Planning and Scheduling Approaches for Urban Traffic Control

Stephen F. Smith, Mauro Vallati,
Scott Sanner

Outline

- Introduction to Urban Traffic Control
- Related Works and landscape
- State of the art of P&S Approaches to UTC
  - QTM
  - SURTRAC
  - SimplifAI
- Future directions of the area & Conclusions

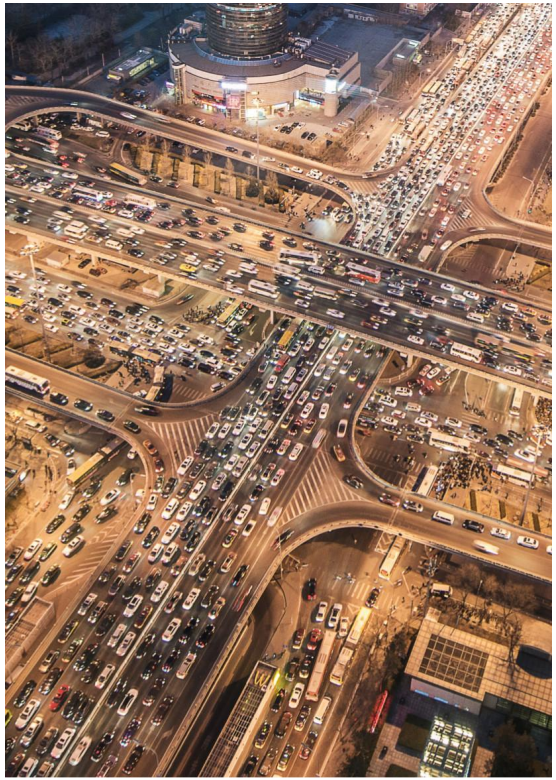
Introduction to Urban Traffic Control

What is UTC about?

In a nutshell: Urban Traffic Control is about dealing with traffic congestion, with the overall goal of *minimising delay*.

- Recurrent congestion
- Unexpected disruption / accidents

Do we have a problem?

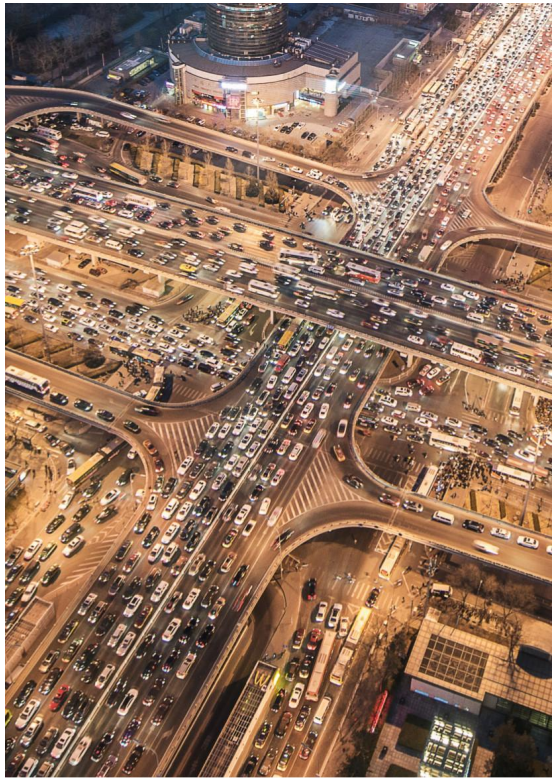


Traffic congestion is increasing worldwide.

The city *immigration* trend is consistently predicted to continue for decades. City population is growing by 1% per annum.

By 2025 there will be 2bn more vehicles on the road.

Do we have a problem? (a UK focus - 1 year)



- Drivers spend 32 hours per annum in traffic jams
- Congestion costs 30 bn to the **economy**

- **Health**..
  - Traffic pollution contributes to (at least) *40,000* premature deaths
  - Traffic accidents contributes to *2,000* premature deaths.

Is the problem going to last?

Two elements are re-shaping the transport area:

- Mobility-as-a-service: a shift away from personally-owned modes of transportation and towards mobility solutions that are consumed as a service.
- Connected Autonomous Vehicles.

Future: optimism or pessimism?

Will MaaS & CAVs relief congestion in the long term?

- CAVs have the potential to improve the throughput of roads by more than 100%
- Improved safety, better service, faster transport

But..

- Travel demand is expected to increase as a consequence of making road travel cheaper, more comfortable, more efficient and accessible
- Increase of number of vehicles (shared and owned) between 30-90%
- Reduction in multi-modal journeys, and reduction in the use of train / flights.

(Analysis made in the C2ART project)

We do have a problem now.

and there will be the same problem **in the future**, despite (or even worsen by) new technologies and the paradigm shift.

Traditional approaches for traffic control

- Optimise Traffic Signal Phases
- Variable Message Signs
- Variable Speed Limits
- Lanes Reduction

...but in Urban Traffic Control...

- Optimise Traffic Signal Phases
- ~~Variable Message Signs~~
- ~~Variable Speed Limits~~
- ~~Lanes Reduction~~

And it can lead to unpleasant surprises

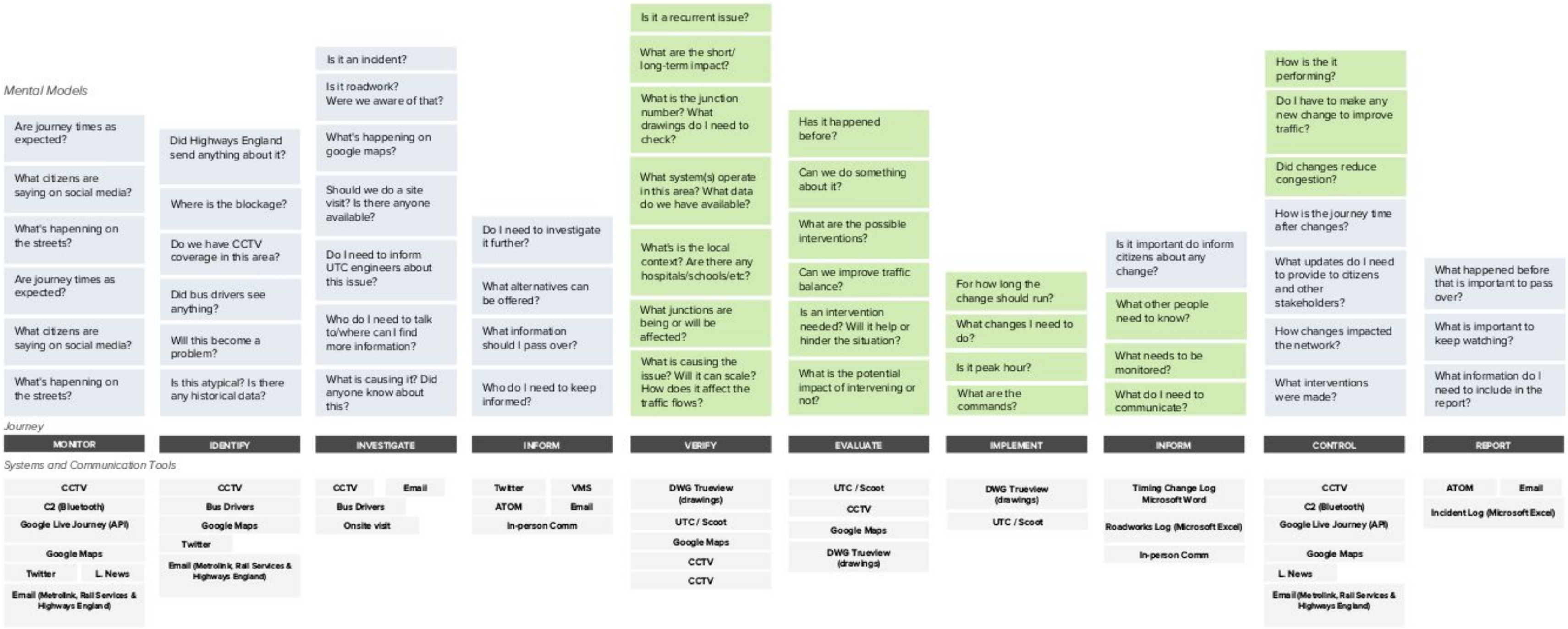
Technically, this is a gridlock. (A quite unusual one, though).

UTC: what is deployed?

- A large number of junctions are usually controlled using **fixed-time** traffic light phases.
  - No information on actual traffic.
- A few junctions are controlled using reactive methods, such as **SCOOT** or **SCATS**.
  - Fast, but can control small areas of the network.
- **Model Predictive Controls** have been engineered to control signals for larger regions.
  - not widespread in application for “real-time” decisions. (computationally expensive and usually slow to converge)

How traffic authorities operate?

| Network Monitoring Officer | UTC Engineer (Control Strategies)



Journey	*Mental Models*	*Systems and Communication Tools*
MONITOR	Are journey times as expected? What citizens are saying on social media? What's happening on the streets? Are journey times as expected? What citizens are saying on social media? What's happening on the streets?	CCTV C2 (Bluetooth) Google Live Journey (API) Google Maps Twitter L. News Email (Metrolink, Rail Services & Highways England)
IDENTIFY	Did Highways England send anything about it? Where is the blockage? Do we have CCTV coverage in this area? Did bus drivers see anything? Will this become a problem? Is this atypical? Is there any historical data?	CCTV Bus Drivers Google Maps Twitter Email (Metrolink, Rail Services & Highways England)
INVESTIGATE	Is it an incident? Is it roadwork? Were we aware of that? What's happening on google maps? Should we do a site visit? Is there anyone available? Do I need to inform UTC engineers about this issue? Who do I need to talk to/where can I find more information? What is causing it? Did anyone know about this?	CCTV Email Bus Drivers Onsite visit
INFORM	Do I need to investigate it further? What alternatives can be offered? What information should I pass over? Who do I need to keep informed?	Twitter VMS ATOM Email In-person Comm
VERIFY	Is it a recurrent issue? What are the short/ long-term impact? What is the junction number? What drawings do I need to check? What system(s) operate in this area? What data do we have available? What's is the local context? Are there any hospitals/schools/etc? What junctions are being or will be affected? What is causing the issue? Will it can scale? How does it affect the traffic flows?	DWG Trueview (drawings) UTC / Scoot Google Maps CCTV CCTV
EVALUATE	Has it happened before? Can we do something about it? What are the possible interventions? Can we improve traffic balance? Is an intervention needed? Will it help or hinder the situation? What is the potential impact of intervening or not?	UTC / Scoot CCTV Google Maps DWG Trueview (drawings)
IMPLEMENT	For how long the change should run? What changes I need to do? Is it peak hour? What are the commands?	DWG Trueview (drawings) UTC / Scoot
INFORM	Is it important do inform citizens about any change? What other people need to know? What needs to be monitored? What do I need to communicate?	Timing Change Log Microsoft Word Roadworks Log (Microsoft Excel) In-person Comm
CONTROL	How is the it performing? Do I have to make any new change to improve traffic? Did changes reduce congestion? How is the journey time after changes? What updates do I need to provide to citizens and other stakeholders? How changes impacted the network? What interventions were made?	CCTV C2 (Bluetooth) Google Live Journey (API) Google Maps L. News Email (Metrolink, Rail Services & Highways England)
REPORT	What happened before that is important to pass over? What is important to keep watching? What information do I need to include in the report?	ATOM Email Incident Log (Microsoft Excel)

How traffic authorities operate? (1)

Mental Models

MONITOR	IDENTIFY	INVESTIGATE	INFORM
Are journey times as expected?	Did Highways England send anything about it?	Is it an incident?	Do I need to investigate it further?
What citizens are saying on social media?	Where is the blockage?	Is it roadwork? Were we aware of that?	What alternatives can be offered?
What's hapenning on the streets?	Do we have CCTV coverage in this area?	What's happening on google maps?	What information should I pass over?
Are journey times as expected?	Did bus drivers see anything?	Should we do a site visit? Is there anyone available?	Who do I need to keep informed?
What citizens are saying on social media?	Will this become a problem?	Do I need to inform UTC engineers about this issue?	
What's hapenning on the streets?	Is this atypical? Is there any historical data?	Who do I need to talk to/where can I find more information?	
		What is causing it? Did anyone know about this?	

