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Rapid Flow

surtrac
Traffic Control

PHAENON
Urban Analytics

PHAENON

Urban Analytics

PHAENON Urban Analytics

- Measure real-time urban traffic conditions …
  - Travel times
  - Congestion
  - Cruising for parking
  - Incident detection

Summer 2016
59 sensor network for ParkDC around the Verizon Center

October 2016
$1 million Phase II SBIR award from U.S. DOT

PHAENON Sensor Networks

Low-cost automatic vehicle identification (AVI) sensors

Dense, ubiquitous sensor network deployments

Reconstructed vehicle routes

PHAENON Sensor Networks

Installation

- Sensors are installed at each intersection in a network
- Low-cost, low-power sensors
- Only requires connection to power
- Easy installation, flexible location
- Sensors send data to the cloud through a low power wide area network

Key Features

- Second-by-second updates
- Completely anonymous data
- Fine-grained data show where and when cruising happens
- Applications include:
  - Link-level travel times
  - Origin-destination data
  - Performance monitoring for traffic signal systems

Measuring Cruising for Parking

- Cruising for parking adds to traffic, causing extra congestion
- Smart parking policies and technology can address the causes of cruising
- What if we want to measure cruising continuously?
  - When and where does cruising happen?
  - How does cruising for parking change over time?

Our Approach

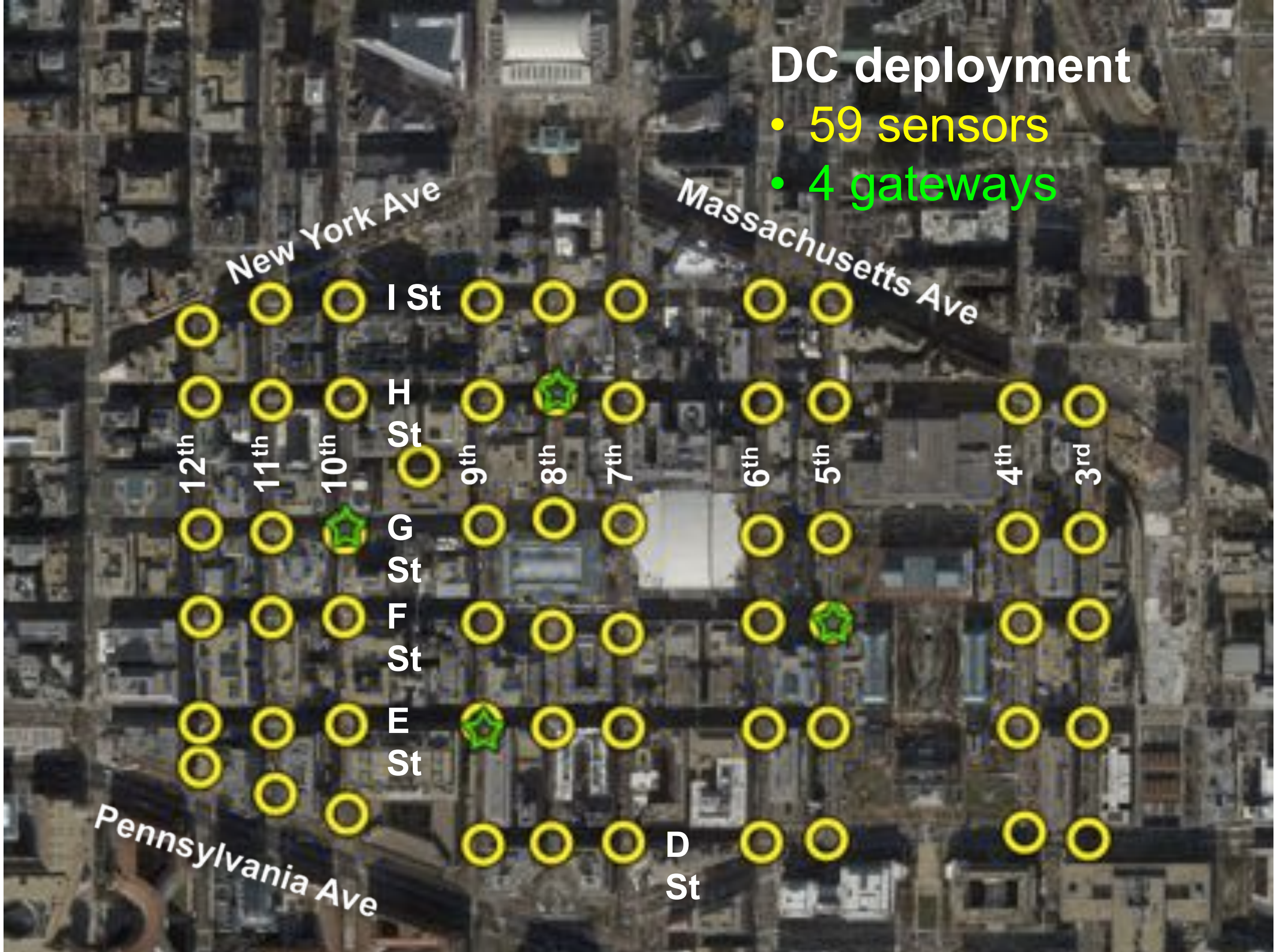
- **Goal**: To directly measure rates of cruising for parking
- Deploy a dense network of low-cost automatic vehicle identification (AVI) sensors (Bluetooth)
- Sensors detect vehicles (anonymized)
- Anonymous vehicle routes are reconstructed from distributed sensor data
- Vehicle routes are classified as cruising or non-cruising

Development Timeline

- 2014 – Early experiments
  - Initial experiments to monitor travel times (TRB paper 15-5913)
- 2015 – U.S. DOT SBIR Phase I
  - Temporary 38 sensor network in Pittsburgh
  - 3 week deployment, controlled study
- 2016 – DC deployment
  - Permanent deployment supporting ParkDC
  - 59 sensors in Chinatown and Penn Quarter
- 2017-2018 – U.S. DOT SBIR Phase II
  - Deployment of ~300 sensors across 2-4 pilot cities
  - Further algorithm development
    - Cloud-based application for continuous reporting
    - Incorporate other information (e.g., occupancy) to improve classification

DC deployment

- 59 sensors
- 4 gateways



What are we hoping to learn?

- How does cruising change over time?
- How do prices change cruising rates?
- Do cruising rates stabilize over time?
- What types of information, analysis, and visualization best support agency goals?
- What does success look like for demand-based pricing in the context of cruising?
- How can agencies use these sensor networks for other purposes to share costs?

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Intelligent Traffic Signal Control

TRAFFIC CONGESTION

costs $120+ billion and produces 56 billion pounds of CO_2 per year in the US alone

POORLY TIMED SIGNALS

are one big reason why

Most intersections run *fixed* timing plans

- Designed for average traffic conditions
- Begin “aging” the moment they are installed

Signal systems with adaptive capabilities have inherent limitations

- Only detect and respond to traffic that is already stopped
- Unable to respond to real-time events
- Are designed strictly for arterials

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Goal: Real-time optimization of complex, dynamic traffic flows

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Traffic signal control that adapts to urban traffic in real-time

In the field ...

26% lower travel time
41% less time idling
31% fewer stops
21% lower emissions

Decentralized control
Coordinated action

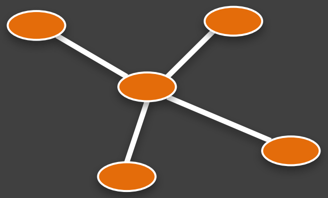
Optimizes signals for the **actual** traffic on the road **right now**

Coordinates networks dynamically

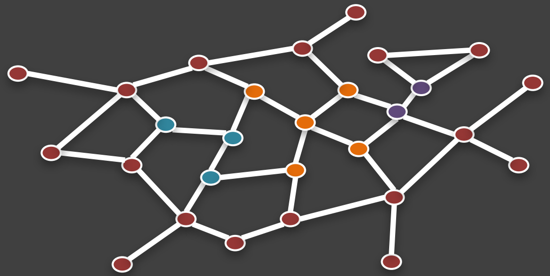

NEVILLE PARK
Optimizes for everyone


Integrations with
Connected Vehicle Technology

Distributed control makes it easy to …

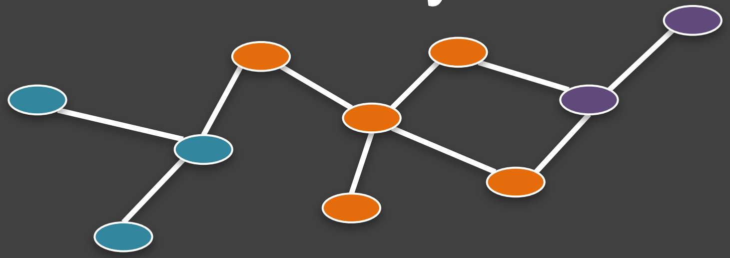


Start small



Scale to large networks

Grow incrementally



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History:

- Developed in the Robotics Institute at Carnegie Mellon University
- Commercialized by Rapid Flow Technologies

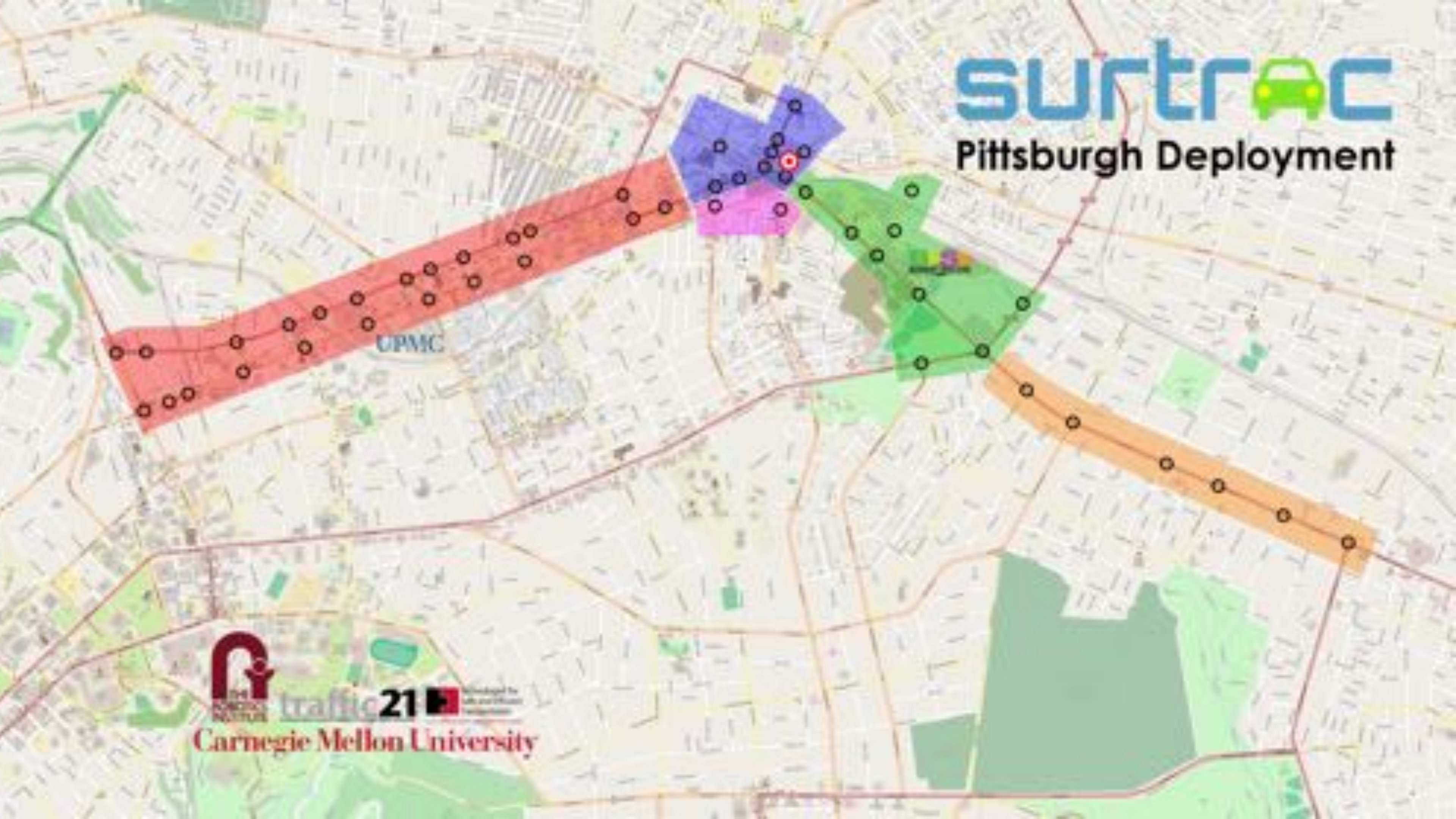
Development Timeline

2010-11: Development of core approach

2011-12: Initial pilot deployment

2013-16: Expansion of pilot test site to 50 intersections

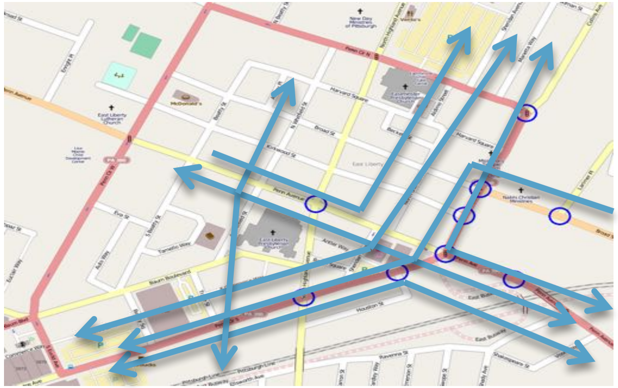
2015-17: Commercialization and integration with connected vehicle technology

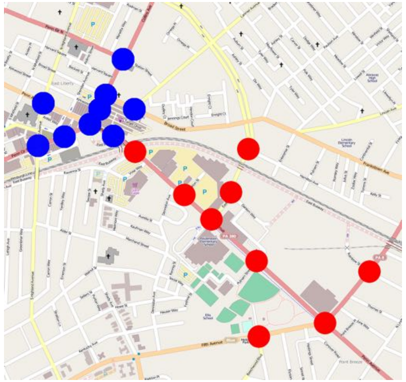

surtrac
Pittsburgh Deployment
UPMC
traffic21
Carnegie Mellon University

Surtrac Pilot – Results and Status

East Liberty Field Test (Jun 2012)

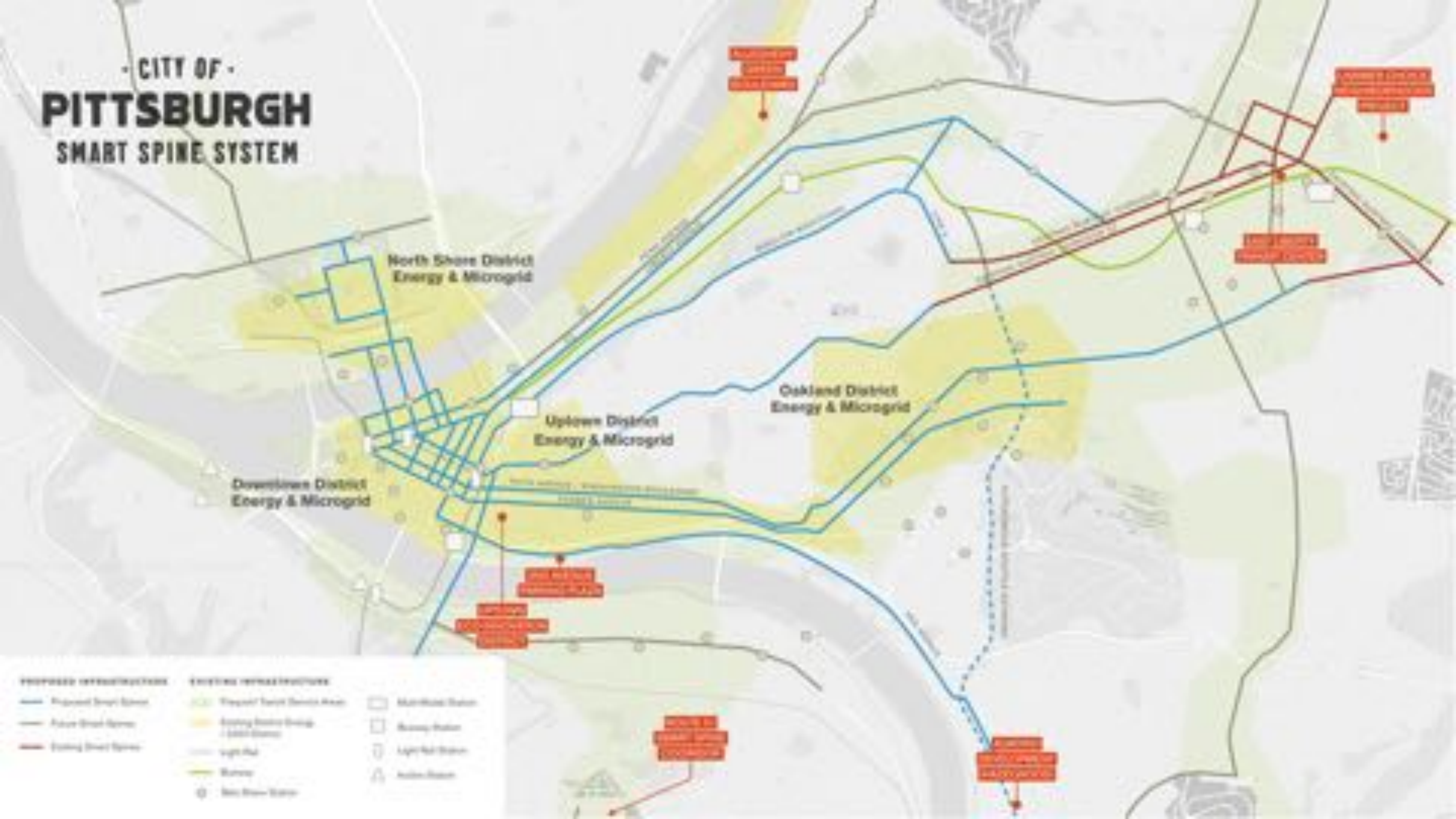
% Improv.	Travel Time	# of Stops	Wait Time	Emissions
AM rush	30%	29%	48%	24%
Mid Day	33%	53%	50%	29%
PM rush	23%	9%	36%	18%
Evening	18%	35%	28%	14%
Overall	**26%**	**31%**	**41%**	**21%**





