Platoon-Based Self-Scheduling for Real-Time Traffic Signal Control

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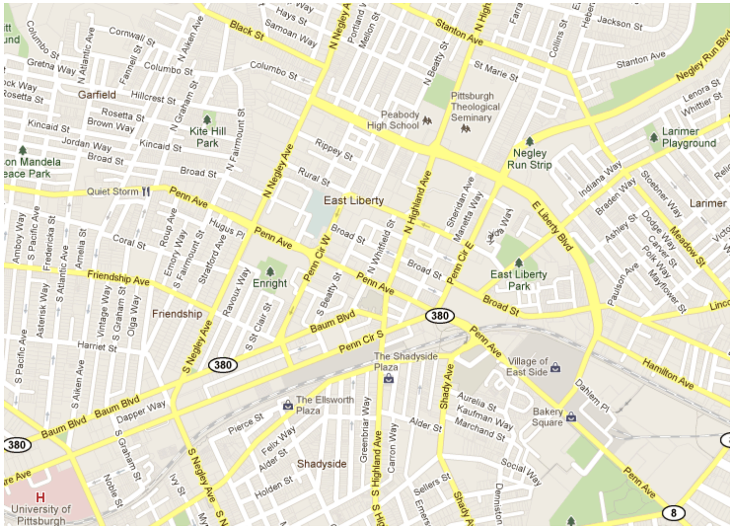
Outline

1. Background & Motivation
2. Platoon-Based Self-Scheduling
3. Simulation Settings & Results
4. Concluding Remarks

Congestion Problems and Traffic Signal Control

- Delay and fuel associated with congestion cost $115 billion in 2009 for 439 urban areas in the U.S. (TTI Annual Report, 2010)
- Effective traffic signal control can reduce congestion
- Traffic signal control is a difficult problem
  - Computational complexity
  - Nonlinear dynamics
  - Uncertainty



Adaptive Traffic Signal Control (ATSC)

❑ **Parametric (Split, Cycle & Offset) Adjustment (e.g., SCOOT)**

✓ Uses historical **moving average data;** Computationally cheap

Limitation: Requires some degree of **stability in traffic flows** over time; Cannot address real-time variability of demands at local controllers

❑ **Self-organizing strategies (Gershenson, 2005) (Lämmer, 2008):**

✓ Reacts quickly by using actual **flow patterns** (e.g., anticipated queues)

Limitation: Myopic; Does not consider real-time performance evaluation

❑ **Model-based optimization (e.g., OPAC, ALLONE-S, RHODES):**

✓ Attempts to optimize by using **real-time data** in a planning horizon

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Platoon-based Self-Scheduling (PBSS)

Basic Approach:

- Self-organization + local scheduling → Self-scheduling
- Each intersection is controlled by a self-interested agent
- Each agent works in a scheduling search space representing its local environment (more like a model-based optimization search)
- Each agent uses actual flow patterns in real-time data to facilitate making decisions (like a self-organizing approach)

Key Ideas:

Aggregate flow representation

Capture the *non-uniformly distributed nature of* real-time traffic flow in a look-ahead horizon

↓

Platoon-based selection policies

Shift focus from clearing queues to maintaining movement of platoons (large groups of vehicles)

Aggregate Flow Representation

Clusters: **height = flow rate, width = duration, area = number of vehicles**

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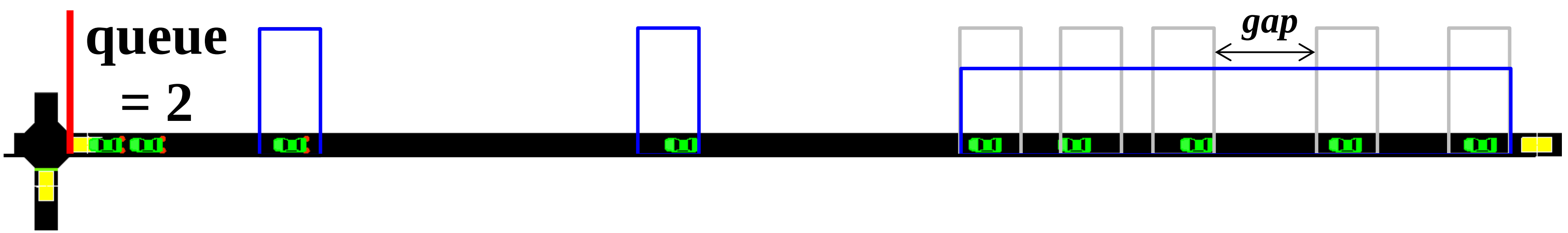
1. **Threshold-based clustering**: **merge clusters with small gaps**



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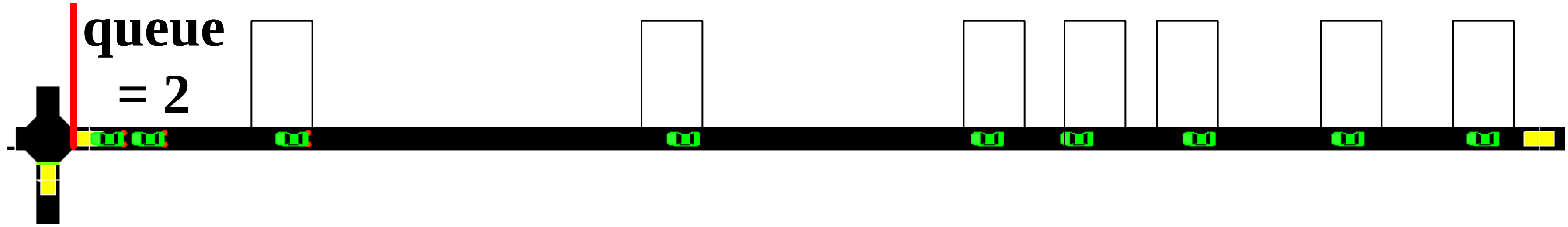
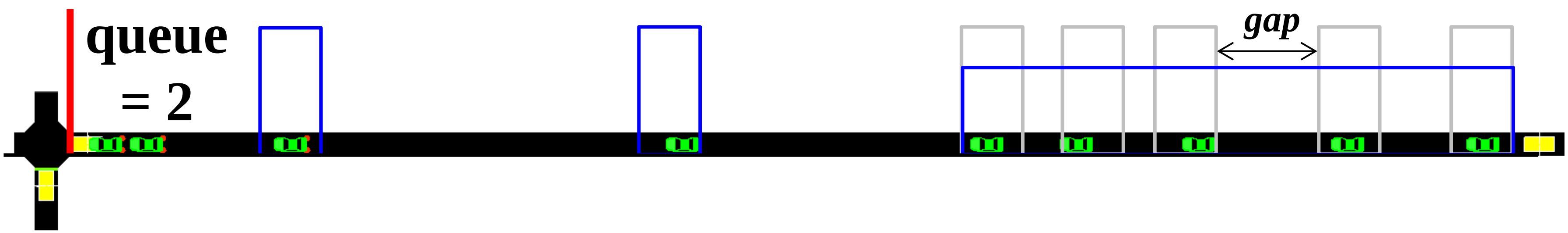
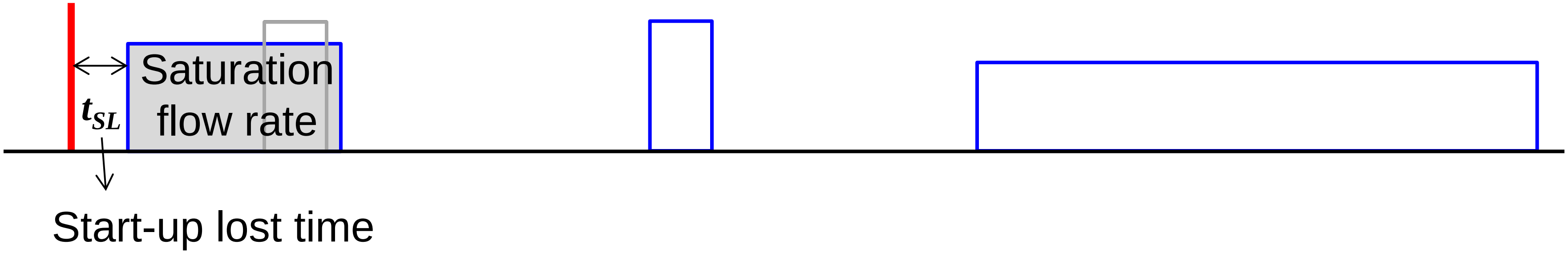