Journey

Systems and Communication Tools

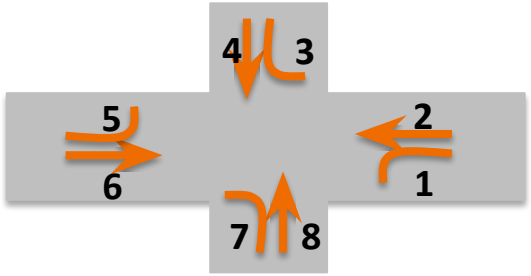
MONITOR	IDENTIFY	INVESTIGATE	INFORM
CCTV	CCTV	CCTV	Twitter
C2 (Bluetooth)	Bus Drivers	Email	VMS
Google Live Journey (API)	Google Maps	Bus Drivers	ATOM
Google Maps	Twitter	Onsite visit	Email
Twitter	Email (Metrolink, Rail Services & Highways England)		In-person Comm
L. News			
Email (Metrolink, Rail Services & Highways England)			

How traffic authorities operate? (2)

VERIFY	EVALUATE	IMPLEMENT	INFORM	CONTROL
Is it a recurrent issue?				How is the it performing?
What are the short/ long-term impact?				Do I have to make any new change to improve traffic?
What is the junction number? What drawings do I need to check?	Has it happened before?			Did changes reduce congestion?
What system(s) operate in this area? What data do we have available?	Can we do something about it?			How is the journey time after changes?
What's is the local context? Are there any hospitals/schools/etc?	What are the possible interventions?		Is it important do inform citizens about any change?	What updates do I need to provide to citizens and other stakeholders?
What junctions are being or will be affected?	Can we improve traffic balance?	For how long the change should run?	What other people need to know?	How changes impacted the network?
What is causing the issue? Will it can scale? How does it affect the traffic flows?	Is an intervention needed? Will it help or hinder the situation?	What changes I need to do?	What needs to be monitored?	What interventions were made?
	What is the potential impact of intervening or not?	Is it peak hour?	What do I need to communicate?	
		What are the commands?		
DWG Trueview (drawings)	UTC / Scoot	DWG Trueview (drawings)	Timing Change Log Microsoft Word	CCTV
UTC / Scoot	CCTV	UTC / Scoot	Roadworks Log (Microsoft Excel)	C2 (Bluetooth)
Google Maps	Google Maps		In-person Comm	Google Live Journey (API)
CCTV	DWG Trueview (drawings)			Google Maps
CCTV				L. News
				Email (Metrolink, Rail Services & Highways England)

Landscape of related works in AI

Traffic Signal Plans



Movement Phases:

Signal Timing Plan:

- Conventional signal systems use pre-programmed timing plans, sometimes with simple actuation
- Adaptive signal systems sense approaching traffic flows and dynamically adjust timing plans in real-time

Approaches to Adaptive Signal Control

- Centralized systems that adjust timing plan parameters have had the most success (SCOOT, SCATS, ACLITE)
  - Can be limiting with respect to real-time response
- Online intersection planning approaches focus on the real-time problem and extend naturally to network level (OPAC, RHODES)
  - But computational requirements restrict planning horizon and/or timing plan precision, which can limit effectiveness
- If single dominant flow, then use of shared global timing plan can be effective (IN-SYNC)

AI-Based Traffic Research

- Reinforcement learning – [Bazaan 2006, MARLIN – U. Toronto 2013]
- Reservation-based intersection control approaches – [Stone et. al]
- Real-time schedule-driven traffic control [Smith et. al. 2013]
- MILP-based network optimization – [Guilliard et al. 2015]
- PDDL-based planning of signal timings for congestion response – [Valeti et. al. 2016]
- Periodic, data-driven timing plan optimization [DiDi]

P&S Approaches: Queue Transmission Model (QTM)

A Non-homogenous Time Mixed Integer LP Formulation for Traffic Signal Control (TRR-16)

Iain Guilliard,
Scott Sanner, Felipe Trevizan

Traffic Signal Control as Optimization

- Encode a **macroscopic model of traffic flow**
  - Often a piecewise linear, discrete time model
  - Let the traffic signals be variables to optimize

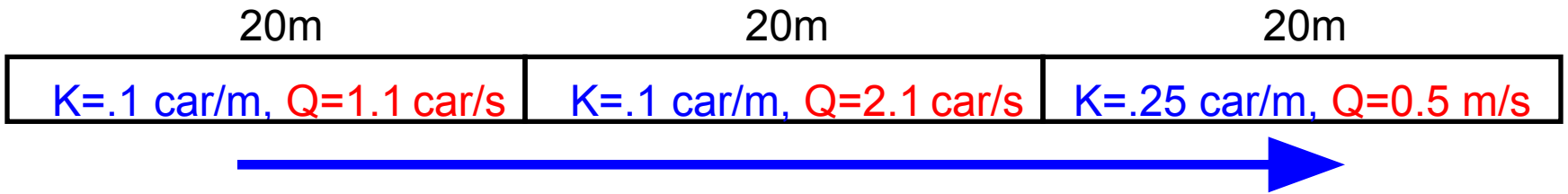
- Define an objective (e.g., minimum delay) and starting state

- Use optimization tools (e.g., MILP solvers) to find best signal control over a time horizon

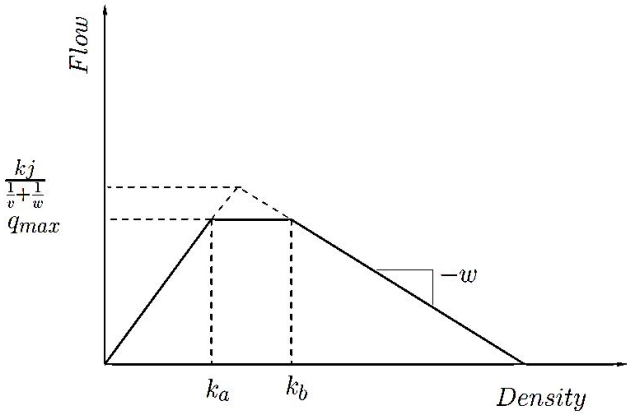
Overview

- Traffic Signal Control via Optimization
  - Existing models & optimization methods
    - **CTM:** Large models, hard to scale
    - **LTM:** Model is compact, but fidelity less than CTM

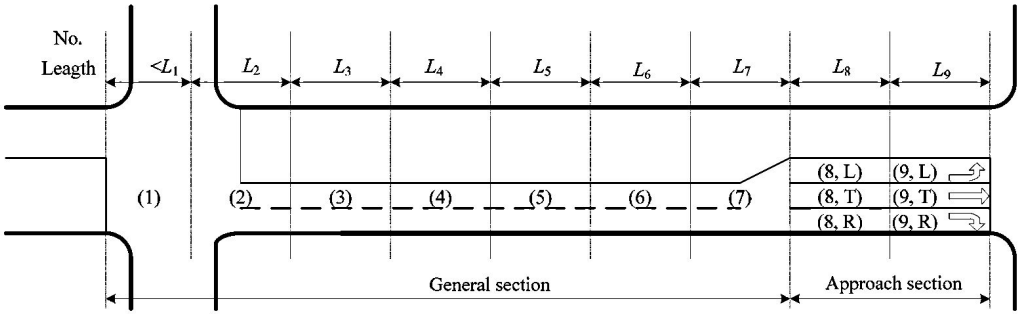
Cell Transmission Model (CTM)



- CTM setup (Daganzo 1994):
  - **Variables:** flow rate, density
  - **Constants:** max capacity, peak and jam densities
  - Piecewise linear difference equation transition model
  - **Provides realistic traffic flow models including shockwaves**

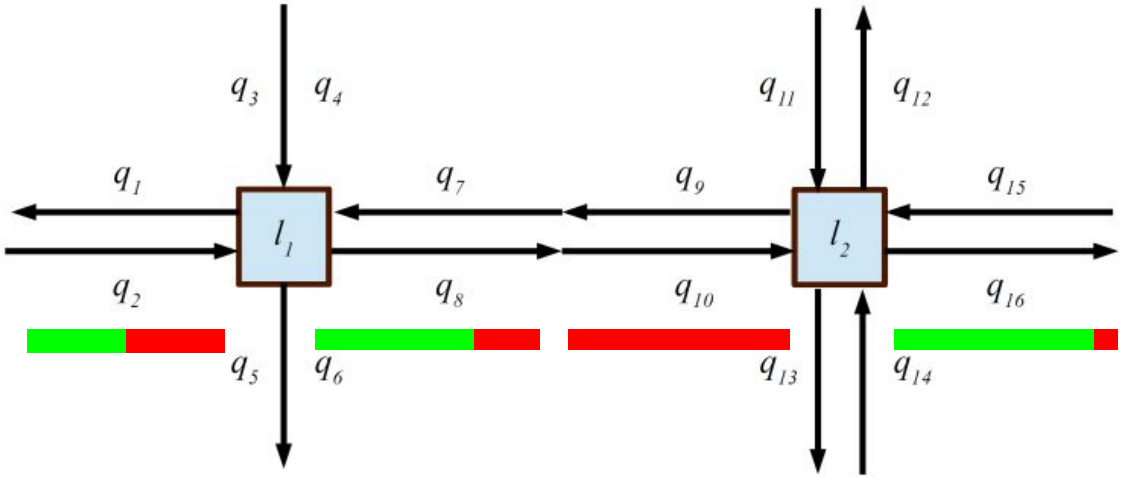


But the CTM requires a **lot** of cells…



Is there a more compact macrosimulation model?

Link Transmission Model (LTM)

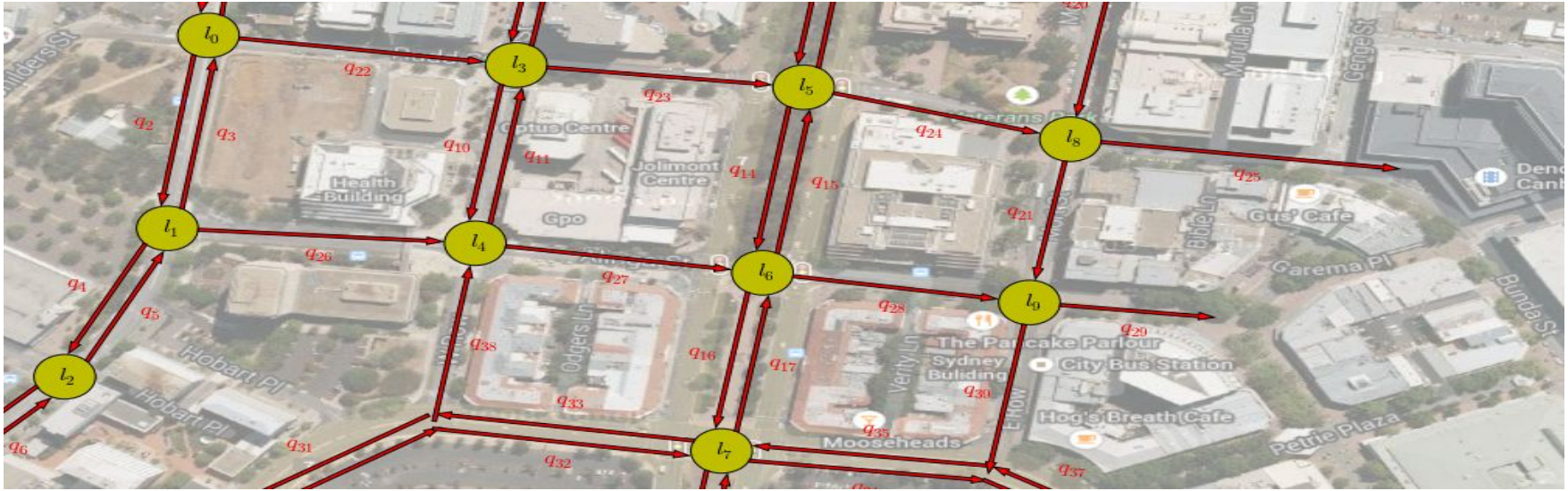


- Link is a traffic queue vertically stacked at stopline
- **Limitations** (Gartner 2002, Han et al 2012)
  - Some versions poorly model delay
  - Single traffic boundary (single platoon)

