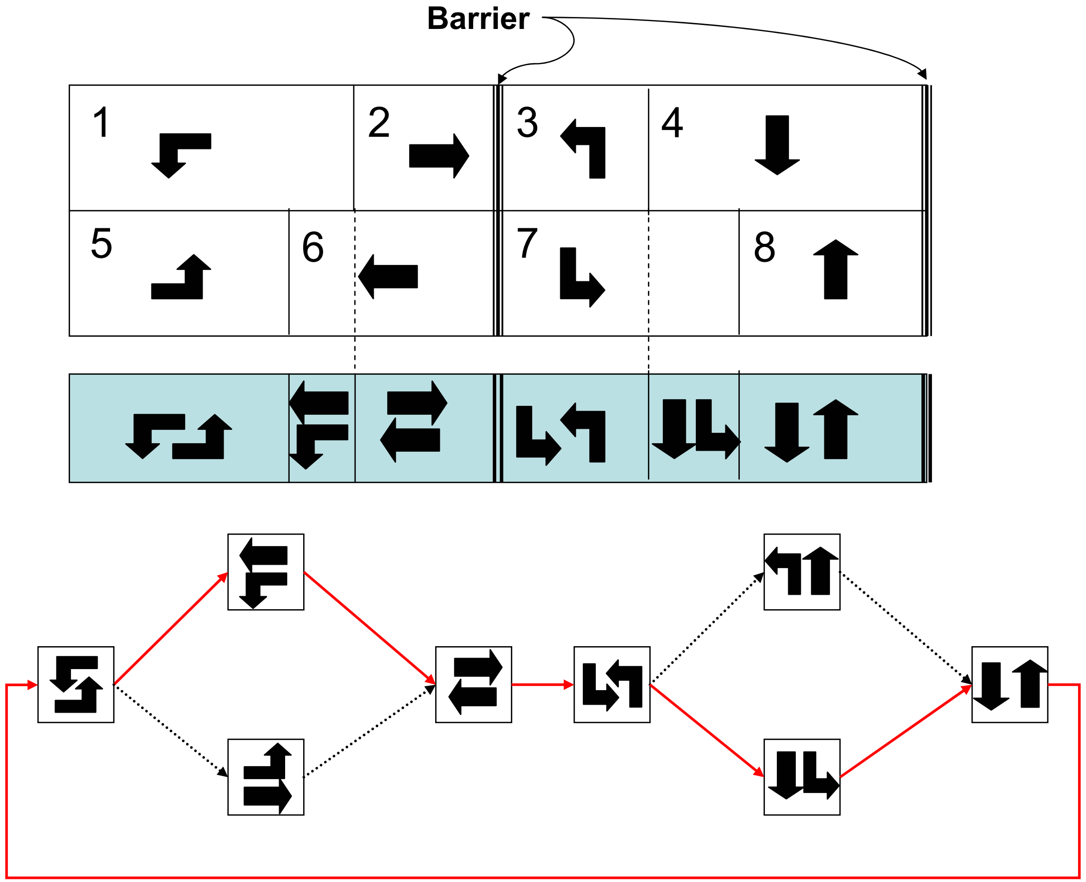
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Adaptive signal control

More sophisticated algorithms:

- include internal models for dynamics and optimization
- compute signal parameters including splits, cycles, offsets in real-time based on measurements

Adaptive strategies

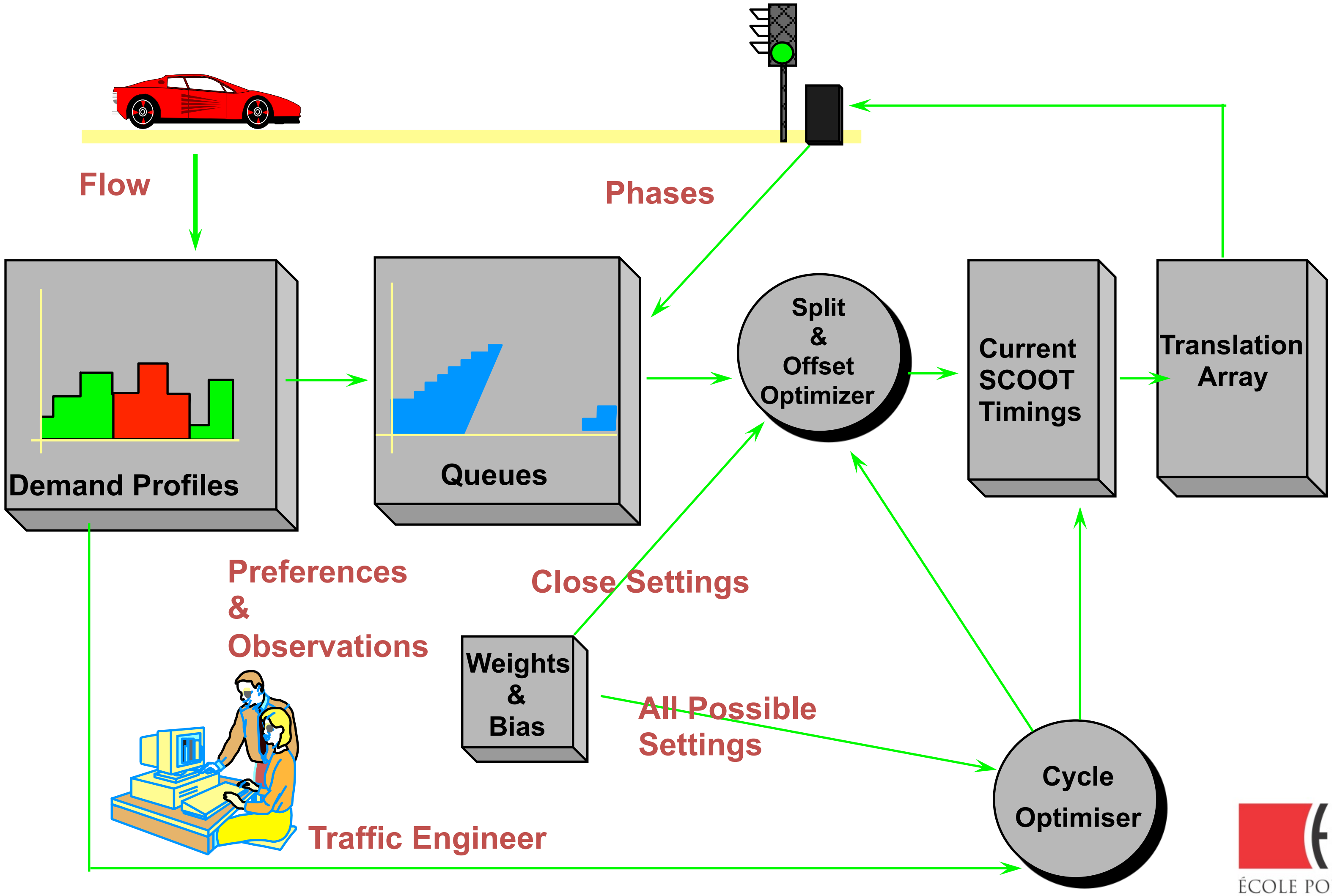
Many strategies (research or commercial):

- SCOOT
- SCATS
- OPAC
- PRODYN
- CRONOS
- RHODES
- UTOPIA
- BALANCE
- TUC
- ACS-Lite

Examples are provided for general knowledge of the students. It will not be taught inside classroom.

SCOOT – UK

Split **C**ycle **O**ffset **O**ptimization **T**echnique:



Flow

Phases

Demand Profiles

Queues

Split & Offset Optimizer

Current SCOOT Timings

Translation Array

Preferences & Observations

Close Settings

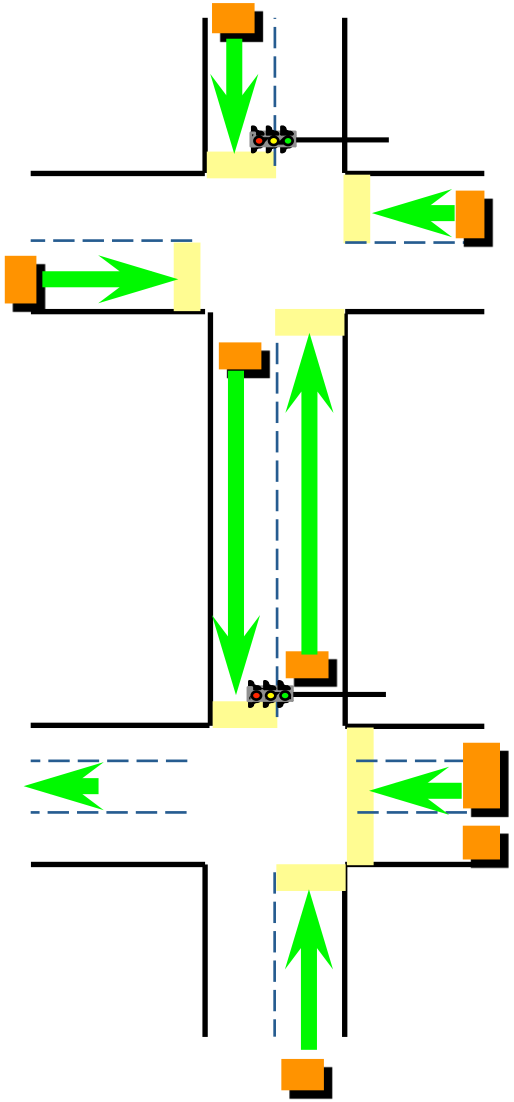
Weights & Bias

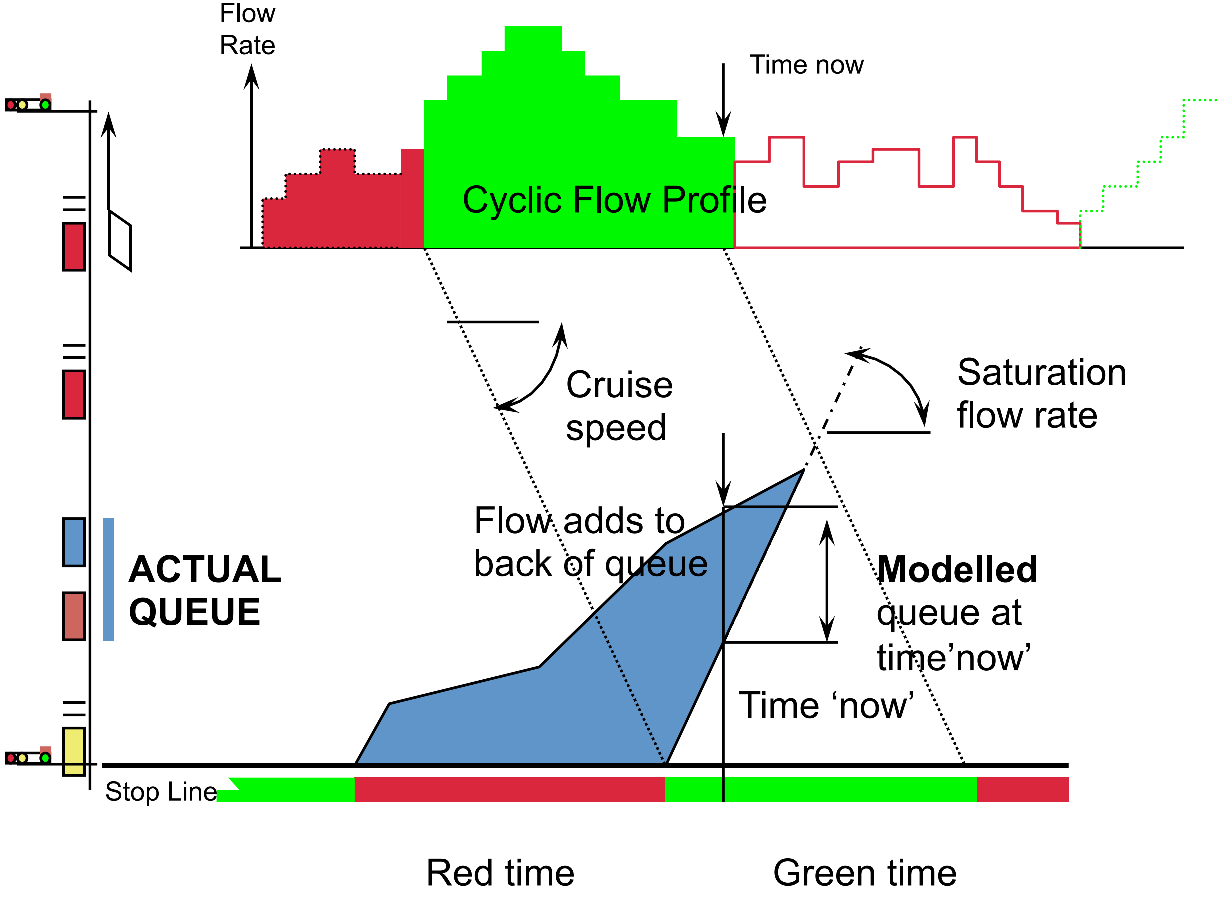
All Possible Settings

Traffic Engineer

Cycle Optimiser

SCOOT – Loop detectors position, demand profile, queue model





Signal optimizers

Optimizer	Frequency	Change time (seconds)
Split	Every stage	-4, 0, +4 (temporary) -1, 0, +1 (permanent)
Cycle	Once per cycle	-4, 0, +4
Offset	Every 2.5 or 5 minutes	-4, 0, +4 (32 to 64) -8, 0, +8 (64 to 128) -16, 0, +16 (128 to 240)

SCATS – Australia

Sydney **C**oordinated **A**daptive **T**raffic **S**ystem:

Objectives:

- Minimize stops (light traffic).
- Minimize delay (heavy traffic).
- Minimize travel time.

- Stopline detection.
- Network divided into regions.
- Each region divided into links and nodes.
- For each region calculate degree of saturation (DS) for all nodes.