1. Threshold-based clustering: merge clusters with small gaps



2. Anticipated queue: Anticipate the number of vehicles that are either *presently in the queue* or *will join it before it clears* (Lämmer & Helbing, 2008)



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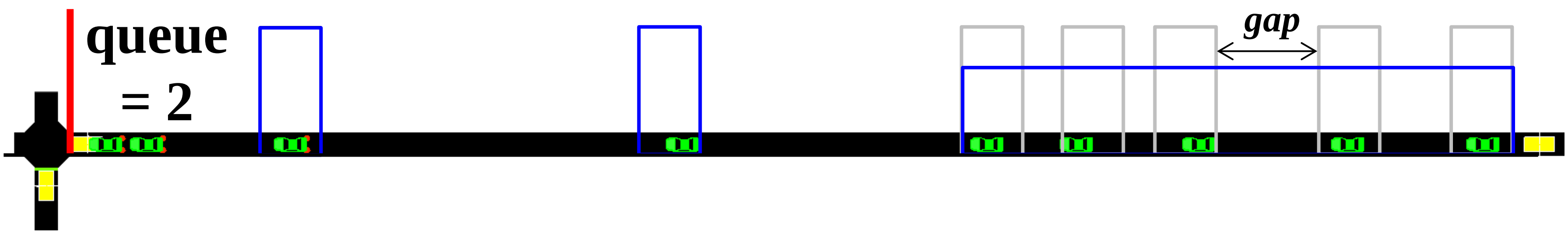

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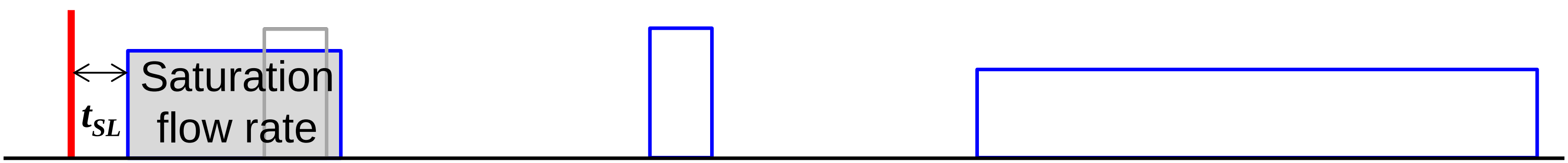


- **Dynamically calculate anticipated queues and clearance times for any future time to aid in look-ahead decision making.**

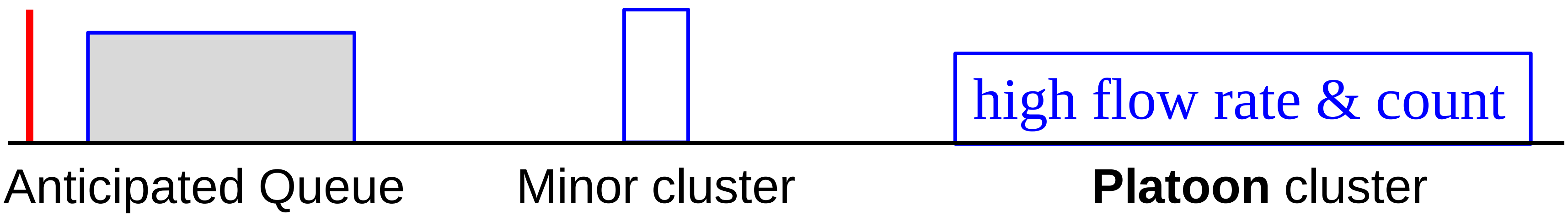
Comparison of Representations

Traditional flow representation

(Data in time steps, used in model-based optimization)

2	0	0	1	0	0	0	0	1	0	0	0	1	1	0	1	0	1	0	1

Aggregate flow representation



Captures the non-uniformly distributed nature of traffic flow

- Defines a compact scheduling search space for optimization
- Identifies critical clusters as well as idle time periods
- Facilitates anticipating future queues and their clearance times
- Supports look-ahead scheduling policies: platoons as critical jobs

Platoon-Based Action Selection

Basic algorithm for controlling the duration of a phase:

1. Clear the anticipated queue of vehicles
2. Decide whether to extend the current phase through an idle period when there is no queue to be serviced

   (this step may be repeated)

Shifts focus from clearing queues to maintaining movement of platoons in a look-ahead horizon

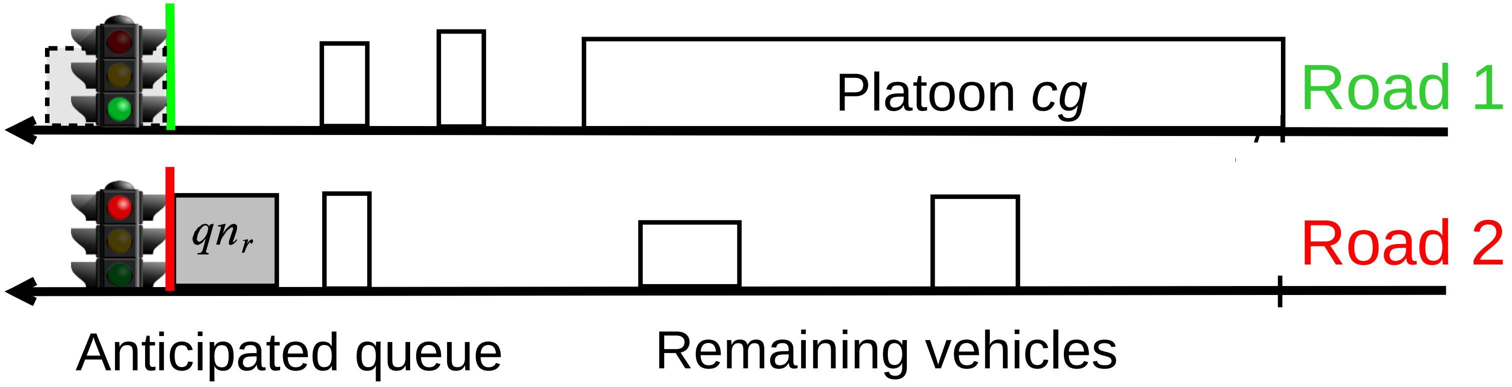
- Avoid changing the signal in the middle of a platoon
- Avoid allowing stopped vehicles to delay a platoon

We propose two selection policies:

- Platoon-based extension (PBE)
- Platoon-based squeezing (PBS)

Platoon-Based Extension (PBE) Policy

If a platoon exists on the road serviced by the current phase (Road 1), should we switch to the next phase (Road 2) or extend the current one?