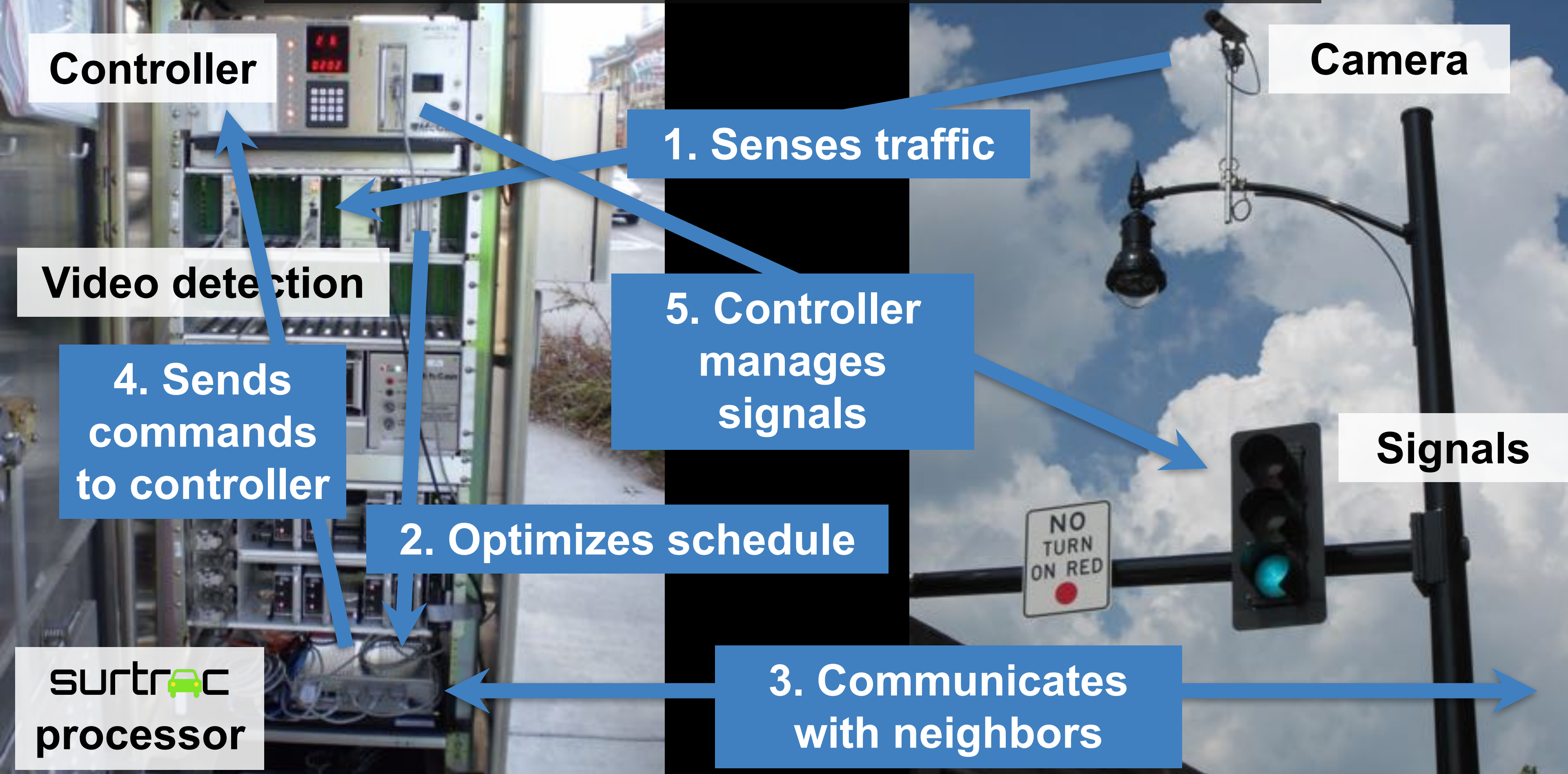
Bakery Square Expansion (Nov 2013)

% Improv.	Travel Time	# of Stops	Wait Time	Emissions
AM rush	17%	34%	33%	16%
Mid Day	21%	37%	38%	18%
PM rush	29%	45%	46%	25%
Overall	**24%**	**40%**	**42%**	**21%**



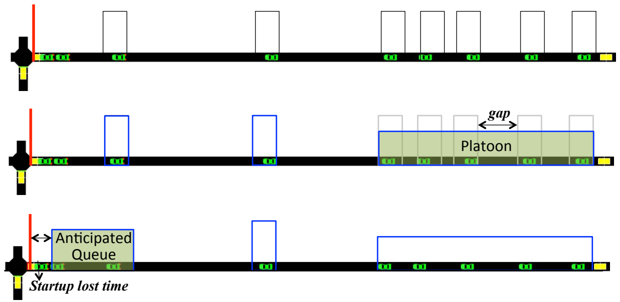
· CITY OF ·
PITTSBURGH
SMART SPINE SYSTEM
North Shore District
Energy & Microgrid
Uptown District
Energy & Microgrid
Oakland District
Energy & Microgrid
Downtown District
Energy & Microgrid

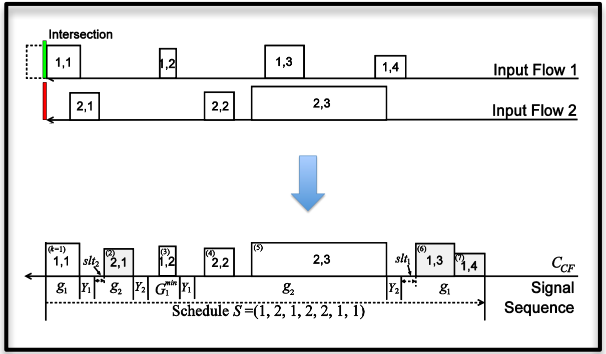
How does surtrac work?