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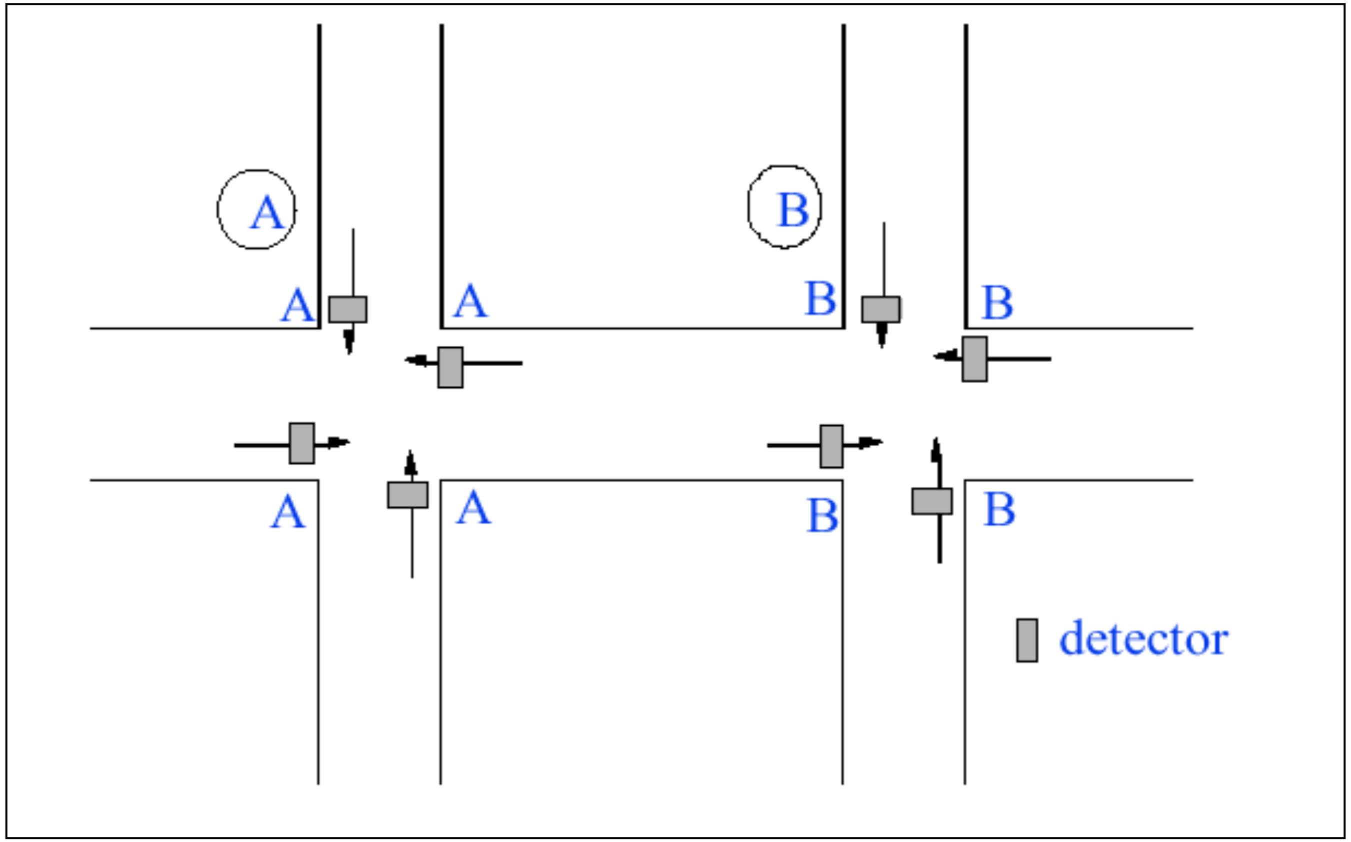
SCATS – Stopline detection



Degree of saturation: DS = [green–(unused green)]/green

SCATS – Optimization

Cycle Length (CL):

- User defined equilibrium DS values are used to determine the relationships between measured DS and CL.
- The relationships are used to select a target CL toward which the actual CL moves.

Offsets:

- Offset plans are selected by comparing traffic flows on the links.
- The weighted three-cycle average volumes are used for each candidate offset.

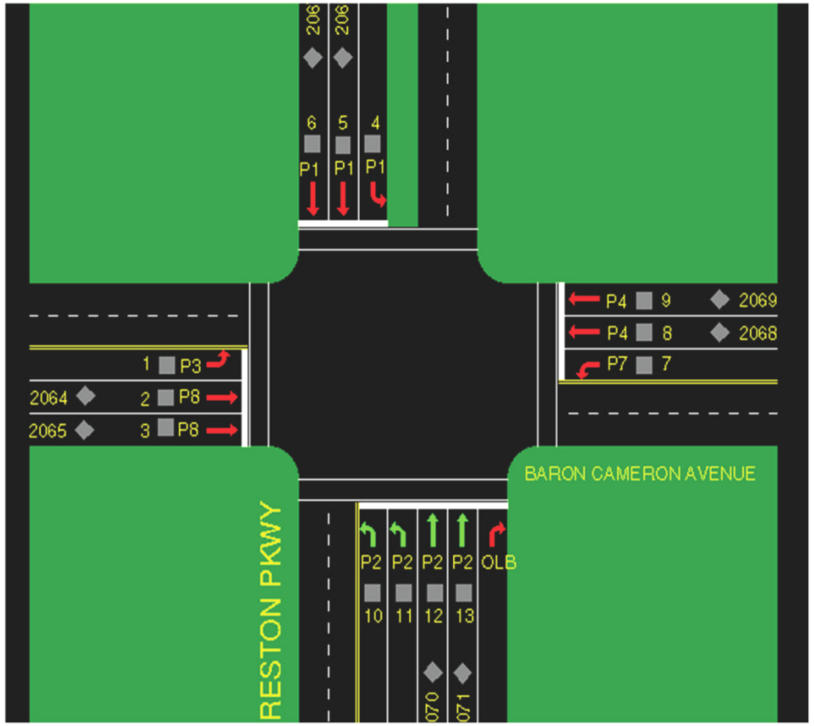
SCOOT vs. SCATS

Model	Algorithm
Central control	Distributed
Upstream detection	Stop-line detection
Fixed traffic region	Adjustable regions

- Closed systems: not all the details are known.
- Involvement of many (implementation specific) heuristics.

OPAC/RHODES: no fixed cycle

- Measured and predicted vehicle arrivals
- Optimization: minimize queues
- Rolling horizon



- Upstream detectors can provide history for demand profiles.
- Smoothed volume can be used for uniform profiles.
- Platoon identification and smoothing can be used for cyclic profiles.

Adaptive Traffic Signal Control: Principles and Applications of Max-Pressure

Jack Haddad

Fundamentals of Traffic Operations and Control (CIVIL-457)

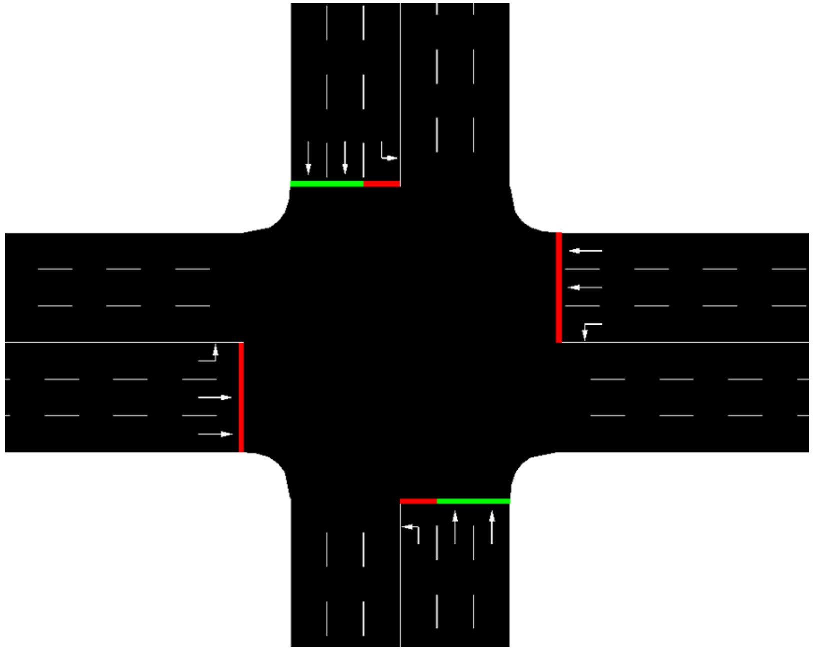
Dec. 11, 2024

Outline

1. Introduction
2. Background
3. Fixed cyclic MP
4. Dynamic cyclic MP
5. Simulation results
6. Experimental study

Large scale urban traffic networks

- Transportation systems play a vital role in ensuring the economic growth and sustainable development of society.
- Poor traffic management could lead to environmental and economical damages due to congestion.
- **Traffic signal is one of the main measures of traffic management.**
- As the network size increases the complexity of the problem increases.



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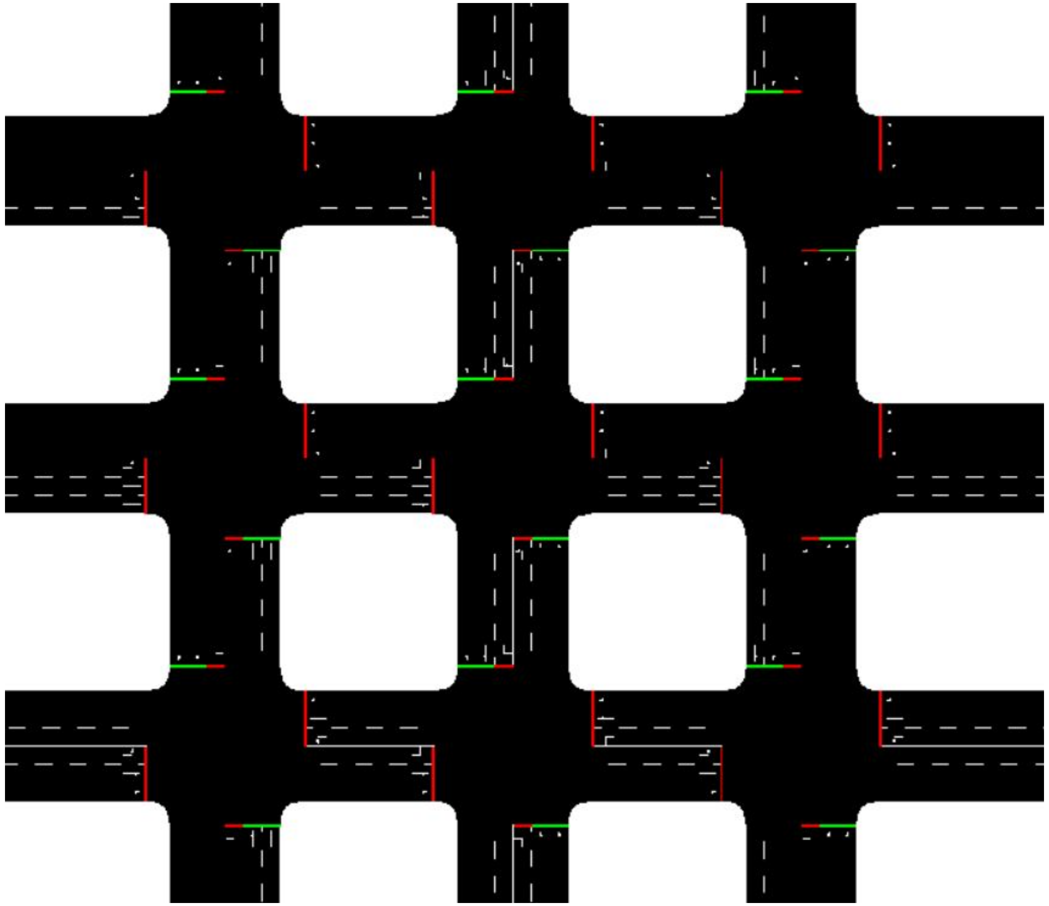
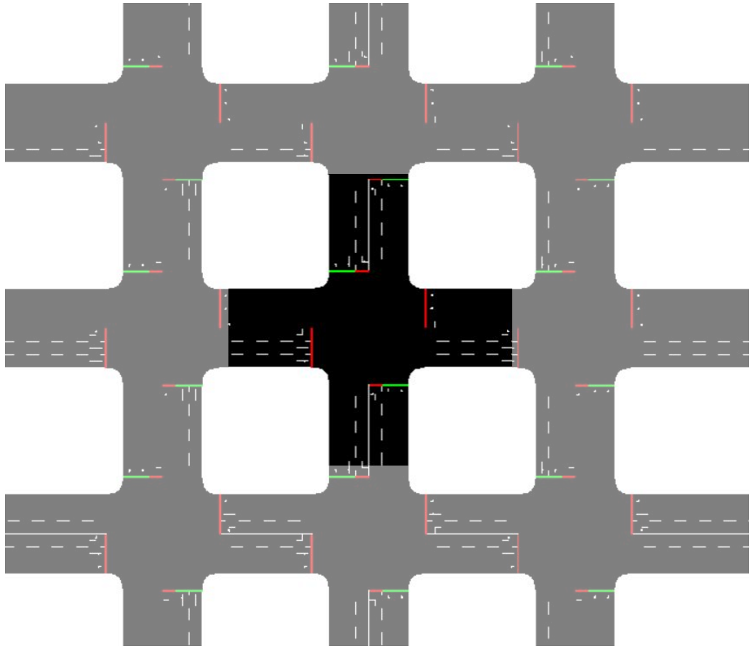


Hence, distributed approaches can provide promising solutions.



Problem formulation - Dynamic cycle time in traffic signal of cyclic max-pressure control

Given:

↪ travel times of all links (or movements) considered

↪ control plans, i.e. phases, cyclic (order of phases), dynamic cycle lengths

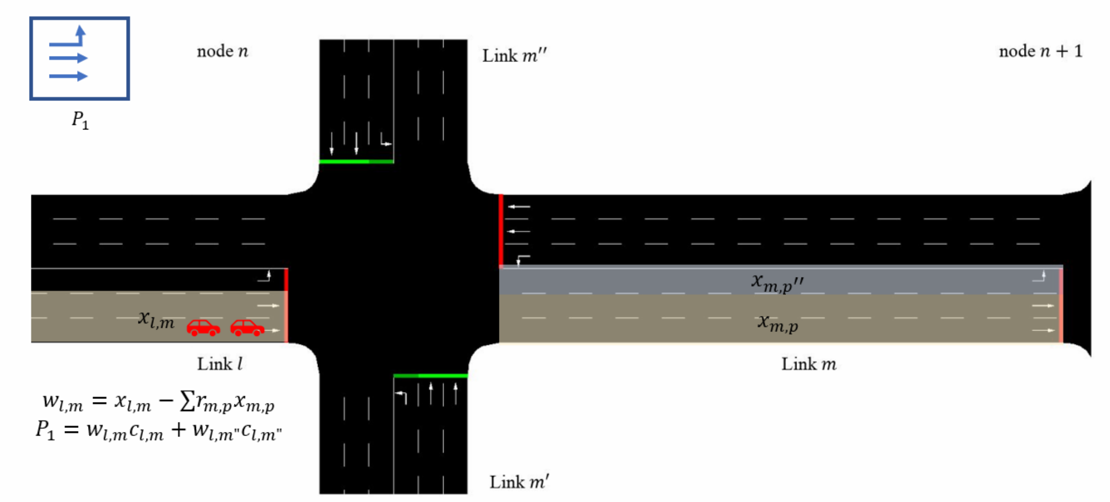
Determine:

↪ green time durations for all phases at all intersections

Outline

Original Max-Pressure algorithm (Varaiya 2013)

- Was initially proposed for scheduling packets in wireless communication networks.
- A distributed algorithm that maximizes throughput while stabilizing the queues.
- Algorithm inputs: queues, turn ratios, control plan (phases).
- Pressure: the difference between the upstream and the (average) downstream queue lengths.