Overview

- Traffic Signal Control via Optimization
  - Existing models & optimization methods
    - **CTM:** Large models, hard to scale
    - **LTM:** Model is compact, but fidelity less than CTM
  - **QTM:** Queue Transmission Model (Guilliard et al, 2016)
    - **Compact, moderate fidelity MILP-based model**

QTM: A New Link-based Model



- Each link is a FIFO queue of traffic
- Vertically stacked at stop line
- Explicitly model link delays (travel time between intersections)

Non-Homogenous Link Flow LP

- Constraints:

$$in_j^n \le Q_j^{IN}$$

$$q_{j,in}^n = in_j^n \Delta t^n + \sum_{i=1}^{Q} f_{i,j}^n \Delta t^n$$

.

$$out_j^n \le Q_j^{OUT}$$

Non-homogenous Δt!

$$q_{j,out}^n = out_j^n \Delta t^n + \sum_{i=1}^{Q} f_{j,i}^n \Delta t^n$$

.

$$f_{j,i}^n = F_{j,i}^{PROB} \sum_{k=1}^{Q} f_{j,k}^n$$

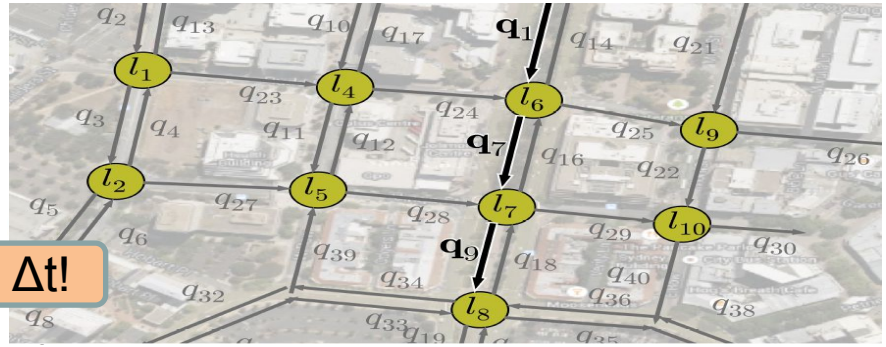
$$q_{j,out}^n \le q_j^{n-1}$$

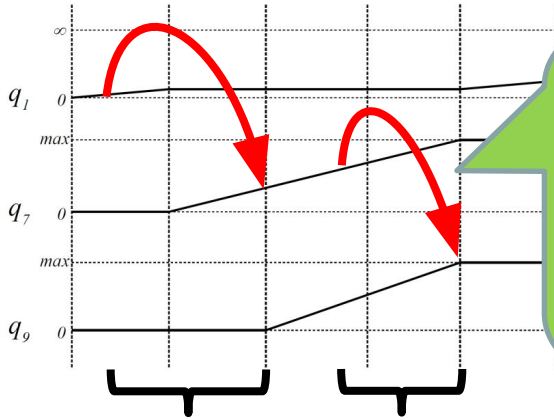
$$q_j^n \le Q_j^{MAX}$$

$$q_j^n = q_j^{n-1} - q_{j,out}^{n-1} + q_{j,in}^{n-delay}$$

.

$$q_{j,in}^{n-delay} + \sum_{k=n-\delta+2}^{n-1} q_{k,in}^k \le Q_j^{MAX} - q_j^{n-1}$$



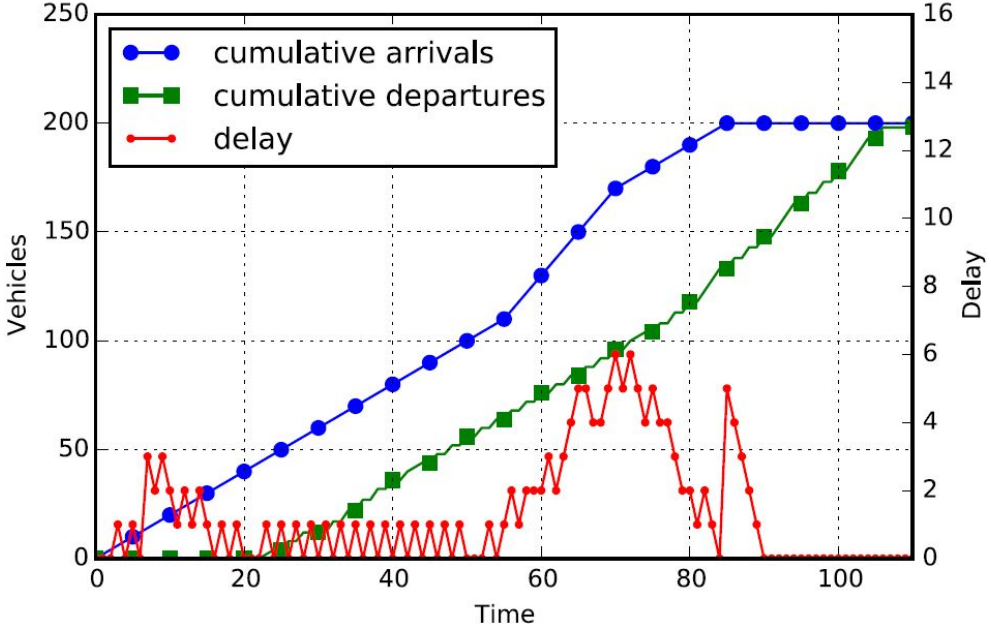


Non-homogenous allows exact modeling of link delays + compact models with fewer time steps

q1-q7 delay q7-q9 delay

What to Optimize?

- **Minimize delay**
  - i.e. area between arrival & departure curves
  - equal to car-seconds of delay



- **Formally:** $$\left(\sum_{n=1}^{N}\sum_{j=1}^{Q}(T^{MAX}-t^n+1)q_{j,out}^n+\sum_{n=1}^{N}\sum_{j=1}^{Q}(T^{MAX}-t^n+1)in_j^n\right)$$

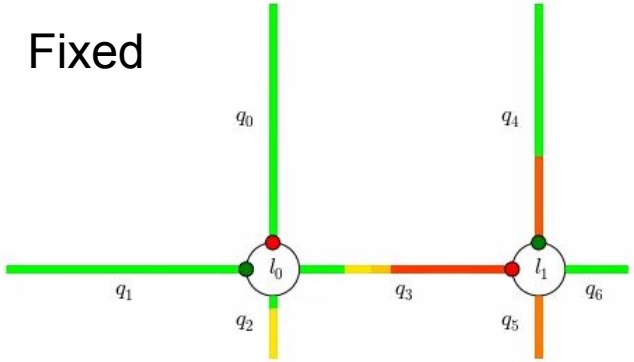
Define the MILP and Solve!

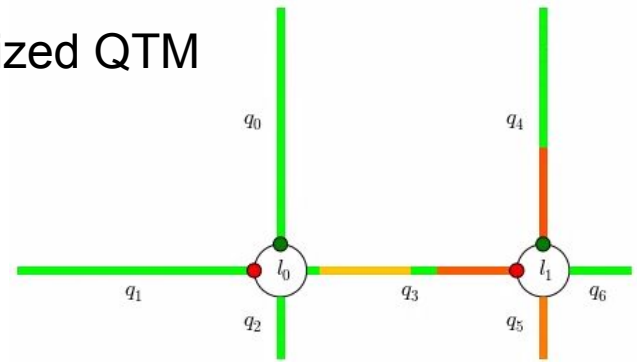
- Determine Δt's, instantiate variables
- p – binary phase, q – queue volumes, f – flows

p0_0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0
p0_1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
p0_2	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0
p0_3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
d0_0	0	1	2	3	3	3	3	3	0	1	2	3	3	3	3	3	0	1	2	3
d0_2	3	3	3	3	0	1	2	3	3	3	3	3	0	1	2	3	3	3	3	3
q0	0	2	2	4	6	8	10	10	6	2	2	4	6	8	10	10	6	2	2	4
q1	0	2	4	6	4	2	2	4	6	8	10	10	6	2	2	4	6	8	10	10
q2	0	0	2	0	4	4	2	0	4	4	2	0	4	4	2	0	4	4	2	0
f_^ 2	2	-0	2	0	0	0	0	0	4	4	2	0	0	0	0	0	4	4	2	0
f_ 2	0	-0	0	0	4	4	2	0	0	0	0	0	4	4	2	0	0	0	0	0
q0_in	2	2	2	2	2	2	2	0	0	0	2	2	2	2	2	0	0	0	2	2
q1_in	2	2	2	2	2	2	2	2	2	2	2	0	0	0	2	2	2	2	2	0
q2_in	2	0	2	0	4	4	2	0	4	4	2	0	4	4	2	0	4	4	2	0
q0_out	2	0	2	0	0	0	0	0	4	4	2	0	0	0	0	0	4	4	2	0
q1_out	0	0	0	0	4	4	2	0	0	0	0	0	4	4	2	0	0	0	0	0
q2_out	2	0	0	2	0	4	4	2	0	4	4	2	0	4	4	2	0	4	4	2

Fixed Time vs. QTM Optimized Control

- Peak queue build up:

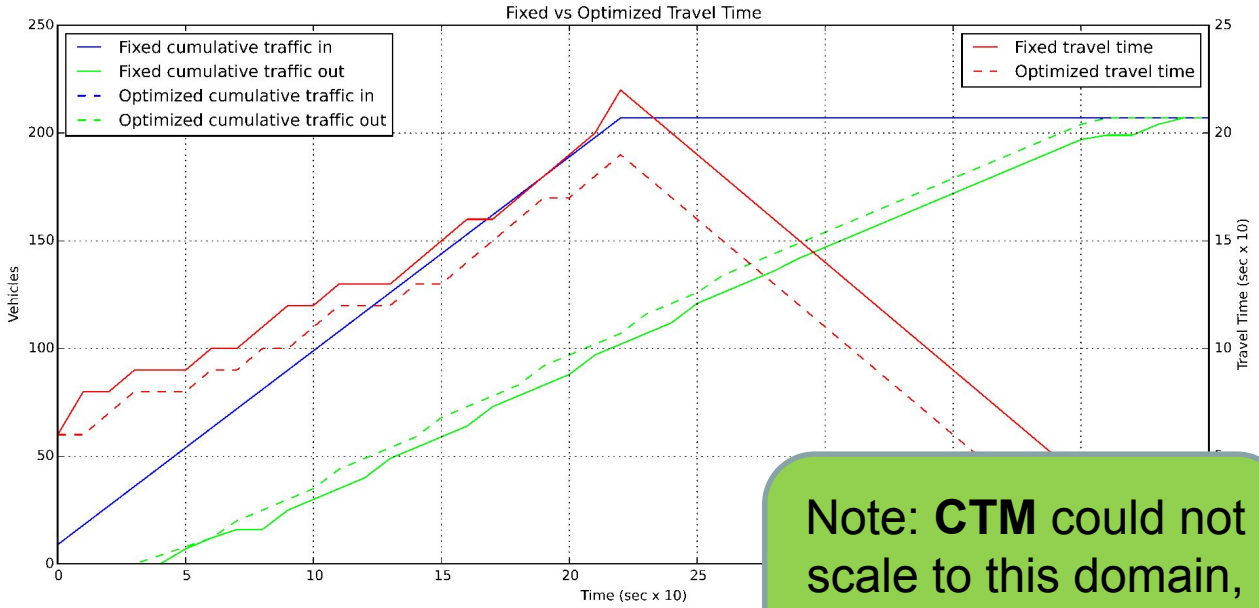




Time to clear network:

- Fixed: 7 min 20 sec
- Optimized QTM: 6 min 40 sec ⇒ 40 sec less delay

Quantitative Comparison of Fixed Time vs. QTM



Note: **CTM** could not scale to this domain, **LTM** model not accurate enough

Time to clear network:

- Fixed (solid): 7 min 20 sec
- Optimized QTM (dashed): 6 min 40 sec ⇒ 40 sec less delay

QTM Summary

- QTM is a compact macroscopic model of traffic flow
- QTM + MILP solver = optimal signal control
  - If there is a complex, optimal pattern, MILP finds it
- Moderate scalability up to ~10 intersections
  - Not clear how to optimally scale to large cities

P&S Approaches: SURTRAC

INTERSECTIONS ARE DUMB

Unnecessarily disrupt traffic flows

- Congestion costs US Cities $160B annually in time and fuel
- Drivers spend 40% of their time on surface streets idling

Programmed for *average* conditions

- Actual conditions vary greatly and change over time

Only use sensors in mundane ways

- Traffic signal control intelligence has not advanced in 40 years

surtrac

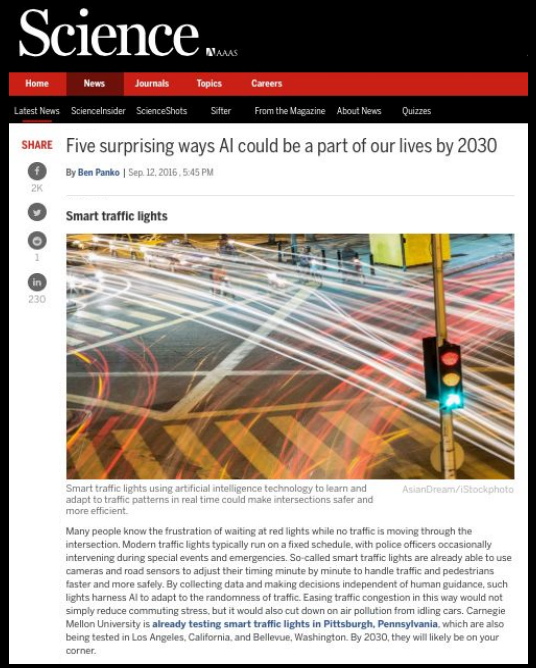
Scalable Urban Traffic Control

Goal: Real-time optimization of urban road networks

Technical Approach:

Collaborative Online Planning

- *Decentralized control*
- *Coordinated Action*



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Five surprising ways AI could be a part of our lives by 2030

By Ben Panko | Sep. 12, 2016 , 5:45 PM

Smart traffic lights

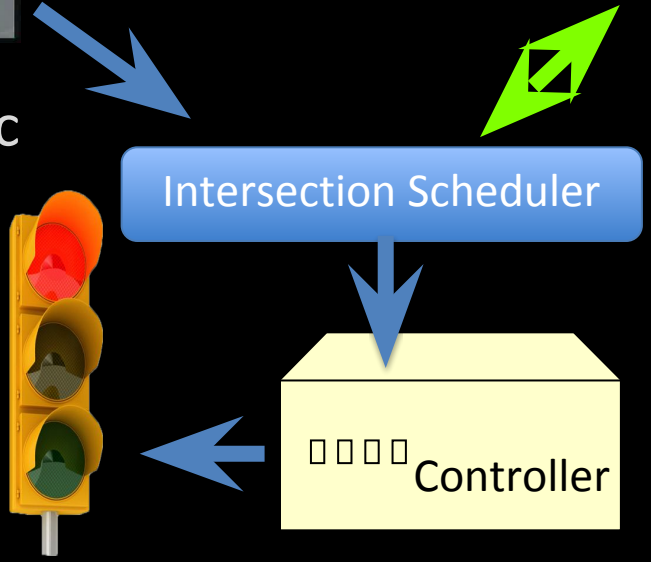
Smart traffic lights using artificial intelligence technology to learn and adapt to traffic patterns in real time could make intersections safer and more efficient.

AsianDream/iStockphoto

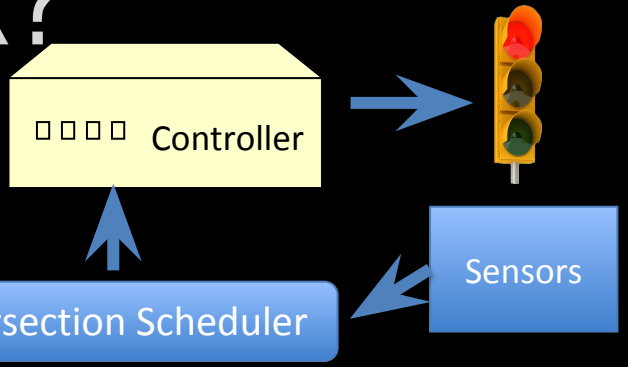
Many people know the frustration of waiting at red lights while no traffic is moving through the intersection. Modern traffic lights typically run on a fixed schedule, with police officers occasionally intervening during special events and emergencies. So-called smart traffic lights are already able to use cameras and road sensors to adjust their timing minute by minute to handle traffic and pedestrians faster and more safely. By collecting data and making decisions independent of human guidance, such lights harness AI to adapt to the randomness of traffic. Easing traffic congestion in this way would not simply reduce commuting stress, but it would also cut down on air pollution from idling cars. Carnegie Mellon University is **already testing smart traffic lights in Pittsburgh, Pennsylvania**, which are also being tested in Los Angeles, California, and Bellevue, Washington. By 2030, they will likely be on your corner.

How Does Surtraffic Work?

1. Observe Traffic



2. Compute phase schedule and begin executing

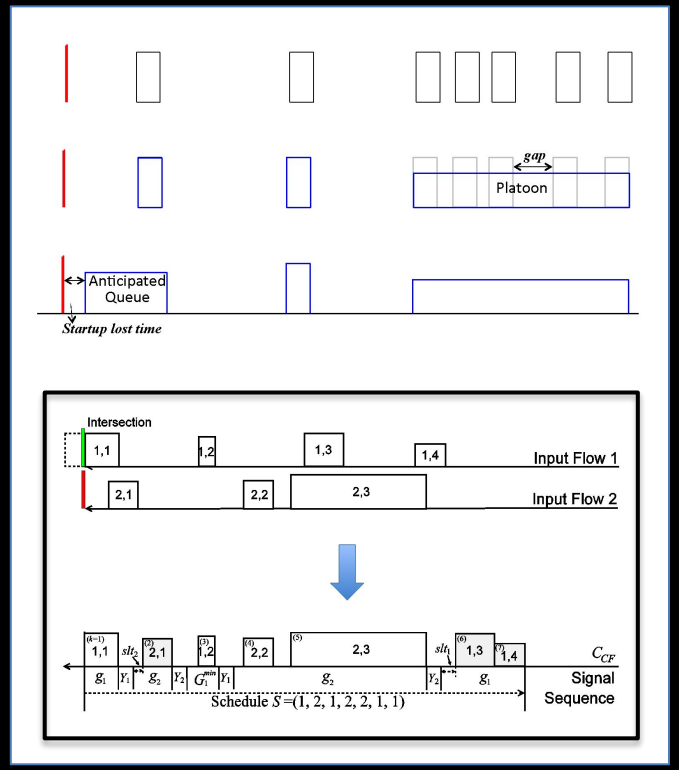


3. Communicate schedule to down-stream neighbors

4. Repeat cycle every few seconds

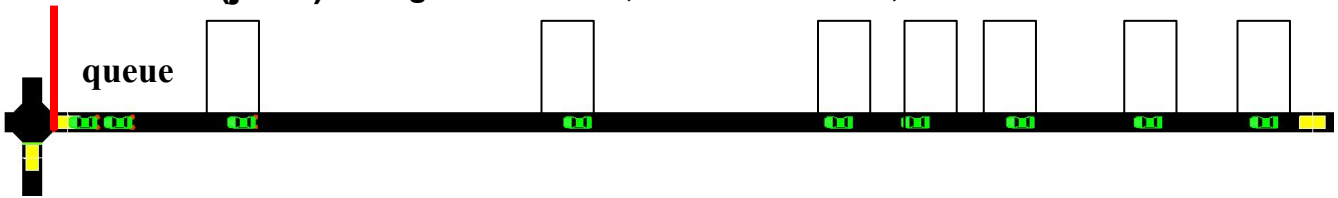
Key Technical Ideas

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

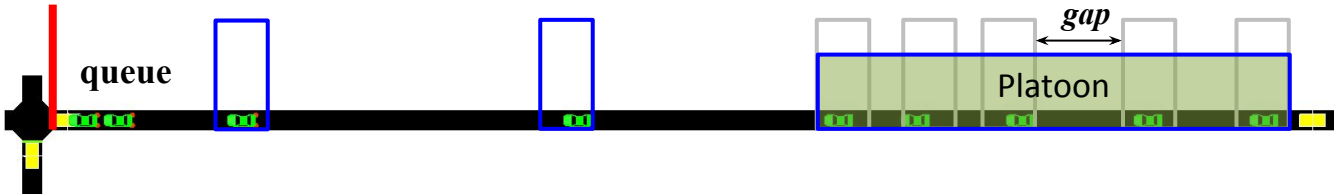


Aggregate Flow Representation

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

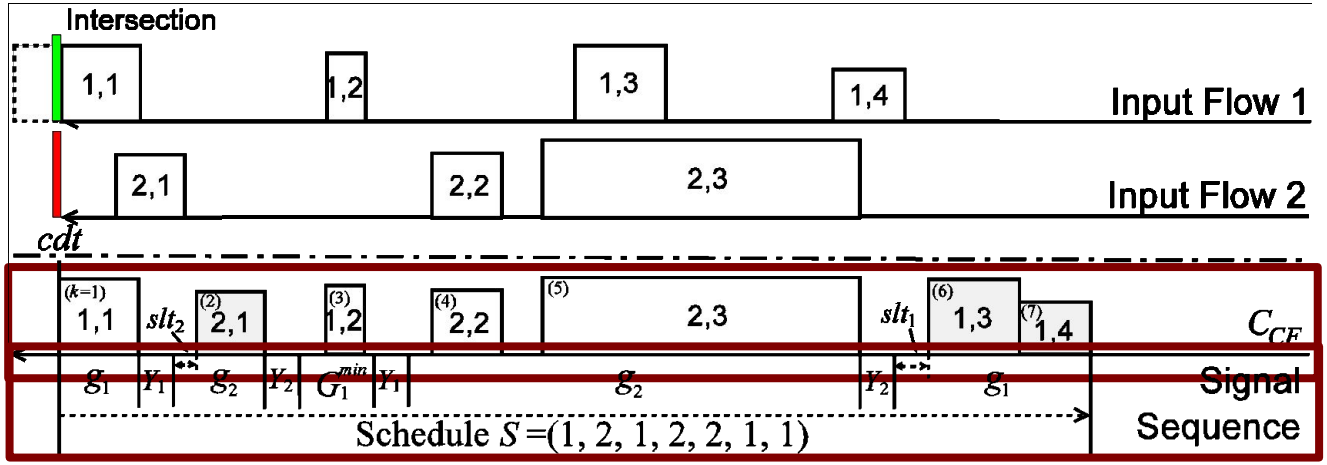


1. Threshold-based clustering: merge clusters with small gaps



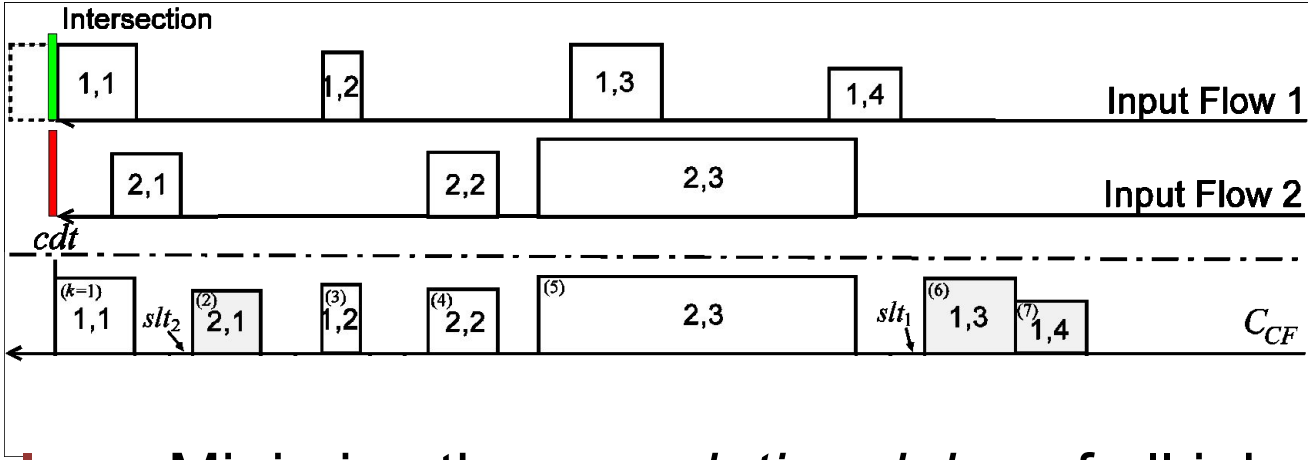
2. Anticipated queue: Anticipate the number of vehicles that are either *presently in the queue* or *will join it before it clears* (Lämmer & Helbing, 2008)