Key Technical Ideas

- Treat intersection control problem as a ***single machine*** scheduling problem
  - Aggregate representation of traffic flows to identify *input jobs*
- Communicate schedules to downstream neighbors to give visibility of future *input jobs*





Surtrac Approach

- Decentralized, real-time control
- Creates coordination via vehicle arrival model
- Discovers dominant flows dynamically
- Doesn’t require pre-selection of coordination
- Can manage coordination of multiple directions under many conditions
- Built for a connected vehicle future

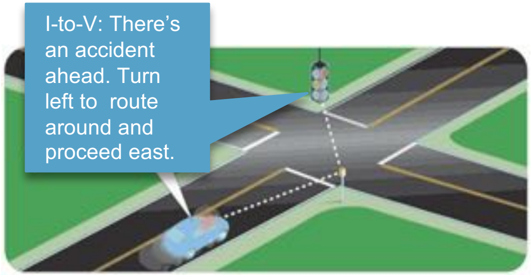
Surtrac System Behaviors

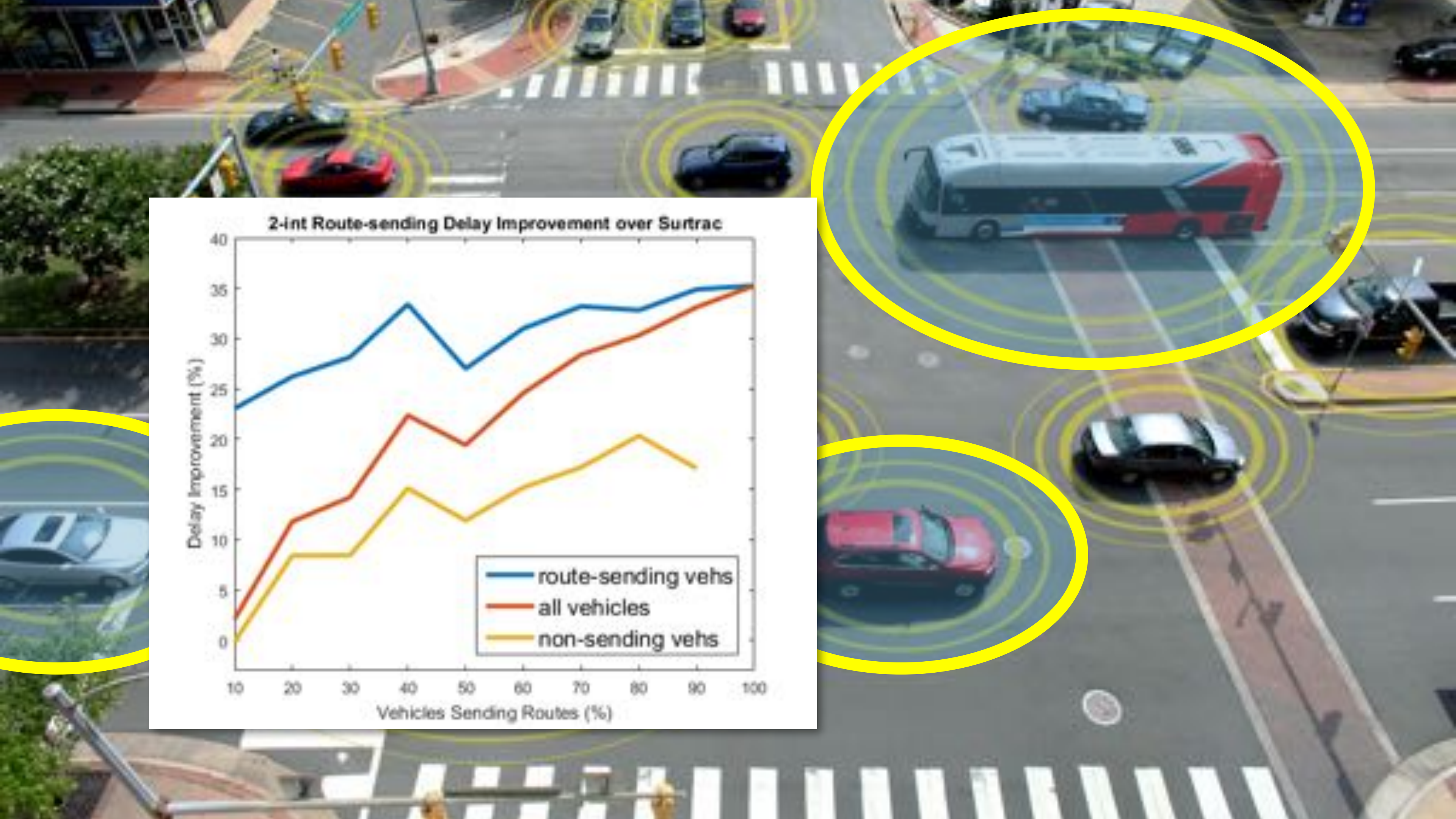
- **Light traffic** – Focus on moving platoons without stopping, durations vary widely, very responsive
- **Shoulder periods** – Shift toward queue management and more defined coordination
- **Saturation** – Queue management, less responsive to individual vehicles, heavy emphasis on dominant flows

Connected Vehicles

Connected Vehicle Vision

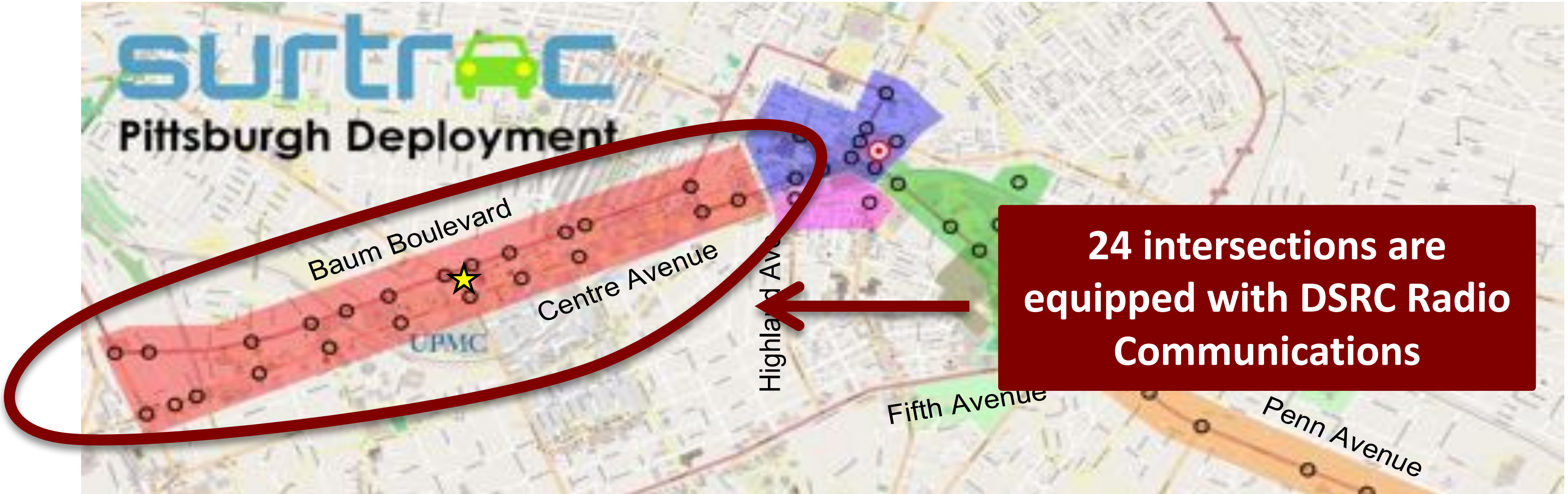
- Connected vehicles will enable new, smarter signal capabilities
  - Better sensing, mode detection
  - Incident detection and alerting
  - Real-time routing
- Ubiquitous sensing technologies will expand traveler awareness
  - Intersections will act as local gateways to real-time information streams and analyses
  - Signal networks will form the back-bone of an Urban Information Grid




2-int Route-sending Delay Improvement over Surtrac
Delay Improvement (%)
Vehicles Sending Routes (%)
route-sending vehs
all vehicles
non-sending vehs
0
5
10
15
20
25
30
35
40
10
20
30
40
50
60
70
80
90
100

Existing CV Deployment

- 24 of our 50 intersections have DSRC roadside equipment
- Also piloting cellular alongside DSRC



Transit signal priority

- Surtrac can accommodate use of external TSP systems, either by allowing these systems to override Surtrac, or by incorporating their requests
- Internal Transit Signal Optimization (TSO) process is also available. This allows transit to be directly factored into optimization and to predict arrival, rather than forcing reactive TSP operations

Installation

Installation

Controller

Surtrac Processor

Video Camera (Detection)

IP Radio (Communication to Neighbors)

DSRC Radio (Communication to Vehicles)

Surtrac processor

- Wide temperature embedded computer
- Commodity computer
- 6 x 6 x 4 inches
- Runs Linux
- Other form factors possible