The original Max-Pressure traffic controller based on queue lengths (MP-QL)

The MP control policy $u^*(t) : x \rightarrow s$, actuates the maximum pressured phase each time step t at each intersection:

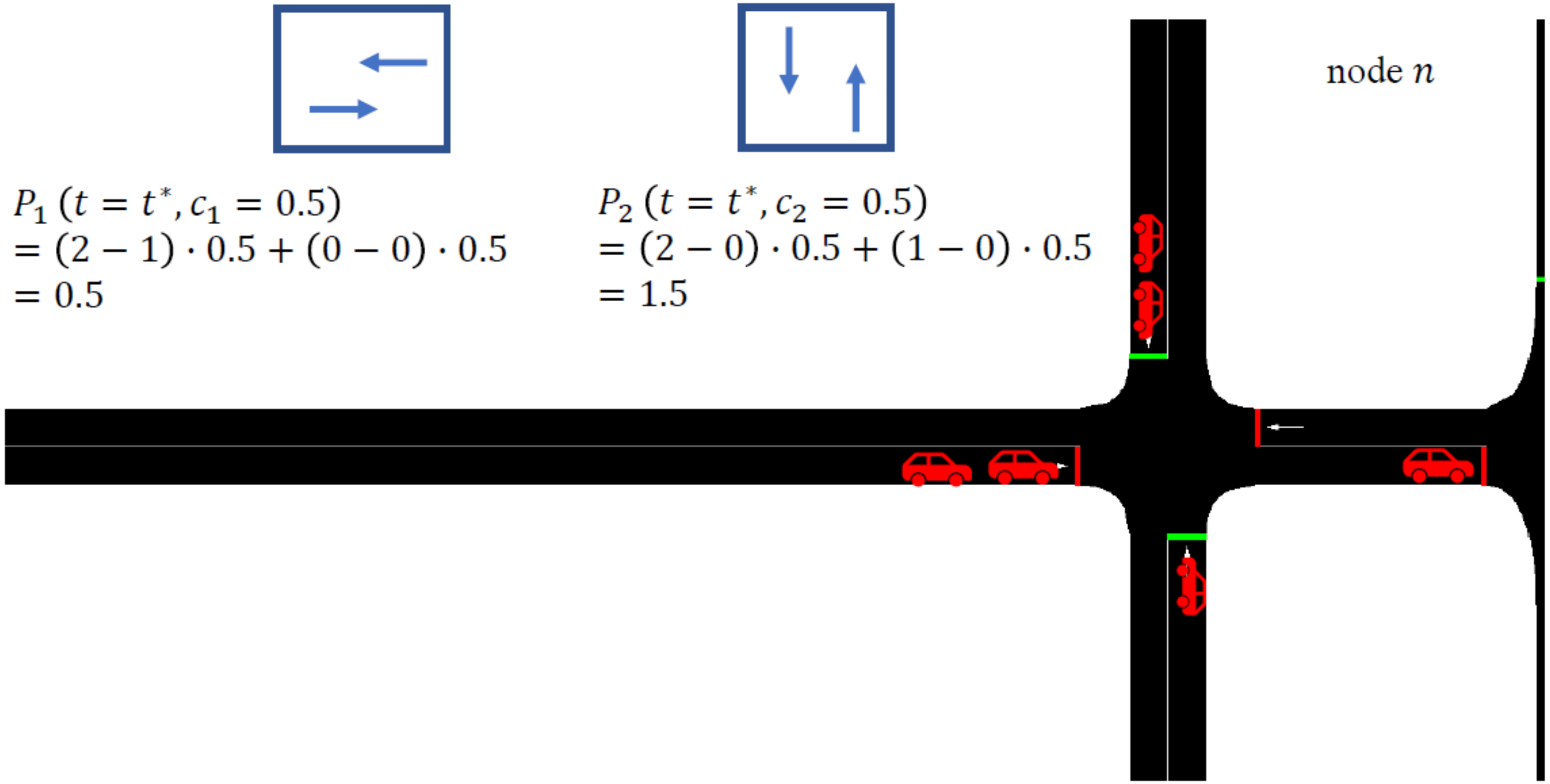
$$u^*(t) = \text{argmax}\left\{P_s(t) | s \in \mathrm{S}_n\right\}, \tag{1}$$

S_n – set of all phases of intersection n.
The pressure of phase s at intersection n is calculated as:

$$\begin{aligned} P_s(t) &= \sum_{(l,m)} w_{l,m}(t) c_{l,m}(t) s_{l,m}(t) \\ &= \sum_{(l,m):s_{l,m}=1} w_{l,m}(t) c_{l,m}(t), \qquad \forall s \in \mathrm{S}_n. \end{aligned} \tag{2}$$

$$w_{l,m}(t) = x_{l,m}(t) - \sum_p r_{m,p}(t) x_{m,p}(t), \qquad \forall m \in \mathrm{Out}_n, \forall l \in \mathrm{In}_n, \forall p \in \mathrm{Out}_{n+1}. \tag{3}$$

Original Max-Pressure traffic controller (MP-QL)



$$P_1\,(t = t^*, c_1 = 0.5)$$
$$= (2 - 1) \cdot 0.5 + (0 - 0) \cdot 0.5$$
$$= 0.5$$

$$P_2\,(t = t^*, c_2 = 0.5)$$
$$= (2 - 0) \cdot 0.5 + (1 - 0) \cdot 0.5$$
$$= 1.5$$

Since then several MP algorithms were developed...

- queue-based vs. time-based
  - Most previous MP algorithm controllers are queue-based feedback.
  - One real application was performed on time-based MP in *Mercader et al. 2020*.
- signal update: every time step vs. every cycle
- features:
  - infinite vs. finite link capacity
  - non-fixed phase sequence (acyclic) vs cyclic
  - stability vs. work conservative
  - phase switching gap (lost time)
  - ...

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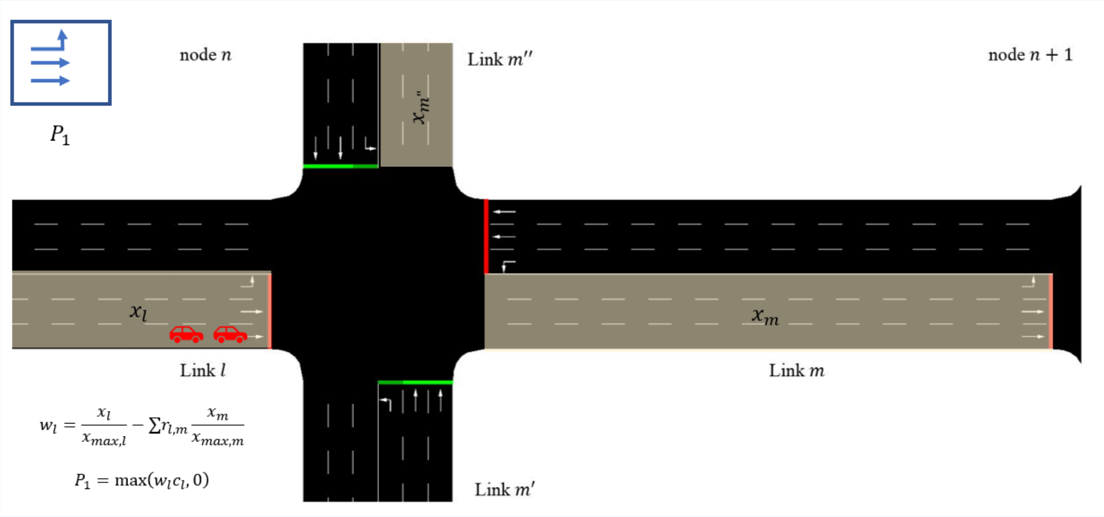
A modified cyclic Max-Pressure traffic controller based on queue lengths (MP-QL) - *Kouvelas et al. 2014*

Pressures:

$$P_{s,n}(t) = \max\left(0, \sum_{(l,m)\in s} w_l(t)c_l(t)\right), \qquad \forall l \in \mathrm{In}_n, \quad s \in \mathrm{S}_n \tag{4}$$

Weights:

$$w_l(t) = \frac{x_l(t)}{x_{\max,l}} - \sum_m r_{l,m}\frac{x_m(t)}{x_{\max,m}}, \quad \forall m \in \mathrm{Out}_n, \quad \forall l \in \mathrm{In}_n \tag{5}$$



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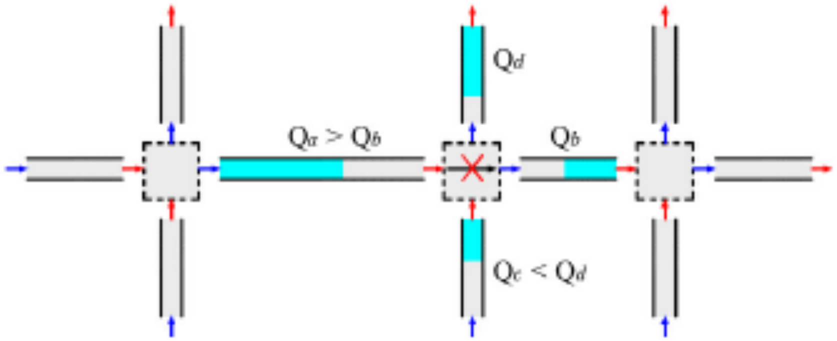
Green allocations for each phase included in each cycle time:

$$G_n = C_n - L_{\mathrm{lost},n} - \sum_s g_{\min,s,n}, \qquad \forall s \in \mathrm{S}_n, \tag{6}$$

$$g_{s,n}(t) = \frac{P_{s,n}(t)}{\sum_s P_{s,n}(t)} G_n + g_{\min,s,n}. \tag{7}$$

Queue based Max-Pressure traffic controller (MP-QL) limitations

- The MP controller in *Kouvelas et al. 2014* considers the queue lengths at *links*, thus being mainly efficient at intersections with link-based phases.
- The spatial distribution of the queues is neglected (*Li and Jabari (2019)*).



- Impractical, due to inefficient online data collection in the real world.

Real implementation (May 30, 2018)

Mercader, Uwayid, and Haddad 2020 (TR-C)

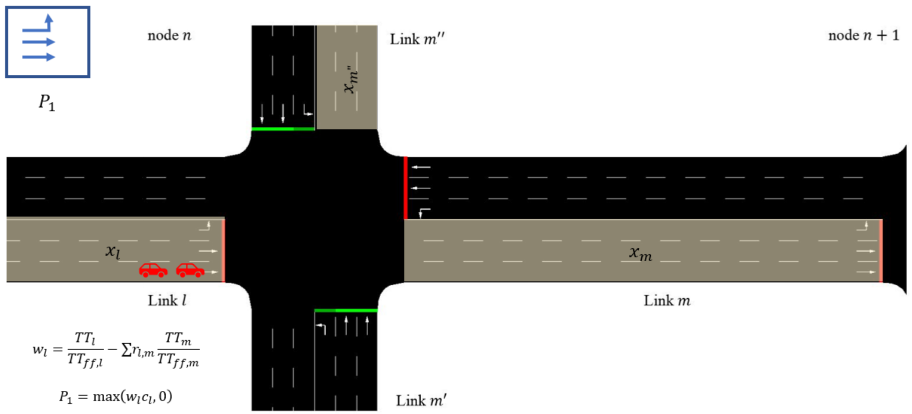
- MP controller based on travel times (TT) achieves better performance than the historic performance delivered by the optimized fixed control used at the intersection.

The cyclic Max-Pressure traffic controller based on Average Travel Time (MP-TT) - *Mercader et al. 2020*

- is a cycle-step algorithm with link structure,
- it shares the same equations of queue length based MP controller (MP-QL) in *Kouvalas 2014*,

$$w_l(t) = \frac{TT_l(t)}{TT_{ff,l}} - \sum_m r_{l,m} \frac{TT_m(t)}{TT_{ff,m}} \ , \quad \forall m \in \mathrm{Out}_n, l \in \mathrm{In}_n \ , \tag{8}$$

$TT_l(t)$ $[\mathrm{s}]$ – average travel time during the cycle t at the link l,
$TT_{ff,l}$ $[\mathrm{s}]$ – travel time in free flow at link l.



Time based MP limitations (in *Mercader et al. 2020*):

- The MP-TT controller uses a link-based approach (similar to Kouvelas et al. 2014).
- It applies conversion from normalized queues to normalized travel times as if the relation is linear $\frac{x_l(t)}{x_{\text{max},l}} \sim \frac{TT_l(t)}{TT_{ff,l}}$, which is not necessarily the case.

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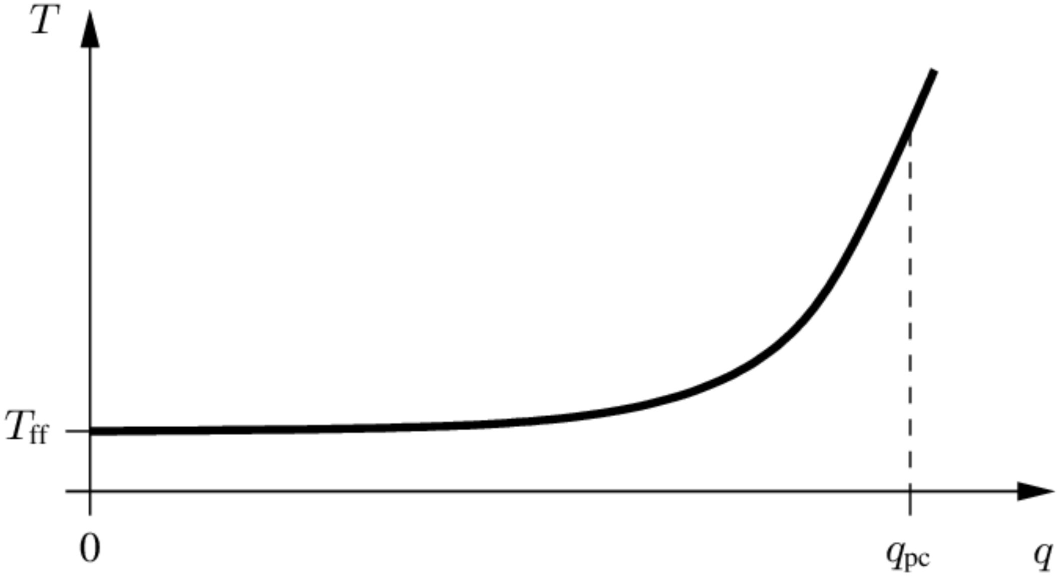
Contributions... Improved cyclic time based MP controller:

(C1) Enhanced relation of the queue normalization with travel time (**delays**),

(C2) Improved generic algorithm that can be applied over a larger variety of intersections (**heterogeneous networks, lane based**).