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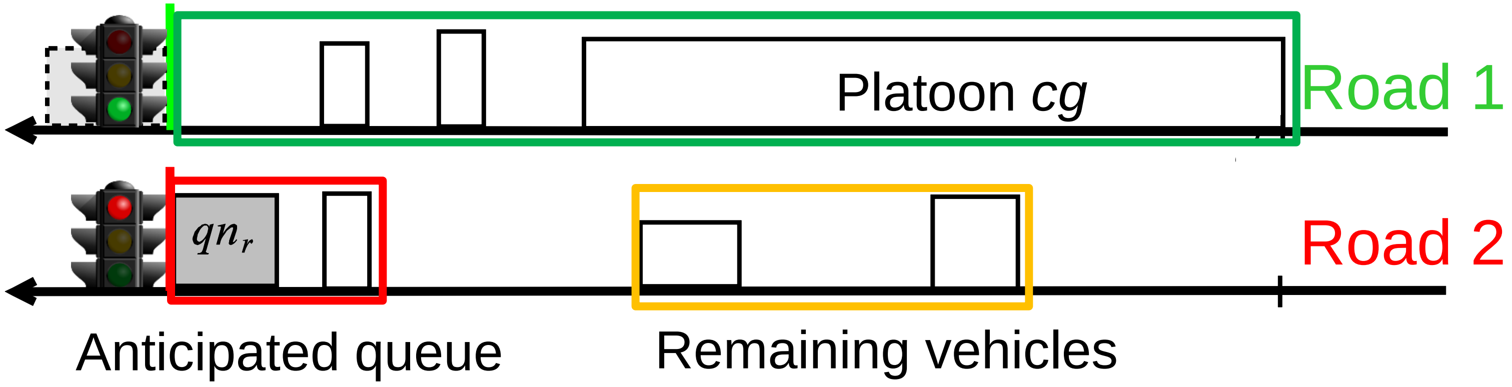

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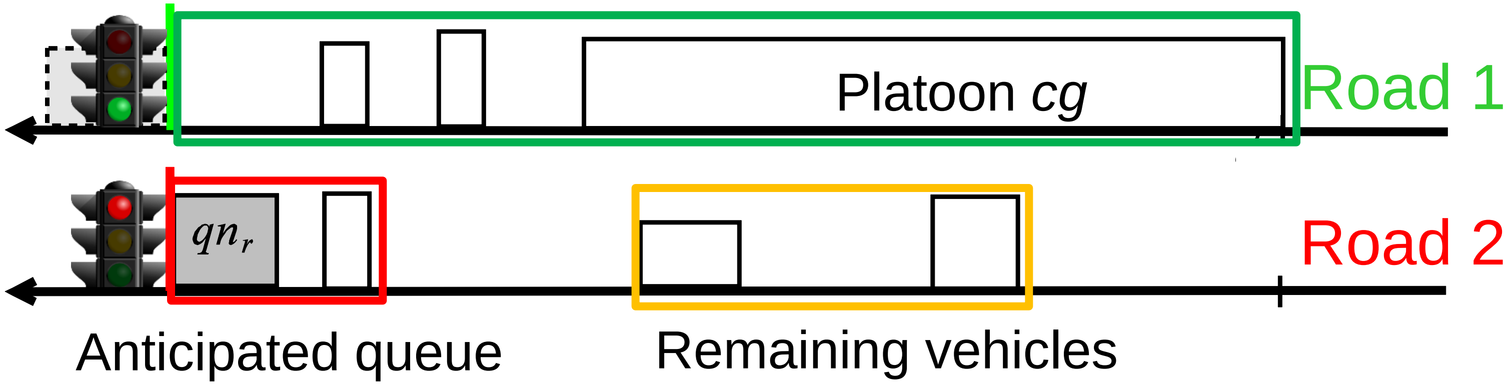

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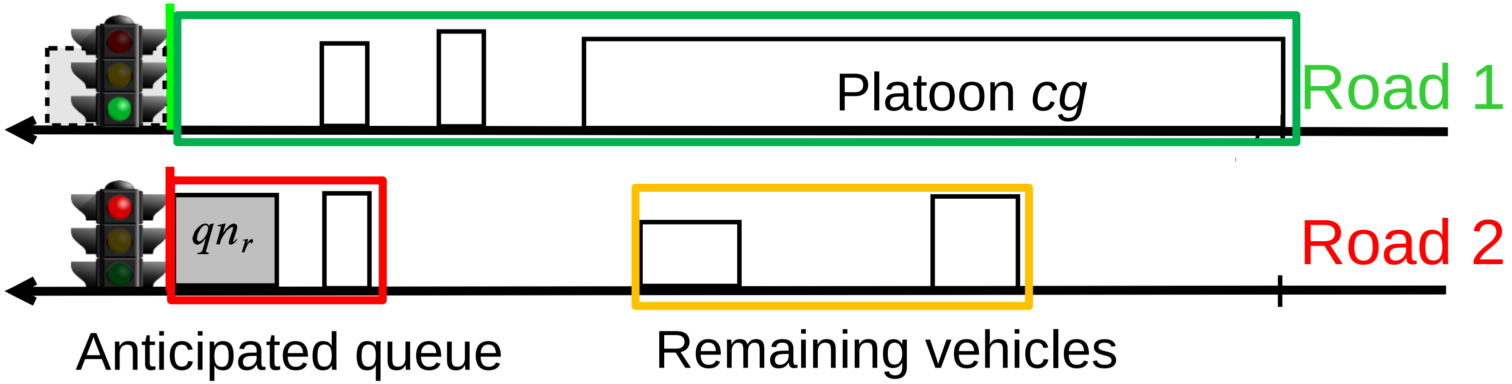

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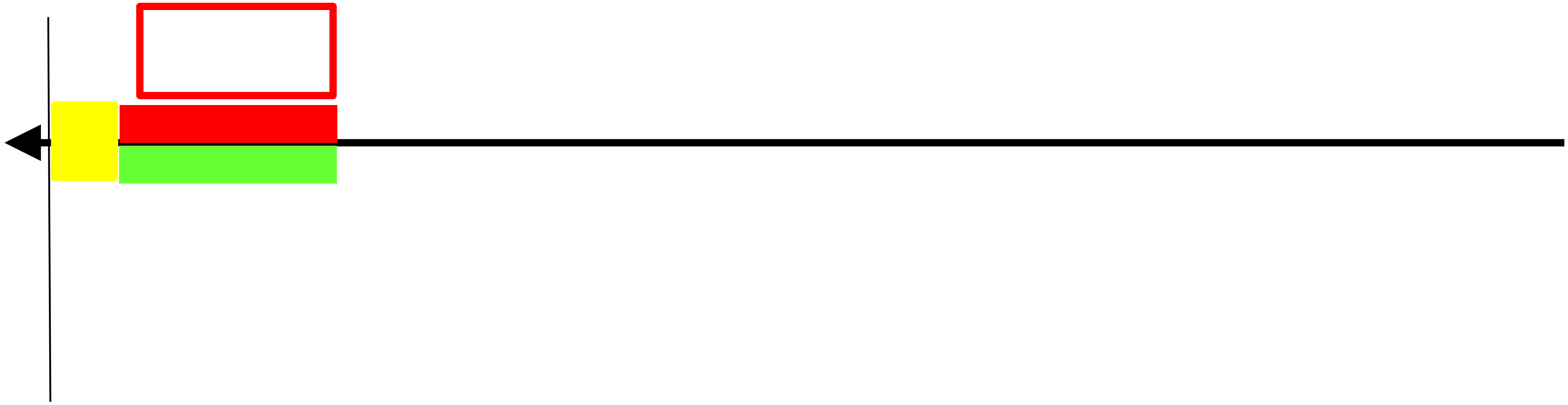

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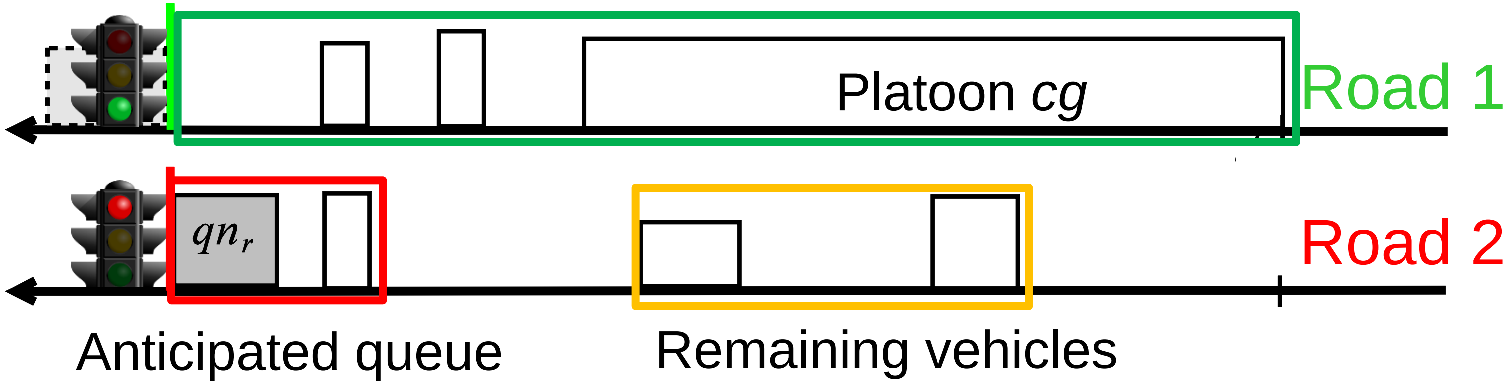