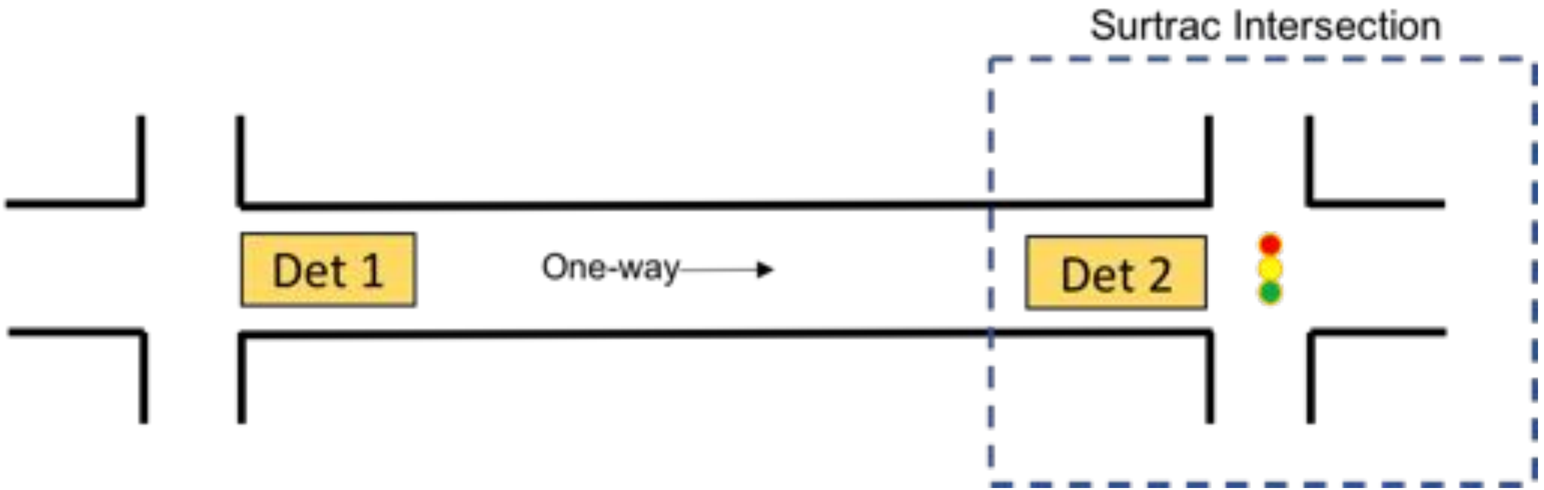
Communications

- Requires reliable Ethernet network between intersections
- Typically use IPv4 (IPv6 supported)
- Remote connection preferred (connection to TMC, cell modem, etc.)
- Fiber is best, wireless radios work well

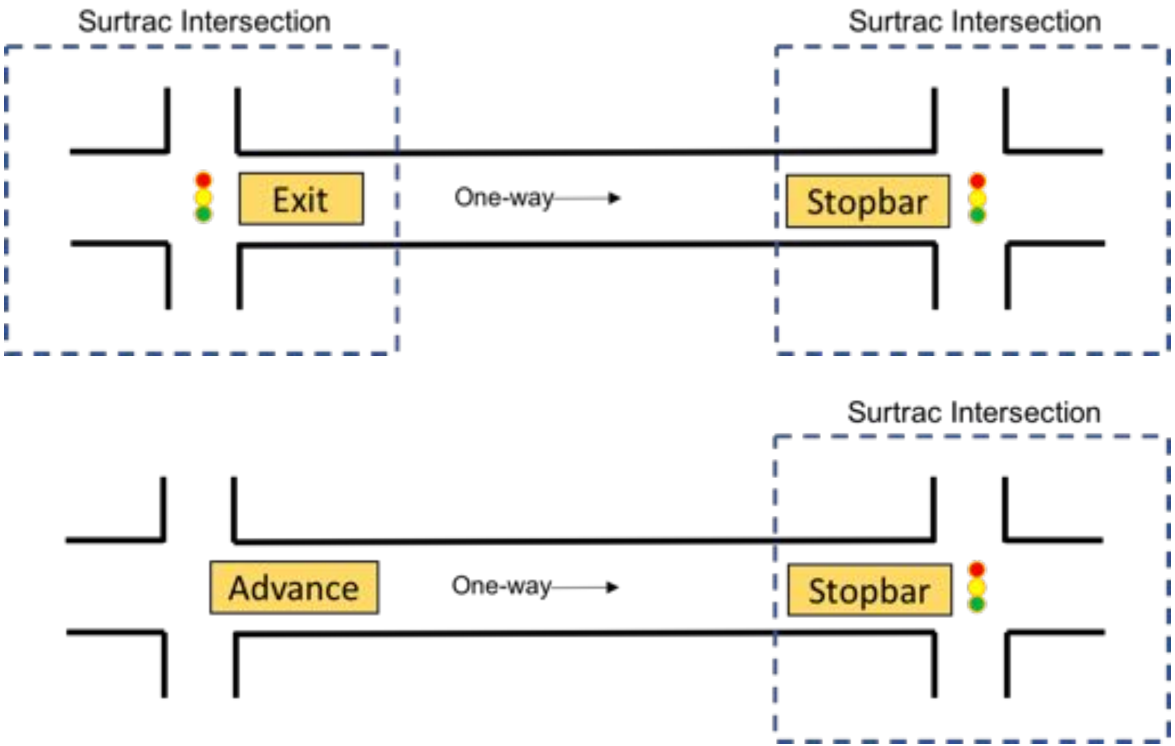
Detection

- Surtrac supports many detection vendors (developed or under development)
  - FLIR, Autoscope, Wavetronix, Iteris, Citilog, Gridsmart, ...
- Loops can be supported, but are not recommended