(C1) Average Travel Time (MP-TT) ⇒ Travel Time Delays (MP-TTD)

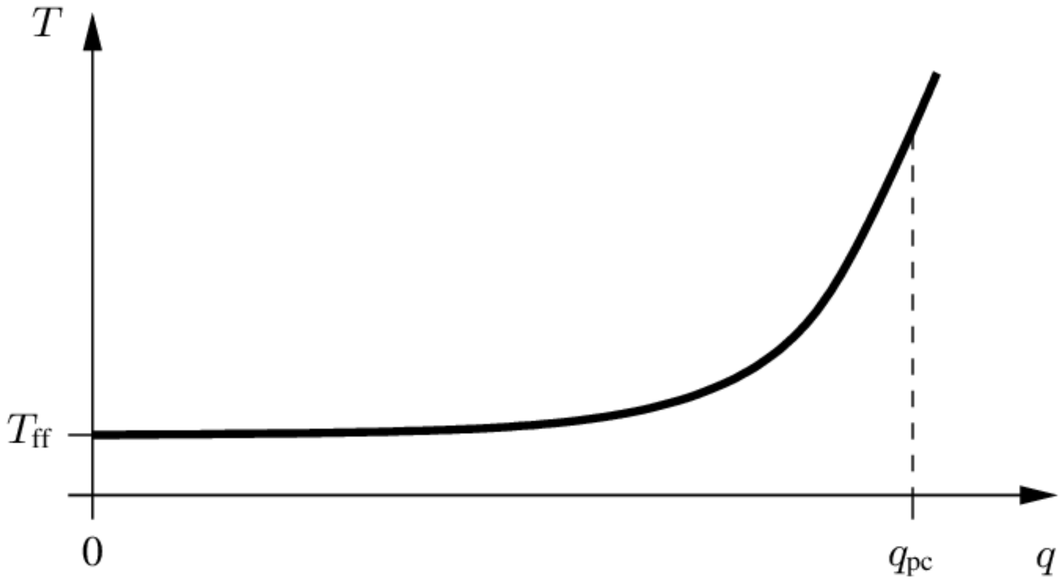
Inspired from Bureau of Public Roads (1964)



(from Maerivoat et al. 2008)

(C1) Average Travel Time (MP-TT) ⇒ Travel Time Delays (MP-TTD)

Inspired from Bureau of Public Roads (1964)



(from Maerivoat et al. 2008)

$$TT = TT_{ff}\left[1 + \alpha\left(\frac{x}{x_{max}}\right)^{\beta}\right]$$

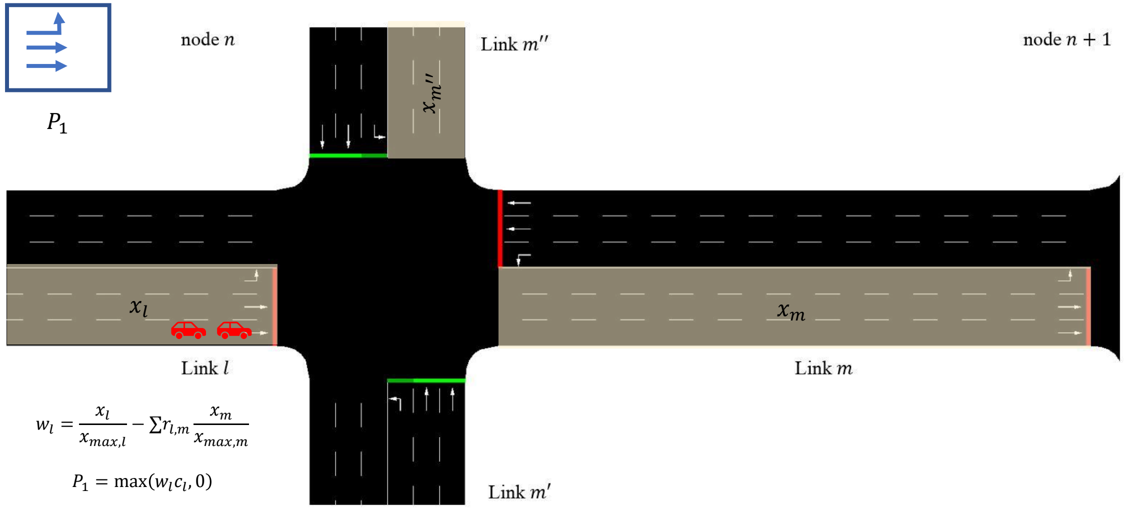
It is used to support the convex relationship between the normalized travel time and the normalized queue length,

$$\sqrt[\beta]{\frac{TT - TT_{ff}}{TT_{ff}}} \sim \frac{x}{x_{\text{max}}} \qquad (9)$$

β – a fitting parameter to the nonlinearity relation.

(C2) Improved generic algorithm (heterogeneous networks, lane based)

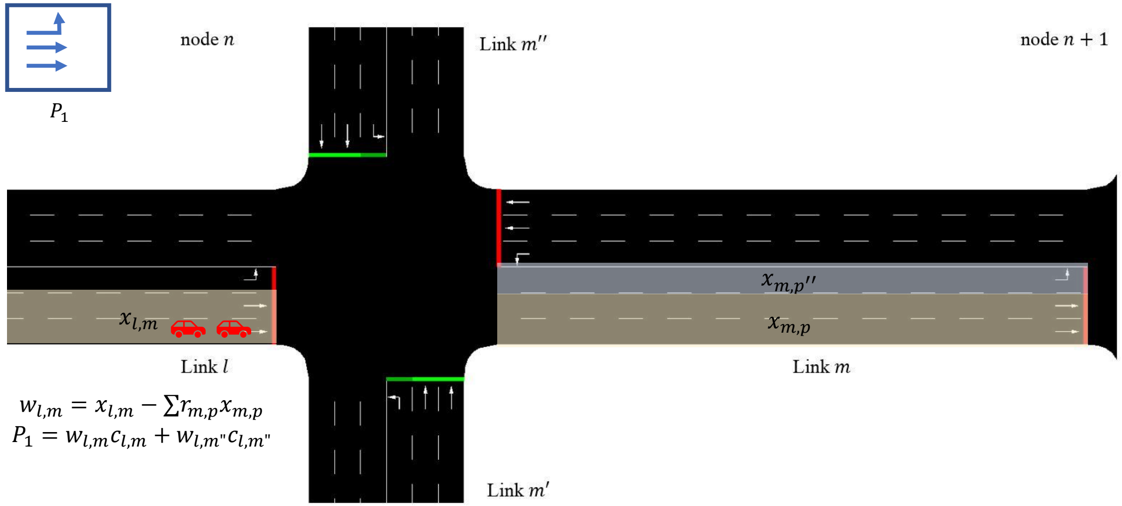
Link based



$$w_l = \frac{x_l}{x_{max,l}} - \Sigma r_{l,m} \frac{x_m}{x_{max,m}}$$

$$P_1 = \max(w_l c_l, 0)$$

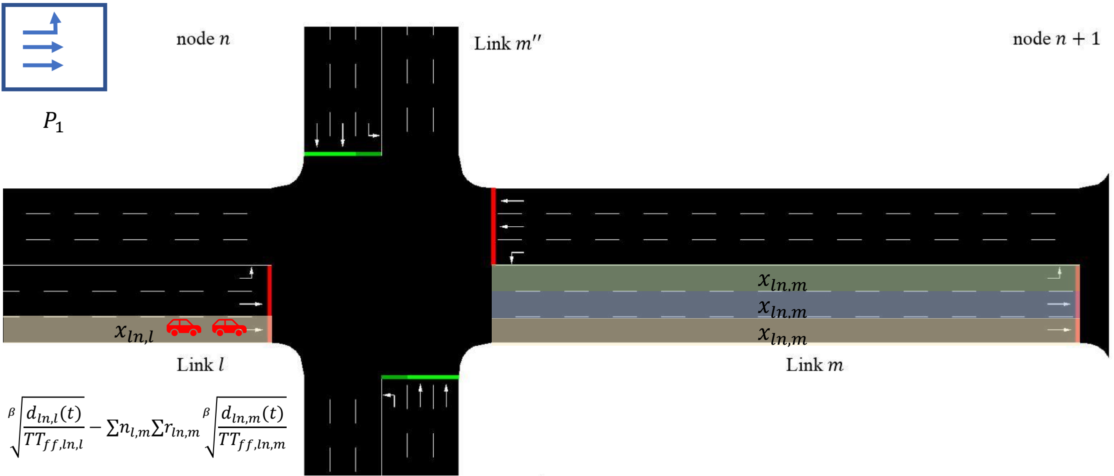
Movement based



$$w_{l,m} = x_{l,m} - \Sigma r_{m,p} x_{m,p}$$

$$P_1 = w_{l,m} c_{l,m} + w_{l,m''} c_{l,m''}$$

Lane based



$$w_l = \sqrt[\beta]{\frac{d_{ln,l}(t)}{TT_{ff,ln,l}}} - \Sigma n_{l,m} \Sigma r_{ln,m} \sqrt[\beta]{\frac{d_{ln,m}(t)}{TT_{ff,ln,m}}}$$

Travel time delays based MP traffic controller (MP-TTD)

The new suggested equations for the pressures and weights are,

$$P_{s,n}(t) = \max\left(0, \sum_{ln \in s} w_{ln}(t) c_{ln}(t)\right), \qquad \forall s \in \mathrm{S}_n \tag{10}$$

$$w_{ln}(t) = \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\mathrm{ff},ln}}} - \sum_{m} n_{l,m}(t) \sum_{ln \in m} r_{ln,m}(t) \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\mathrm{ff},ln}}}$$

$$\forall ln \in s\,,\;\; m \in \mathrm{Out}_{ln,n}\,,\;\; l \in \mathrm{In}_n\,, \tag{11}$$

where

$$d_{ln}(t) = max(TT_{ln}(t) - TT_{\mathrm{ff},ln}, 0)\,, \tag{12}$$

$$r_{ln,m}(t) = \sum_{p} \frac{r_{m,p}(t)}{N_{m,p}}\,, \quad \forall m \in \mathrm{In}_{n+1},\; p \in \mathrm{Out}_{ln,n+1}\,, \tag{13}$$

Green allocations with fixed cycle: (similar to Mercader et al. 2020, Kouvelas et al. 2014)

$$G_n = C_n - L_{\mathrm{lost},n} - \sum_s g_{\mathrm{min},s,n} \ , \qquad \forall s \in \mathrm{S}_n \, , \tag{14}$$

$$g_{s,n}(t) = \frac{P_{s,n}(t)}{\sum_s P_{s,n}(t)} G_n + g_{\mathrm{min},s,n} \, . \tag{15}$$

Outline

1. Introduction
2. Background
3. Fixed cyclic MP
4. Dynamic cyclic MP
5. Simulation results
6. Experimental study

Dynamic cyclic structure of MP algorithm

Problem

Previous works of cyclic-based MP control have offered a cyclic notion to actuate the controller in a cyclic manner. Yet no input has been provided for

- optimal cycle length for each intersection,
- offset problem: in a grid network structure along with the dynamic and stochastic nature of the trips, it is not clear what the main phase of the intersections and how to coordinate them.

Dynamic cyclic structure of MP algorithm

Motivation

- developing two dynamic cyclic schemes (bounded and unbounded cycle lengths) with low computational complexity,
- evaluating the developed control schemes via comparing traffic performances from simulation results between dynamic and fixed cycle lengths.

Fixed Cycle

- Fixed phase sequence (cannot skip phases)
- A fixed cycle is determined a priori, and is equal in consecutive intersections
- Green allocations are updated each cycle time

Dynamic Cycle

- Fixed phase sequence (cannot skip phases)
- The phase actuation is updated each time step
- If the activated phase holds the maximum pressure it is re-activated another time step, else, the next phase in the sequence is activated

Travel time delays based MP traffic controller (MP-TTD)

The new suggested equations for the pressures and weights are,

$$P_{s,n}(t) = \sum_{ln \in s} w_{ln}(t) c_{ln}(t)\,, \qquad \forall s \in \mathrm{S}_n \tag{16}$$

$$w_{ln}(t) = \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\mathrm{ff},ln}}} - \sum_{m} n_{l,m}(t) \sum_{ln \in m} r_{ln,m}(t) \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\mathrm{ff},ln}}}$$
$$\forall ln \in s\,,\; m \in \mathrm{Out}_{ln,n}\,,\; l \in \mathrm{In}_n\,, \tag{17}$$

where

$$d_{ln}(t) = max(TT_{ln}(t) - TT_{\mathrm{ff},ln}, 0)\,, \tag{18}$$

$$r_{ln,m}(t) = \sum_{p} \frac{r_{m,p}(t)}{N_{m,p}}\,, \quad \forall m \in \mathrm{In}_{n+1},\; p \in \mathrm{Out}_{ln,n+1}\,, \tag{19}$$

Dynamic cyclic structure of MP algorithm - Unbounded length

Algorithm 1 Dynamic Cyclic Max-Pressure - Unbounded

```
procedure DynamicCycleMP($g_{S_n,\min}, S_n, s_{i,n}, t$) #Cycle fixed sequence should be determined
    if $t < g_{s_{i,n},\min}$ then
        $t \leftarrow t + 1$
    else
        $t \leftarrow 0$
        # Calculate the weights and the pressure based on the MP-controller
        $w_{ln}(t) \leftarrow \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\text{ff},ln}}} - \sum_m n_{l,m}(t) \sum_{ln\in m} r_{ln,m}(t) \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\text{ff},ln}}}$
        $P_{s_{i,n}}(t) \leftarrow \sum_{ln\in s_{i,n}} w_{ln}(t) c_{ln}(t)$
        if $s_{i,n} = \arg\max_i(P_{s_{i,n}})$ then
            return $s_{i,n}$ #Actuate the same phase again
        else
            return $s_{i+1,n}$ #Actuate the next phase in the sequence
        end if
    end if
end procedure
```

Dynamic cyclic structure of MP algorithm - Bounded length

Algorithm 2 Dynamic Cyclic Max-Pressure - Bounded

```
procedure DynamicCycleMP($maxCycle, g_{S_n,\min}, S_n, s_{i,n}, t, m$) #Cycle fixed sequence should be determined, m - number of phase activation within the cycle, e.g. m=1 is the first phase activated in a cycle.
    if $t < g_{s_{i,n},\min}$ then
        $t \leftarrow t + 1$ for
    else
        $t \leftarrow 0$
        $m \leftarrow m + 1$
        # calculate maximum times phase i can be activated in a single cycle (a cycle with bounded length)
        $maxNumber_{S_{0,n}} \leftarrow (maxCycle - L - \sum_{j=1}^{length(S_n)} g_{s_{i,n},\min})/g_{s_{0,n},\min}$
        for $j$ in $length(S_n) - 1$ do
            $maxNumber_{S_{j+1,n}} \leftarrow 1 + (maxNumber_{S_{j,n}} - m)\frac{g_{s_{i,n},\min}}{g_{s_{i+1,n},\min}} + m$ # If the phases share the same minimum green then this equation would be static, $maxNumber_{S_{j+1,n}} \leftarrow 1 + maxNumber_{S_{j,n}}$
        end for
        # Calculate the weights and the pressure based on the MP-controller
        $w_{ln}(t) \leftarrow \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\text{ff},ln}}} - \sum_m n_{l,m}(t) \sum_{ln \in m} r_{ln,m}(t) \sqrt[\beta]{\frac{d_{ln}(t)}{TT_{\text{ff},ln}}}$
        $P_{s_{i,n}}(t) \leftarrow \sum_{ln \in s_{i,n}} w_{ln}(t) c_{ln}(t)$
        if $s_{i,n} = \arg\max_s(P_{s_{i,n}})$ and $m < maxNumber_{S_{i,n}}$ then
            return $S_{i,n}$ and $m$ #Actuate the same phase again and return the phase number in the cycle.
        else
            if $s_{i+1,n} = s_{0,n}$ then
                $m \leftarrow 1$ #If the cycle ends return the count of phases m back to 1
            end if
            return $s_{i+1,n}$ and $m$ #Actuate the next phase in the sequence
        end if
    end if
end procedure
```

