

RWR 4013

# Digital Twins for Smart Cities

Dr. Ahmad Mohammadi

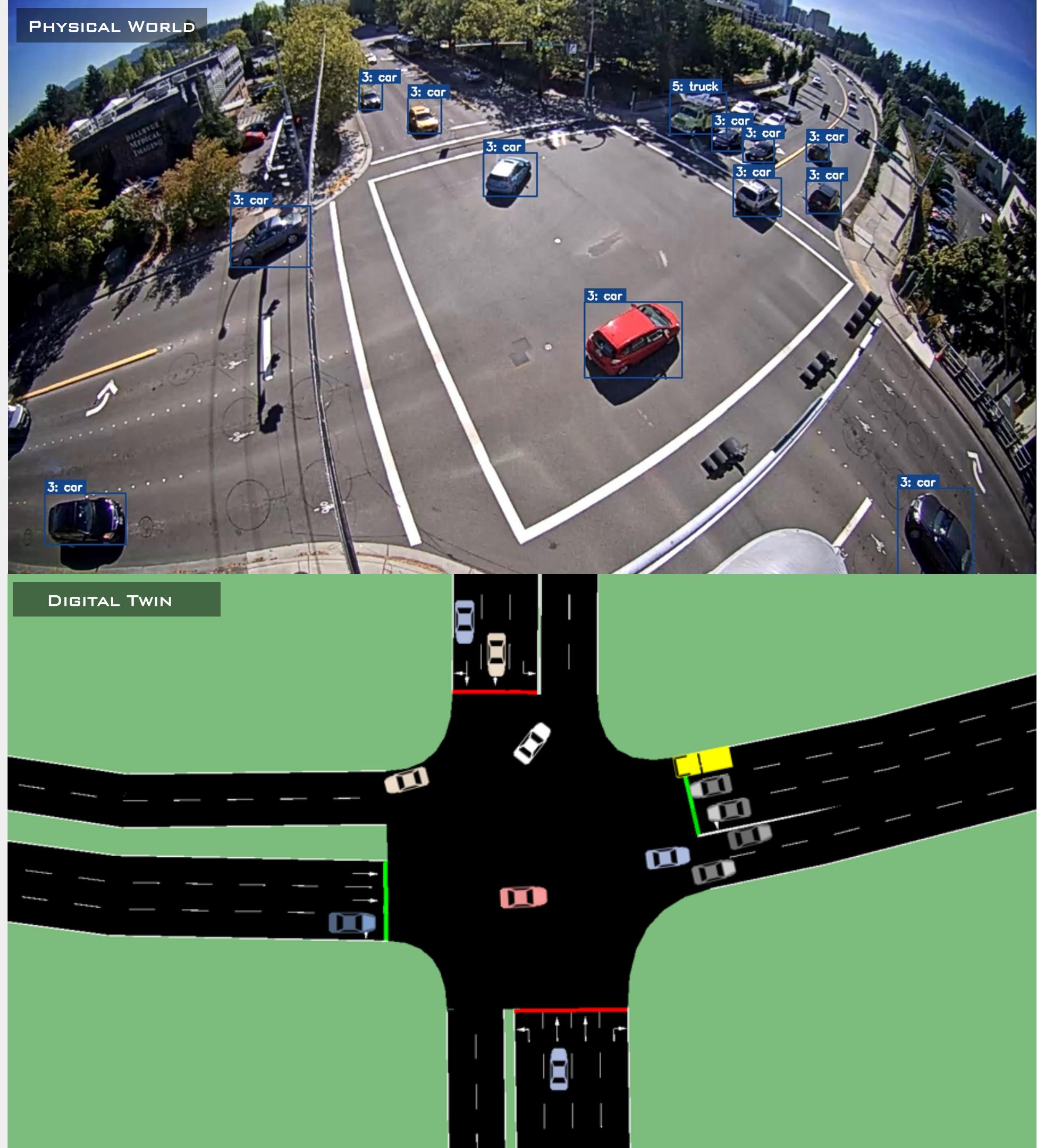
Week 9 | Session 1:  
Optimization (Traffic Signal)

Fall 2026

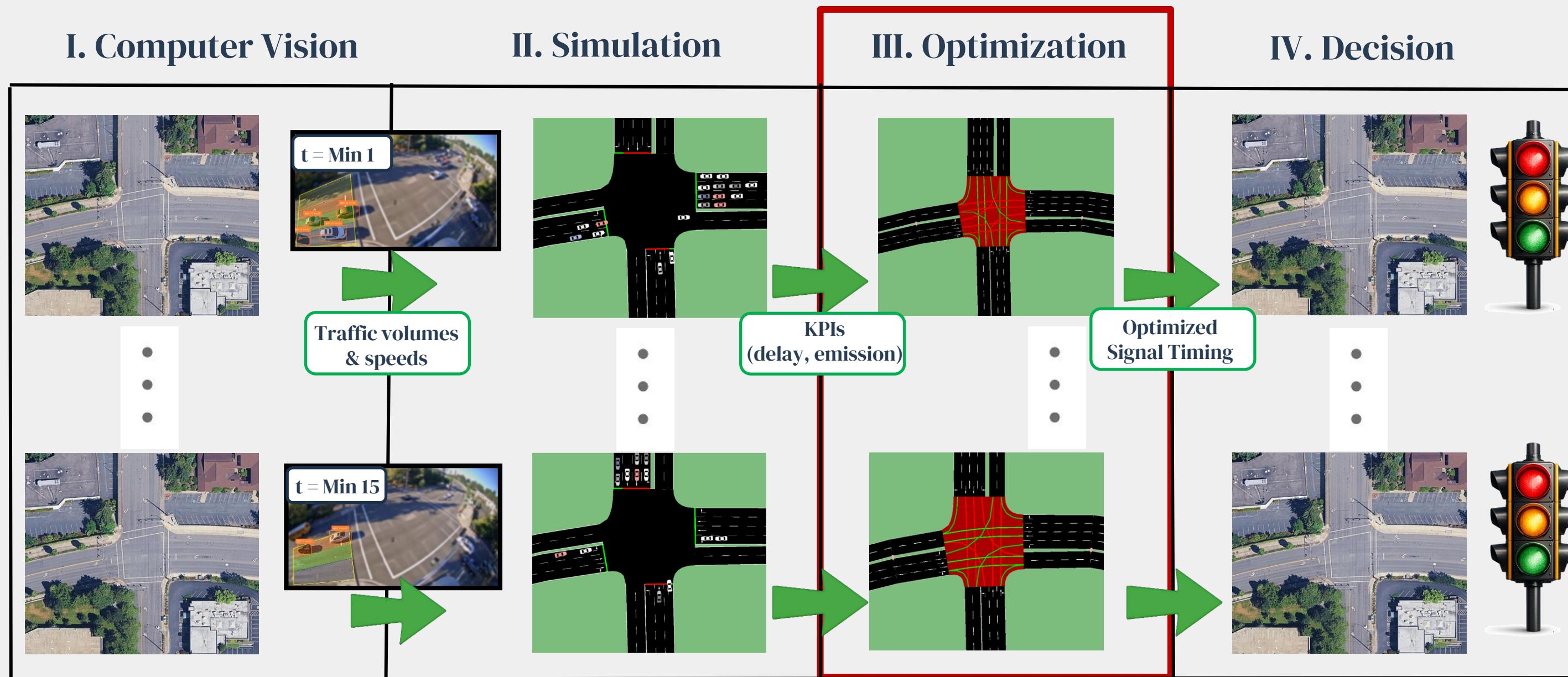
RoadwayVR

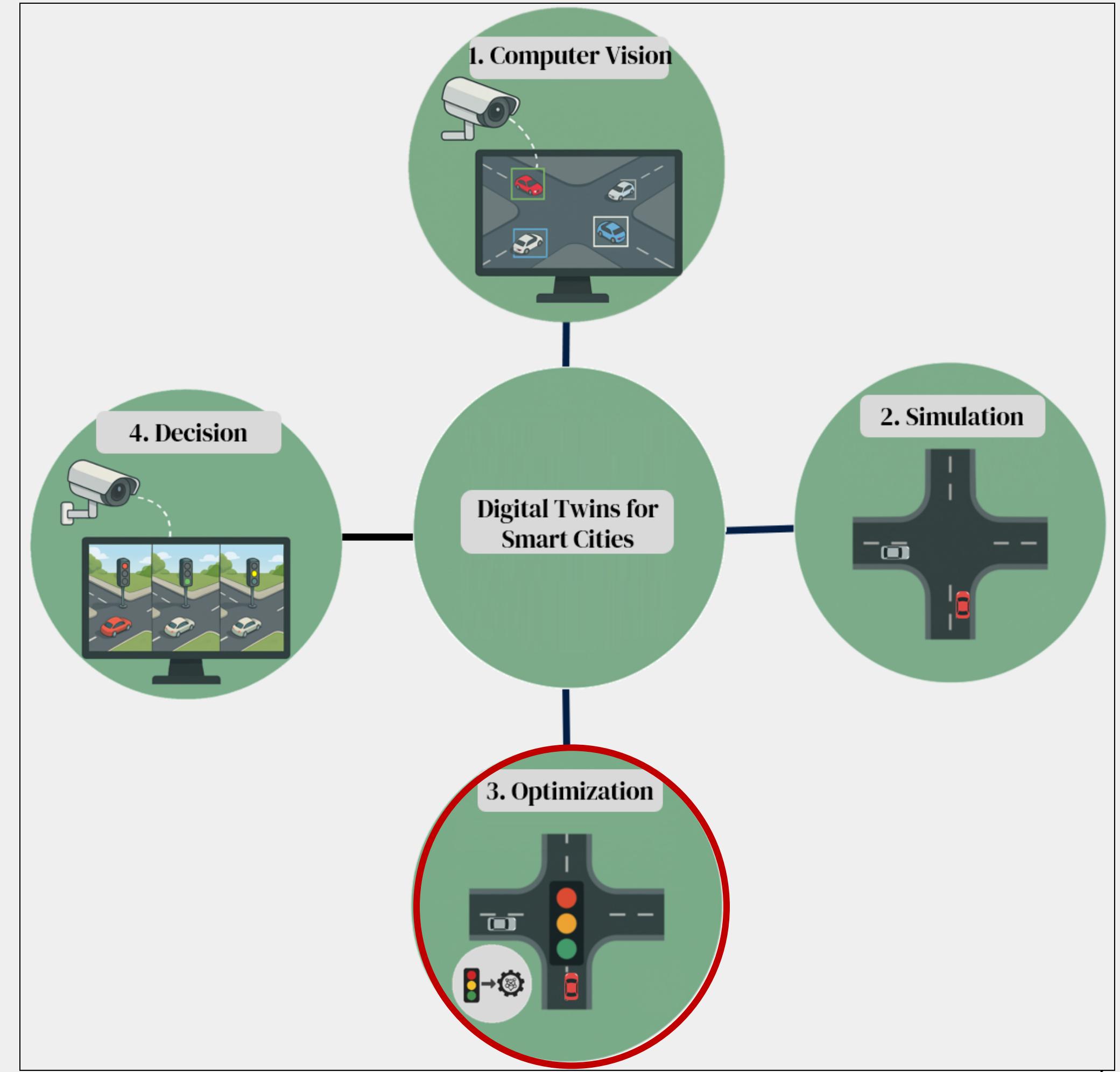


[roadwayvr.github.io/DigitalTwinsforSmartCities](http://roadwayvr.github.io/DigitalTwinsforSmartCities)