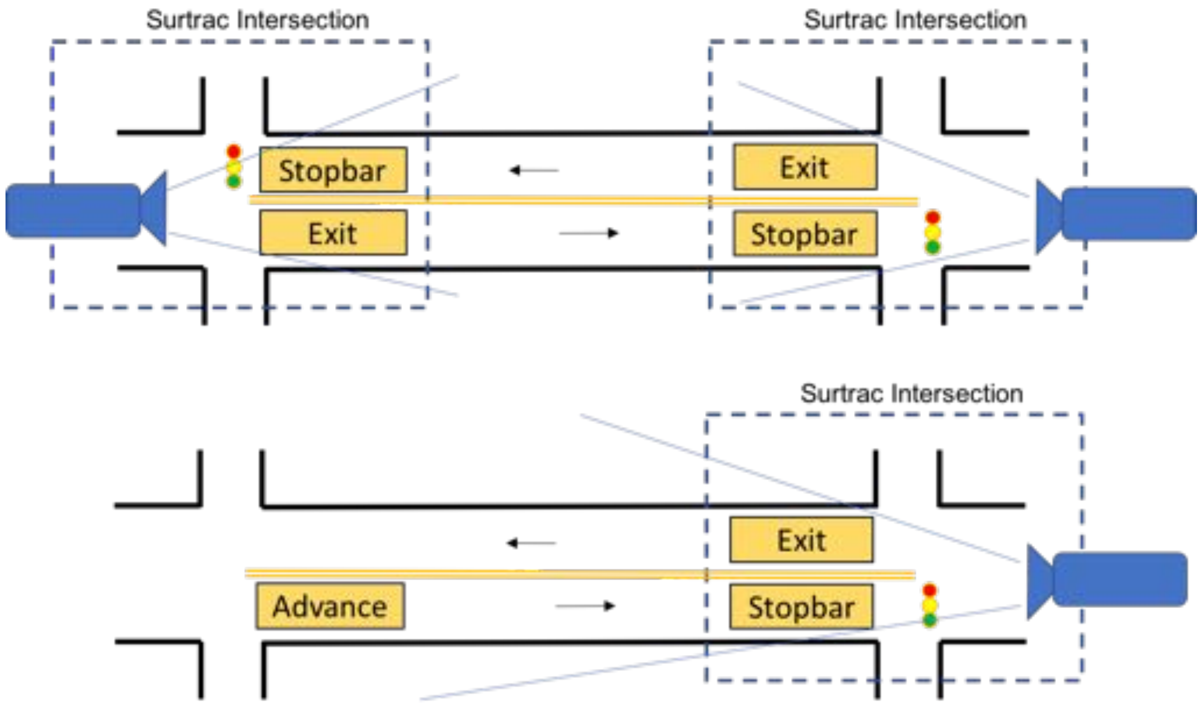
Required Detection Locations



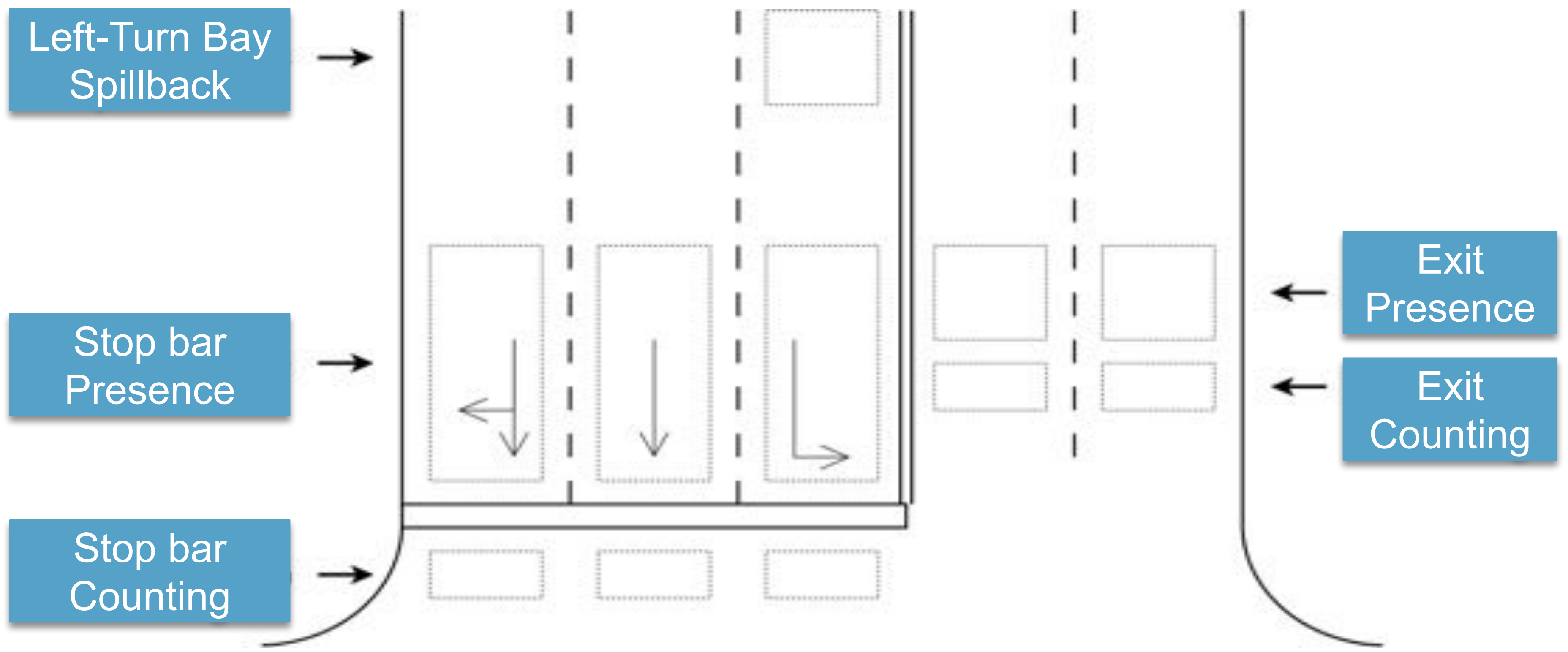
Detection Zone Types in Surtrac



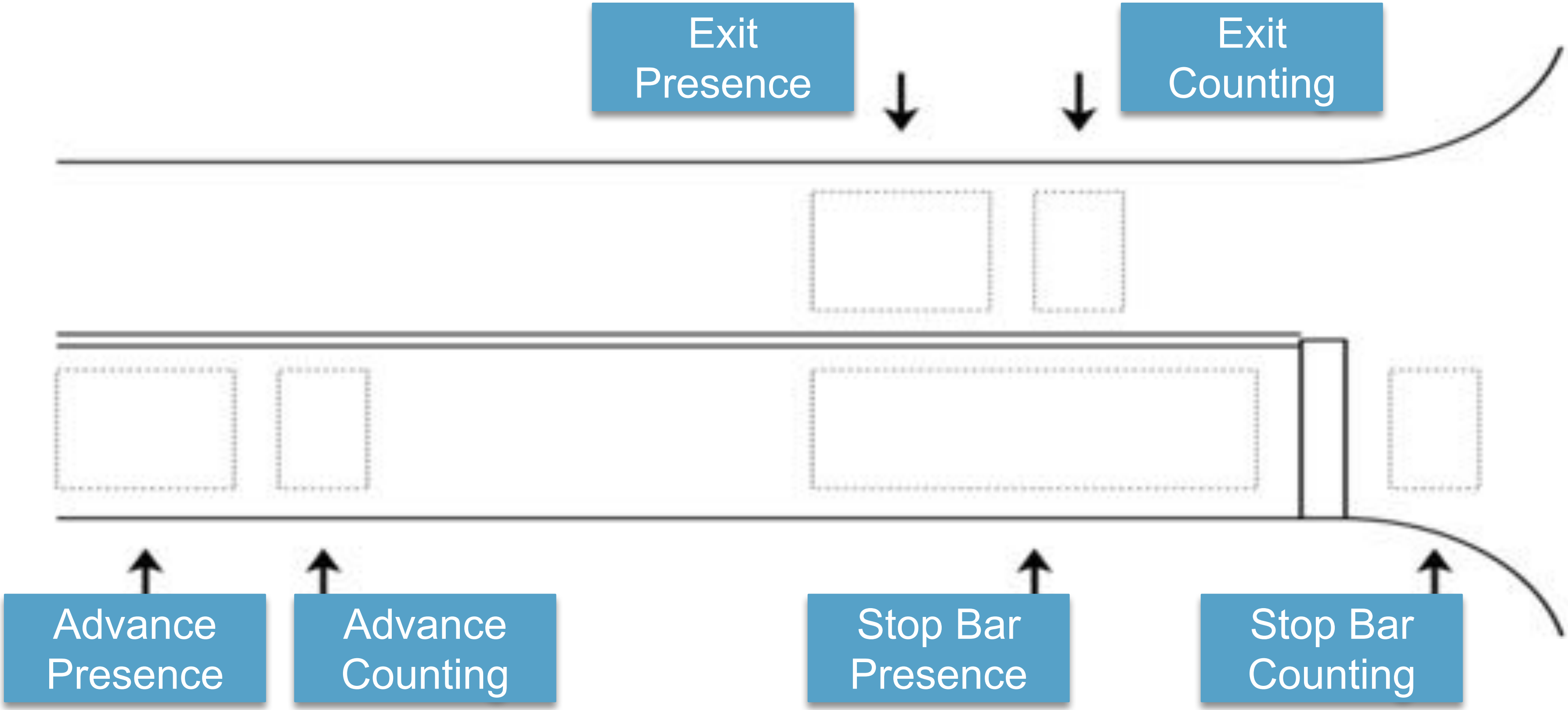
Achieving Detection in Deployment



Detection – Interior Approach



Detection – Edge Approach

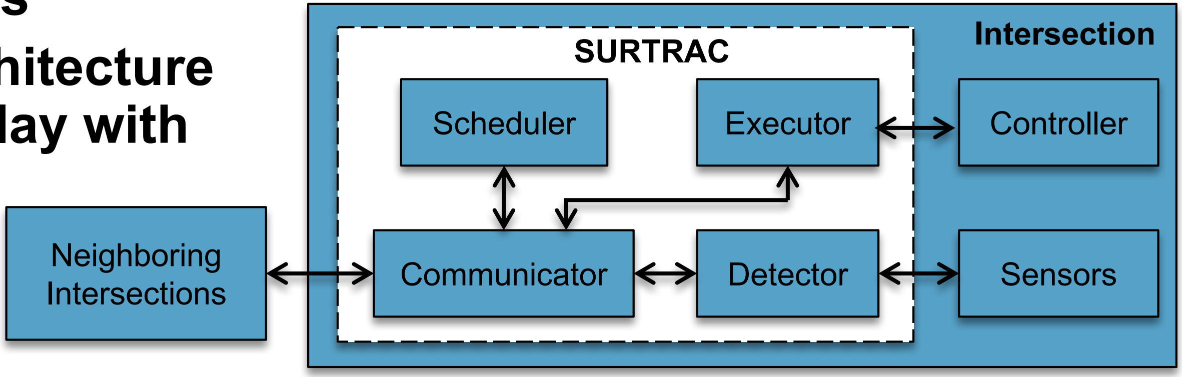


Controller compatibility

- Surtrac is designed to be modular, so it is easy to develop and deploy integrations to controllers, detection, and other systems
- Surtrac is compatible with most controllers, including Siemens, Econolite, McCain, Intelight, and even 170 controllers
- Most interfaces use NTCIP, other options possible as necessary