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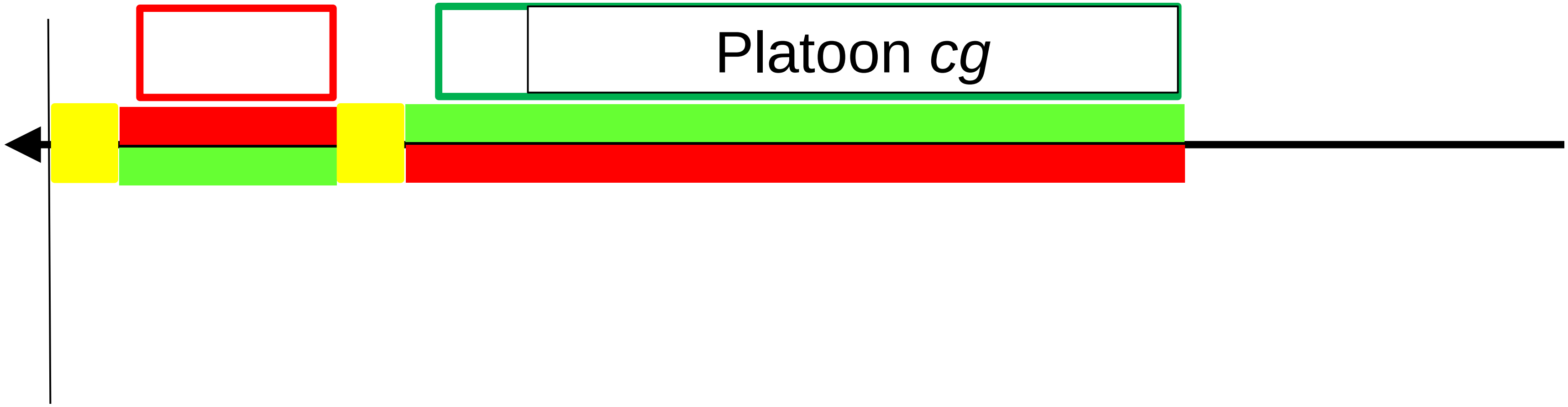

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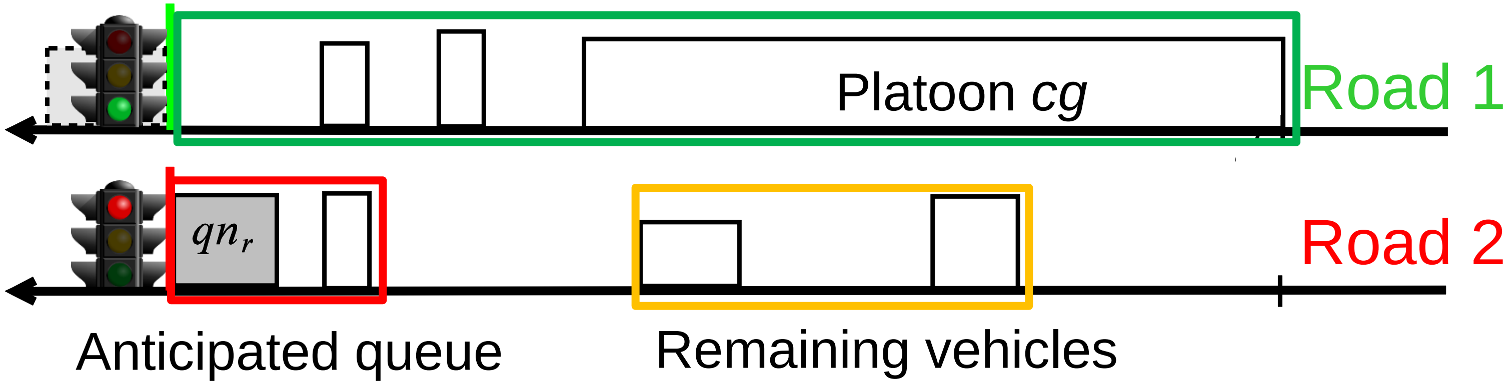

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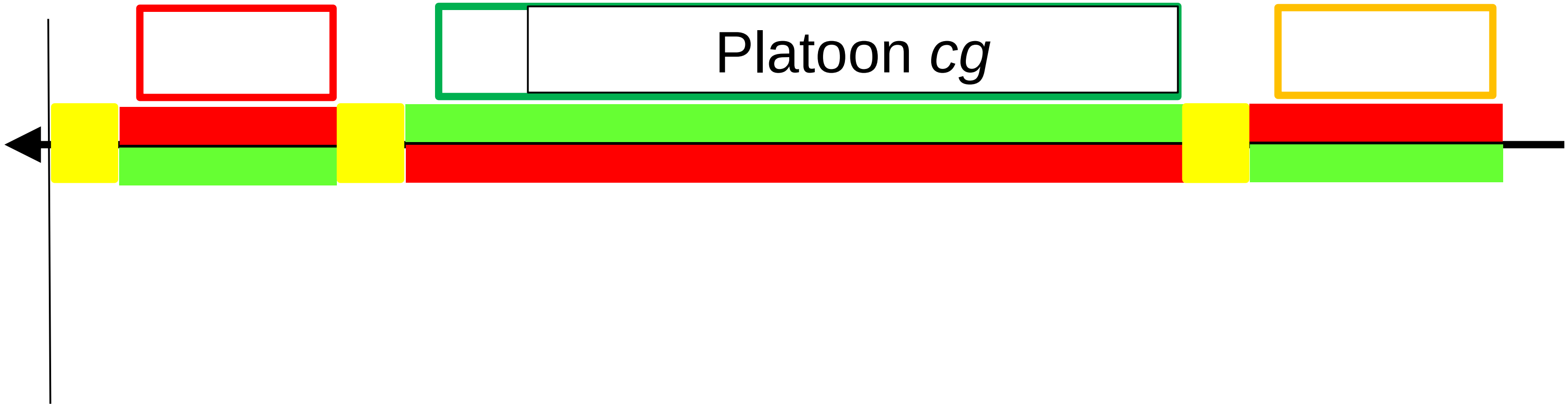

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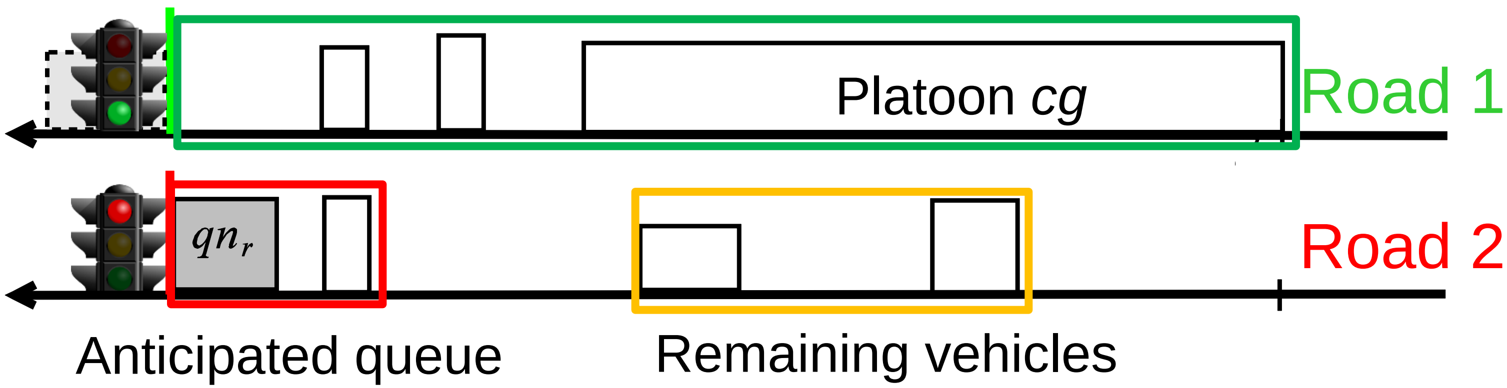