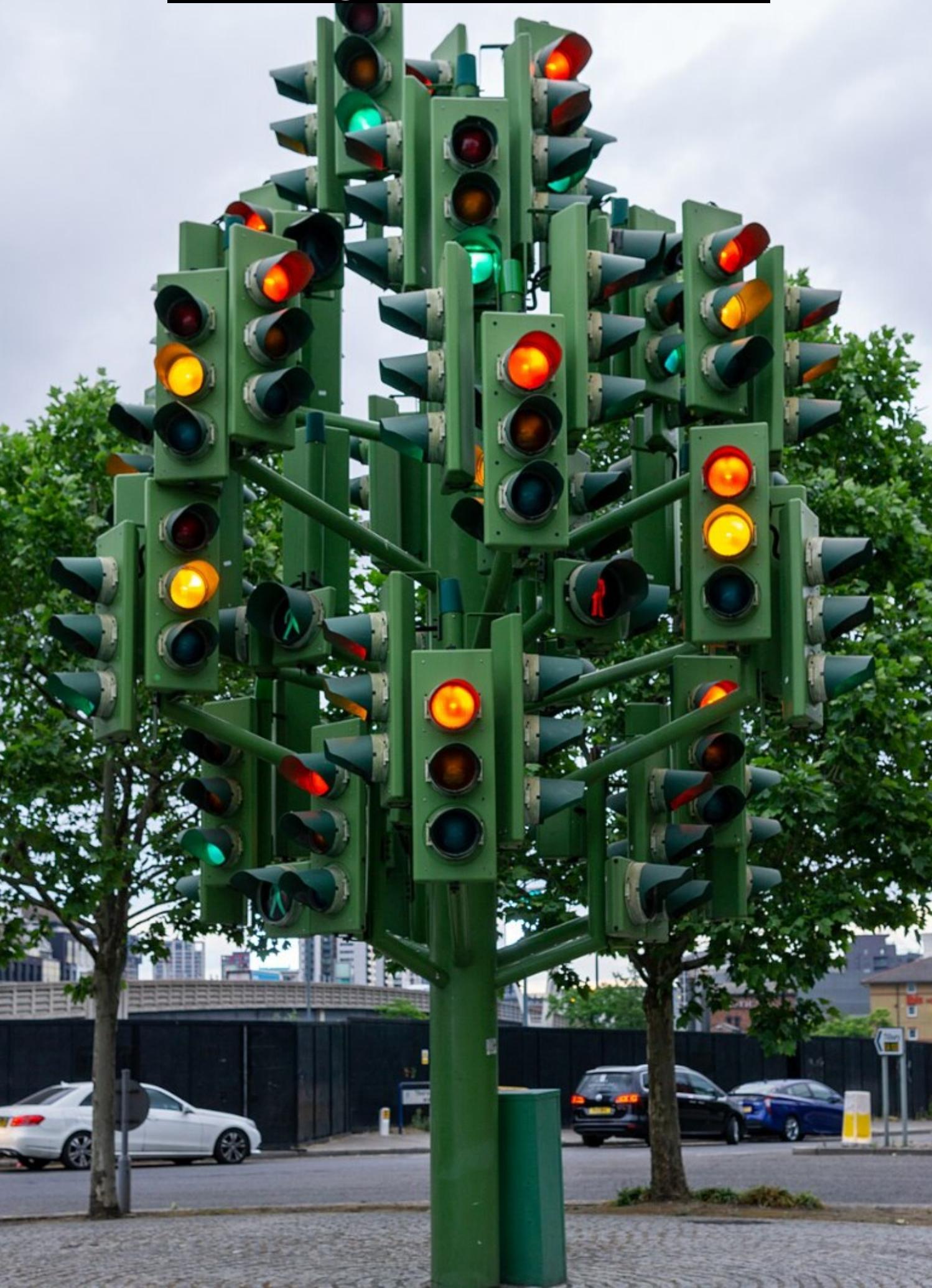
# Overview of Course Syllabus in One Shot





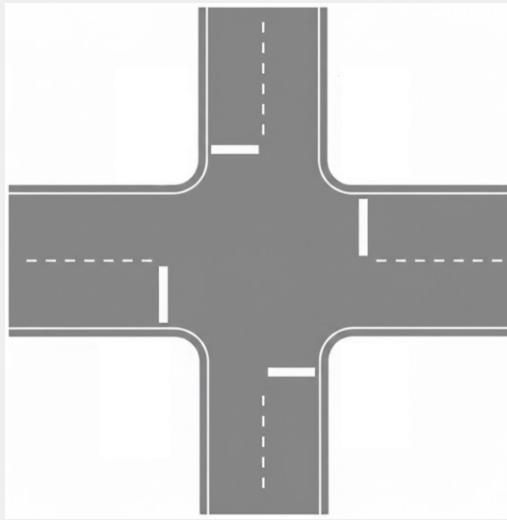
# Agenda

- Common Types of Intersection Control
- Identify the Types of Intersection Control
- Traffic Light History
- Traffic Signal Technology
- Traffic Signal Planning
- Type of Signal Control
- Signal Phasing
- Case Studies in Traffic Signal Planning

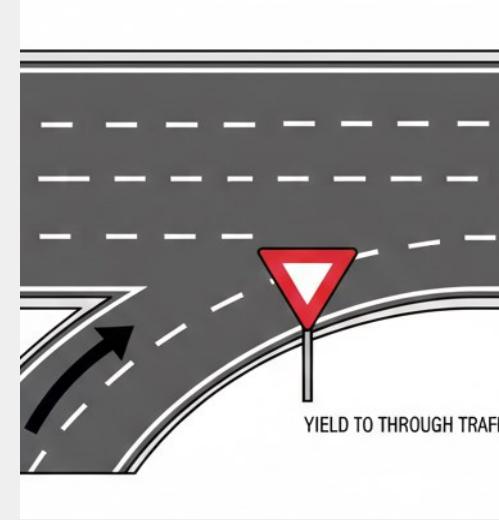


# Common Types of Intersection Control

Unsignalized



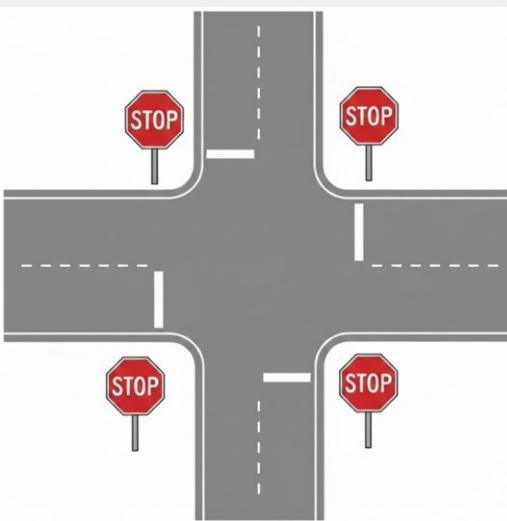
Unsignalized (YIELD Sign)



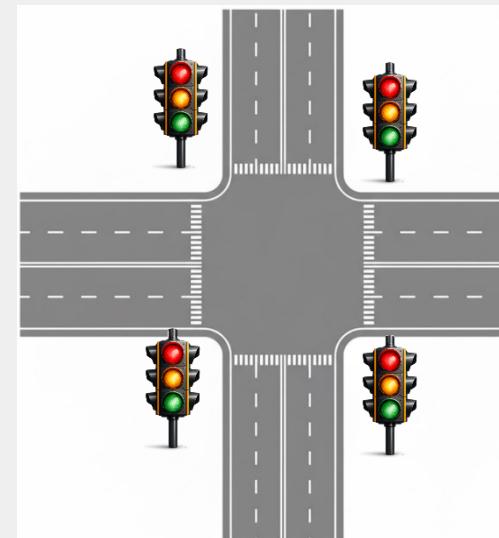
Unsignalized (two-way STOP control)



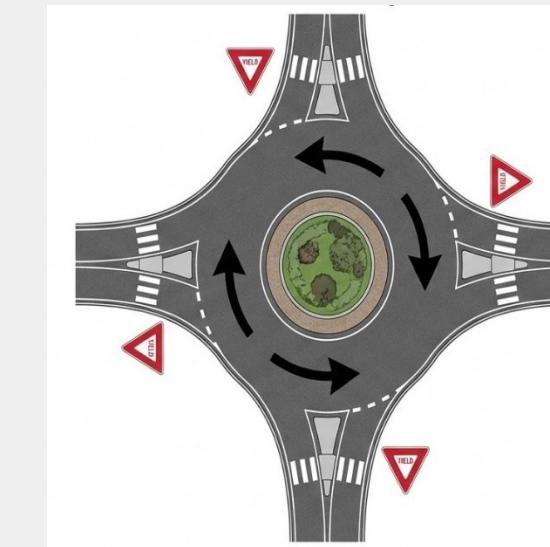
All-way STOP control



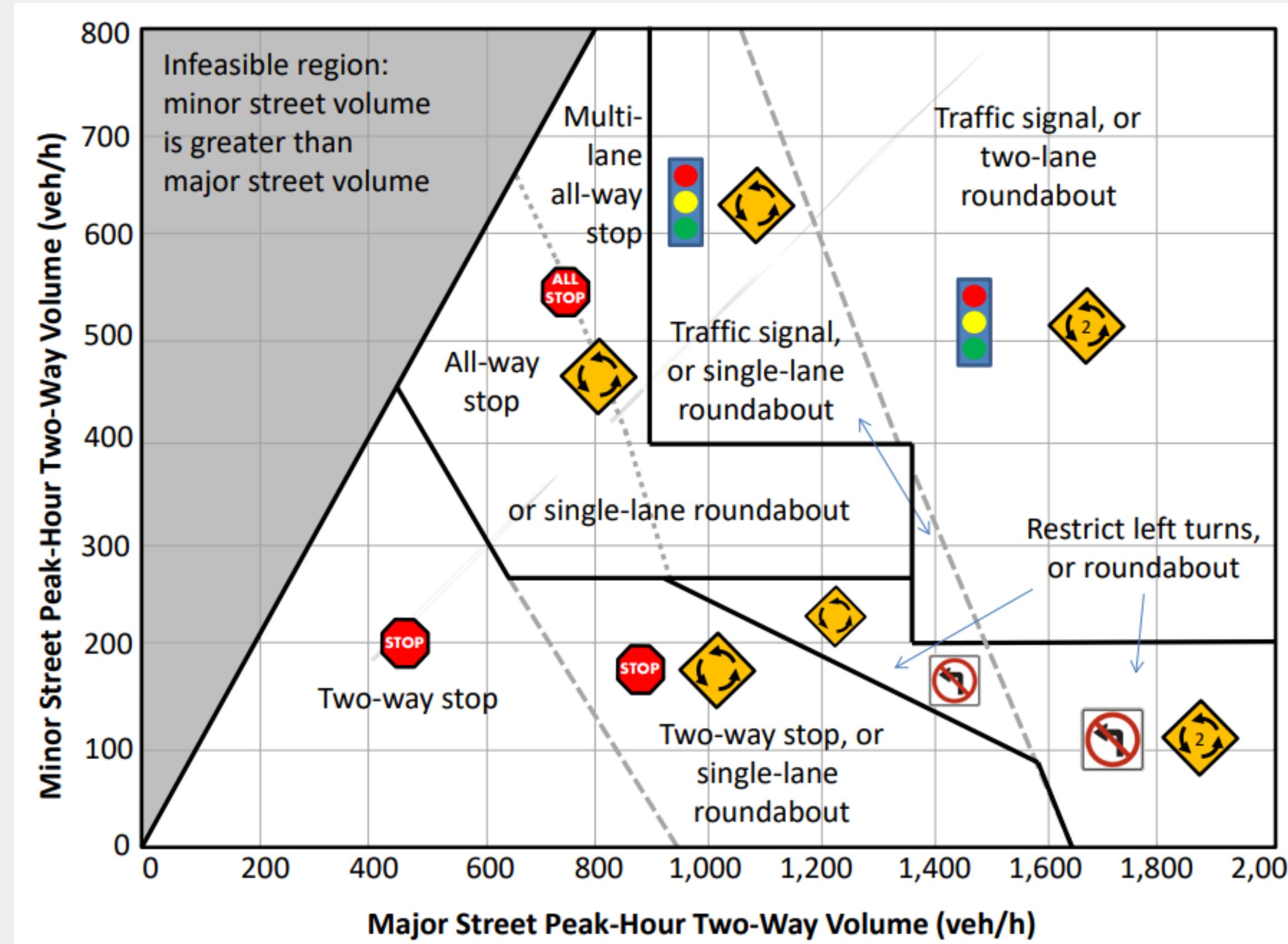
Signalized Intersections



Roundabouts



# Identify the Types of Intersection Control



Florida Department of Transportation (FDOT), *Intersection Control Evaluation Procedure* (Topic No. 750-010-003, Sept 2017; Revised: Nov 2020), Appendix A, Figure A1: "Intersection Control Type by Peak Hour Volume Thresholds" (page A-7)