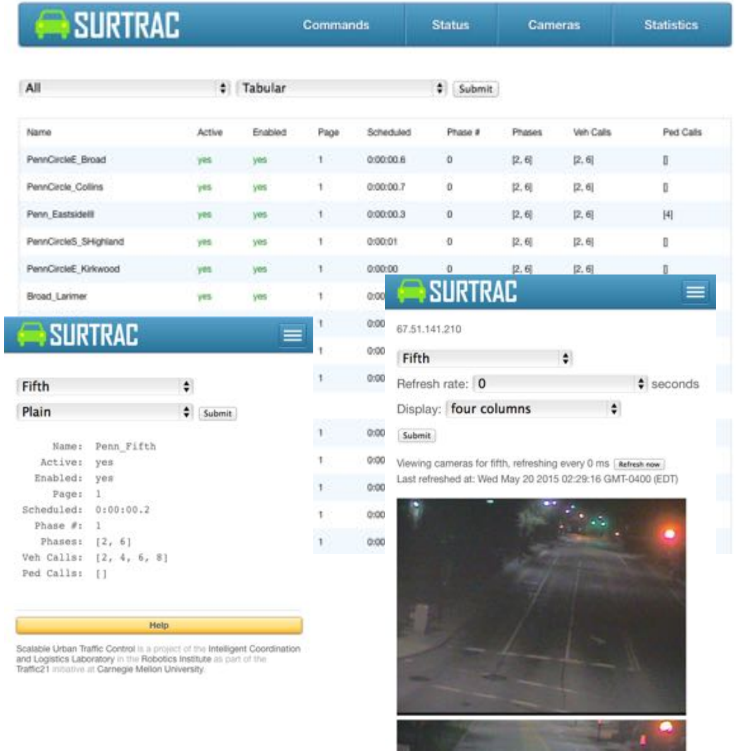
System Operation

- **Operates by over-riding pre-existing timing plans and reverts in the event of unexpected problems**
- **Tolerates loss of communication with its neighbors**
  - Automatically shifts to use of moving average flow forecasting to compensate for any loss in real-time input data streams
- **Reduces traffic flow uncertainty by integrating sensor information from different sources**
- **Service Oriented Architecture facilitates plug and play with different controllers and detection equipment**



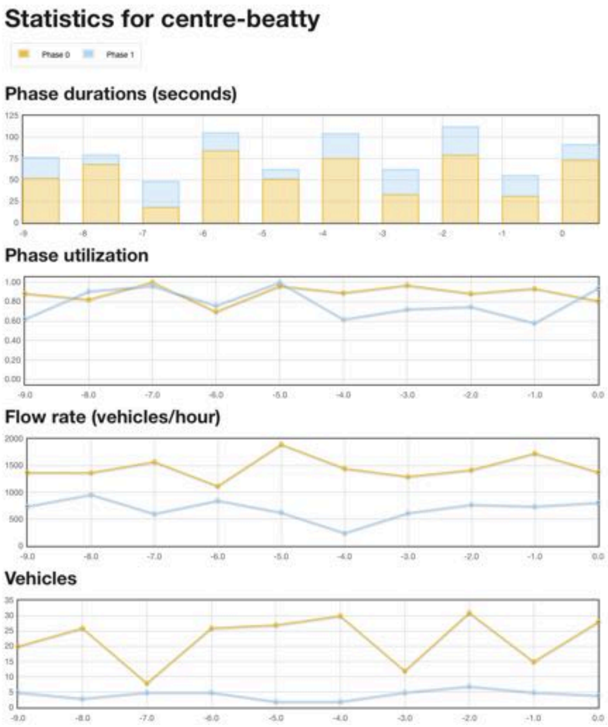
Surtrac interface

- Multiple methods for remote monitoring and control, including mobile web
- Can be integrated with central systems
- Rich data logging
- Flexible alerts



Real-time statistics

- Surtrac produces lots of data that can be used to monitor performance
- Outliers in the data can be used to identify non-recurring sources of congestion



Project Timeline

- Project design
- Install and configure all other required upgrades (detection, networking)
- Install and configure Surtrac processors
- Test detection (Surtrac running passive)
- Test Surtrac (Surtrac running active)
- Tune Surtrac installation
- Operate

Rapid Flow

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Emergency vehicle preemption

- Our preference is for EVP to work directly with the controller
- Surtrac recovers after EVP event is complete
- Surtrac can prepare for upcoming EVP event

Transit signal priority

- Surtrac can accommodate use of external TSP systems, either by allowing these systems to override Surtrac, or by incorporating their requests
- Internal Transit Signal Optimization (TSO) process is also available. This allows transit to be directly factored into optimization and to predict arrival, rather than forcing reactive TSP operations

Key Technical Ideas

Schedule-Driven Intersection Control

- Treat each intersection as a single machine scheduling problem
- Use aggregate representation of traffic flows (as sequences of queues and platoons) to identify input jobs
- Use schedule to decide whether to extend or switch phase

Schedule-Driven Coordination

- Communicate schedules to downstream neighbors to give visibility of future input jobs
- Layer mechanisms for coping with mis-coordinated situations (e.g., spillback) to account for fact that schedules might change

Current Approaches

- **Parametric (Split, Cycle, Offset) Adjustment:**
  - Use historical moving average data; Computationally cheap
  - **Limitation:** Requires some degree of stability in traffic flows over time; not sensitive to real-time variability of demands
- **Reinforcement Learning:**
  - Find policies for mapping local observations to signal actions
  - **Limitation:** Slow to converge and difficult to apply in dynamic traffic flow
- **Online Planning:**
  - Optimize in a planning search space using current observation
  - **Limitation:** Scalability (especially in a long planning horizon)

Network Level Coordination

- **Hierarchical/centralized coordination**

  Limitation: Less than real-time adjustment due to need to integrate traffic data over time

- **Distributed constraint optimization (DCOP)**

  Limitation: extensive computational and communication demands

- **Shared global network view**

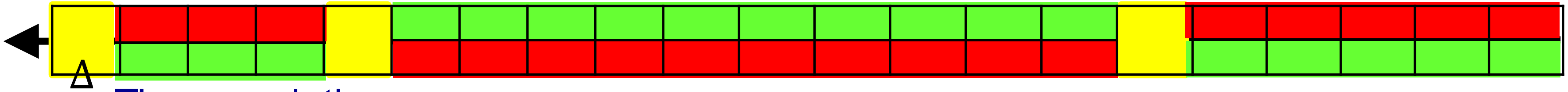
  Limitation: requires a priori specification of dominant flows

Real-Time Challenges

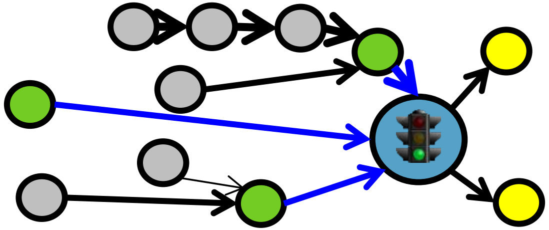
- **Planning Complexity**
  - State Space (Observations): Exponential in a prediction horizon

Multiple Roads, Multiple lanes

  - Action Space (Signal sequences): Exponential in a planning horizon



Time resolution



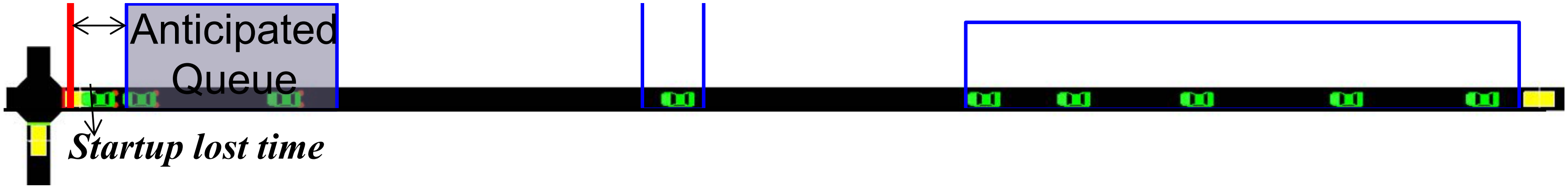
- **Sensing uncertainty**
- **Non-local impacts between intersections**
- One nice property: networked problem structure