Outline

1. Introduction
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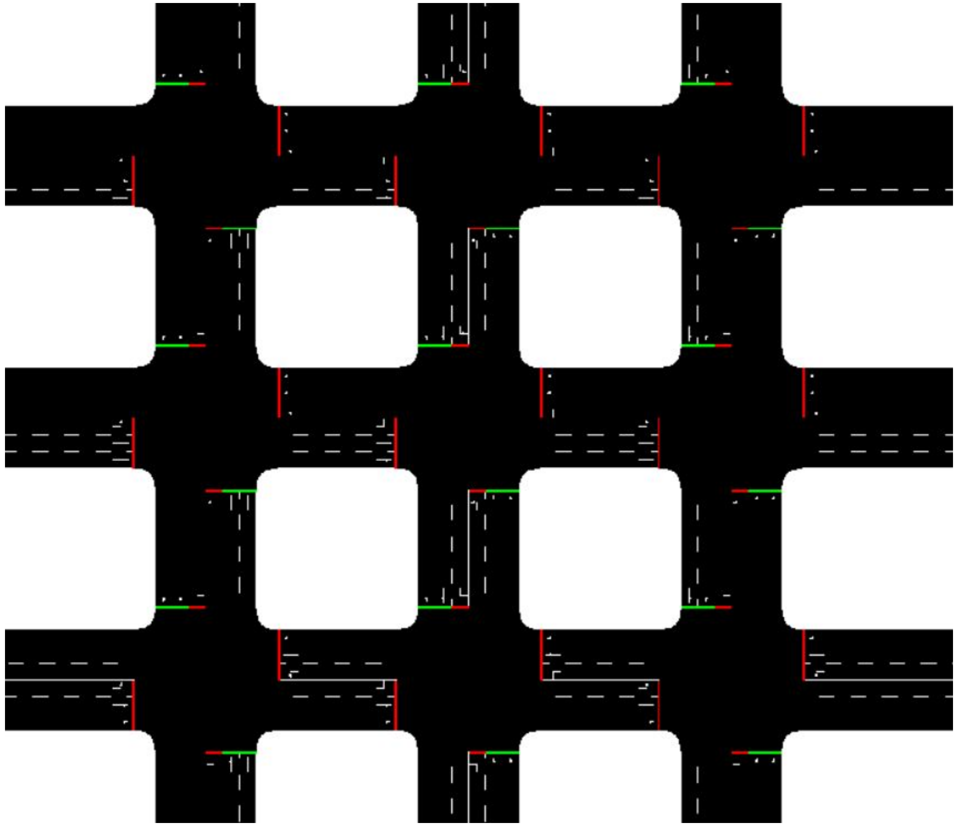
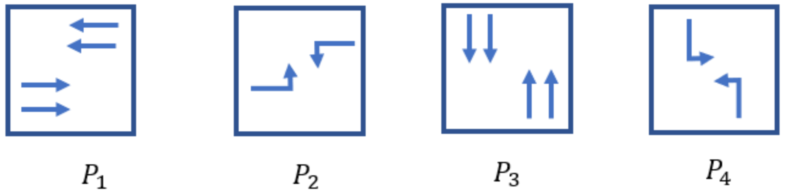
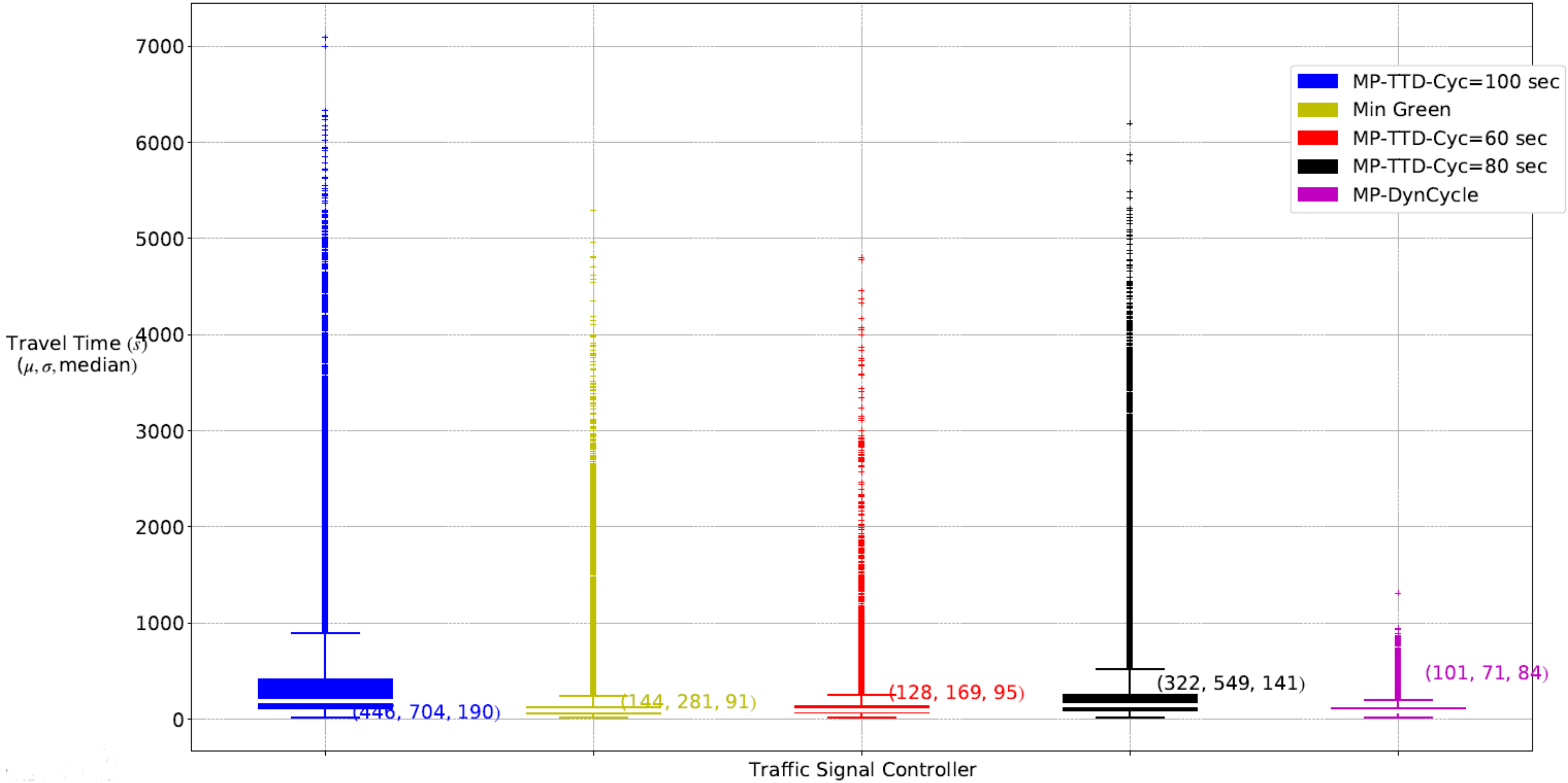
Case study: 3x3 Grid Network Results



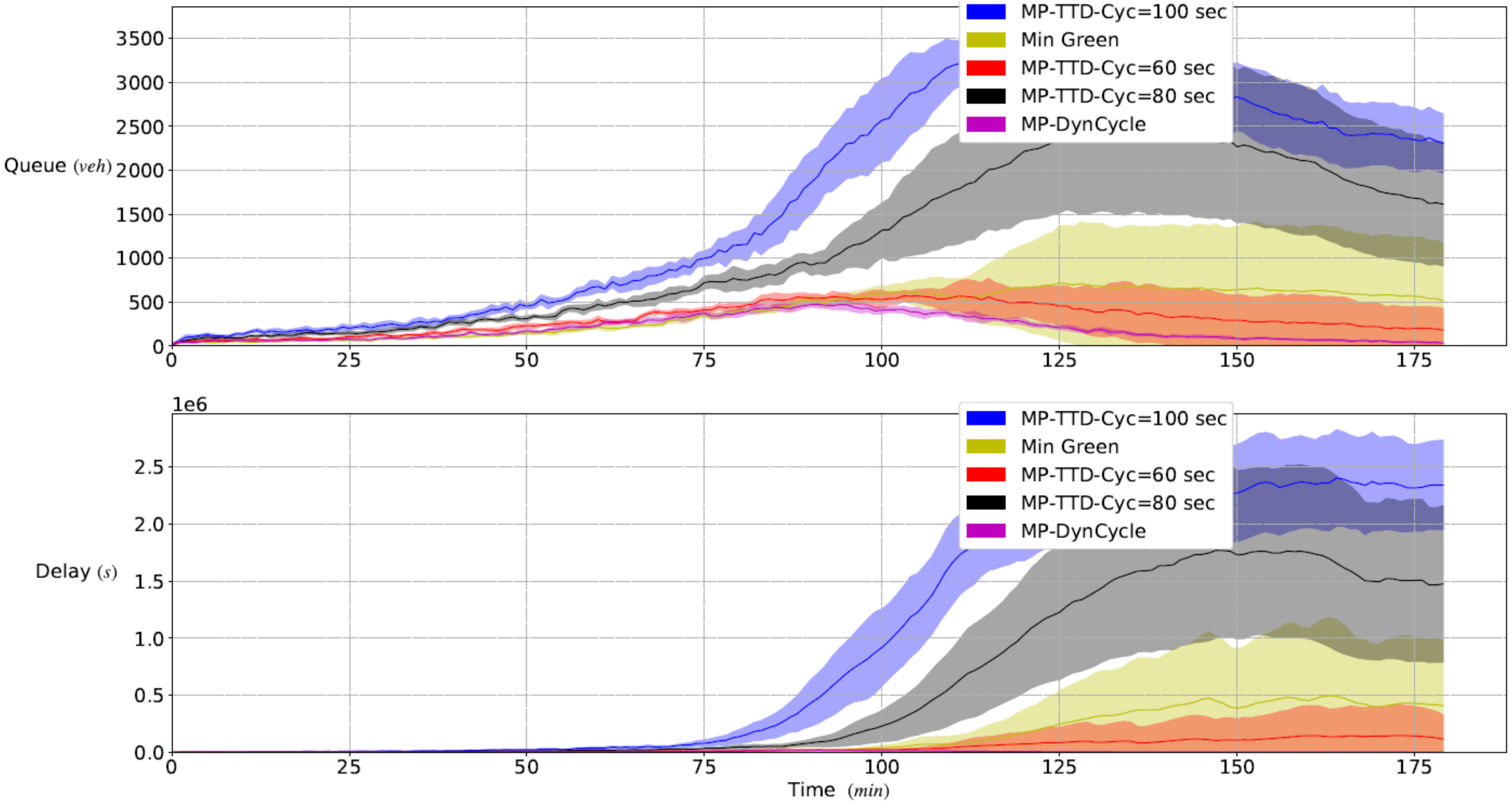


MP-TTD: fixed cycle vs. dynamic (unbounded) cycle

- different fixed cycles $(60, 80, 100)$ vs. dynamic cycle.



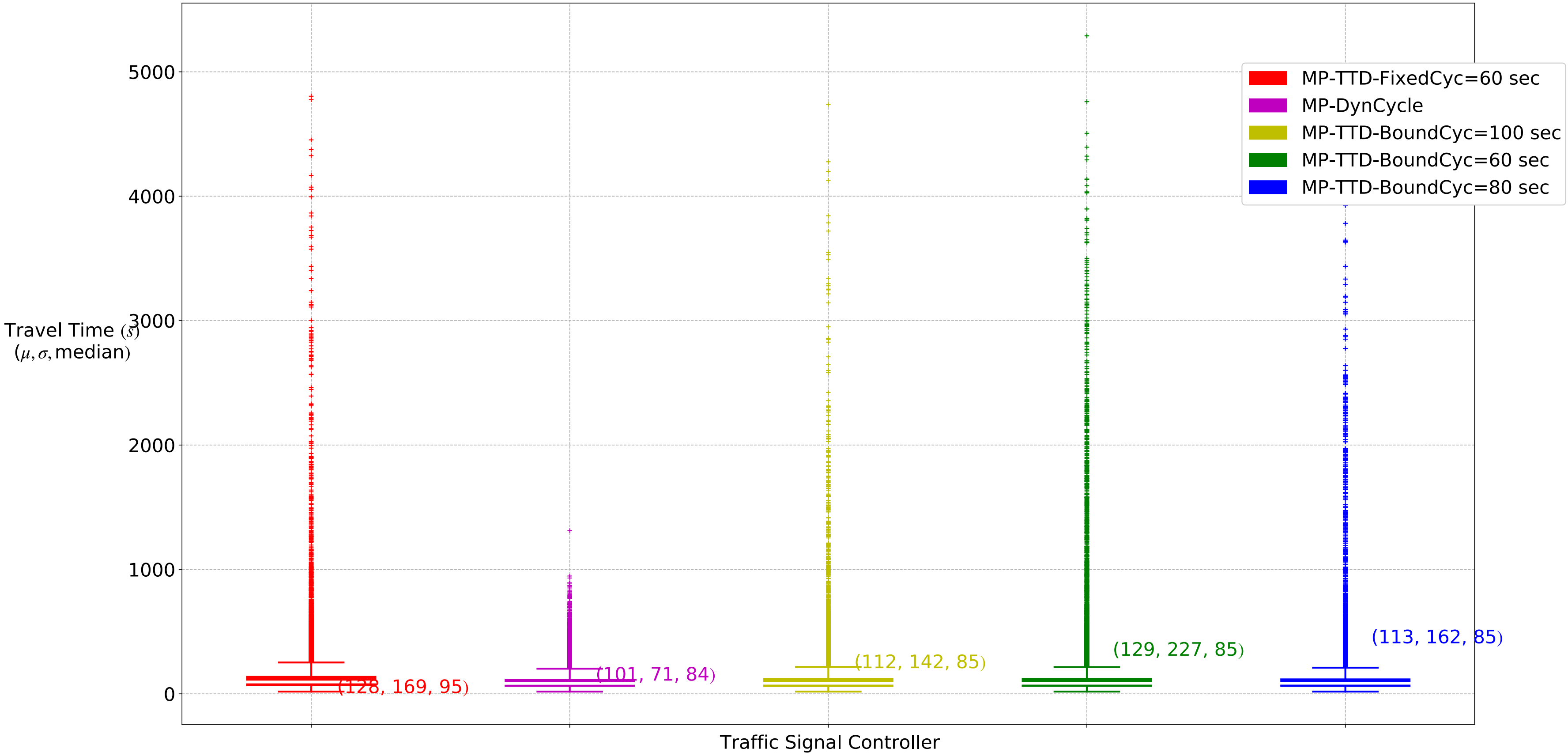
MP-TTD: fixed cycle vs. dynamic cycle



- dynamic cycle provides superior performance compared with fixed cycle MP.