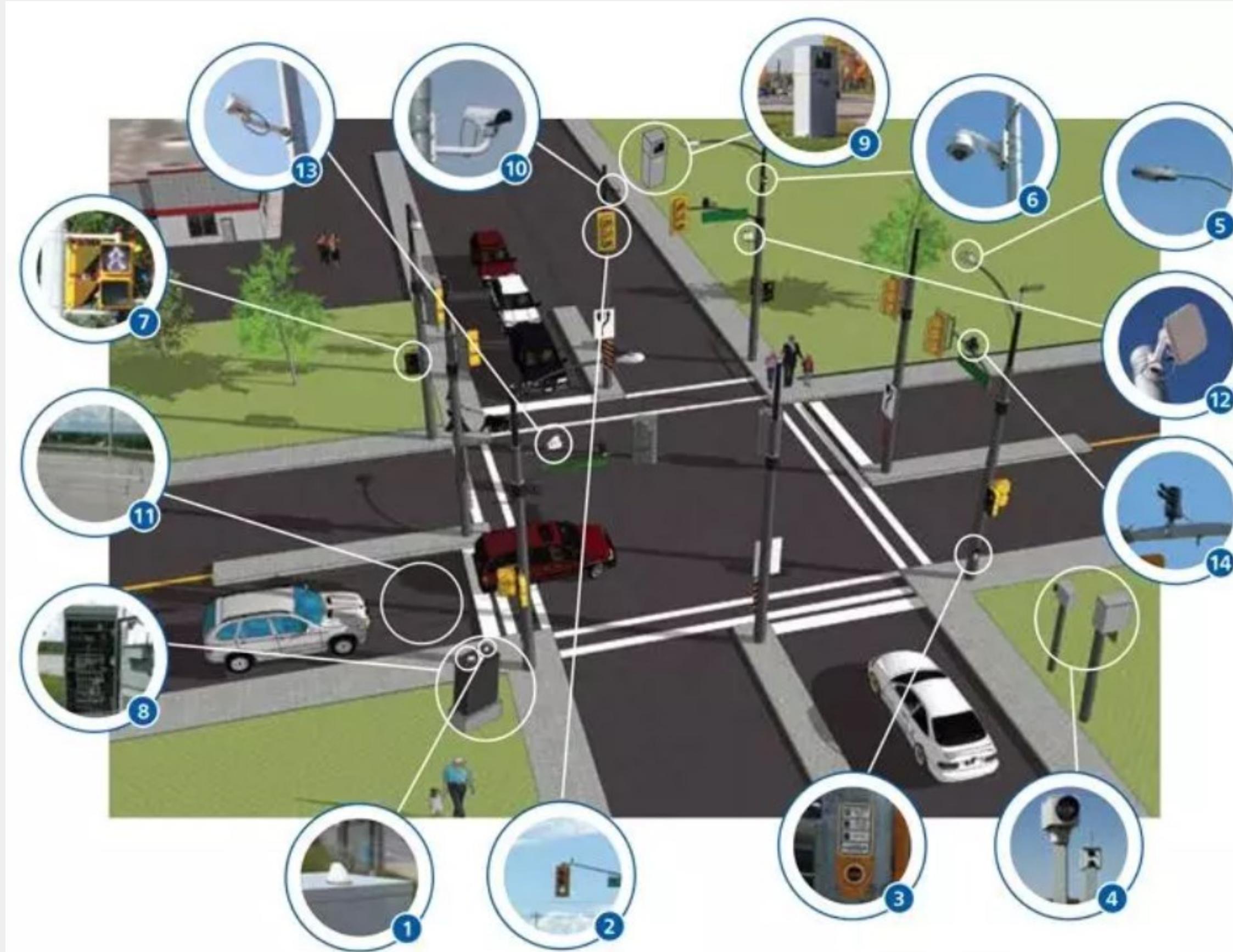
[https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/traffic/trafficservices/studies/mice/fdot-ice-manual\\_january-2021\\_v7.pdf?sfvrsn=178f93f1\\_0](https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/traffic/trafficservices/studies/mice/fdot-ice-manual_january-2021_v7.pdf?sfvrsn=178f93f1_0)

# Traffic Light History

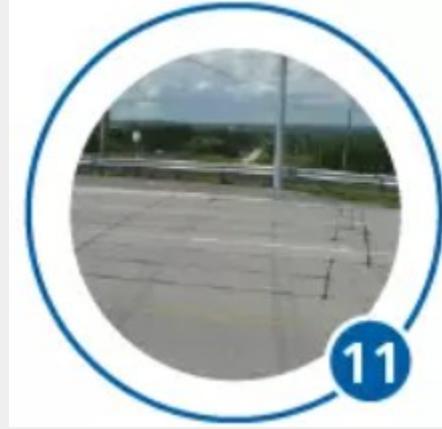
- In 1868: First traffic signal outside the Houses of Parliament in London
  - Manually operated by a police officer who controlled it based on traffic flow
  - Using gas-lit; it exploded about a month later, injuring the operator
- In 1912: an advanced traffic signal in Salt Lake City in Utah (USA)
  - Manually operated by a police officer who controlled it based on traffic flow
  - Using electricity instead of gas



# Traffic Signal Technology



# Vehicle Detectors



**Underground Detection Loops**



**Video Detection**

# Underground Detection Loops

- Detects vehicles passing or arriving at a certain point (at the intersection)
- Wire loops buried in pavement carry electrical current
- When a vehicle drives over the loop, it changes the magnetic field, alerting the signal controller

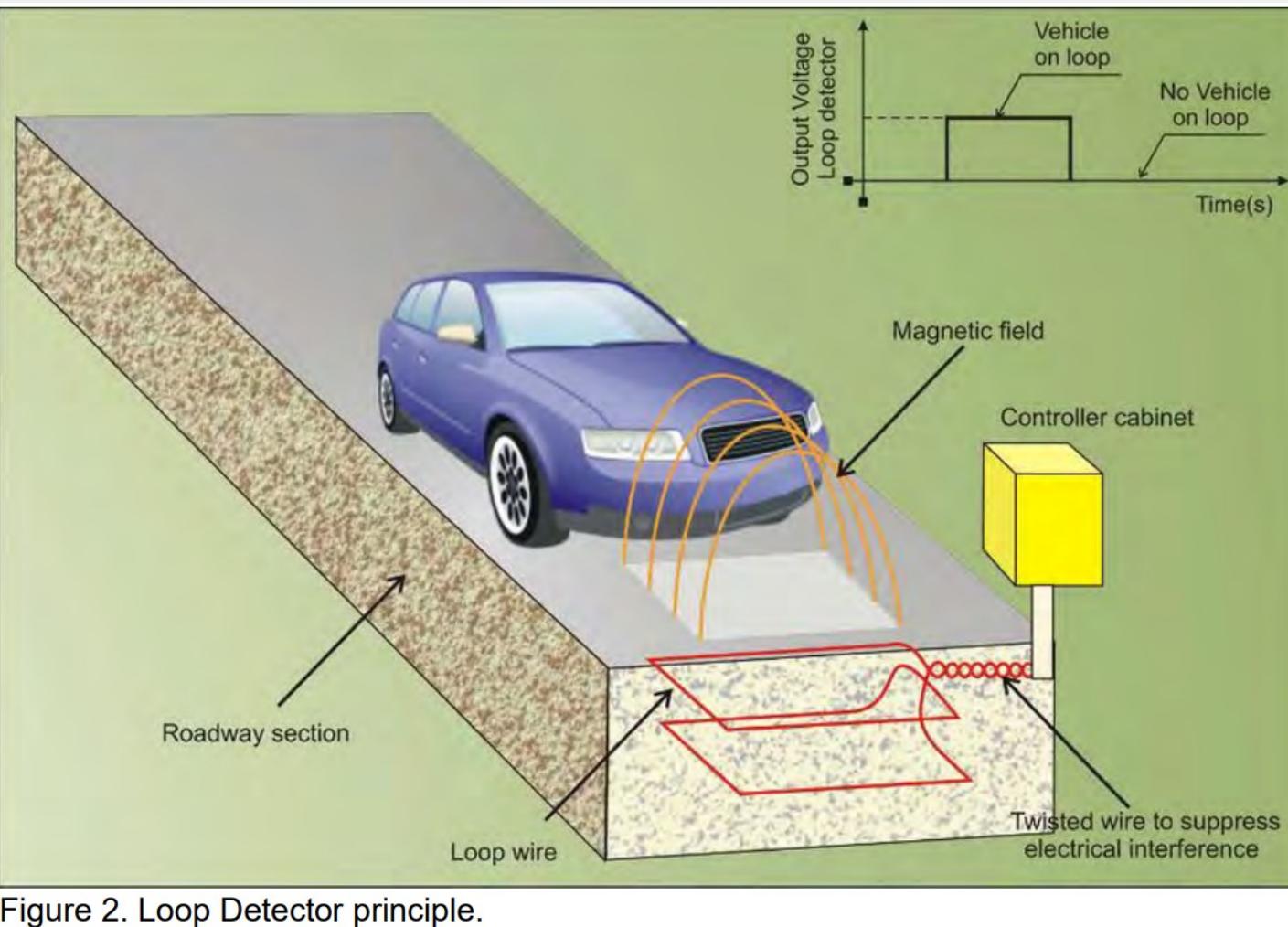
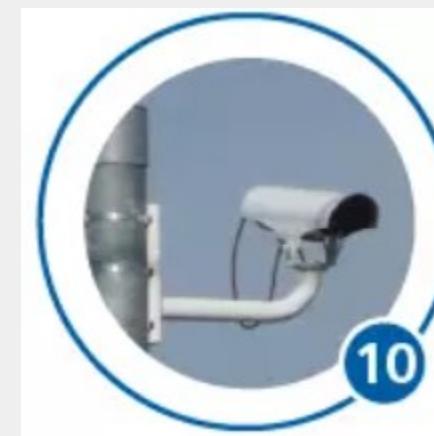


Figure 2. Loop Detector principle.



# Video Detection

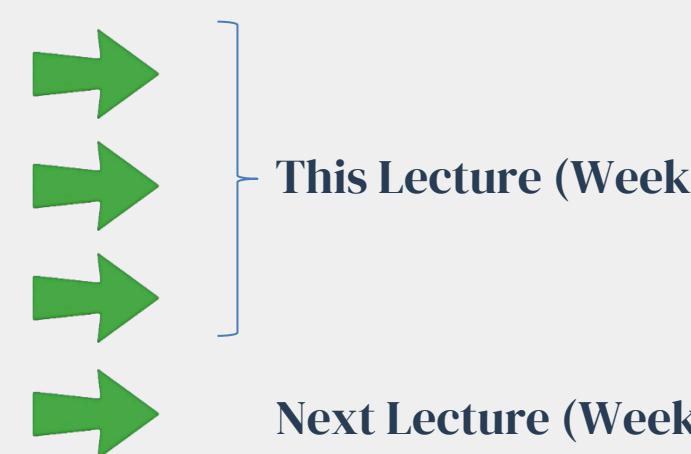
- ❑ Pole mounted cameras to detect the presence of vehicles
- ❑ Uses computer vision to detect object type, count and speed



# Traffic Signal Planning

**Definition:** The systematic process of determining WHERE, WHAT, and HOW traffic signals should be implemented to optimize intersection performance while ensuring safety.

## Key Questions:

- Where we need to implement Traffic Signal? (Warrant analysis) →
  - What type of signal control? (Fixed-time vs. actuated) →
  - How many phases are needed? (Signal phasing) →
  - How long should each phase be? (Signal timing) →
- 

# What is a Signal Warrant?

**Definition:** A WARRANT is a threshold condition that JUSTIFIES installing a traffic signal.

**Think of it like a prescription:**

- A doctor needs symptoms (warrants) before prescribing medicine (signals)
- We need evidence (traffic data) before installing expensive signals

**Key Principle:**

**Signals are NOT always the answer!**

- Unnecessary signals create delay and pollution
- Signals cost \$250,000-500,000 to install

**The Question:**

**Does the BENEFIT of a signal outweigh the COST?**

# Warrant Analysis

## Nine Warrants, Three Categories

### Category 1: VOLUME-BASED (Most Common)

- ✓ Warrant 1: Eight-Hour Vehicular Volume
- ✓ Warrant 2: Four-Hour Vehicular Volume
- ✓ Warrant 3: Peak Hour

**When to use:** High traffic volumes justify signal

### Category 2: SAFETY-BASED

- ✓ Warrant 4: Pedestrian Volume
- ✓ Warrant 5: School Crossing
- ✓ Warrant 7: Crash Experience

**When to use:** Safety concerns justify signal

### Category 3: SYSTEM-BASED

- ✓ Warrant 6: Coordinated Signal System
- ✓ Warrant 8: Roadway Network
- ✓ Warrant 9: Intersection Near Grade Crossing