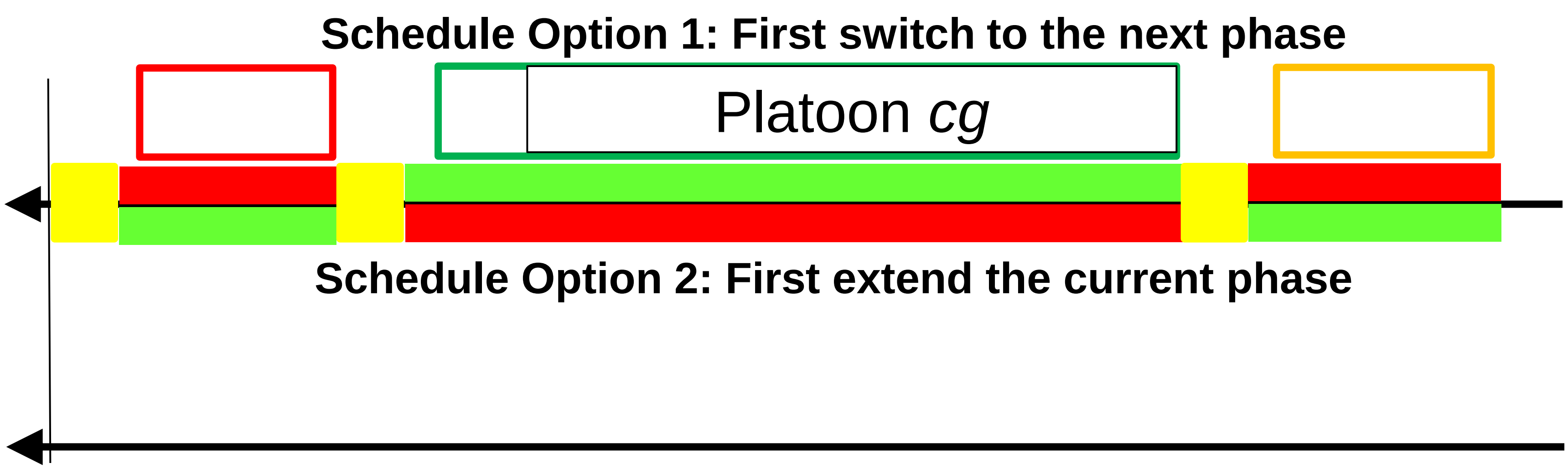

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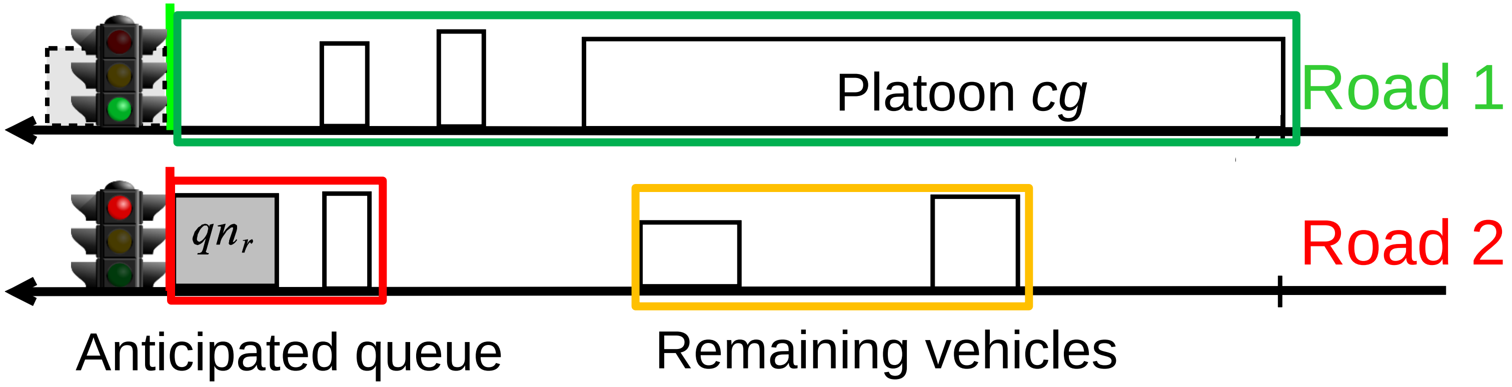