Scheduling Problem



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

Scheduling Problem

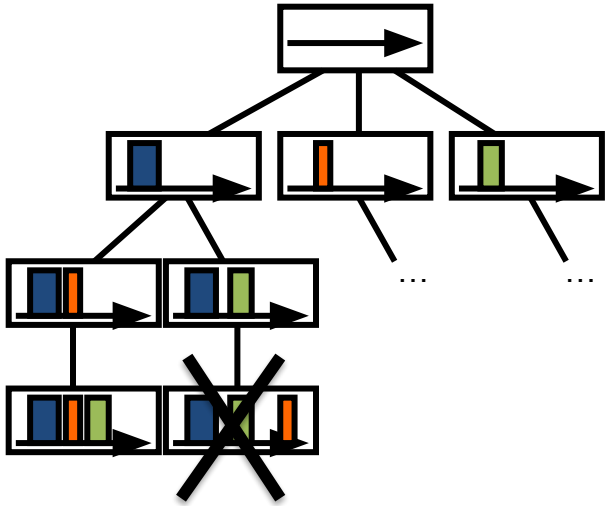


Problem: Minimize the *cumulative delay* of all jobs, subject to:

- timing constraints for safety (yellow time) and fairness (G_i^{min} and G_i^{max} for each phase)

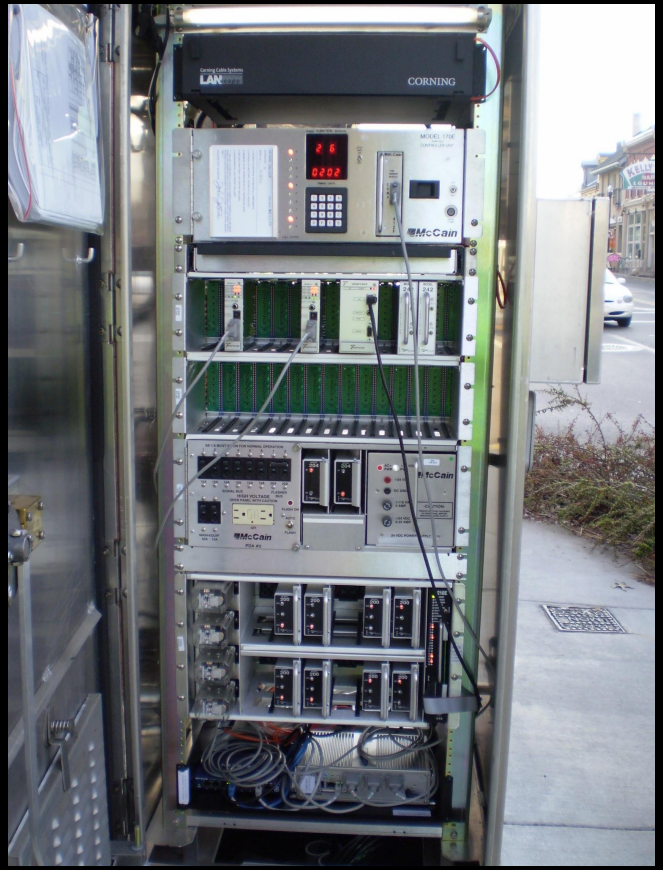
Scheduling Strategy

- Forward dynamic programming search
  - New job added to 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)



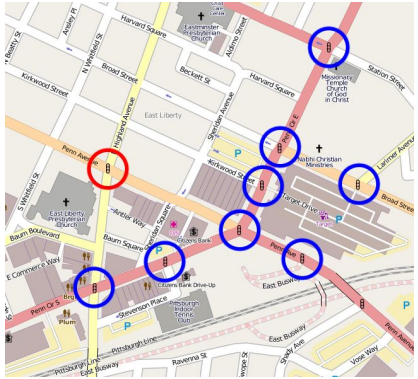
  - Time complexity: $|phases|^2 * \Pi\ (|clusters_i|+1)$

Setup in the Field



Surtrac in East Liberty

HILLMAN FOUNDATION
The Heinz Endowments
Howard Heinz Endowment • Vira I. Heinz Endowment
Richard King Mellon Foundation
BREATHE

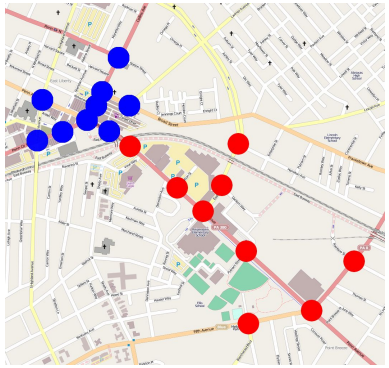


Penn Circle Test Site (Jun 2012):

% 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):

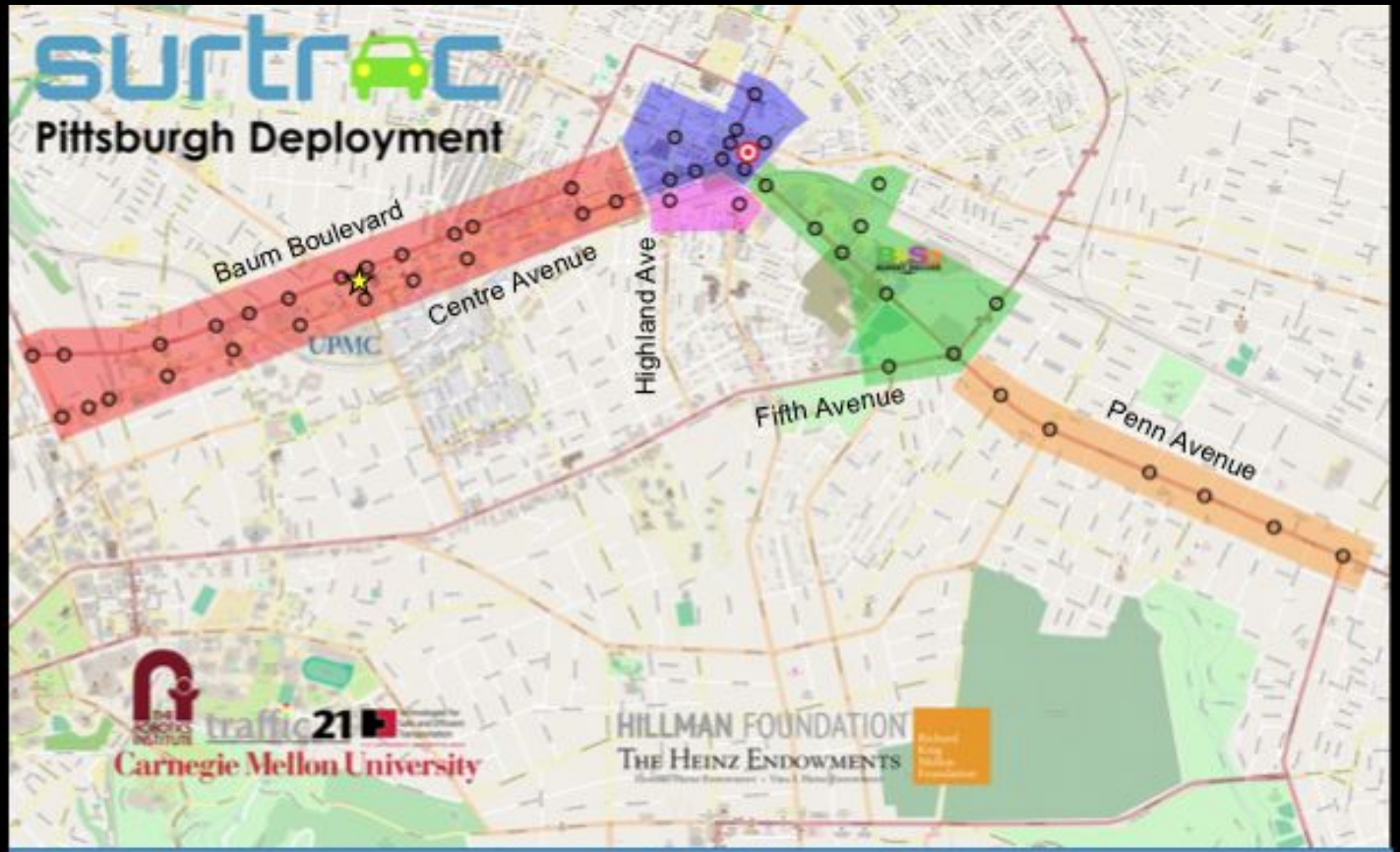
% Improv.	Travel Time	# of Stops	Wait Time	Emissions
AM rush	17%	34%	33%	16%
Mid Day	21%	37%	38%	18%
PM rush	29%	45%	46%	25%
Overall	24%	40%	42%	21%