**When to use:** Network efficiency or special conditions justify signal

# Warrant Analysis

**Warrant 1: Eight-Hour Vehicular Volume (This is the most commonly used warrant)**

**The Logic:** If an intersection is BUSY for most of the day, it needs a signal.

**The Test:** For ANY 8 hours of an AVERAGE day:

**Major Street (higher volume road):** - Must have  $\geq 600$  vehicles/hour (both directions combined)

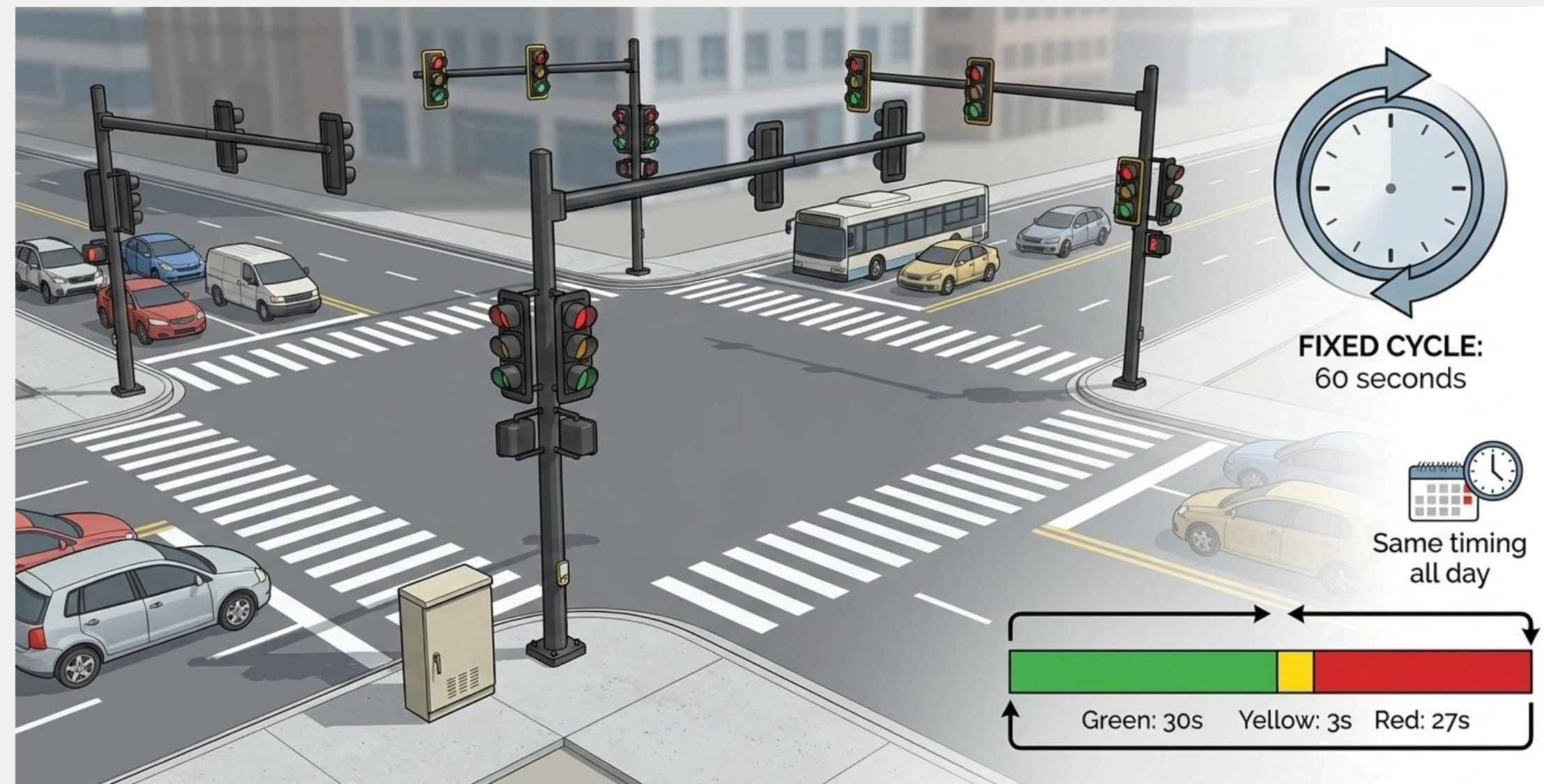
**AND Minor Street (lower volume road):** - Must have  $\geq 150$  vehicles/hour (highest volume approach)

# Example

Time Period	Major (Yonge)	Minor (Side St)	Met?
7-8 AM	850 veh/hr	200 veh/hr	✓
8-9 AM	920 veh/hr	180 veh/hr	✓
9-10 AM	750 veh/hr	160 veh/hr	✓
...			
...			

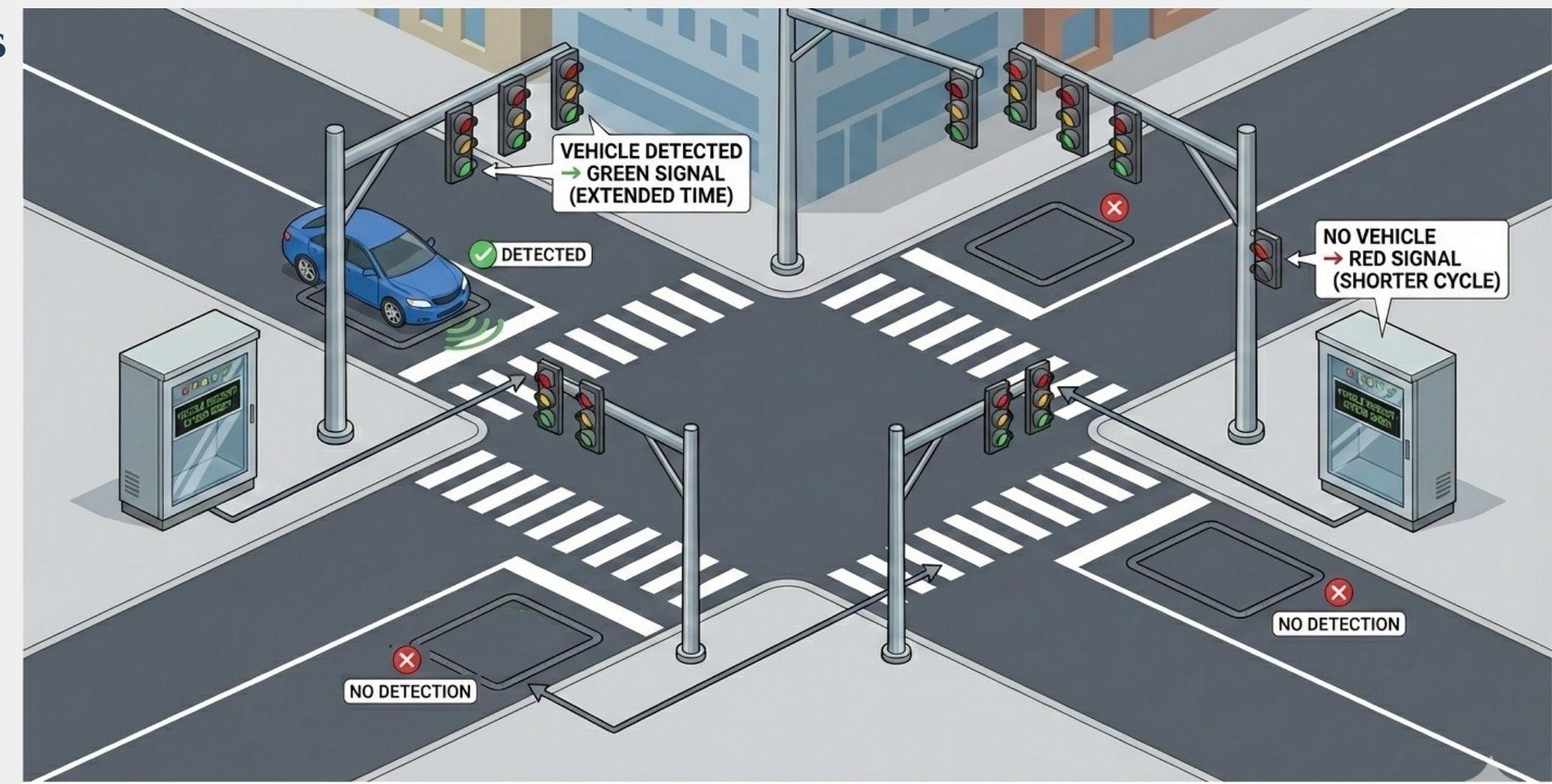
# Types of Signal Control (Fixed-Time vs. Actuated)

- Fixed-time: Repeat a preset constant cycle and signal plan



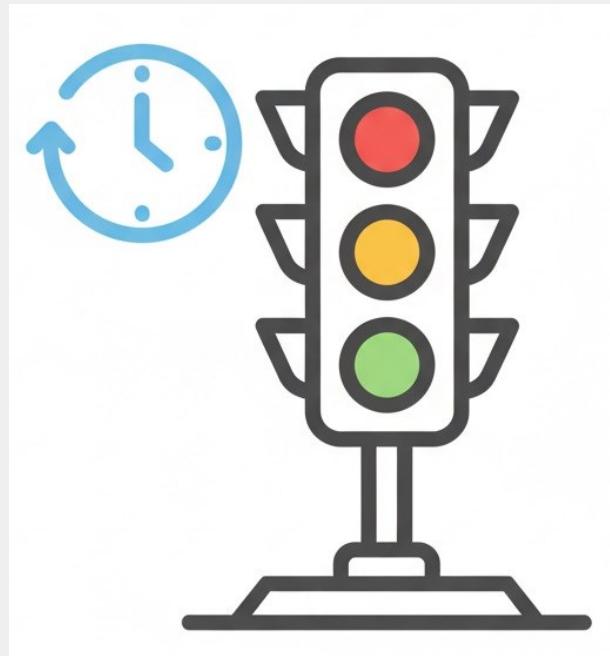
# Types of Signal Control (Fixed-Time vs. Actuated)

- ✓ **Actuated:** Respond to the presence of vehicles
- ✓ **Semi-actuated:** Detectors placed only on the minor approach
- ✓ **Fully actuated:** Detectors are installed at all approaches
- ✓ **Green time are allocated based on the incoming traffic on each approach**



# Types of Signal Control (Fixed-Time vs. Actuated)

**Fixed-Time**



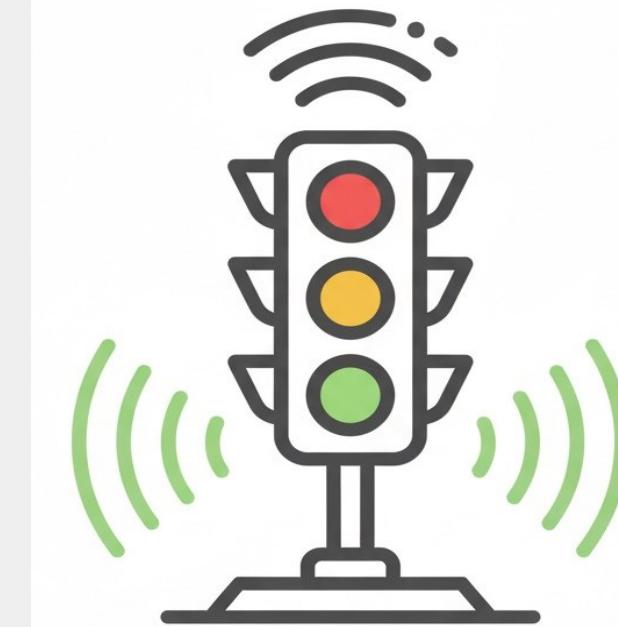
**Advantage:**

- Simple Construction
- Inexpensive to install and maintain

**Disadvantage:**

- Inflexible to traffic conditions
- Causes avoidable delay during low-traffic periods

**Actuated**



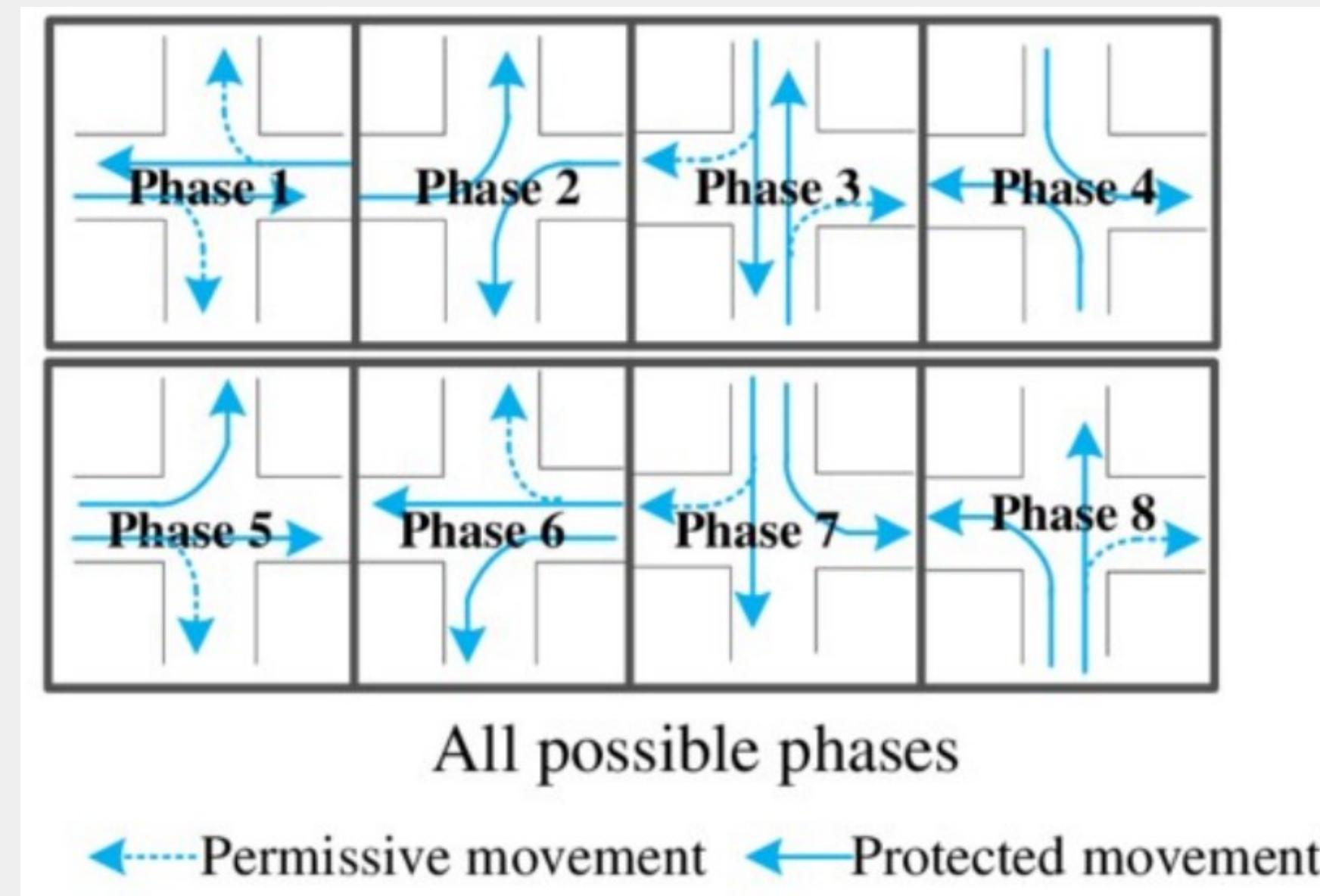
**Advantage:**

- Flexible – adjusts according to traffic demand
- Minimizes delay to attain maximum capacity