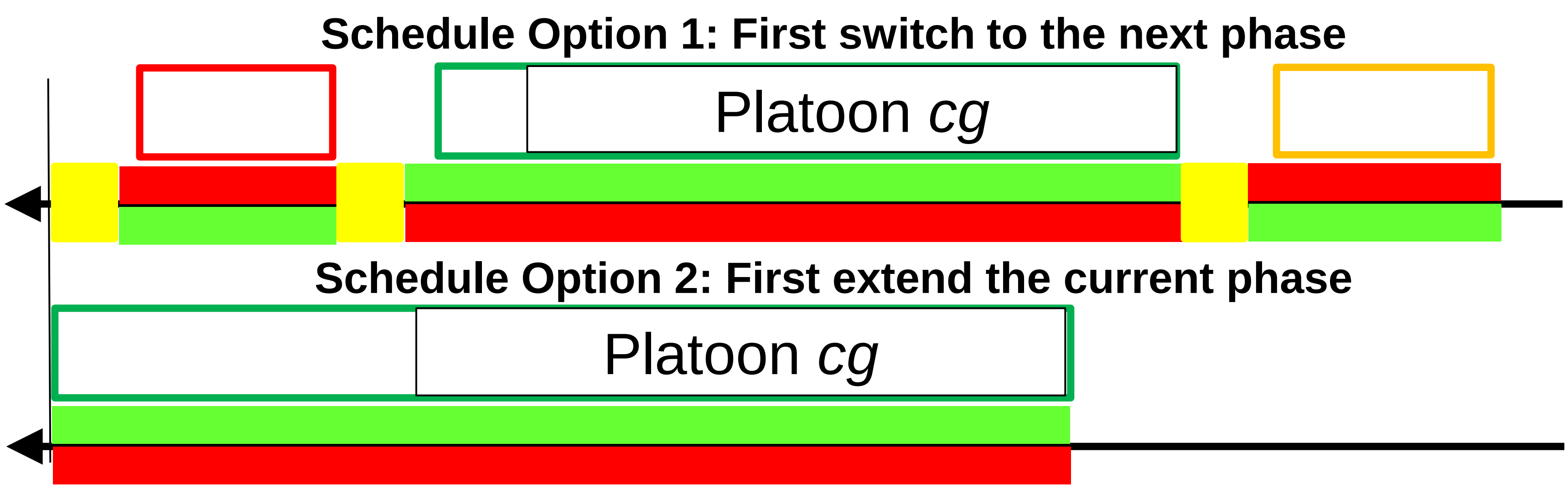

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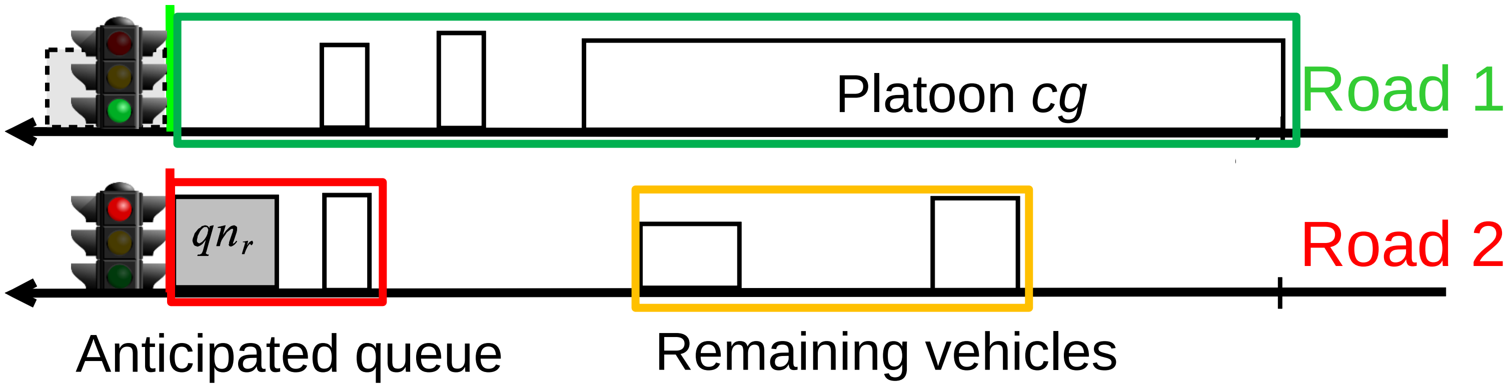

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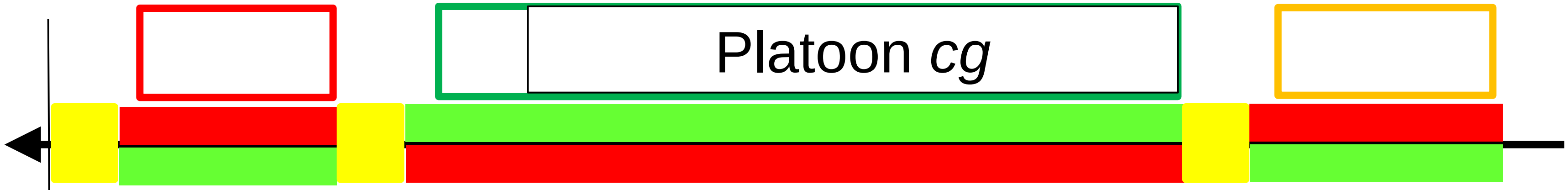
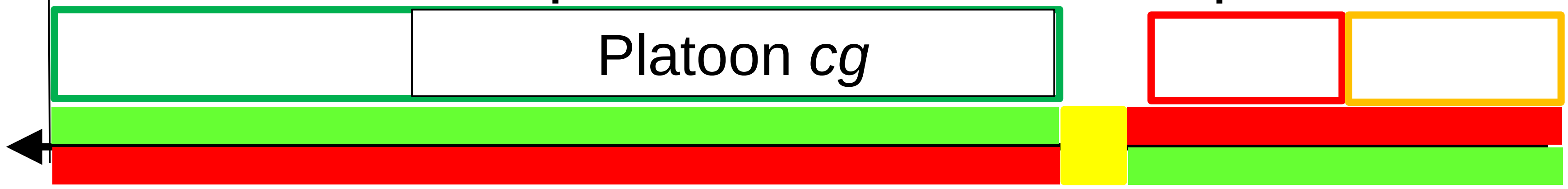


Schedule Option 2: First extend the current phase



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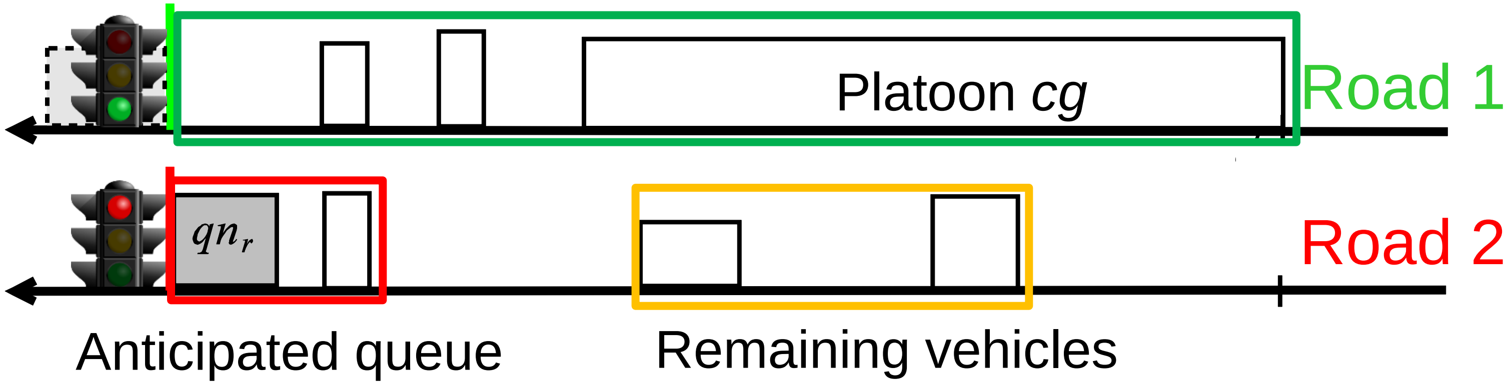

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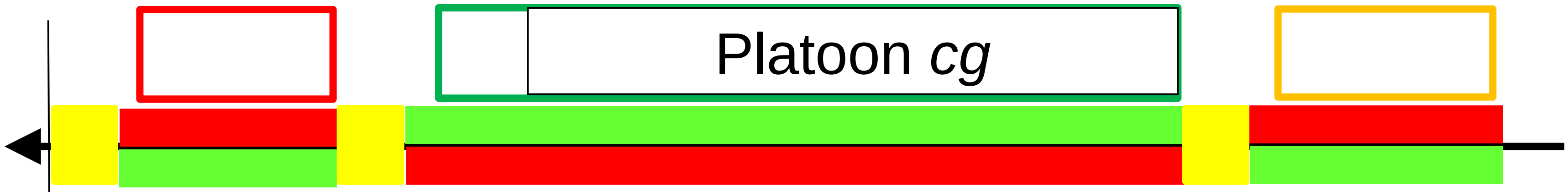

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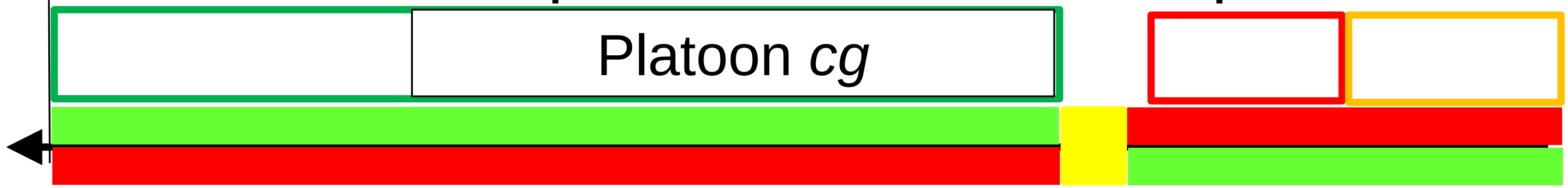
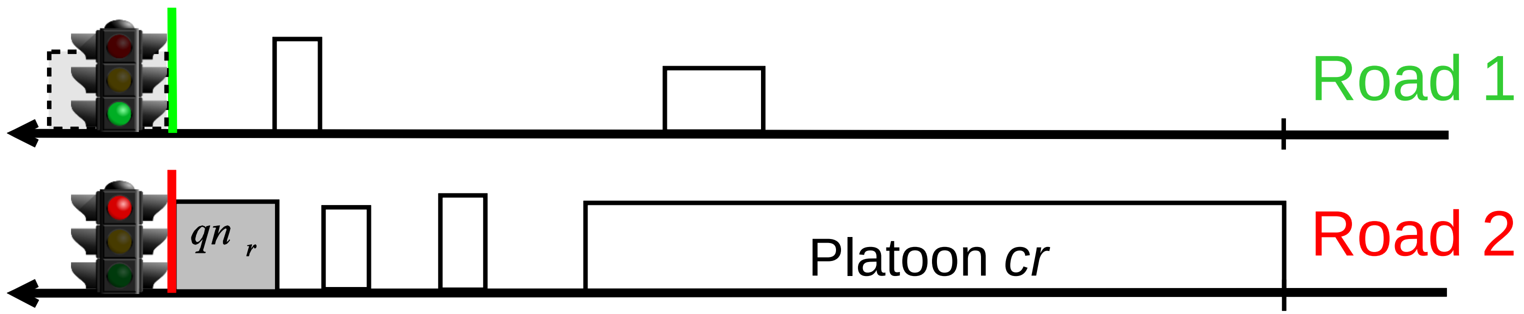


Choose the option that **minimizes cumulative delay**

Platoon-Based Squeezing (PBS) Policy

Should we extend the current phase (Road 1) in order to compress a platoon serviced by the next phase (Road 2)?