Technologies for Safe and Efficient Transportation

Carnegie Mellon THE ROBOTICS INSTITUTE

traffic21



surtrac

intelligent traffic signals

surtrac.net
@surtrac
info@surtrac.net

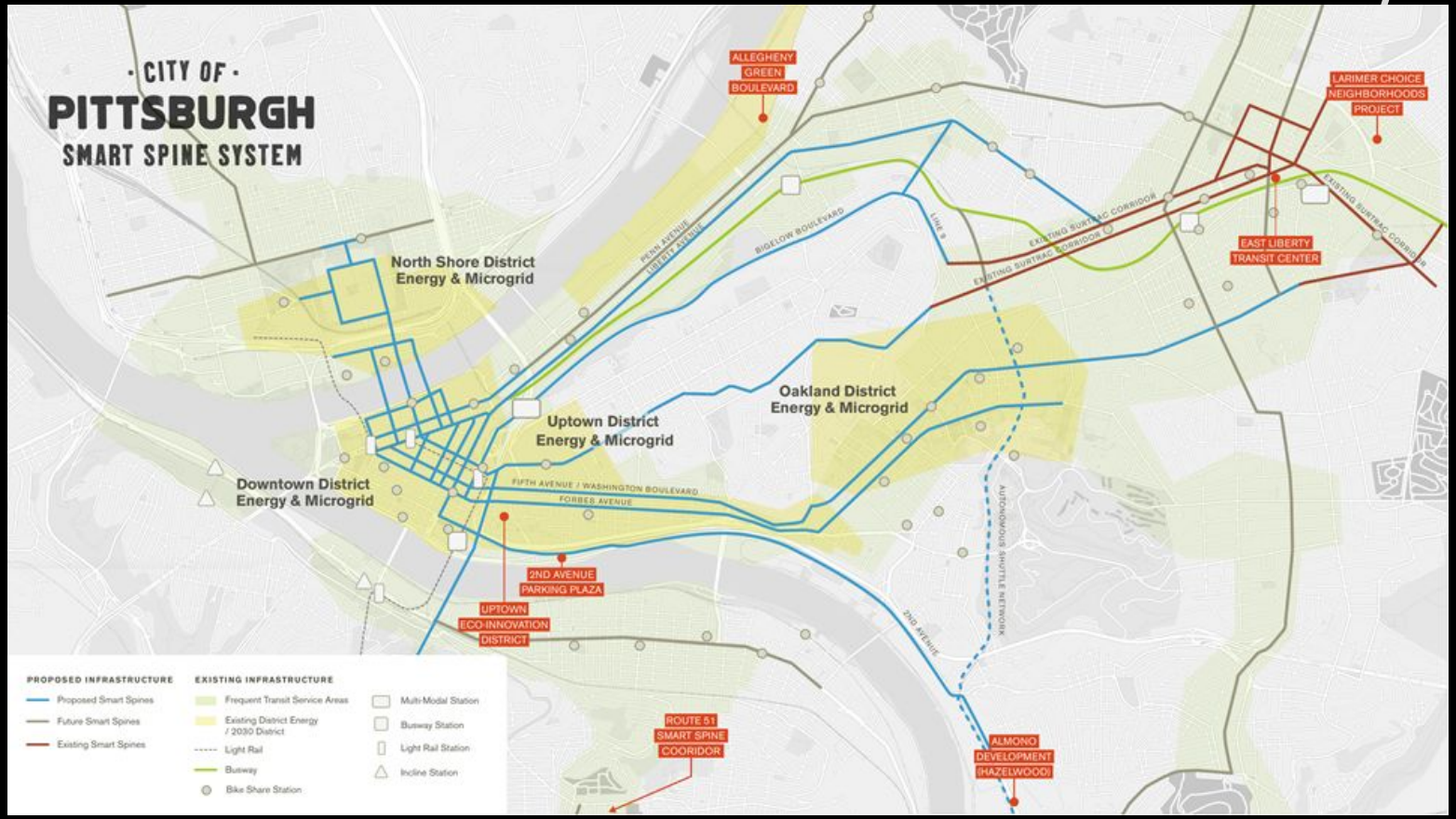
In the field ...

- **25%** lower travel times
- **40%** less time idling
- **30-40%** fewer stops
- **21%** lower emissions

Key Capabilities

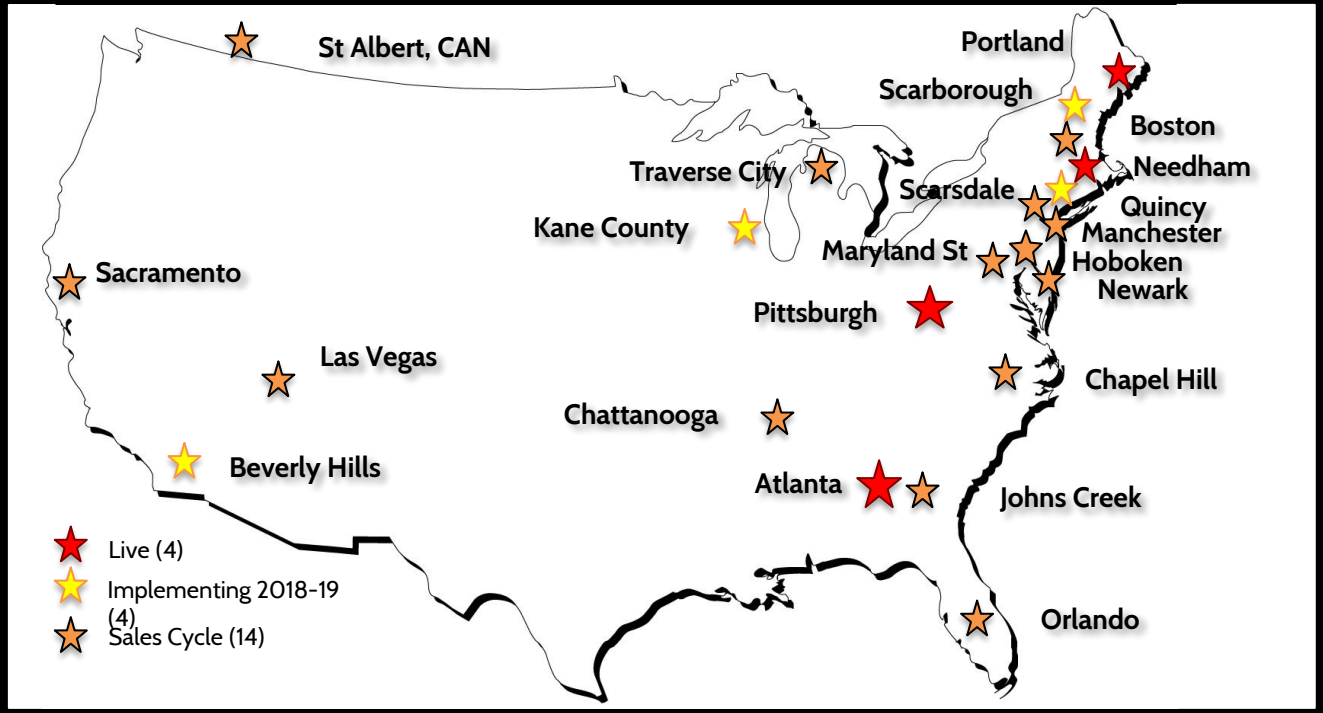
- True real-time response to traffic conditions
- Manages multiple dominant flows
- Scalable to road networks of arbitrary size
- Multi-modal optimization

150 More Intersections are on the way



Rapid Flow

Broader Deployment



Rapid Flow

Accounting for Network Pressure

[Hu & Smith IJCAI 2017]

Issue: As road network becomes saturated, coordination between intersections deteriorates

Approach:

- Define and measure "network pressure"
- Weight intersection clusters to bias optimization toward queue management

Local Pressure:

$\Delta F = InFlow_{NS} - InFlow_{EW}$

$\Delta F' = InFlow_{EW} - InFlow_{NS}$

Neighbor Pressure:

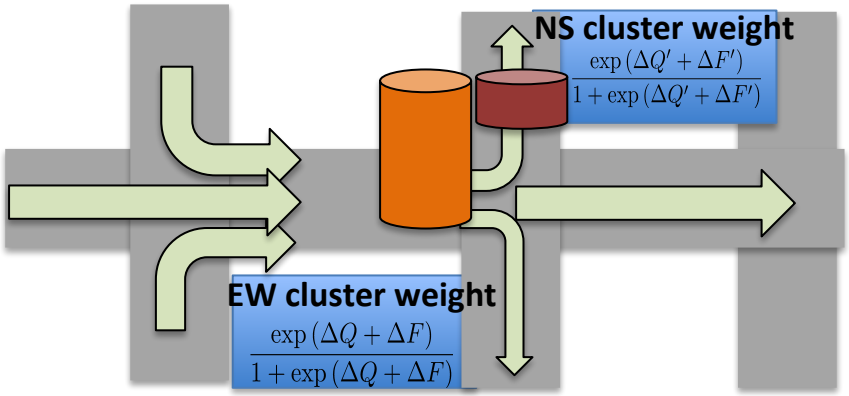
$$Q = Q_{up} + Q_{local} - Q_{down}$$
$$Q' = Q'_{up} + Q'_{local} - Q'_{down}$$
$$\Delta Q = Q - Q'$$
$$\Delta Q' = Q' - Q$$

where

$$Q_{up} = \sum_k \alpha_k Q_{up}^{(k)}$$

$$Q_{down} = \sum_k \alpha_k Q_{down}^{(k)}$$

α_k = turning prop. of route k

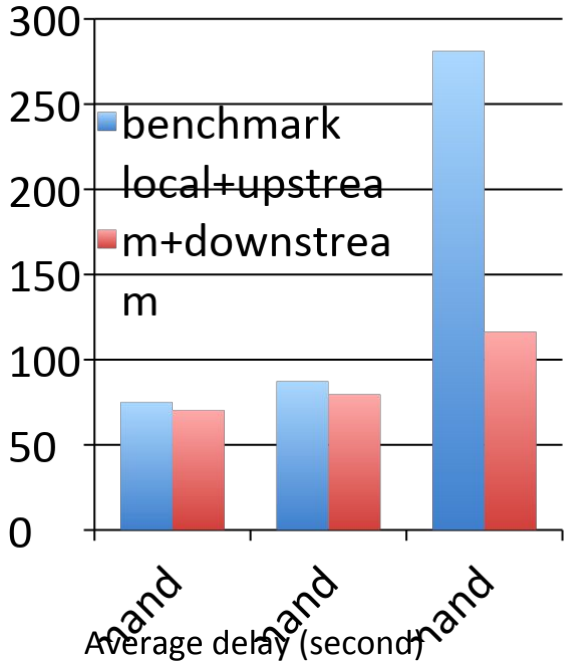


Performance at Different Demand Levels

- Simulation results using Baum-Centre corridor model

Observations:

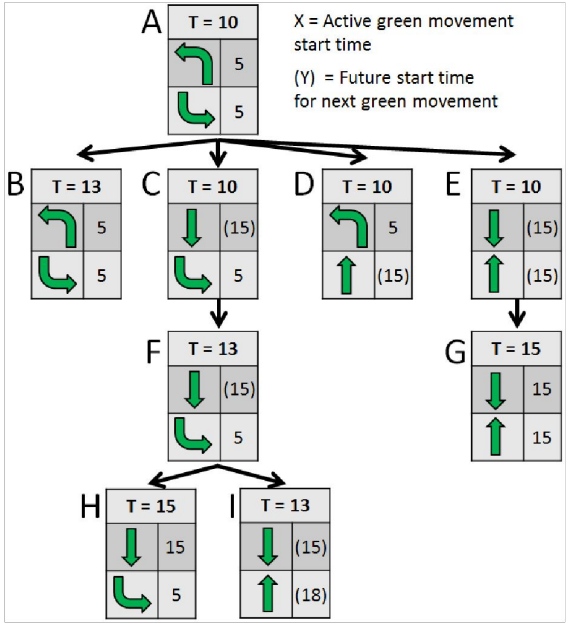
- Negligible effect at low, medium traffic levels
- Substantial improvement in heavy traffic conditions



Expressive Real-Time Intersection Scheduling

[Goldstein & Smith AAAI 2018]

- Expand precision of intersection control scheduling to lane-based flow models
- Cope with extended search space through use of A*
- 5-10% improvement in delay over Surtrac in simulation



Decentralized Optimization of Urban Traffic Flows

Advantages:

- Optimizes signals for the actual traffic on the road right now
- Coordination for networks, not just arterials
- Optimizes for multiple travel modes
- Scalable, incremental deployment