**Disadvantage:**

- Requires costly equipment including detectors
- More complex maintenance

# Signal Phasing



# Signal Phasing

**Cycle length:** Total time for a signal to complete all phases and return to the start

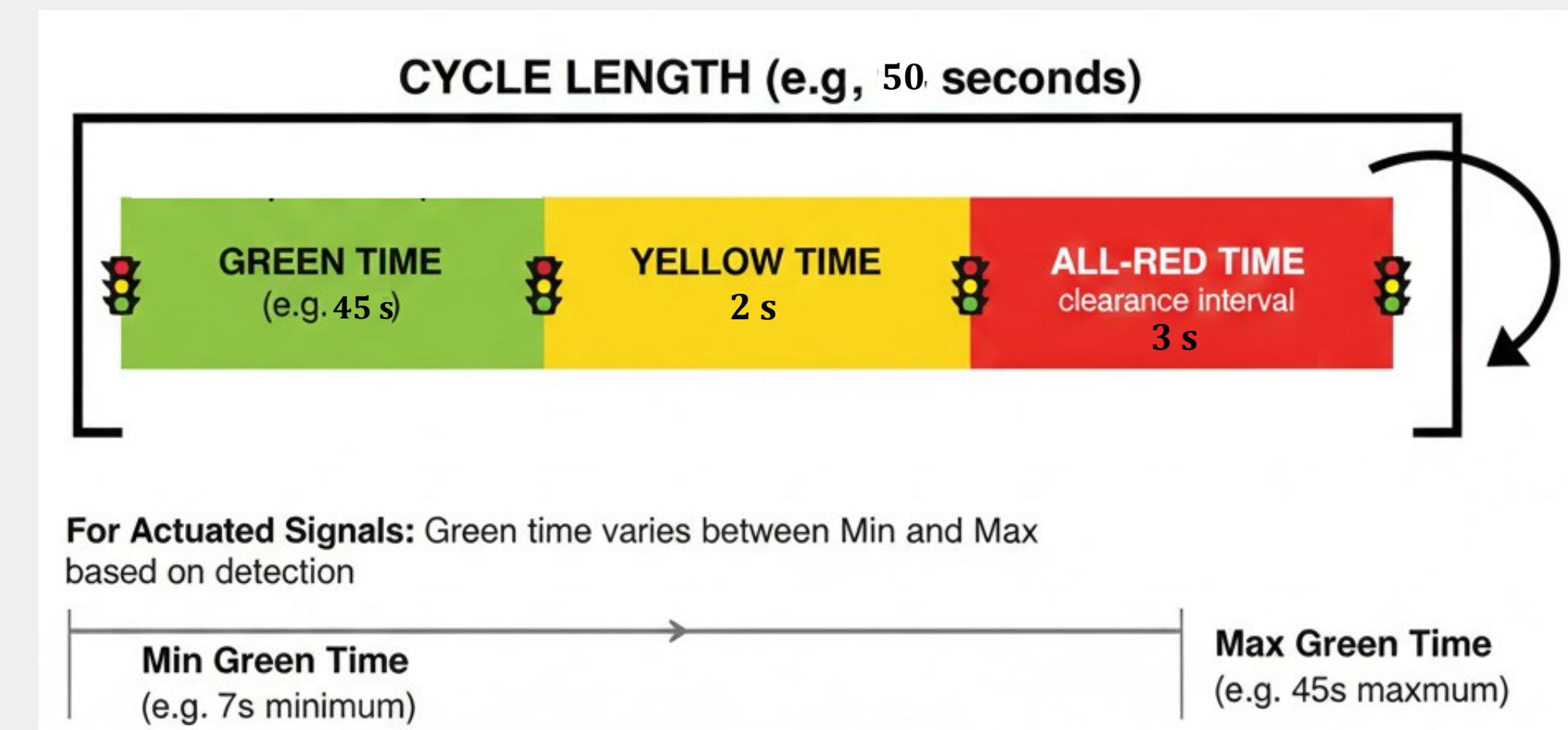
**Green Time:** Duration of green indication for vehicle movement

**Yellow Time:** Transition period warning drivers the signal is about to turn red

**All Red Time:** Brief period when all approaches show red to clear the intersection

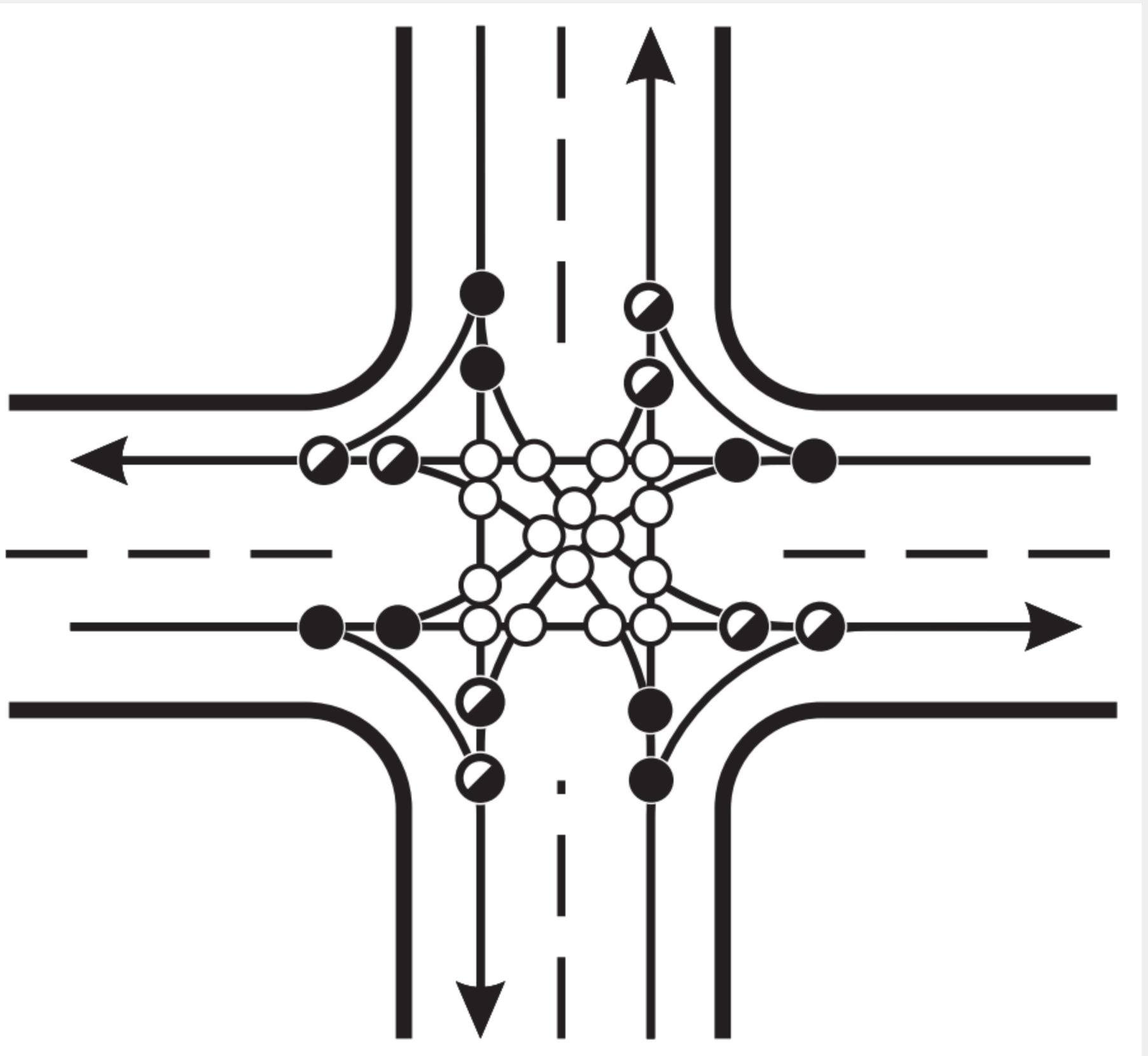
**Min Green Time:** Shortest green duration allowed (ensures safety for detected vehicles)