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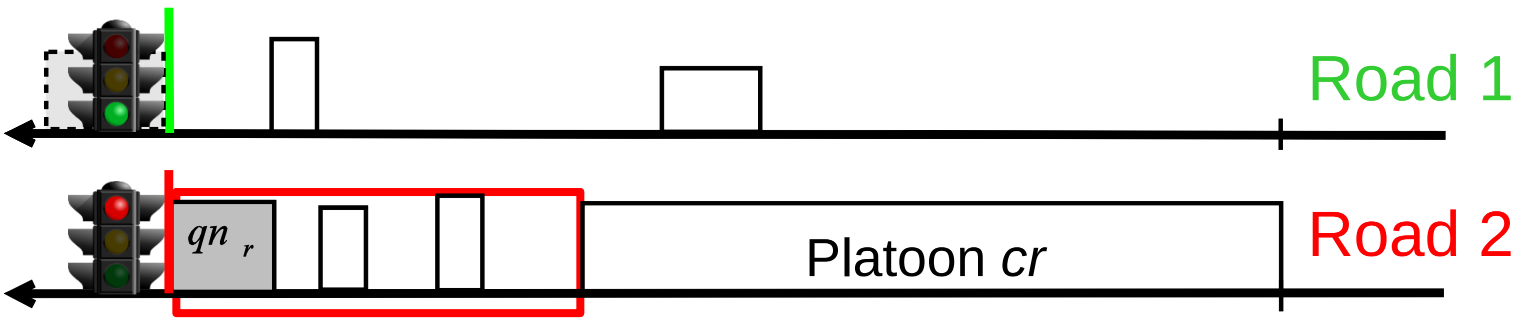

- Extending the current phase squeezes out the idle time on Road 2 without stopping the platoon
- Compressed platoons are easier for downstream intersections to service

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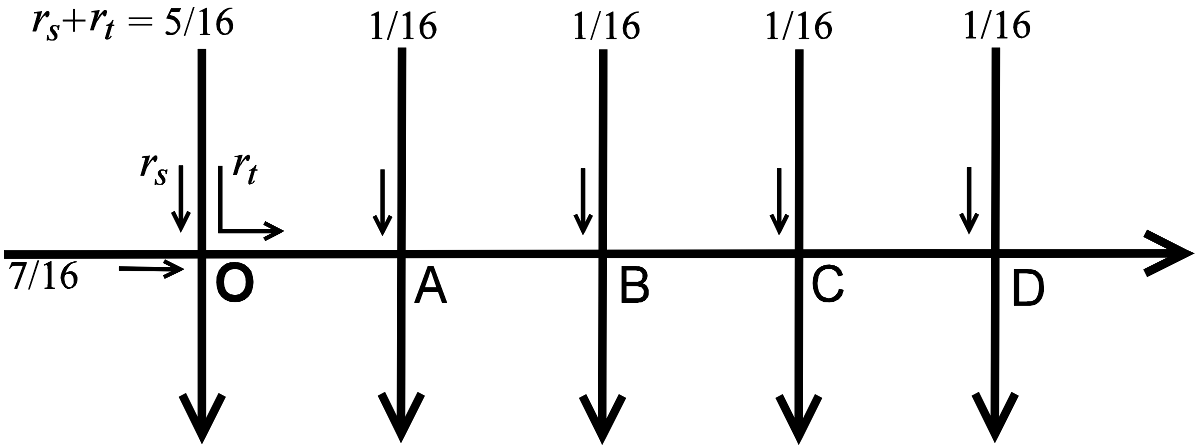
Arterial Network with a Bottleneck Intersection



- **O** is a bottleneck with a fixed timing plan
- **A-D** are managed by control strategies
- The amount of traffic turning onto the artery at **O** increases by Δr_t every 20 minutes over an hour

Control strategies

FIX	Fixed timing plan	Optimized for artery
ASRm	Automatic signal retiming	Webster's model
AAC	All clearing of anticipated queues	(Lämmer, 2008)
PBSS	Platoon-based self-scheduling	AAC plus PBE and PBS

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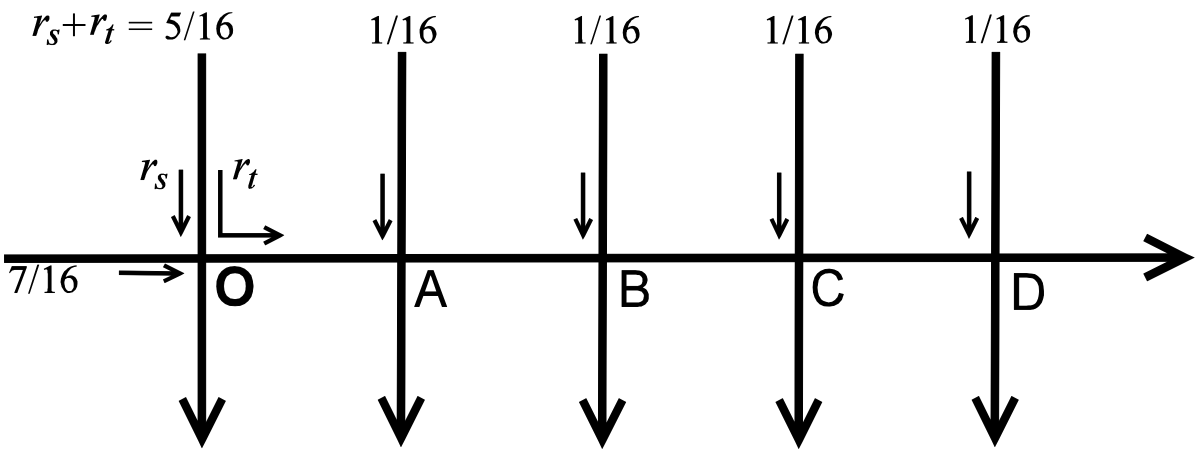

- Produces implicit arterial coordination

	$\Delta r_t = 0$		$\Delta r_t = 1/16$		$\Delta r_t = 2/16$	
	Wait on artery	Wait on **A-D**	Wait on artery	Wait on **A-D**	Wait on artery	Wait on **A-D**
FIX	0.00	6.07	1.92	6.93	6.58	9.73
ASRm	27.54	22.70	27.32	23.25	28.64	24.94
AAC	6.42	7.94	6.56	8.40	7.10	9.33
PBSS	1.36	5.01	2.03	5.73	2.58	6.50