P&S Approaches: SimplifAI

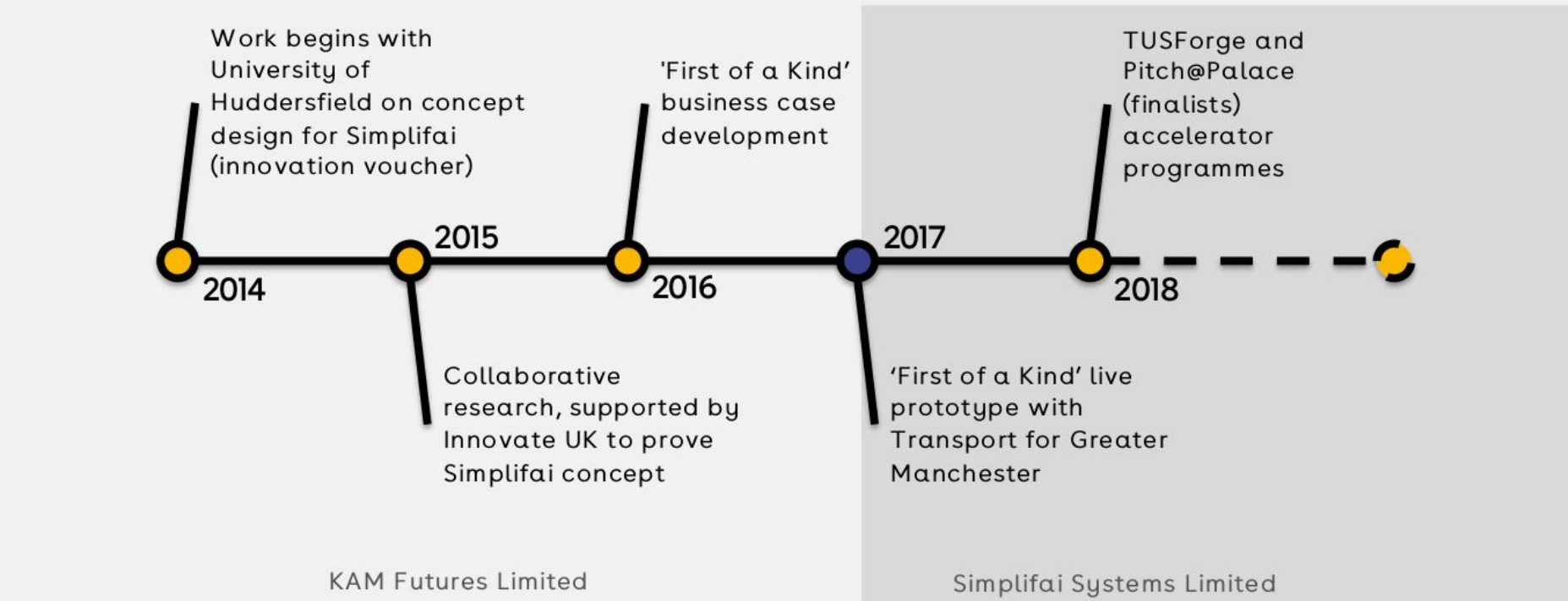
Introduction to SimplifAI

Simplifai exploits planning for dealing with unexpected traffic conditions in a large urban area.

Initially involving BT, Transport for Greater Manchester, 2 SMEs, and the University of Huddersfield

- **Overall aims**: To use traffic, air quality and environmental data to automatically produce signal strategies for regions of a city centre in order to address unforeseen events.

SimplifAI evolution



The PDDL+ Approach of SimplifAI

PDDL+ is an expressive planning language that allows to describe Mixed discrete-continuous problems (modelling durations and continuous changes).

- Processes have been used for describing flows of vehicles and modelling green times.
- Events control limits
- The planner can control traffic phases using actions.

Scalability is not an issue (up to 11k vehicles problems solved in few seconds)!

Required Information

- For each junction, minimum and maximum time of phases
- Description of the network
- Current occupancy of links in the network
- Description of the (expected) amount of vehicles entering the network

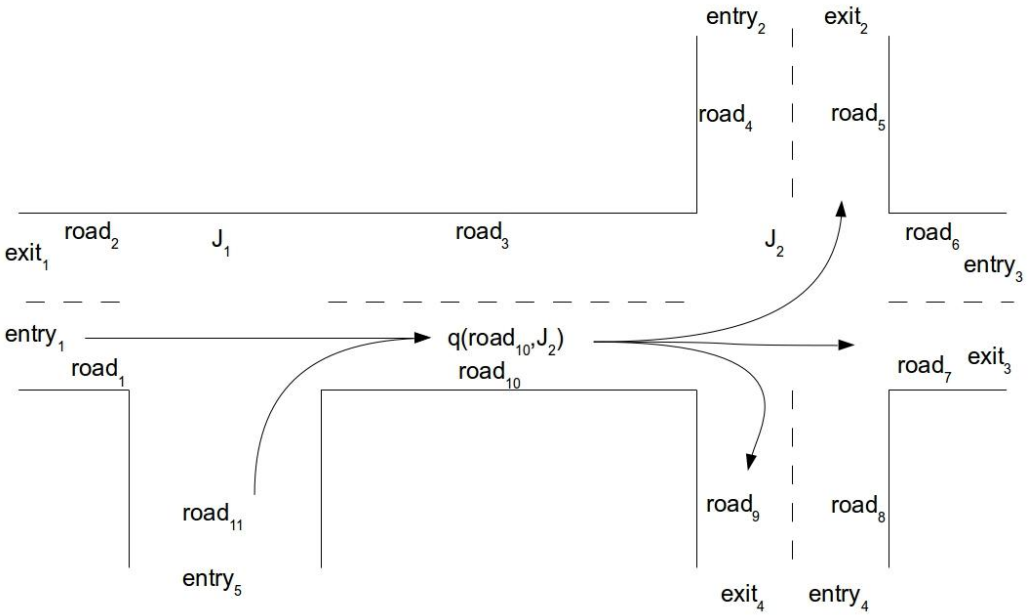
Different kind of goals can be specified

Example of the Model: Information

(= (queue R10) 5.0)
(= (max_queue R10) 35.0)

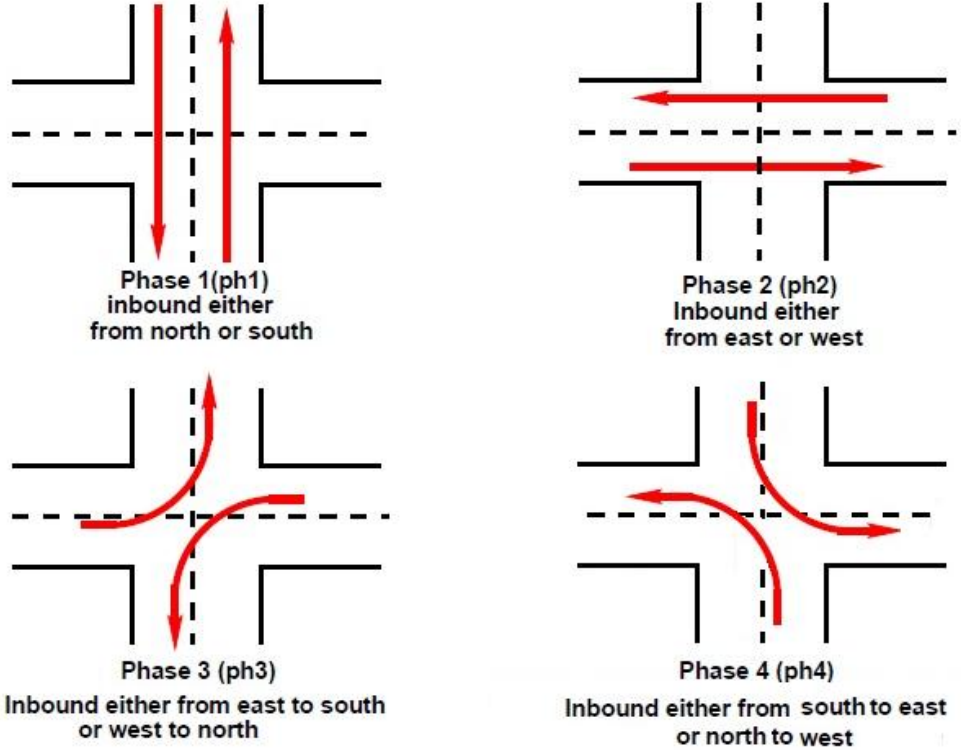
(= (flowvalue s1 R10 R7) 0.7)
(= (flowvalue s1 R10 R9) 0.5)

(= (greentime s1) 0)
(= (mingreentime s1) 5)
(= (mingreentime s0) 5)
(= (maxgreentime s1) 40)
(= (maxgreentime s0) 20)
(active s0)
(contains J2 s0)
(next s0 s1)
(next s1 s0)



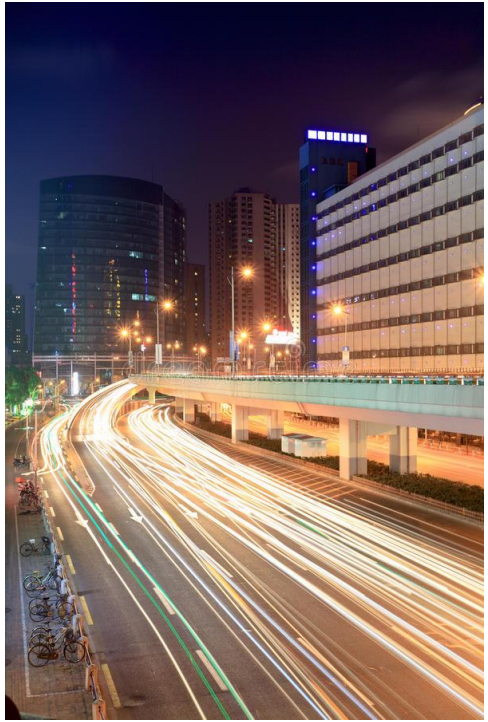
Part of the Domain Model

```
(:action switchPhase
:parameters (?p - phase ?i - intersection)
:precondition (and
        (controllable ?i)
        (active ?p) (contains ?i ?p)
        (> (greentime ?i)
(mingreentime ?p) )
        )
:effect (and
        (trigger ?i)
))
```



How Traffic Moves?

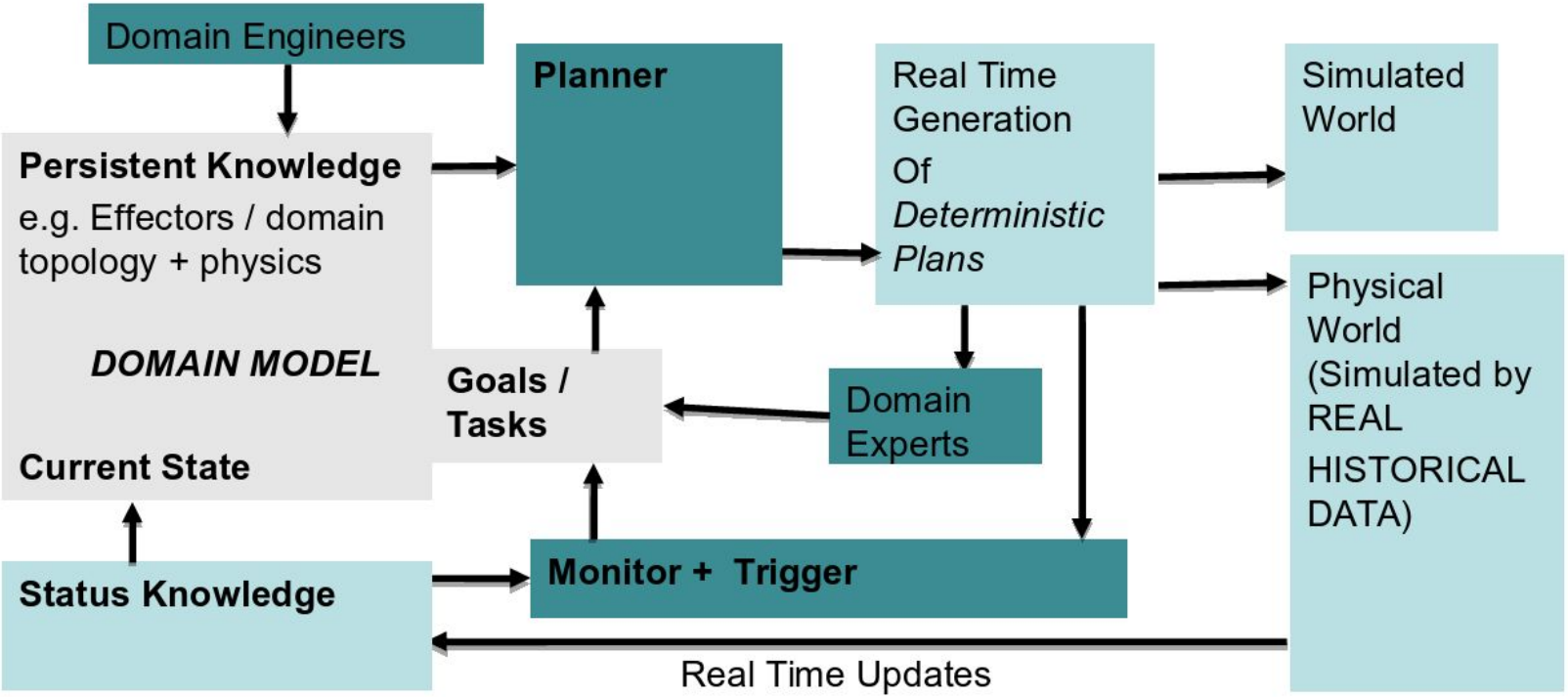
```
(:process flowrun_green
:parameters (?p - phase ?r1 ?r2 - road)
:precondition (and
                (active ?p)
                (> (queue ?r1) 0.0)
                (> (flowvalue ?p ?r1 ?r2) 0.0)
                (< (queue ?r2) (max_queue ?r2))
)
:effect (and
                (increase (queue ?r2) (* #t (flowvalue ?p ?r1 ?r2)))
                (decrease (queue ?r1) (* #t (flowvalue ?p ?r1 ?r2)))
))
```