**Max Green Time:** Longest green duration allowed (prevents excessive delay on other approaches)

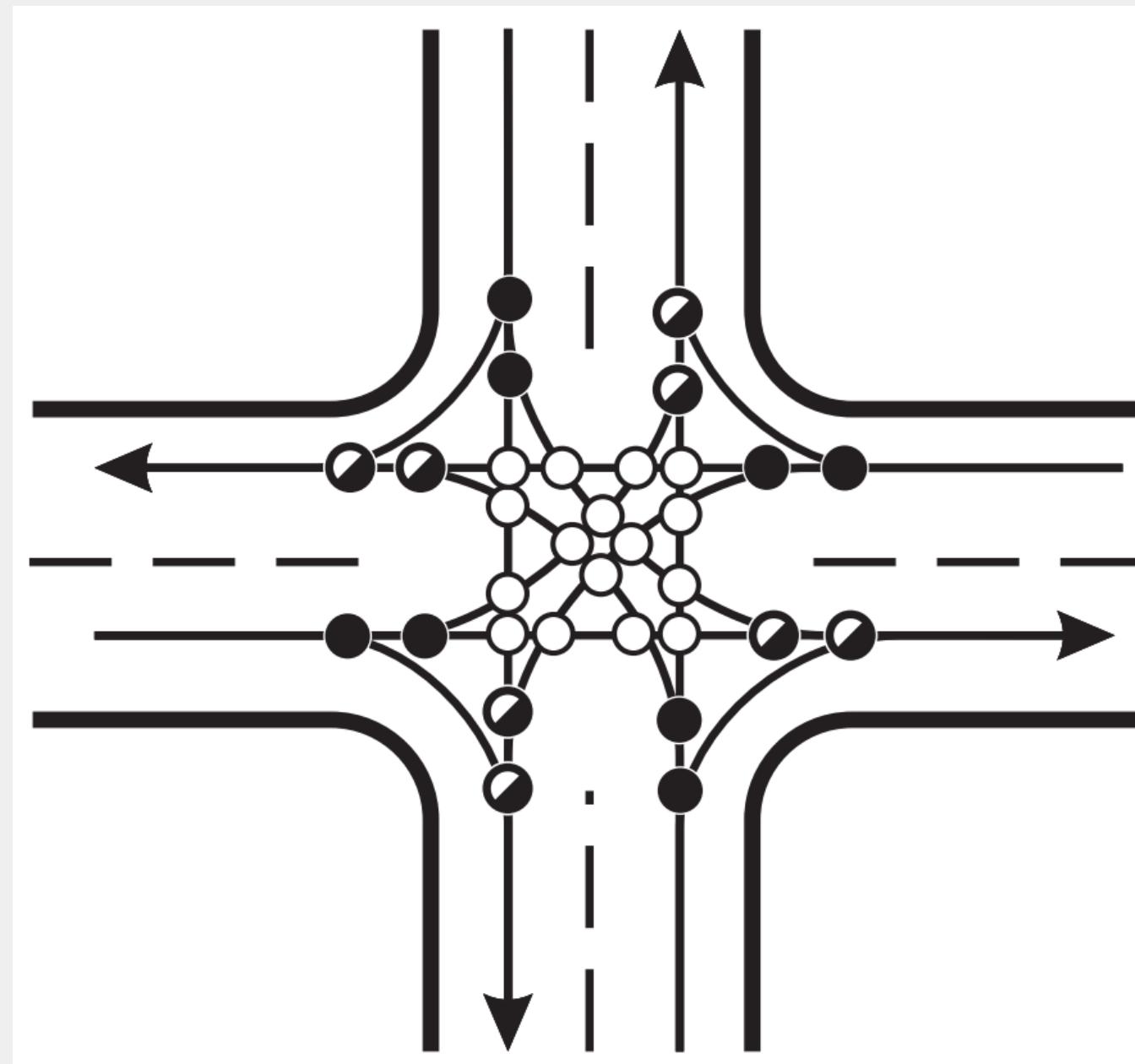


# Overview of Intersections

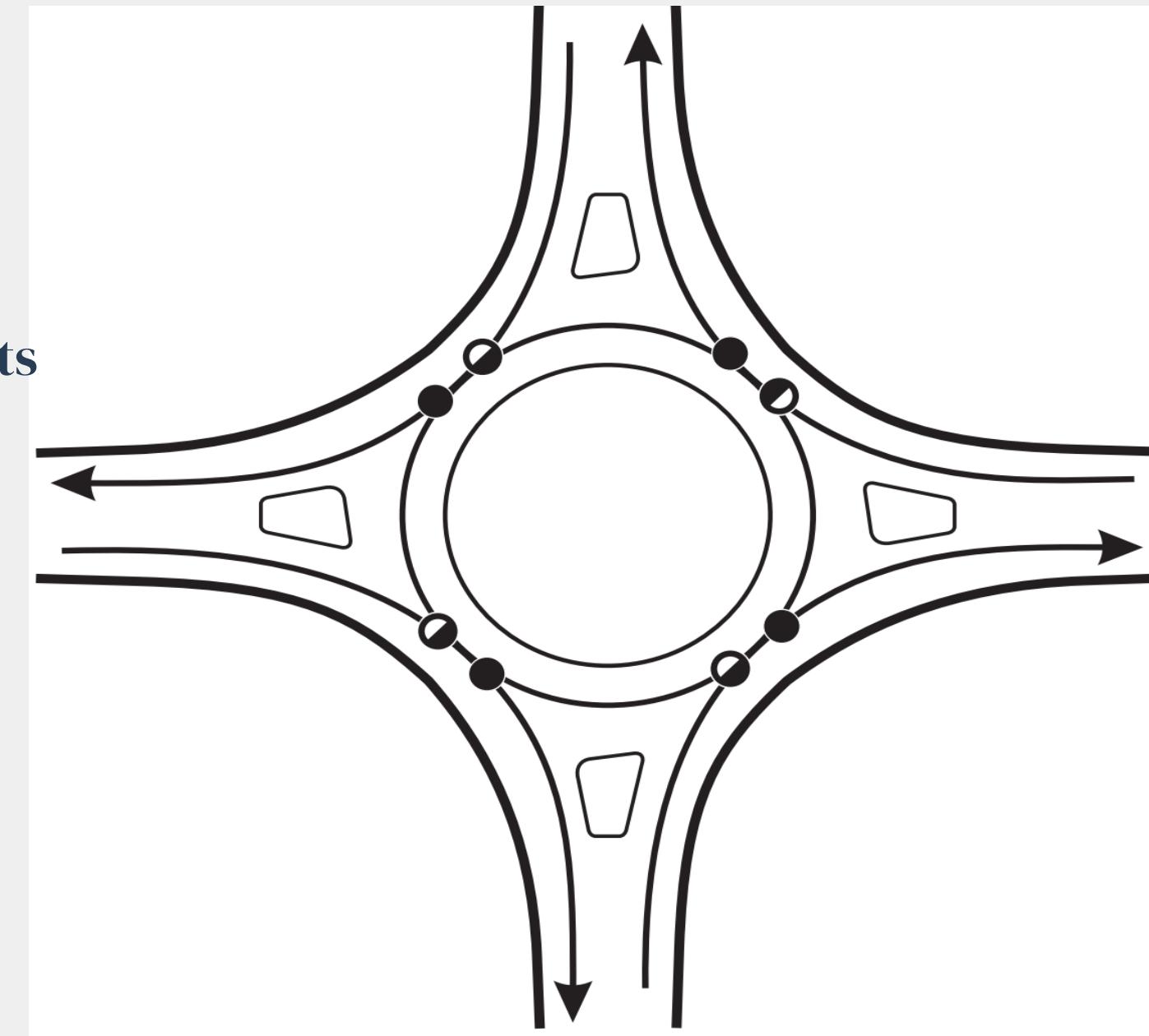
- In a 4-approach intersection:



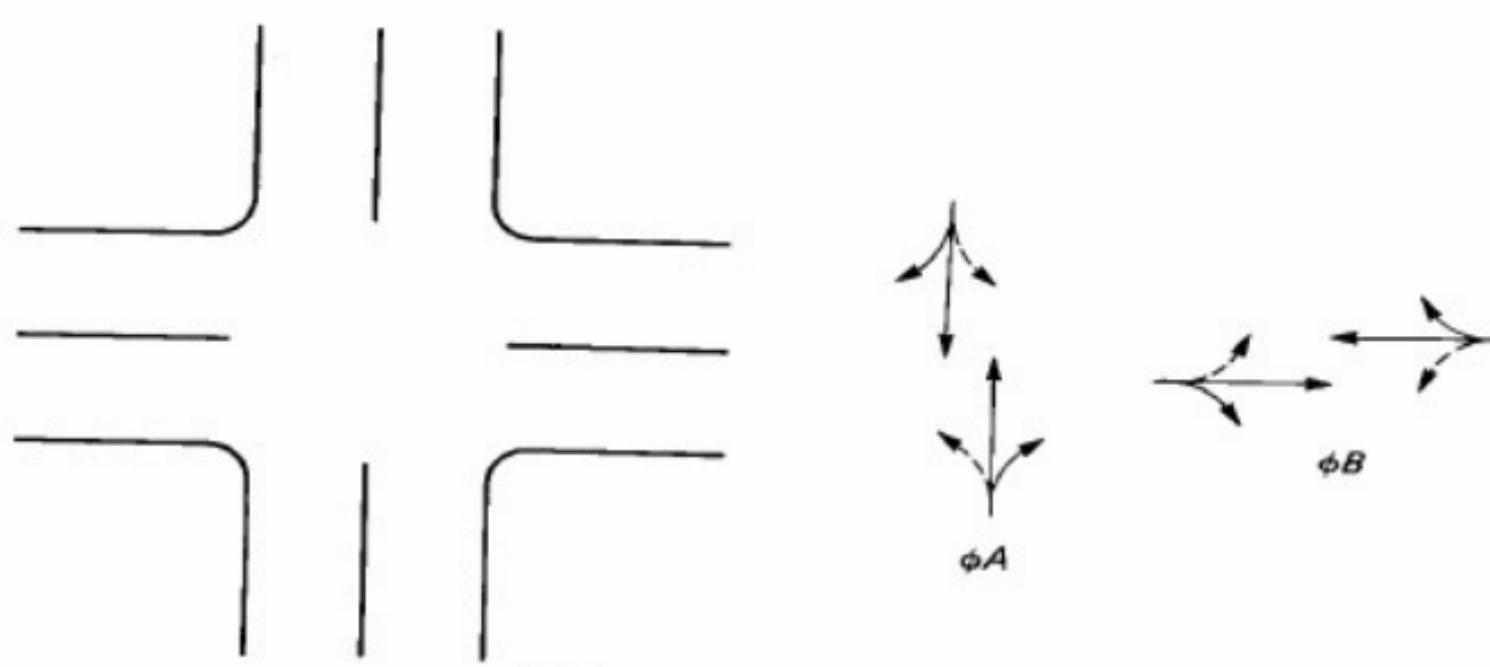
# Overview of Intersections



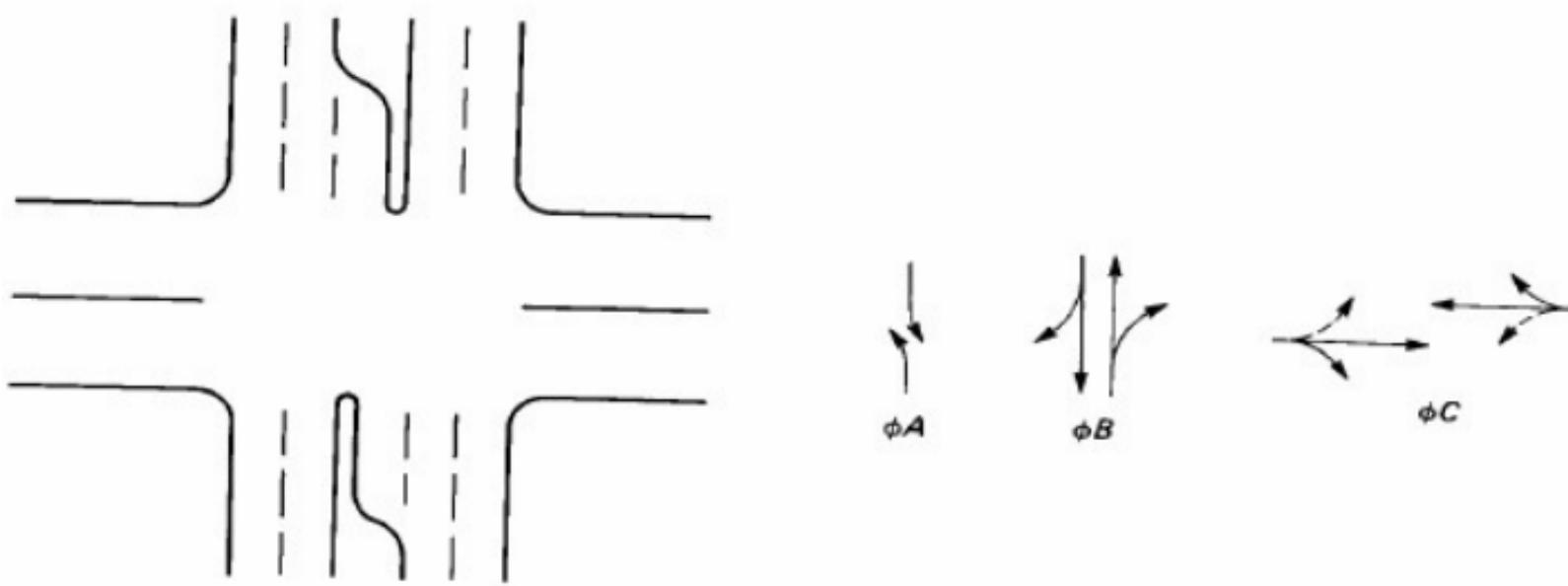
75% fewer vehicle conflict points



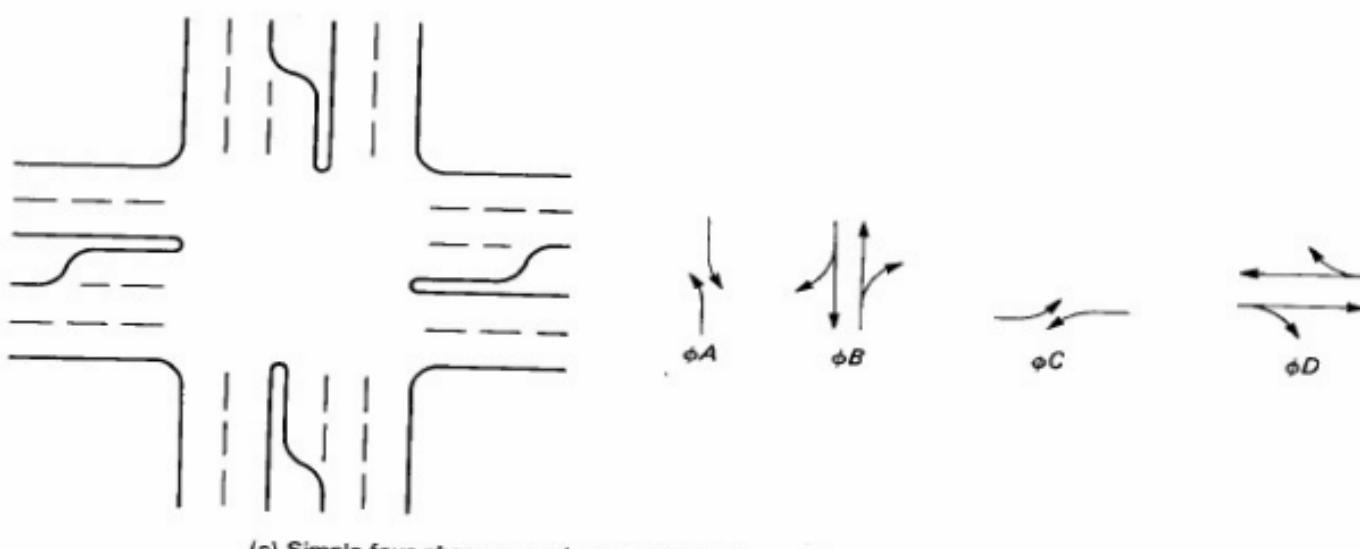
- Diverging
- Merging
- Crossing



(a) Simple two-phase operation



(b) Simple three-phase operation, protected turns on one street



(c) Simple four-phase operation, protected turns on two streets

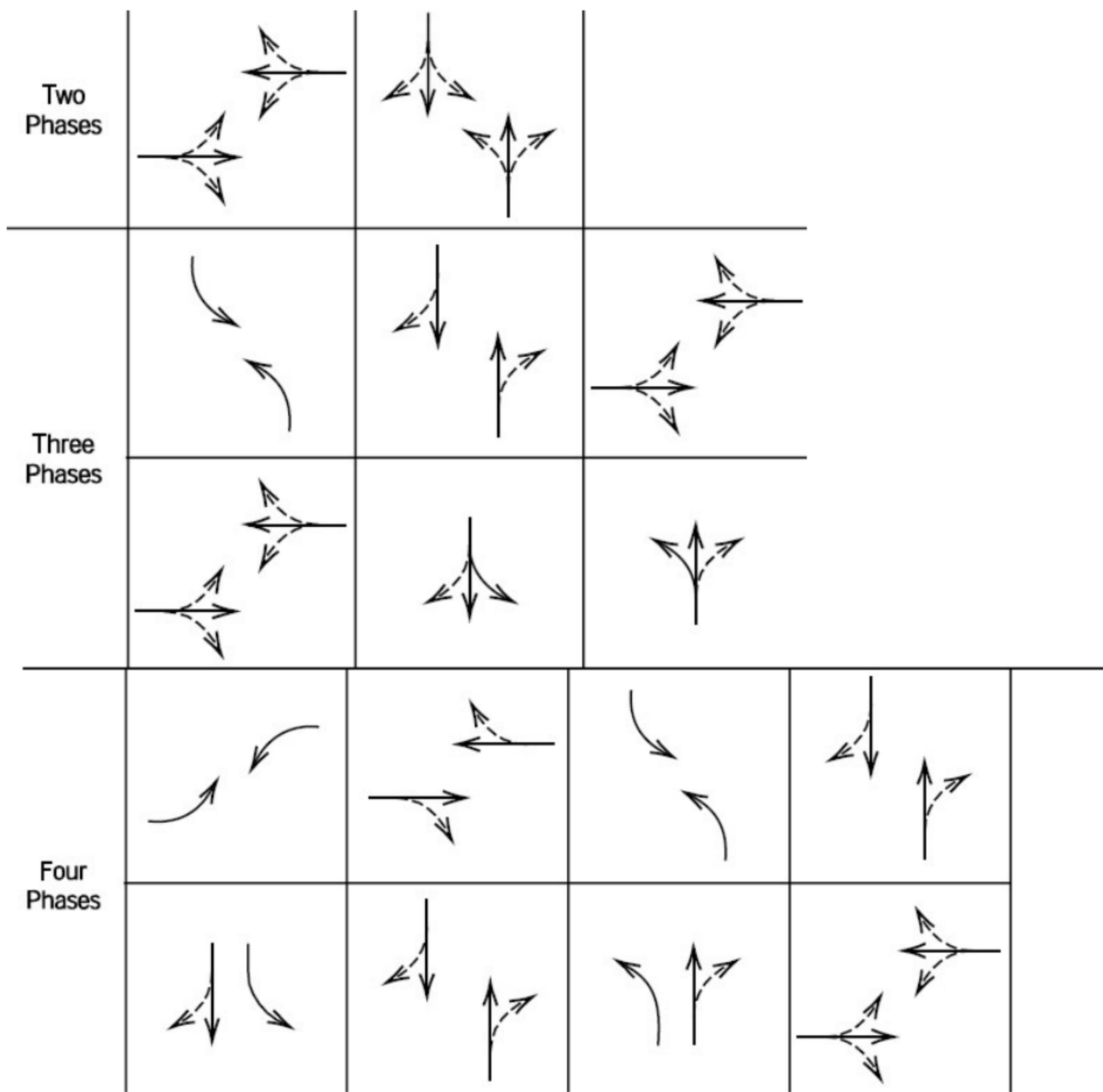
Two phases

Three phases

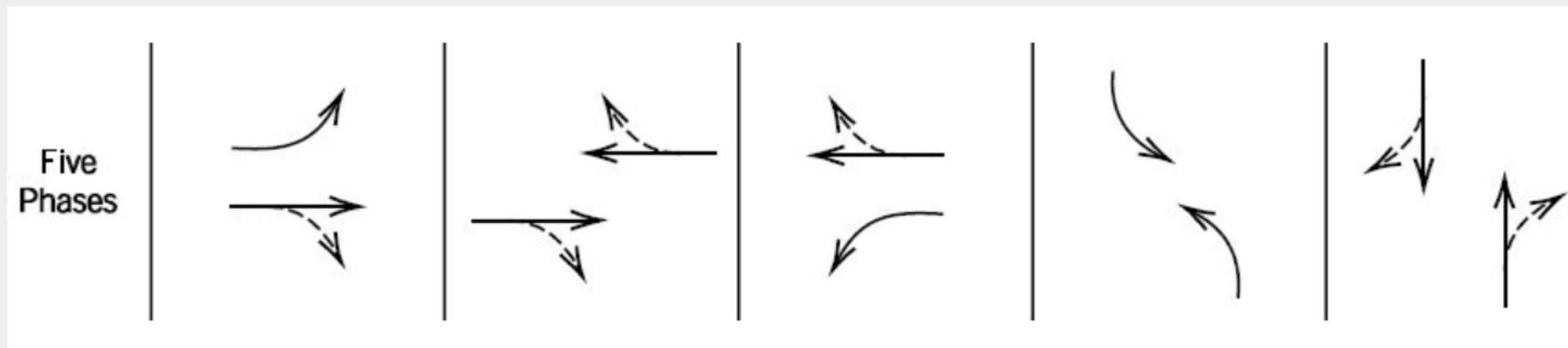
Four phases

# Signal Phasing

# Signal Phasing



# Signal Phasing



# Case Study 1: MioVision

**Company Type:** Private (Canadian)

**Product:** Miovision TrafficLink + Surtrac Adaptive Control System

**Study Area:** Lansdowne Street Corridor, Peterborough, Ontario, Canada - 6 signalized intersections

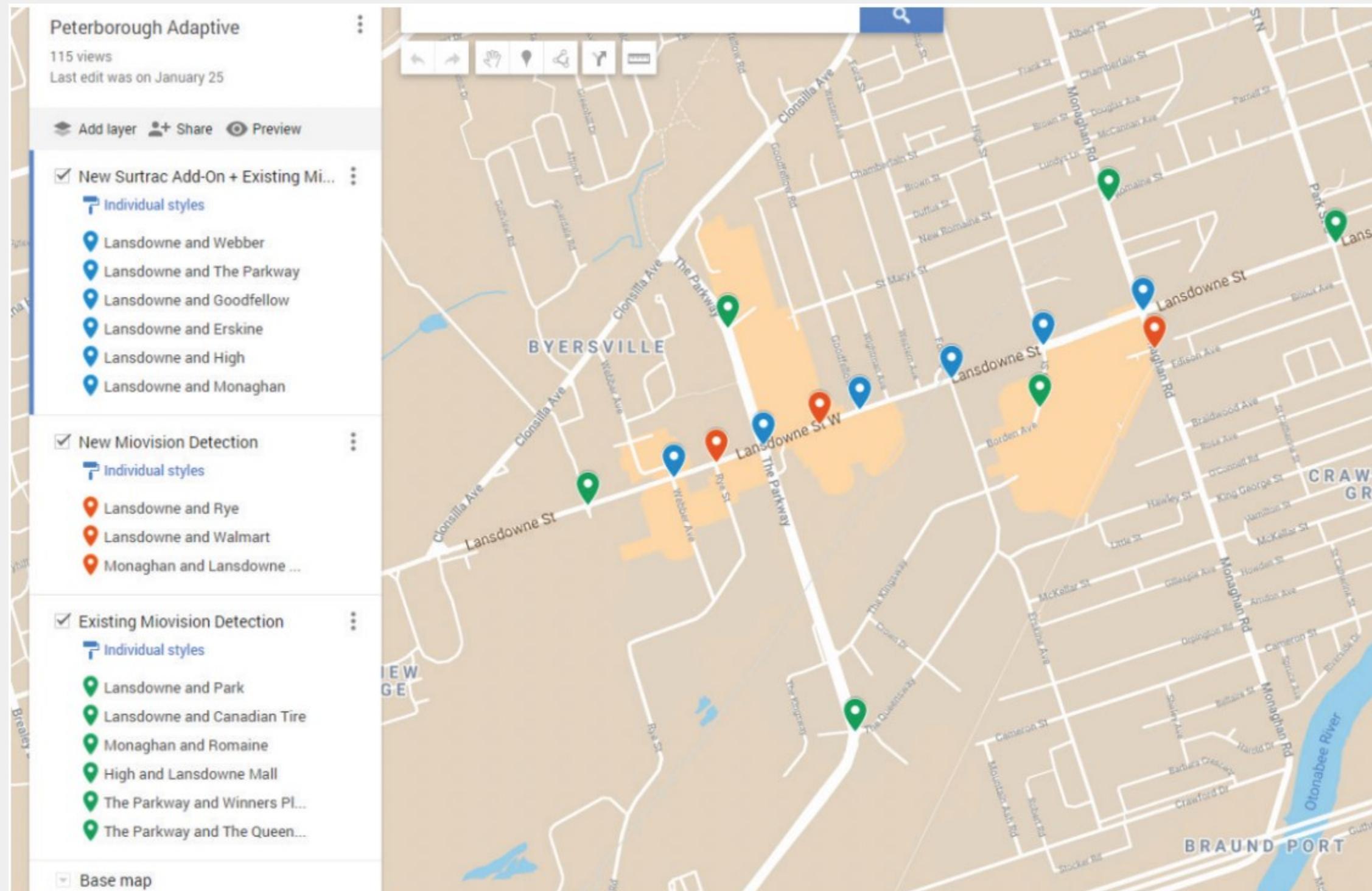


Reducing Congestion  
and Optimizing Signal  
Timing Systems With  
Miovision Solutions

Peterborough Case Study

# Case Study 1: MioVision

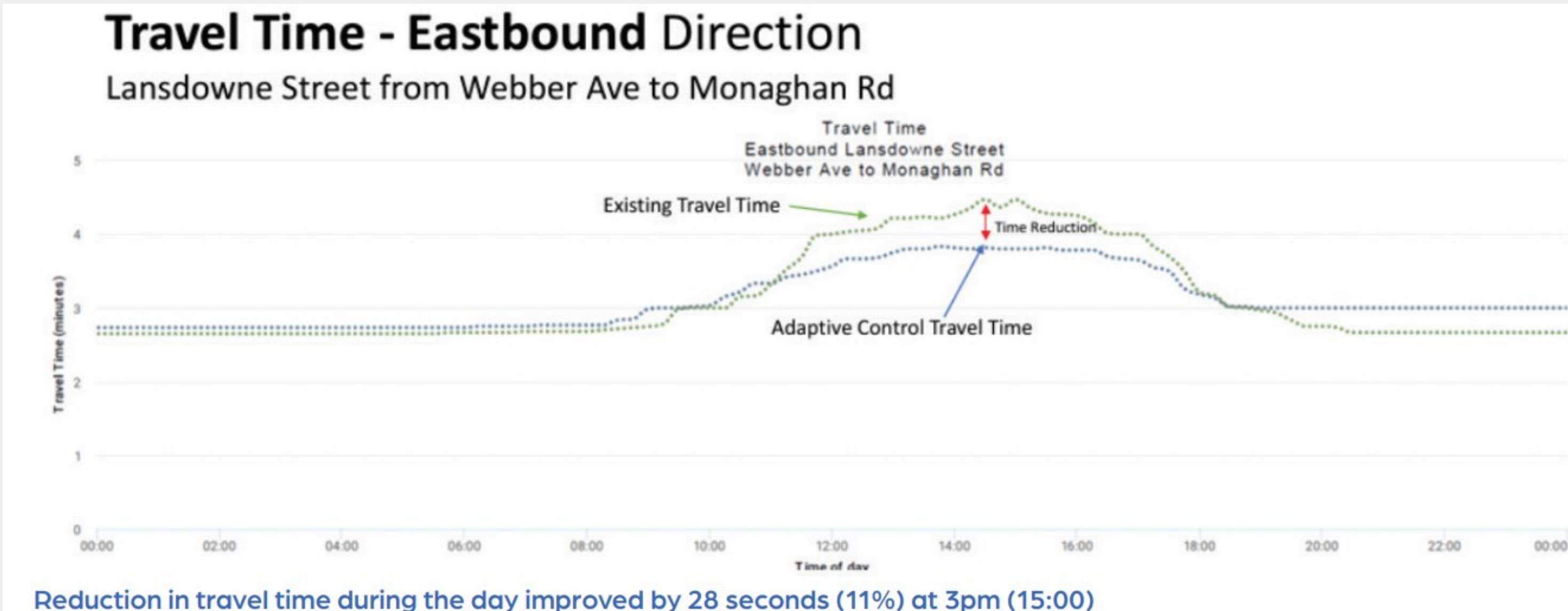
- 1.75 km corridor from Webber Avenue to Monaghan Road
- 6 signalized intersections
- August 2021
- Input: Traffic detection sensors (Traffic volumes/speeds etc)
- Optimization: Miovision Surtrac Adaptive Traffic Signal Control vs Traditional Fixed timing
- Output: Travel Time Reduction; Corridor Stops Reduction; Emissions



The selected corridor, with intersections included, the Surtrac deployment (blue), the additional Miovision detection locations (red) and the existing Miovision detection deployment locations (green) located near the corridor.