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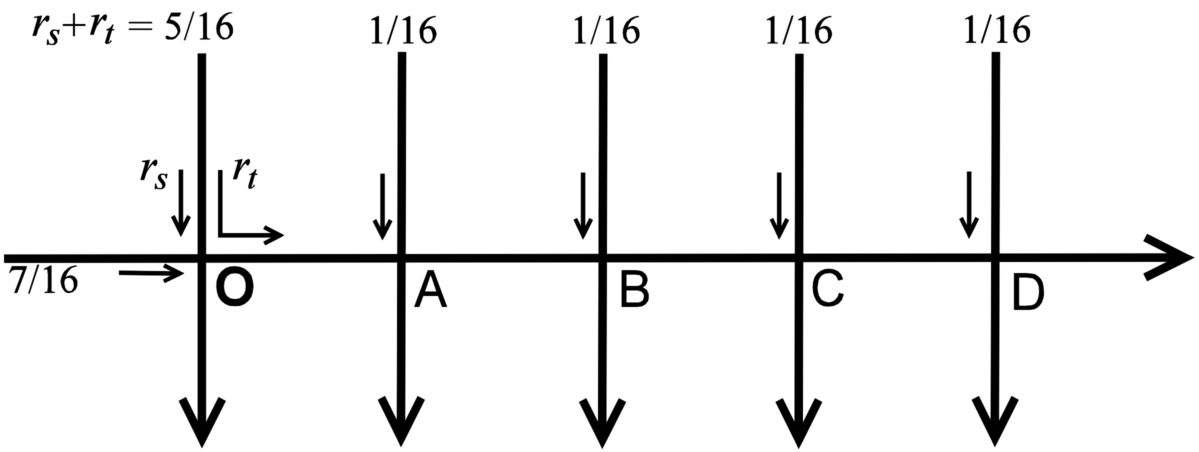

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  - Handles uncertainty

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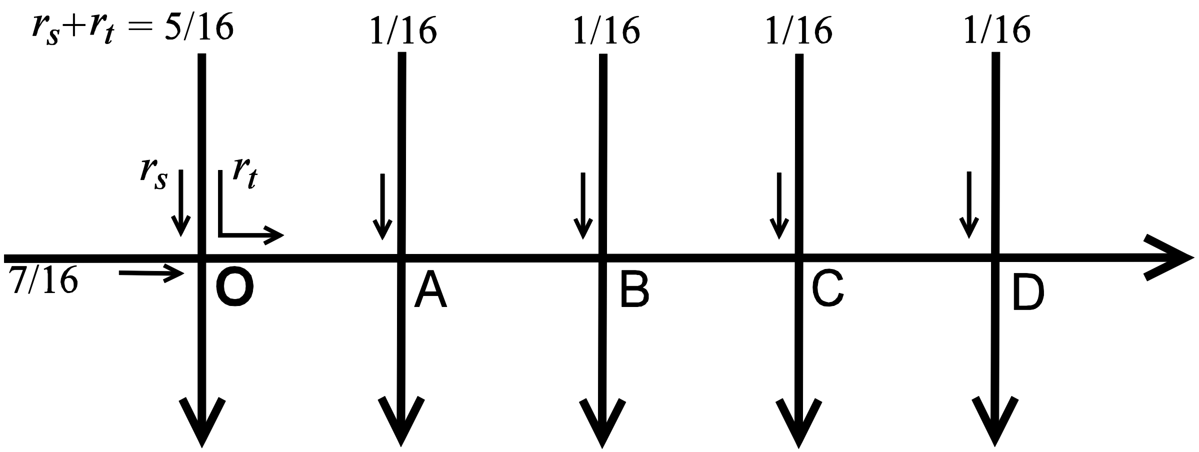

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  - Shows that "green waves" ≠ optimal

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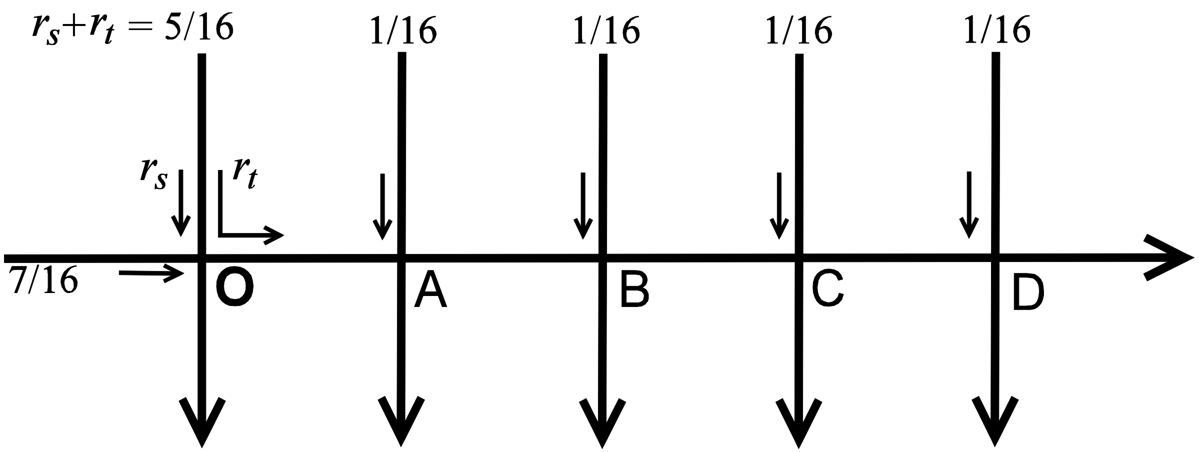

- Produces implicit arterial coordination
- Handles uncertainty
- Shows that "green waves" ≠ optimal
- ➢ Demonstrates the advantage of look-head

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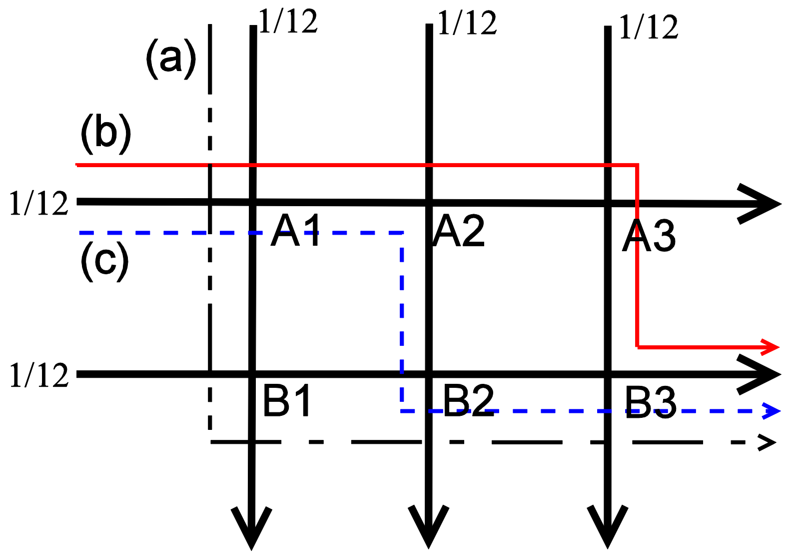
2X3 Grid Network



- A different major route (**a**, **b** or **c**) generates 7/12 of the total traffic for each 20 minute interval over 1 hour
- Changing the route from (**a**) to (**b**) *changes the dominant flow* for the intersections **A1** and **B3**.
- Changing from (**b**) to (**c**) could simulate *rerouting effect* after an accident near the intersection **A3**.

	PBSS		Gain over AAC		Gain over ASRm	
	Speed	wait time	Speed	wait time	Speed	wait time
A1	6.96	5.74	1.3%	0.0%	15%	76%
A2	7.93	3.15	7.7%	15.5%	30%	203%
A3	8.01	2.90	7.7%	24.0%	26%	207%
B1	7.89	3.29	5.5%	5.2%	11%	85%
B2	7.81	3.69	4.4%	0.1%	17%	107%
B3	7.88	3.51	7.0%	12.0%	26%	163%

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Platoon-based selection policies

- Shift focus from clearing queues to maintaining movement of platoons (large groups of vehicles)

Results: Self-scheduling using platoons as critical jobs

- Reduces average travel times and wait times over basic queue clearing and fixed coordination strategies
- Retains the ability to effectively handle real-time demand variability
- Enables implicit coordination between successive intersections

Current Research

Basic Approach:

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- Work on more complex intersections and realistic traffic flows

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Explicit coordination mechanisms

- Enhance overall performance by incorporating non-local impacts between tightly-coupled neighbor intersections

Thanks for your attention

Questions?