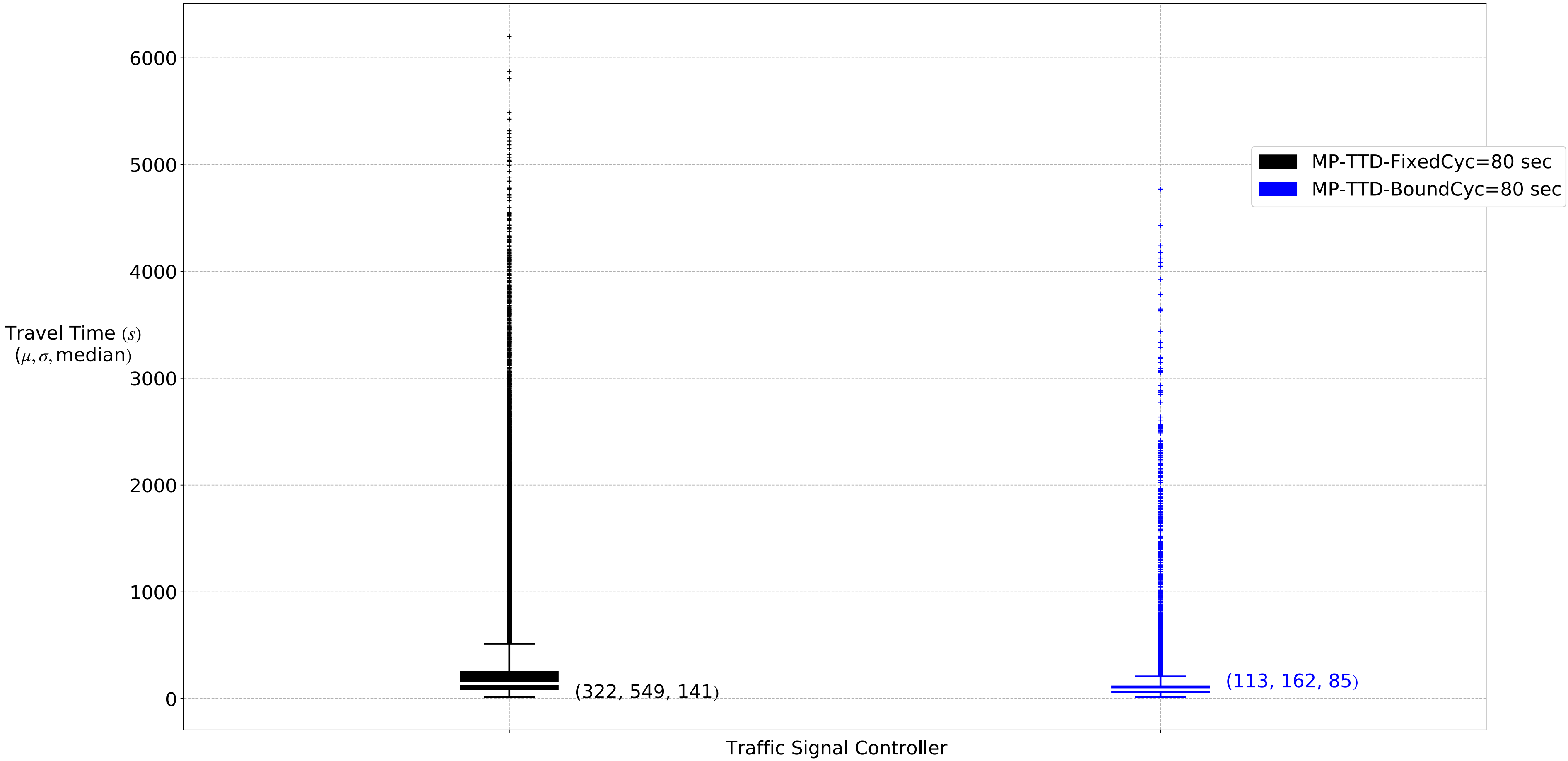
MP-TTD: Bounded vs. unbounded dynamic cycle

- different **bounded** cycles $(60, 80, 100)$ vs. dynamic cycle.



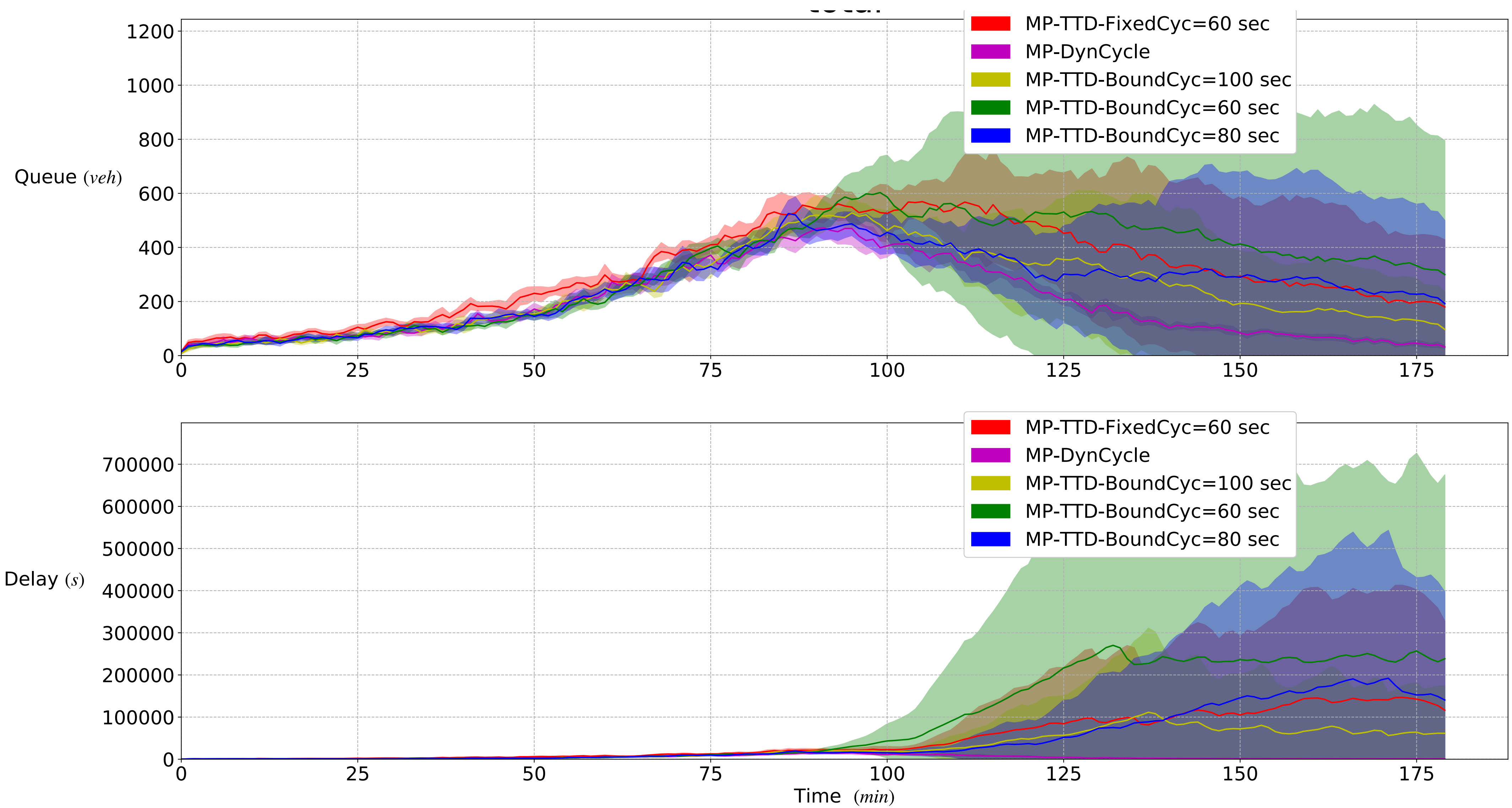
- The less algorithm is bounded the more stable and less performance variation.

MP-TTD: Fixed vs. bounded dynamic cycle



- A bounded dynamic cycle (maximum cycle 80s) algorithm can perform better than a fixed cycle (80s) scheme.

MP-TTD: Bounded vs. unbounded dynamic cycle



Summary of simulation results

- Choosing appropriate fixed cycle is vital to ensure better utilization of the cyclic MP controller.
- The developed dynamic cyclic MP algorithm can manage to surpass other existing fixed cyclic MP schemes, providing better coordination and better green allocations, both result in better performances.
- The less bounded dynamic cycle is the more stable and less performance variation, and it performs better than the existing fixed cycle scheme.

Outline

1. Introduction
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4. Dynamic cyclic MP
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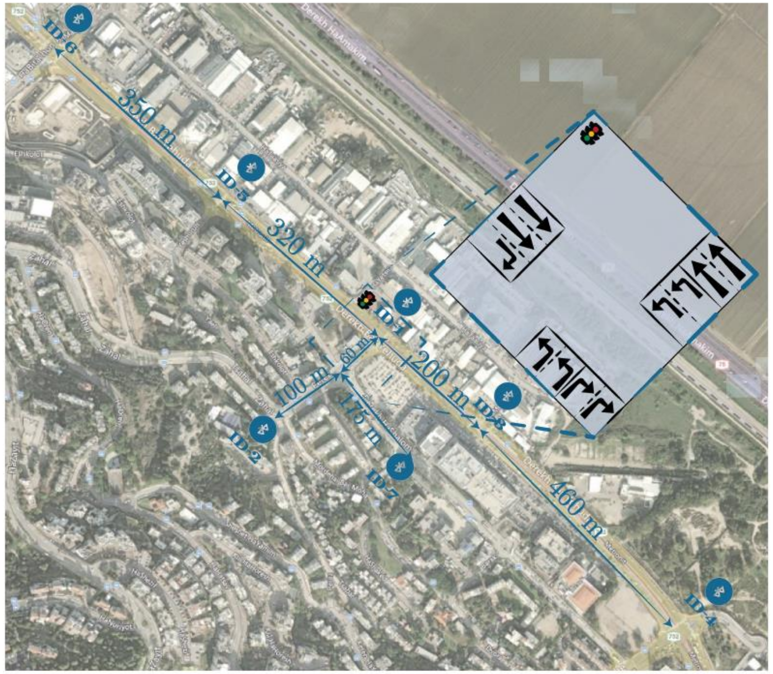
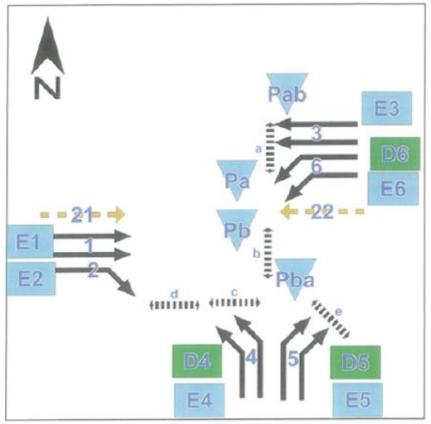
6. **Experimental study**

Experimental case study



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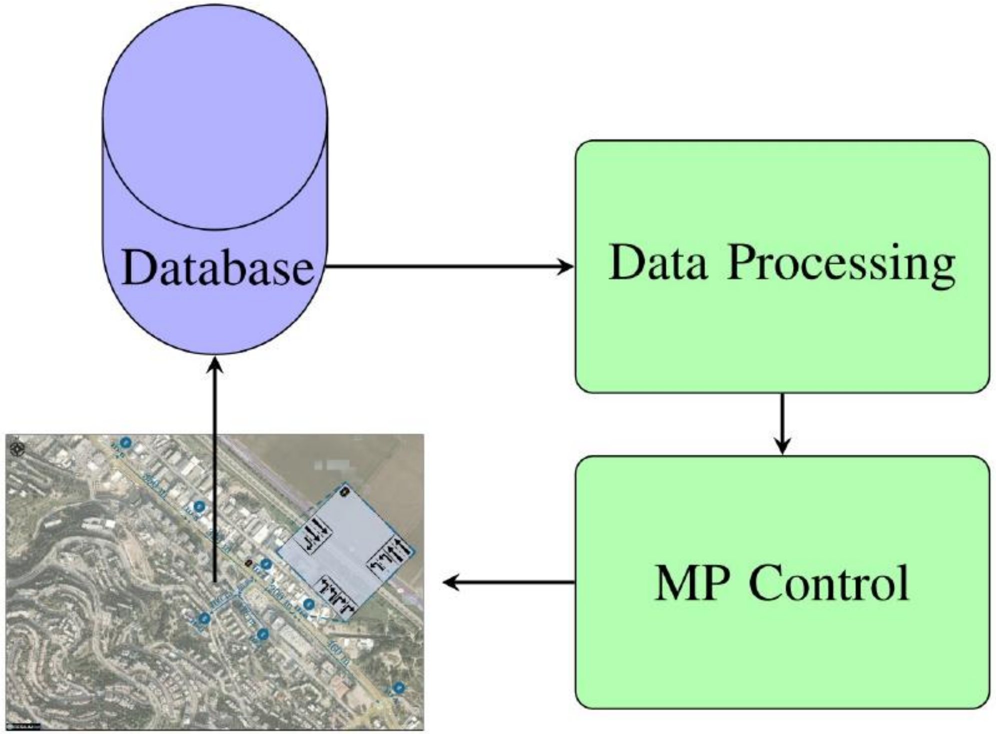
Communication architecture

- **Bluetooth Sensor Database**: This component serves as the central repository where data from Bluetooth sensors is collected and stored.
- **Data Processing**: In this stage, the raw data collected from the sensors is processed to prepare it for further subsequent analysis.
- **MP Control**: Here, the processed data is analyzed using the MP-TTD algorithm, performing adaptive algorithm calculations.
- **Environment Activation**: Based on the results from the MP-TTD calculations, the system adjusts the green time durations, directly interacting with the traffic signals in the real-world environment.



Database

Data Processing

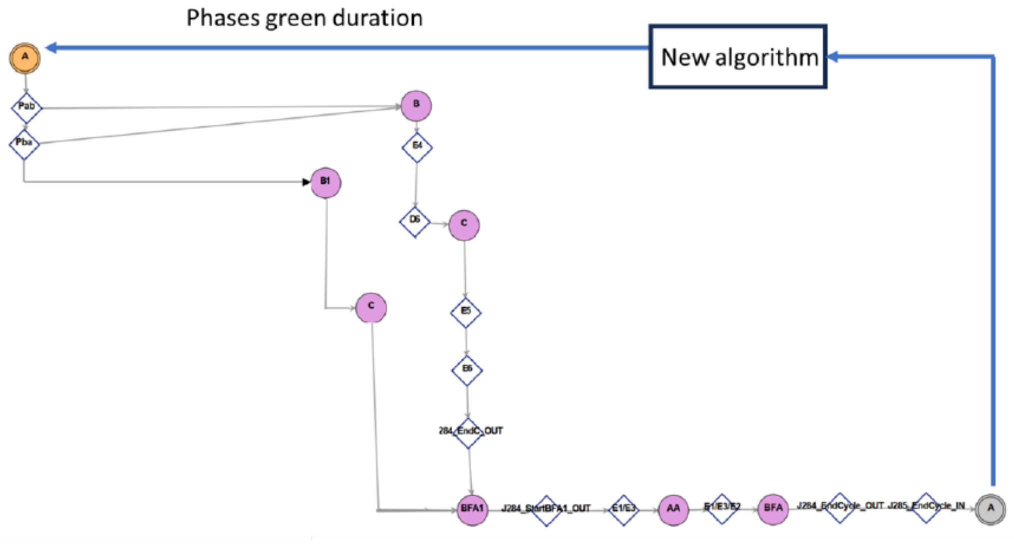
MP Control

Constraints

- **Same Flow chart**: adapt to the same flow chart, without loop detectors.
- **Fixed cycle time & effective green**: no change for the cycle.
- **Pedestrian green wave** : pedestrian cross without stopping.

Challenges of Data collection

- **Feedback delay**: the control is activated in large delay.
- **low penetration rate**: 5-10% penetration rate.
- **Data Filtering** : difficult to filter with high variations.