Aggregate Flow Representation

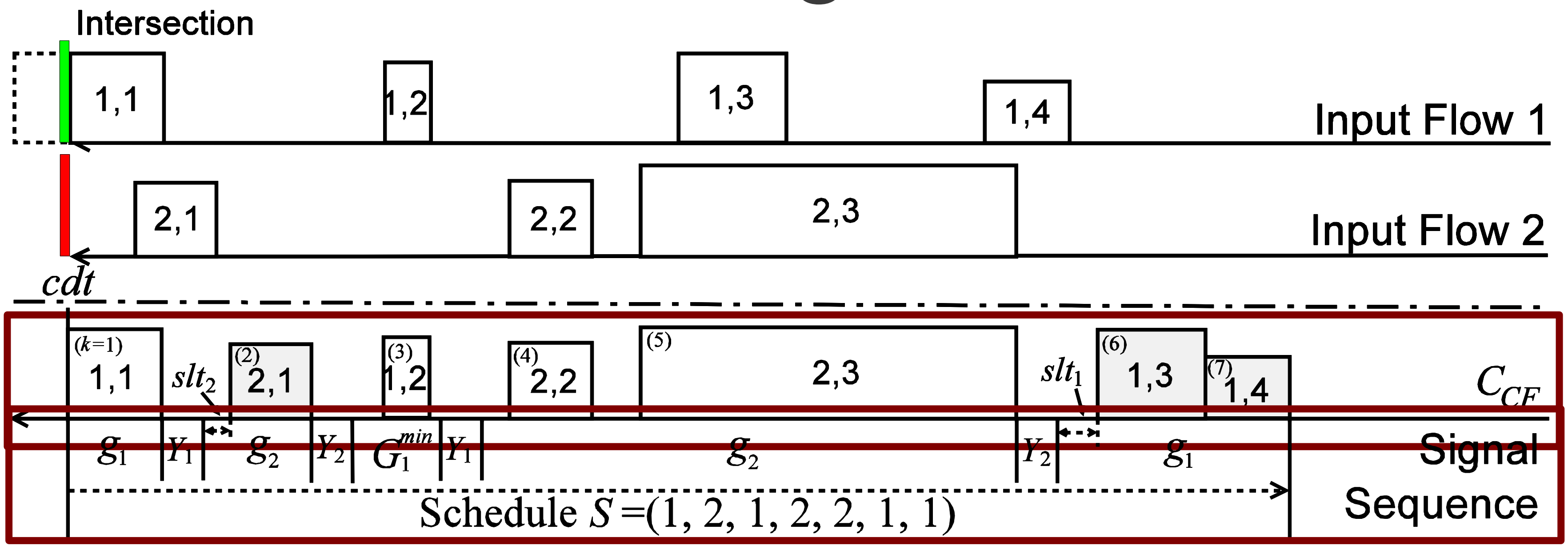
Clusters (jobs): **height = flow rate, width = duration, area = number of vehicles**

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)**

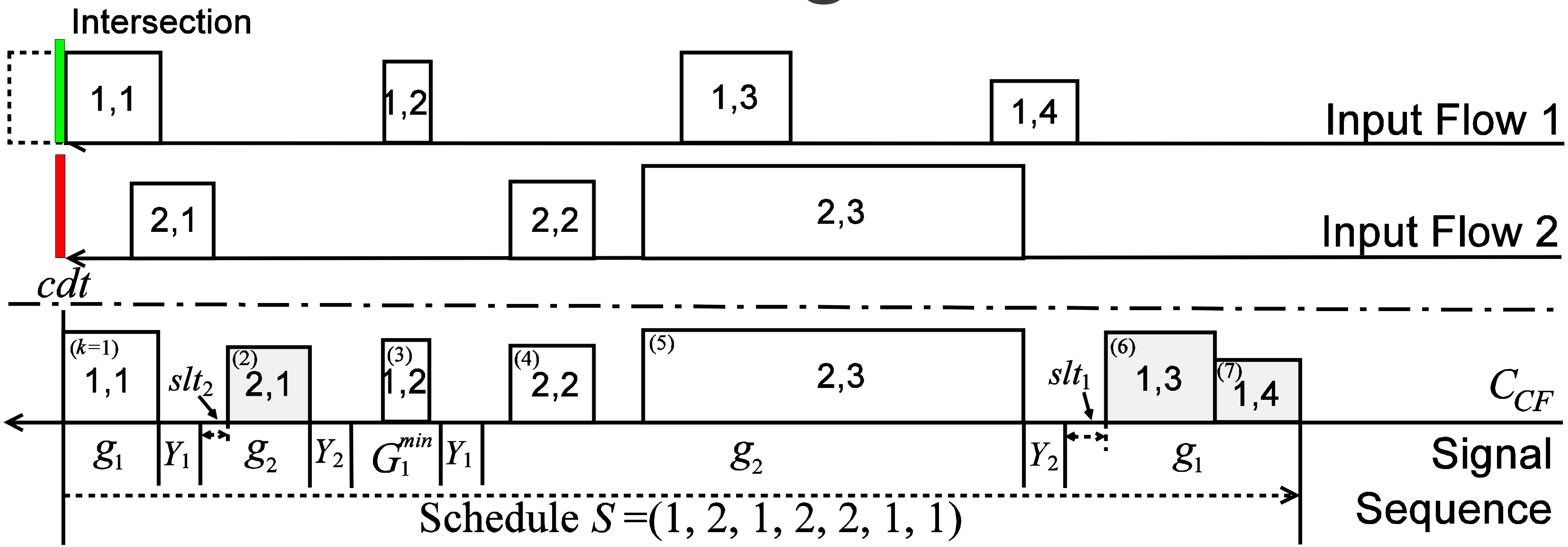


Scheduling Problem



- A **Schedule** = a sequence of all clusters (indivisible *jobs*)
- Schedule → **Planned Signal Sequence** (for traffic light)

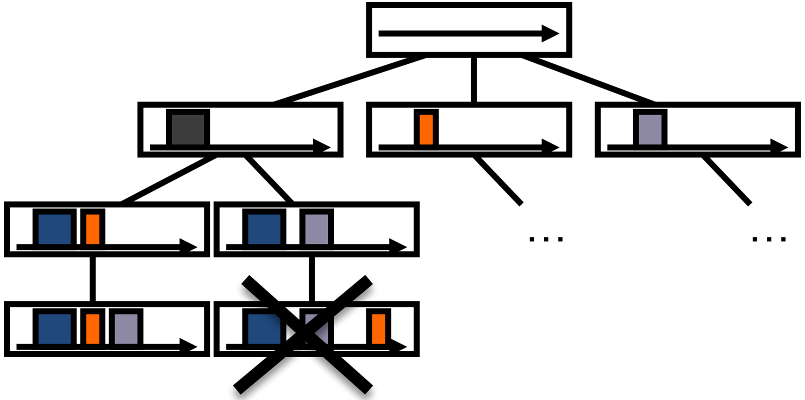
Scheduling Problem



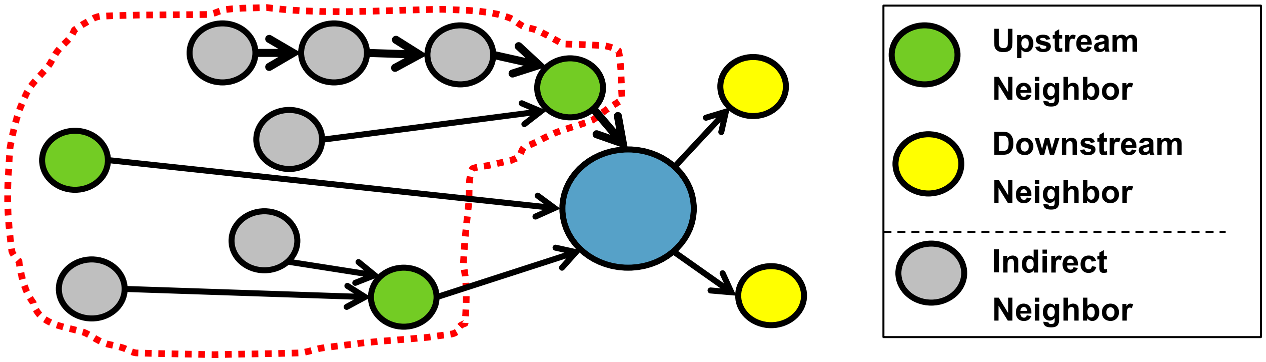
- **Problem:** Minimize the *cumulative delay* of all jobs, subject to
  - timing constraints for safety (yellow time) and fairness (G_i^{min} and G_i^{max} for each phase)

Scheduling Strategy

- Forward dynamic programming search
  - New job added at each decision stage
  - Eliminate dominated solutions at each stage (same current phase, same jobs, *different orders*)
  - Only keep the state with minimum delay for each extension (greedy)
  - Time complexity: $|\text{phases}|^{2} * \Pi\ (|\text{clusters}_i|+1)$



Optimistic Non-local Observation



- Optimistically assume that all neighbors follow their schedules and communicate planned output flows to amplify local views
  - Planned Output Flows => Predicted Input Flows for downstream neighbors
  - Input Flows = Predicted (Local) Input Flows + Predicted (Non-local) Input Flows from upstream neighbors