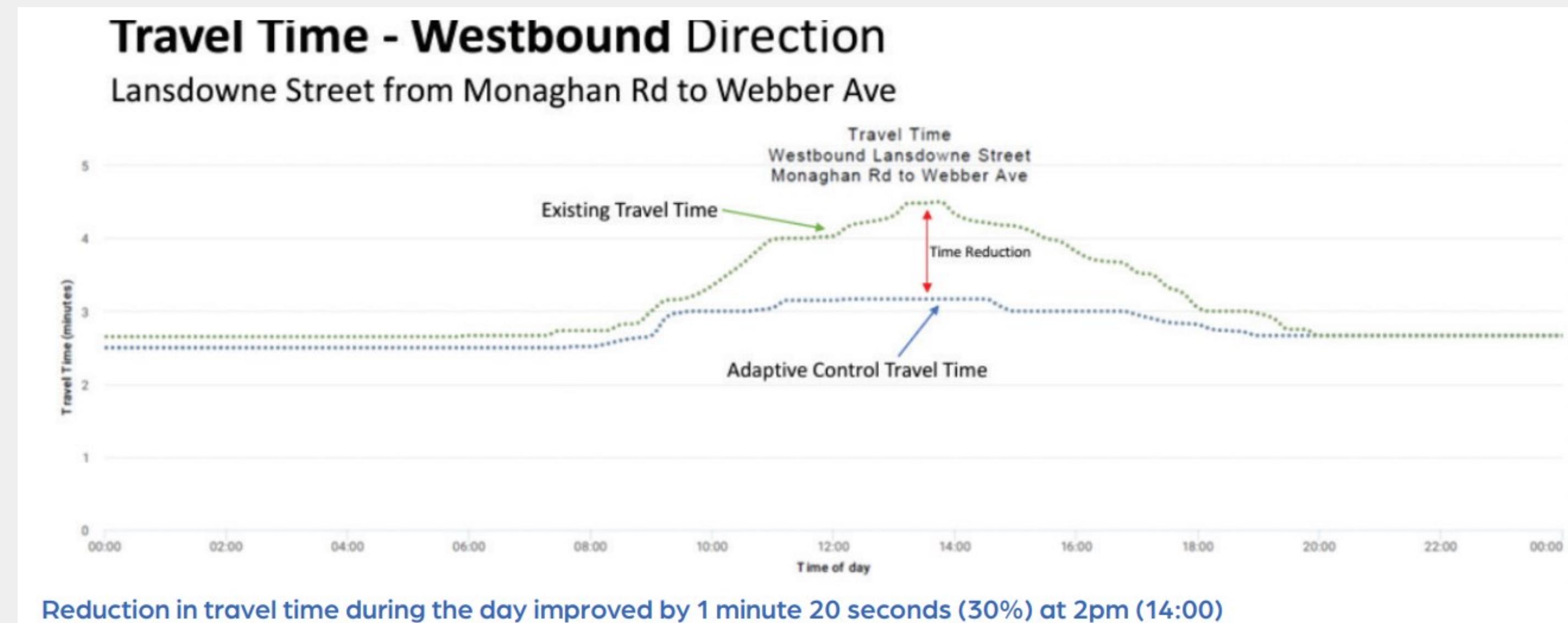
# Case Study 1: MioVision

- **Eastbound direction: showing 28-second reduction**



# Case Study 1: MioVision

- Westbound direction: showing 80-second reduction



# Results

- **Travel time reduction:** 11% eastbound, 30% westbound
- **Corridor stops reduction:** 37% eastbound, 53% westbound
- **Emissions:** 20% reduction (273 tons CO2/year)
- **User cost savings:** \$977,000/year
- **Fuel savings:** 106,700 liters/year (\$213,000/year)
- **Level of Service:** Improved from D to C (6% capacity increase)

# Case Study 2: City of Toronto

- Signal Optimization Program: 2012-2024
- Traditional Way of Controlling Signal (Fixed Timing)
- Smart Control of Traffic Signals (SCATS)

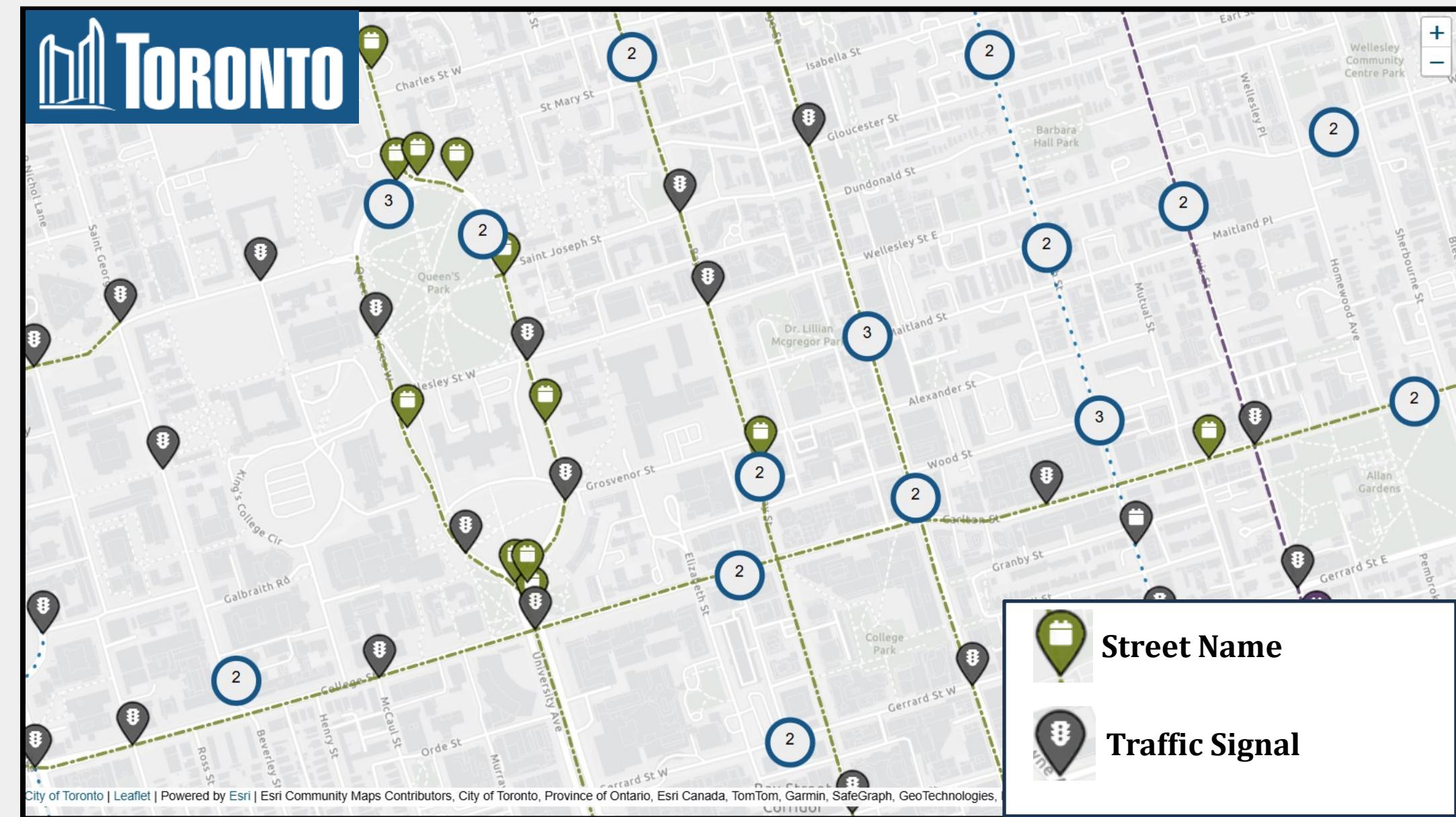
## Signal Optimization (Coordination) Program



# Traditional Way of Traffic Signal Control

- The City of Toronto's Signal Optimization (Coordination) Program enhances the efficiency of over 2,500 traffic signals across the city.
- Fixed-time coordinated signal timing → Simulation
- "Uses Synchro® software for optimization" "6 time-of-day periods: AM peak, day off-peak, PM peak, evening off-peak, night, weekend"

Map showing optimized corridors (2014-2024)



# Smart Way of Traffic Signal Control

- Sydney Coordinated Adaptive Traffic System (SCATS)
- Unlike fixed-time plans, SCATS adapts in real-time based on actual traffic conditions
- 89 signals use SCATS

Inductive loop detector embedded in pavement detects vehicles via magnetic field changes

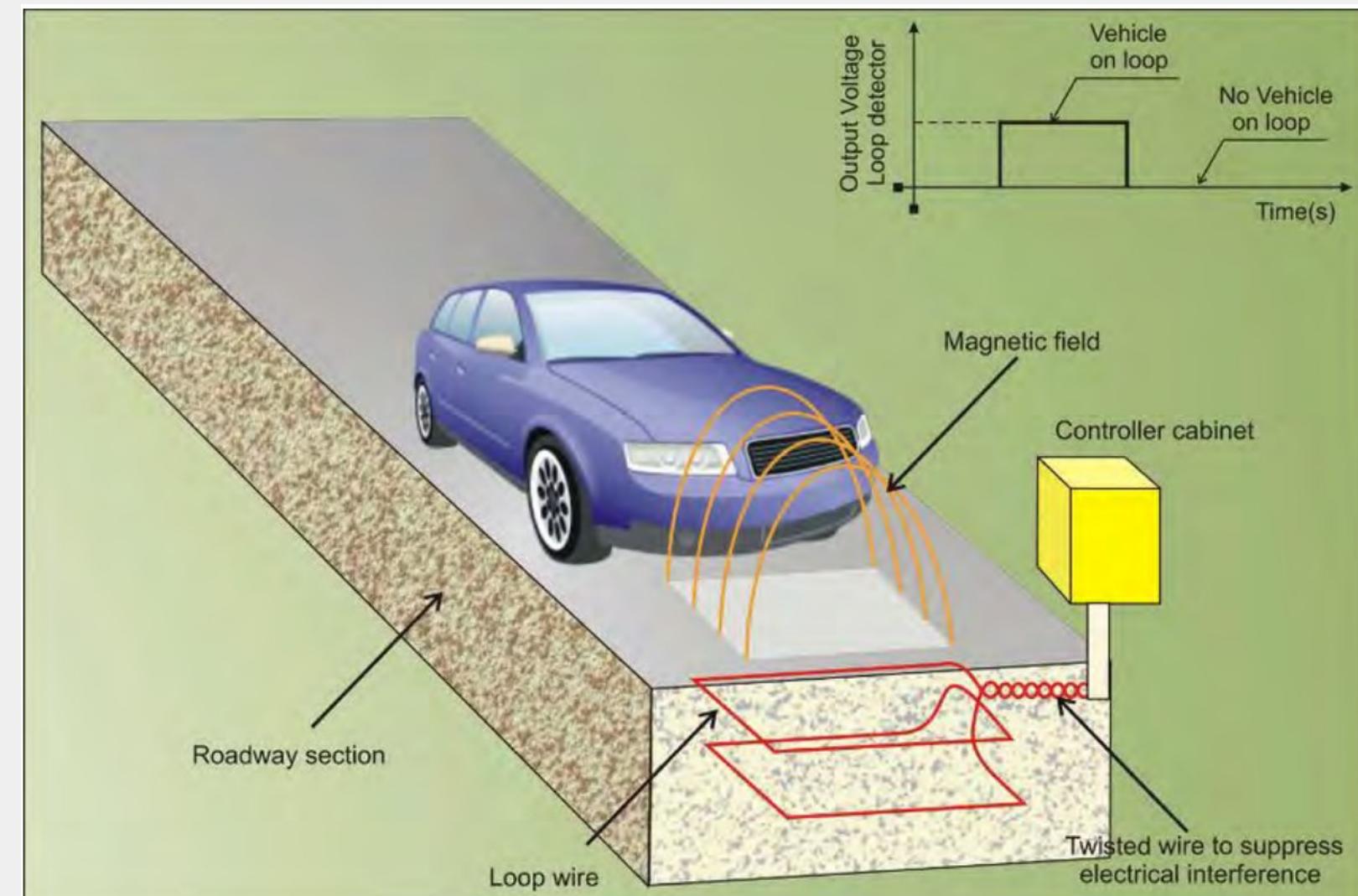


Figure 2. Loop Detector principle.



<https://www.toronto.ca/services-payments/streets-parking-transportation/traffic-management/traffic-signals-street-signs/traffic-signals-in-toronto/types-of-traffic-signal-systems/>

<https://appliedtechnology.humber.ca/assets/files/civil-engineering-show/2024/SmartSolutionsForTorontoTrafficAdvancementsInATMS.pdf>

# SCATS Deployment in Toronto (2019-2023)

- Focus on major corridors: Queensway, Lake Shore Blvd, Kingston Rd
- These are mostly in western/central Toronto

Route	From	To	No. of Signals	Year
Lake Shore Blvd.	Windermere Ave.	Yonge St.	28	2023
Spadina Ave.	Front St.	Bremner Blvd / Fort York Blvd	2	2023
The Queensway	Kipling Ave.	Colborne Lodge Dr	19	2022
Kingston Rd.	Cliffside Dr/Claremore Rd.	Fenwood Hts	11	2022
Kingston Rd.	Bellamy Rd.	Beechgrove Dr.	17	2021
Morningside Ave.	Casebridge Crt.	Milner Ave.	2	2019
Sheppard Ave. E.	Neilson Rd.	Meadowvale Rd	10	2019
Total			89	

# Benefits of Signal Optimization Program in City of Toronto (Primarily Fixed-Time Coordination, 2012-2016)

- Overall benefit/cost ratio: 53:1 (for every \$1 invested, \$53 saved to public)
- Total cumulative saving over 3-year lifecycle: \$271.1 million
- Fuel consumption reduction equivalent to:
  - CO2 emissions from 6,458 homes' electricity use for one year
  - Carbon sequestered by 41,395 acres of forest in one year
- Annual Investment: \$850,000/year (2012-2015)



# Benefits of SCATS in Toronto (Sheppard Avenue, 2018-2019)

- Travel time reduction: 2.6% (peak hours)
- Benefit-cost ratio: 3:1
- Improvements above already-optimized baseline