Experimental case study:Data collection

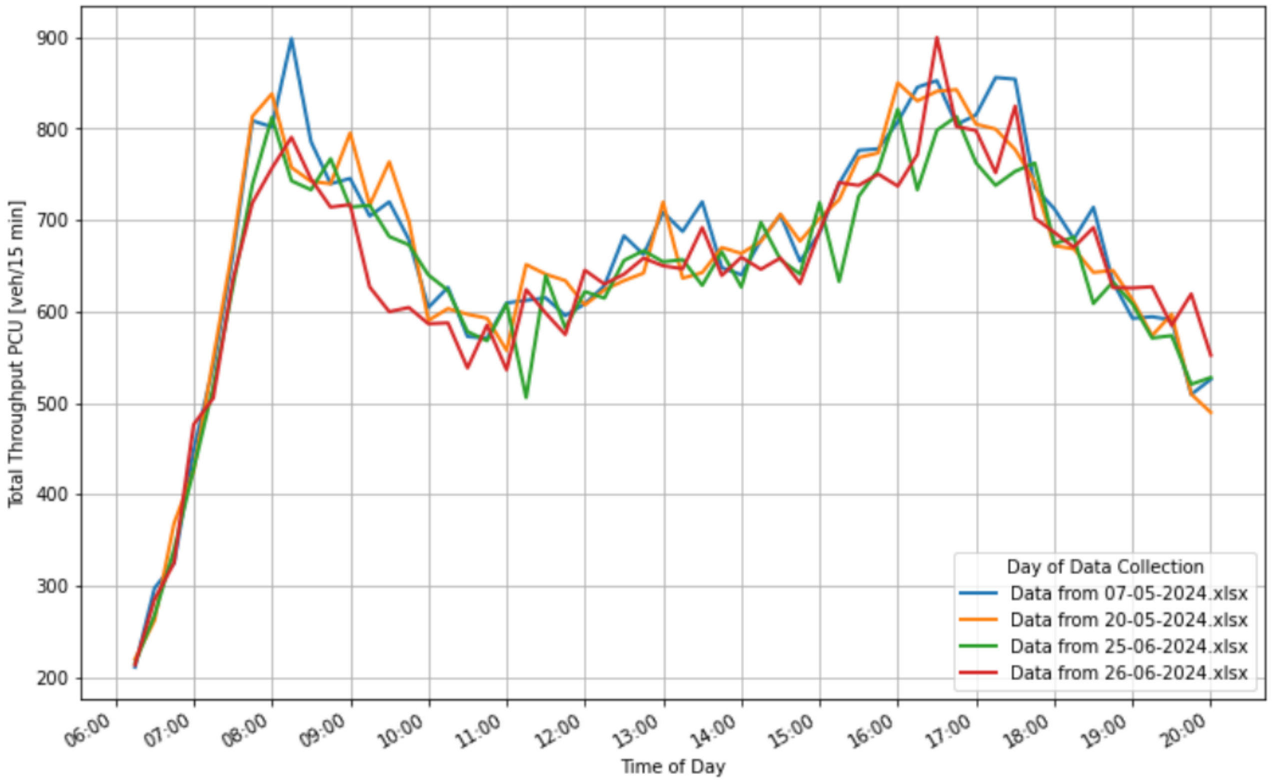


Figure: Use case Total throughput Passenger car unit over Time Intervals by Data Collection Day

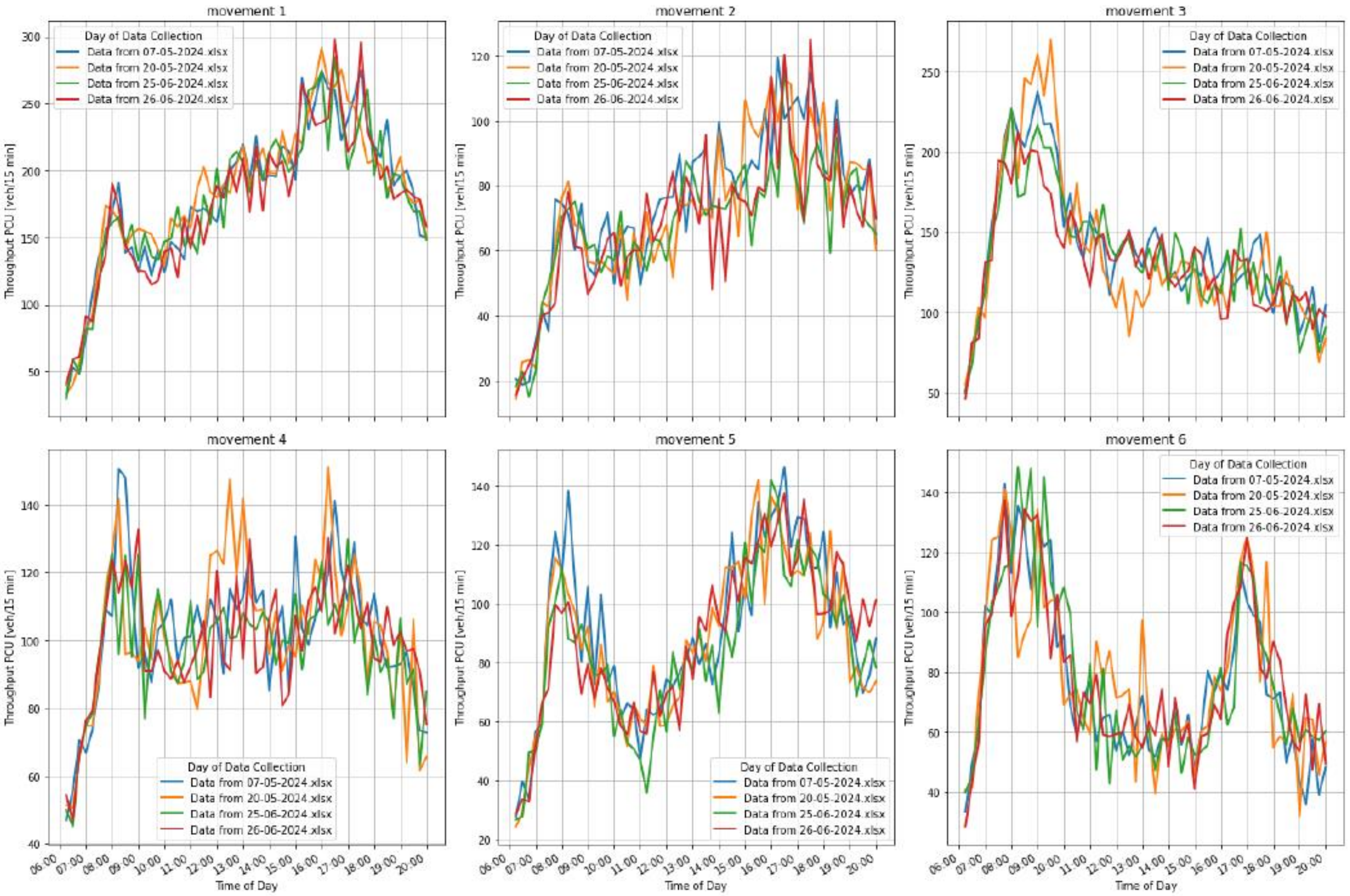
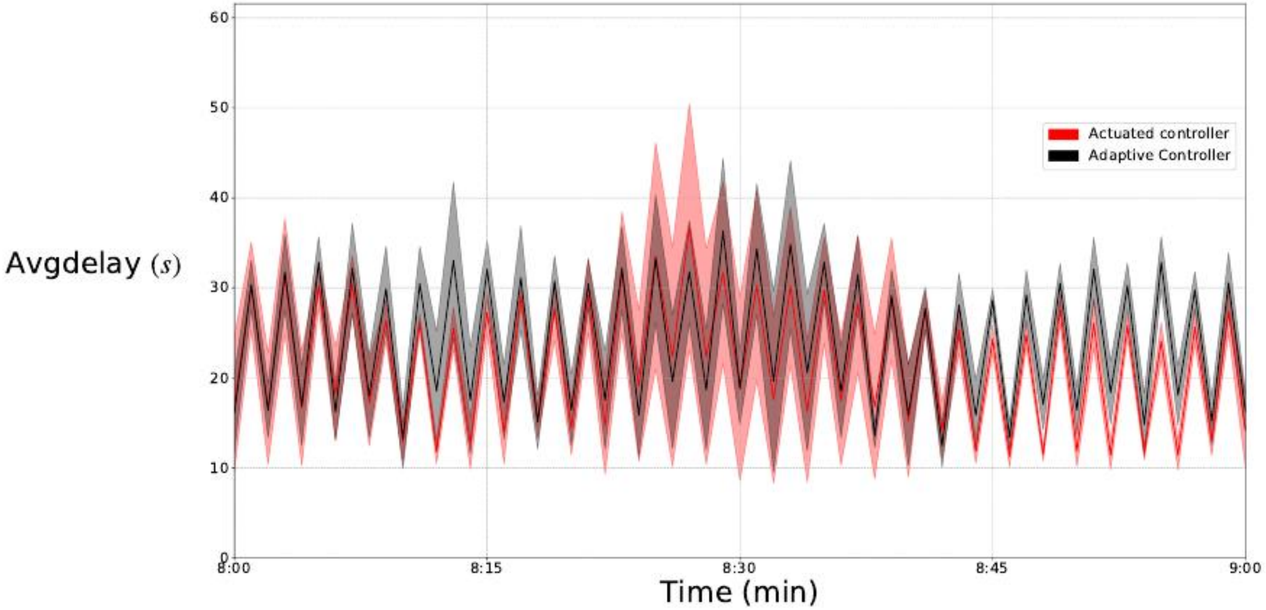
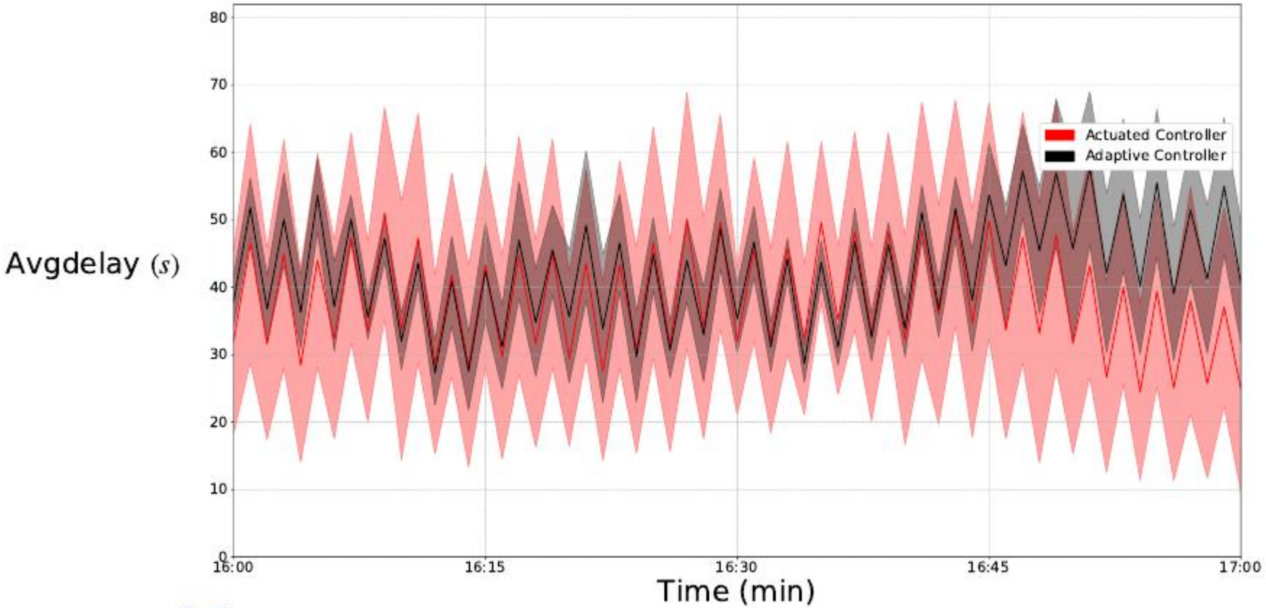
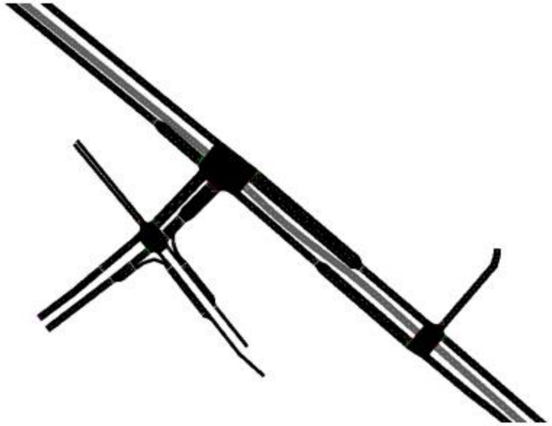


Figure: Use case Throughput PCU Data by Movement and Day


Avgdelay (s)
0
10
20
30
40
50
60
8:00
8:15
8:30
8:45
9:00
Time (min)
🟥 Actuated controller
■ Adaptive Controller

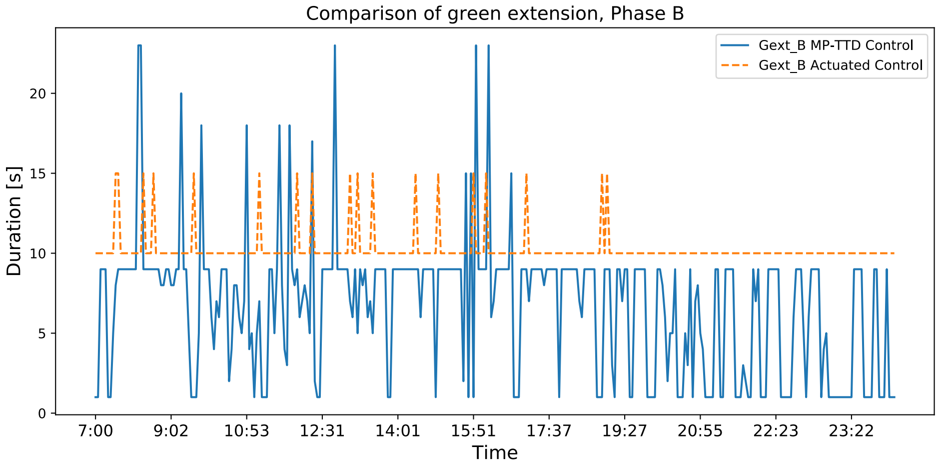

Avgdelay (s)
0
10
20
30
40
50
60
70
80
16:00
16:15
16:30
16:45
17:00
Time (min)
🟥 Actuated Controller
■ Adaptive Controller

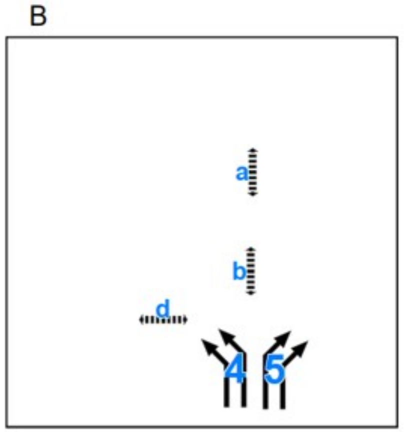

350 m
320 m
200 m
100 m
176 m
460 m

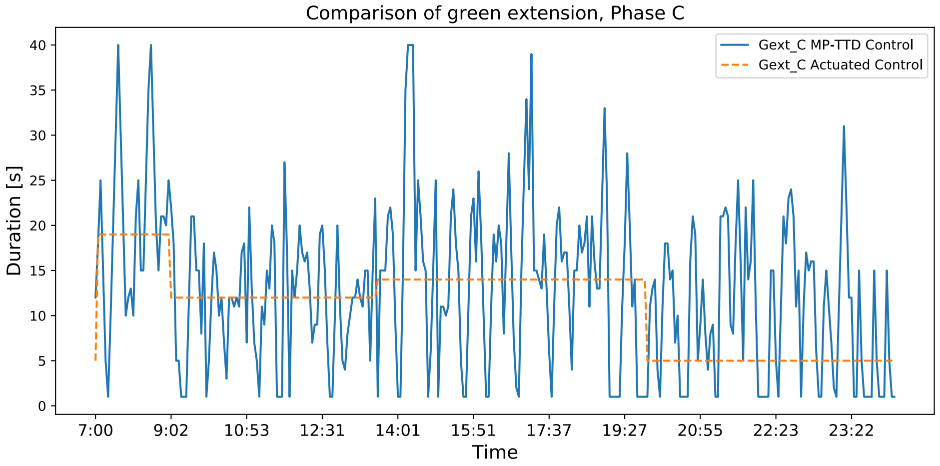


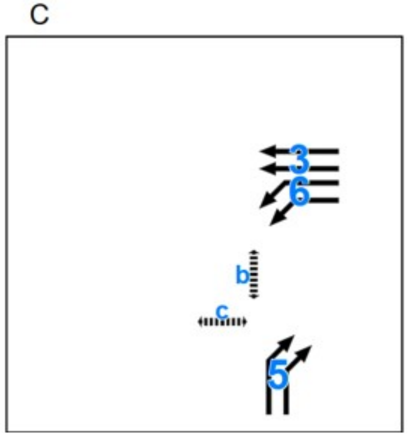
Experimental case study:Field Test

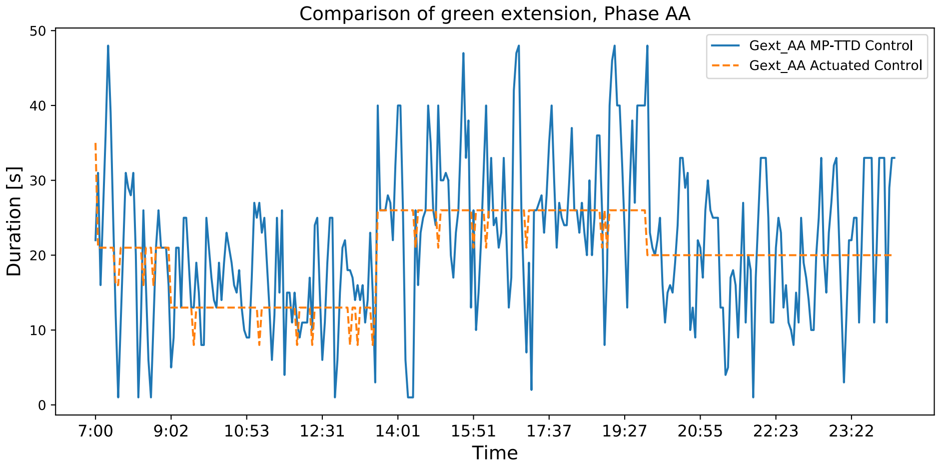
Experimental case study: Activation results

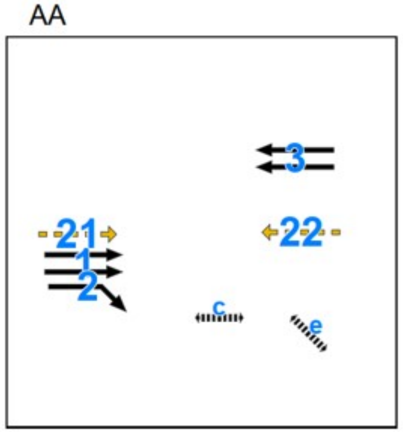

Comparison of green extension, Phase B

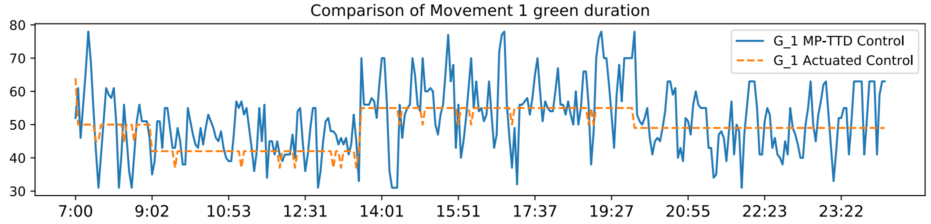


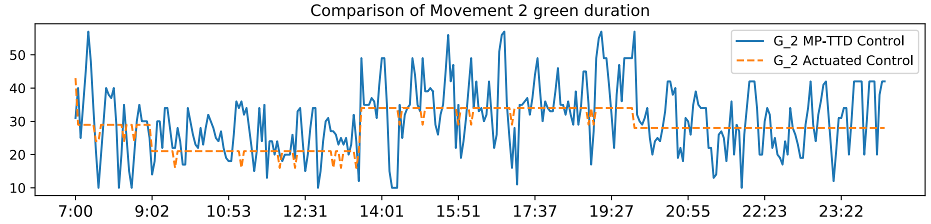

Comparison of green extension, Phase C

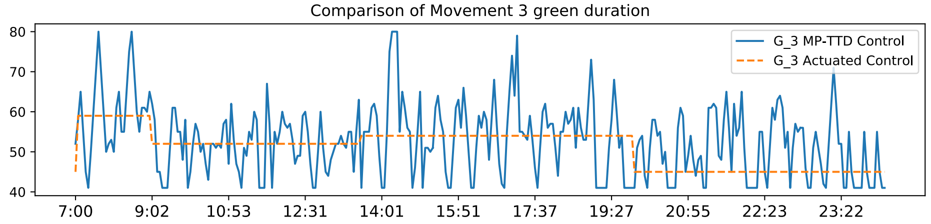


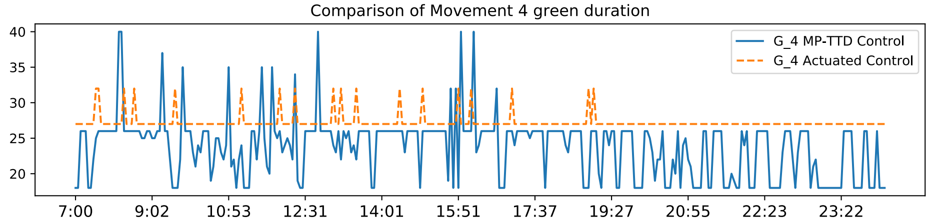

Comparison of green extension, Phase AA

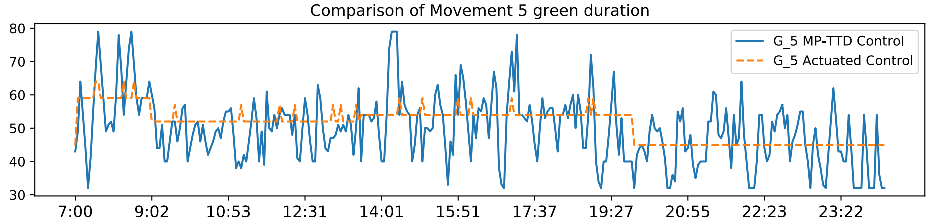


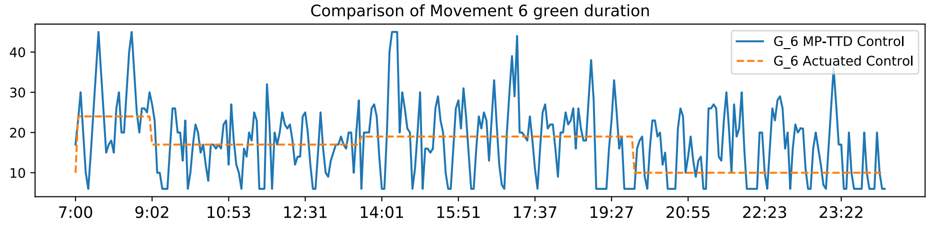

Comparison of Movement 1 green duration
80
70
60
50
40
30
7:00
9:02
10:53
12:31
14:01
15:51
17:37
19:27
20:55
22:23
23:22
G_1 MP-TTD Control
G_1 Actuated Control


Comparison of Movement 2 green duration
50
40
30
20
10
7:00
9:02
10:53
12:31
14:01
15:51
17:37
19:27
20:55
22:23
23:22
G_2 MP-TTD Control
G_2 Actuated Control

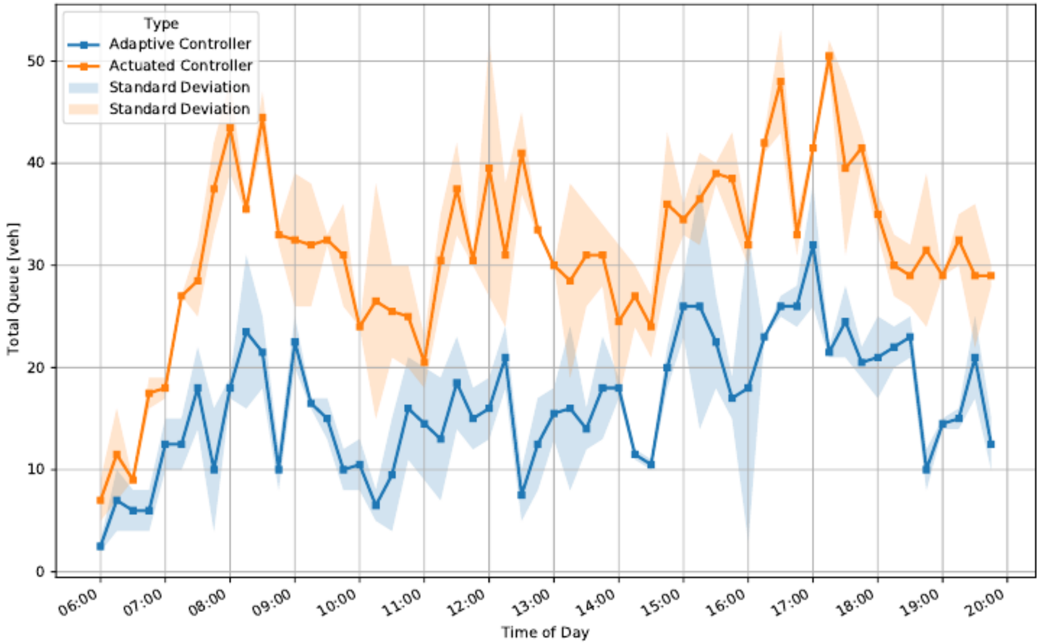

Comparison of Movement 3 green duration
80
70
60
50
40
7:00
9:02
10:53
12:31
14:01
15:51
17:37
19:27
20:55
22:23
23:22
G_3 MP-TTD Control
G_3 Actuated Control


Comparison of Movement 4 green duration
40
35
30
25
20
7:00
9:02
10:53
12:31
14:01
15:51
17:37
19:27
20:55
22:23
23:22
G_4 MP-TTD Control
G_4 Actuated Control


Comparison of Movement 5 green duration
80
70
60
50
40
30
7:00
9:02
10:53
12:31
14:01
15:51
17:37
19:27
20:55
22:23
23:22
G_5 MP-TTD Control
G_5 Actuated Control


Comparison of Movement 6 green duration
40
30
20
10
7:00
9:02
10:53
12:31
14:01
15:51
17:37
19:27
20:55
22:23
23:22
G_6 MP-TTD Control
G_6 Actuated Control

Experimental case study:Performance results



The data reveals a 47.5% queue improvement with the adaptive controller over the actuated control from 07:00 to 20:00.

Experimental case study:Performance results

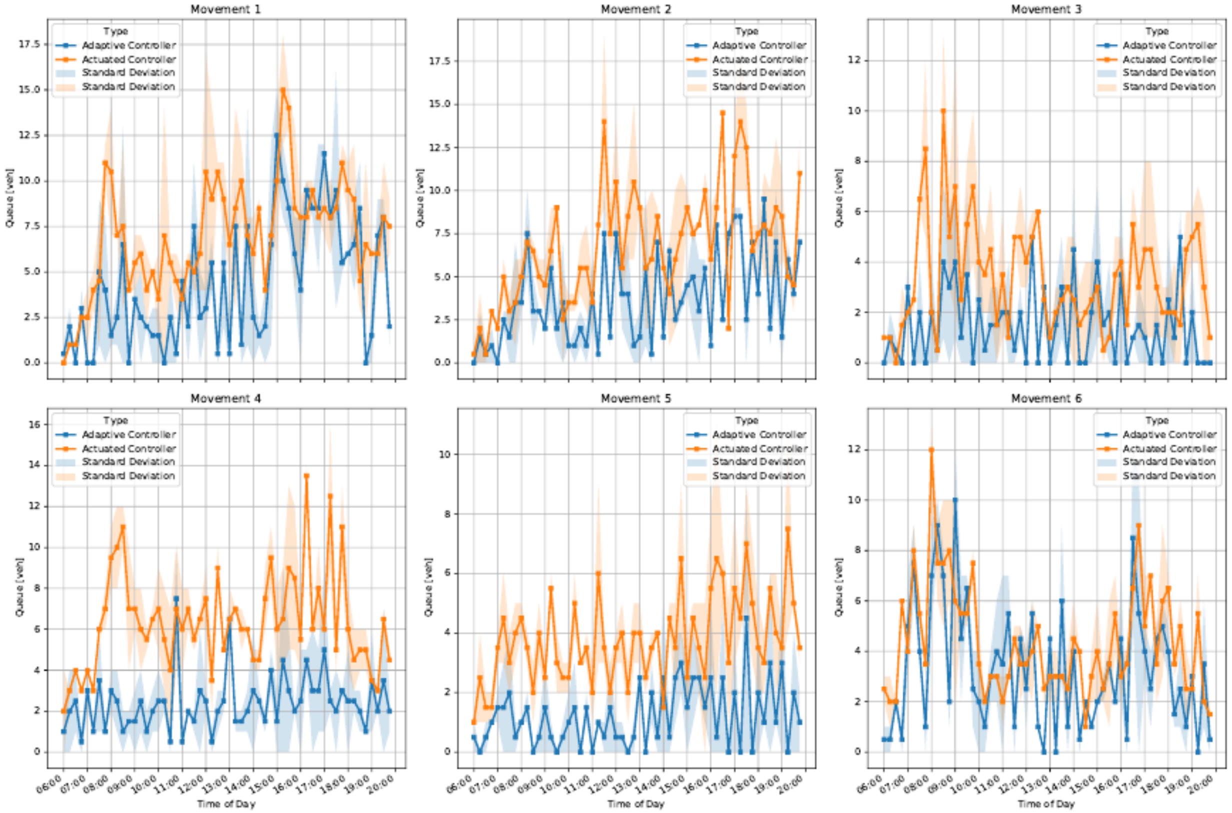


Figure: Experimental case study results: Queue per movement throughout the day from 7:00 to 20:00.

Outline

Conclusions

- The developed MP-TTD controller can manage surpass other existing max pressure schemes, providing an enhanced estimation of the traffic state and an improved green allocation, both result in better performance.
- The adaptive signal control algorithm, through experimental application, demonstrated potential for enhancing traffic flow.
- in a practical experimental case study using real-time data from Bluetooth sensors, the MP-TTD controller was integrated with existing traffic signal systems without requiring major infrastructure changes.
- the MP-TTD controller shows promise as a tool for improving urban traffic signal control. Its real-world efficacy and adaptability suggest it could be beneficial for urban and possibly rural settings.