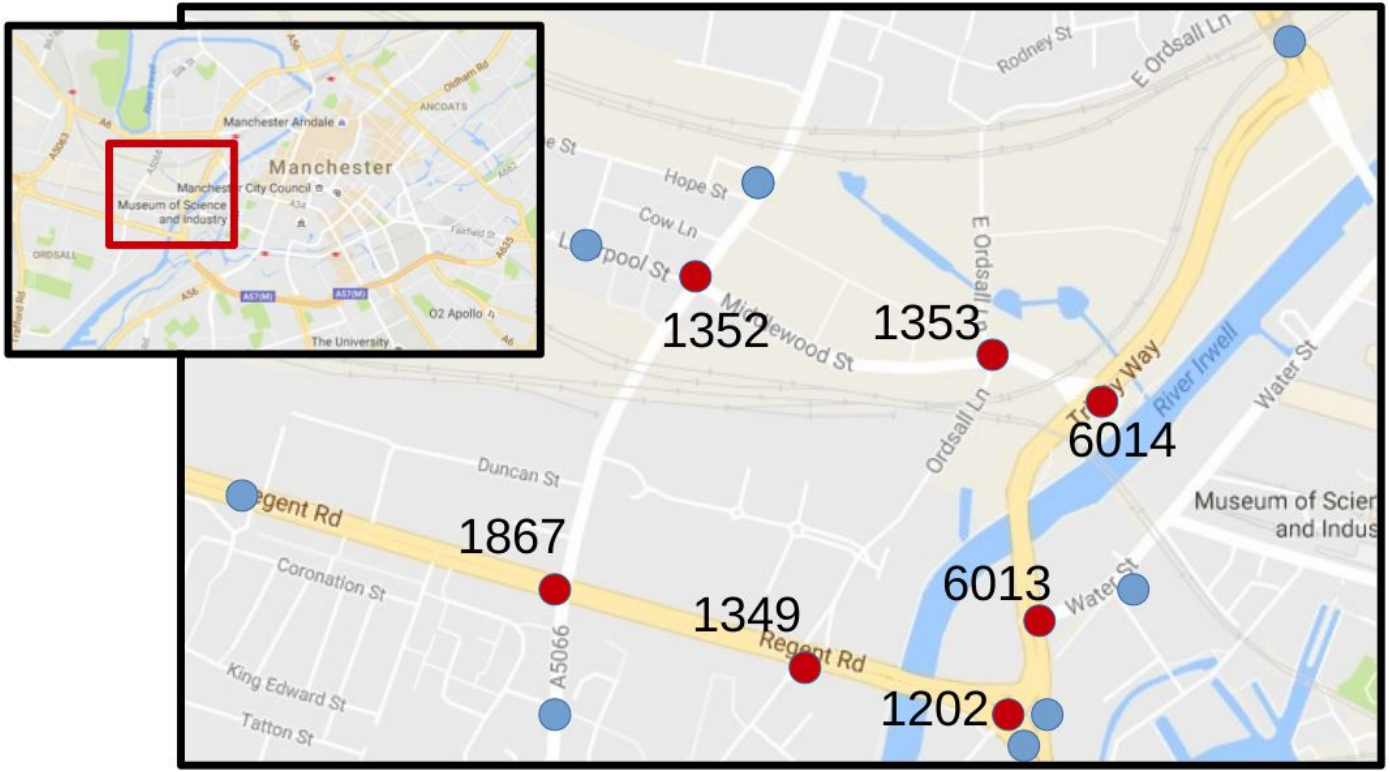
How Does a Plan Look Like?

```
05.0: ( switchphase l1867_4574 l1349_1867 s1867_s0 n1867) [0.000]
65.0: ( switchphase l6013_5840 l1202_6013 s6013_s0 n6013) [0.000]
65.0: ( switchphase l6014_6013 l6159_6014 s6014_s1 n6014) [0.000]
65.0: ( switchphase outside l1349_1353 s1353_s1 n1353) [0.000]
65.0: ( switchphase l1202_6013 l1349_1202 s1202_s2 n1202) [0.000]
65.0: ( switchphase l1349_3621 l1202_1349 s1349_s0 n1349) [0.000]
70.0: ( switchphase outside l1352_1353 s1353_s2 n1353) [0.000]
70.0: ( switchphase l1349_3621 l1202_1349 s1349_s1 n1349) [0.000]
70.0: ( switchphase l1202_6013 l1349_1202 s1202_s3 n1202) [0.000]
70.0: ( switchphase l6013_5840 l6014_6013 s6013_s1 n6013) [0.000]
```

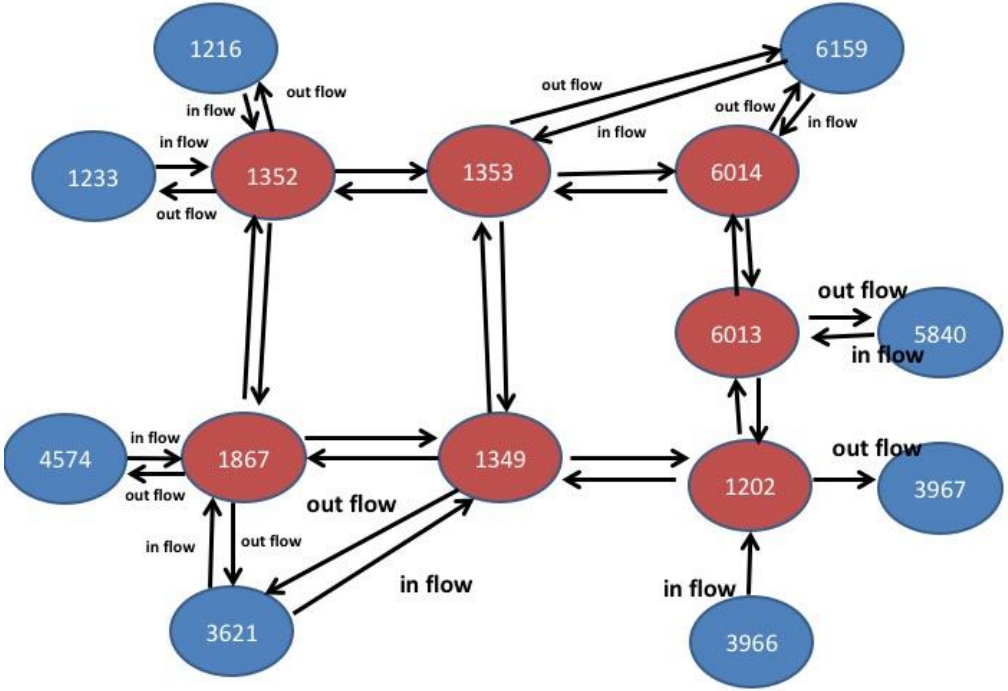
Deployment Architecture



Evaluation with Transport for Greater Manchester



A Schema of the Area



High Complexity of Junctions

STAGE 1: flows L3966_1202 to L1202_1349 = 0.64522; L3966_1202 to L1202_6013 = 0.71739; L6013_1202 to outside = 0.41067

INTERGREEN 0 seconds

STAGE 2: Etc etc

.....

STAGE 7: flows L6013_1202 to outside = 0.41067; L6013_1202 to outside = 0.41067; L6013_1202 to L1202_1349 = 0.165

INTERGREEN 5 seconds
(GO BACK TO STAGE 1)

Test Cases

Set 1 Clear saturated road link asap
Set 2 Clear several saturated road links asap
Set 3 Clear region asap
Set 4 Clear saturated road link with nearby road works
Overall: Investigate Tailpipe Emission Savings

Tests and Evaluation done using ENHSP and UPMUrphi, extended with a domain-specific heuristic.

Results (1)

Generated plans tested by **Visual inspection**

- Human experts checked for “common sense” strategy: maximise green time to light stages allowing vehicles to leave goal links, minimise others. In case where goals are concurrent, a balance among green light stages is expected.

- **Result**: *All strategies had recognisable common sense parts*

Results (2)

Generated plans tested by **Traffic Simulators**

- SUMO and AINSUM
- Compared against fixed-time manually optimised strategies which would be in place in the case of exceptional event

- **Result**: *generated strategies cleared links better than manually optimised timings, typically by 25%*

SimplifAI: In a Nutshell

- Project's "AI planning" work demonstrated the effectiveness of the auto-generation of goal-directed strategies within an area of Manchester.

- Strategies of 5–30 minutes are produced in real-time using the ENHSP planner and domain-specific heuristics.

- In terms of emissions, a 5% reduction has been observed on average.

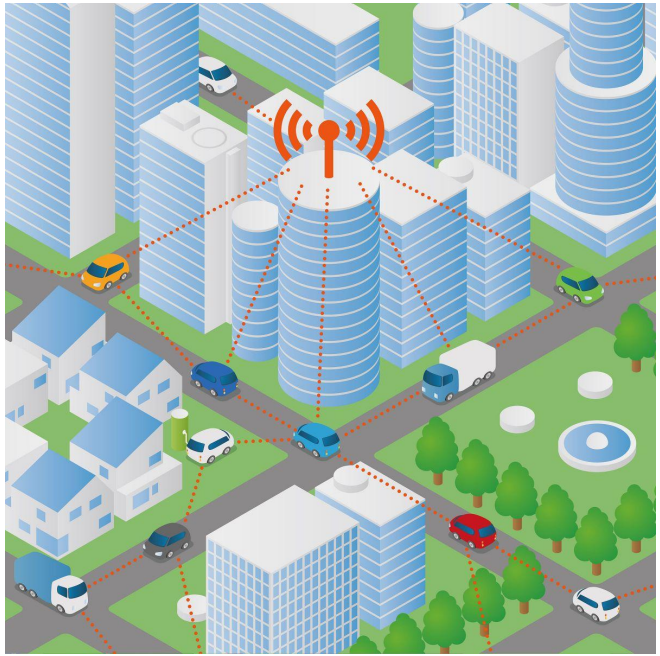
SimplifAI: And Now?

- Working on a specifically-designed planning engine
- Real-world collaborations and exploitation are ongoing
- We are looking to merge and reason upon information gained from other traffic means and authorities (e.g., highways)
- Connected vehicles...

AI4ME: EPSRC Funded Project

- Vehicles approaching a urban region communicate to the traffic control centre their destination, and preferences / requirements for the route

- The AI controller, on the basis of the current network situation and provided metrics to maximise, calculates a route for the vehicle



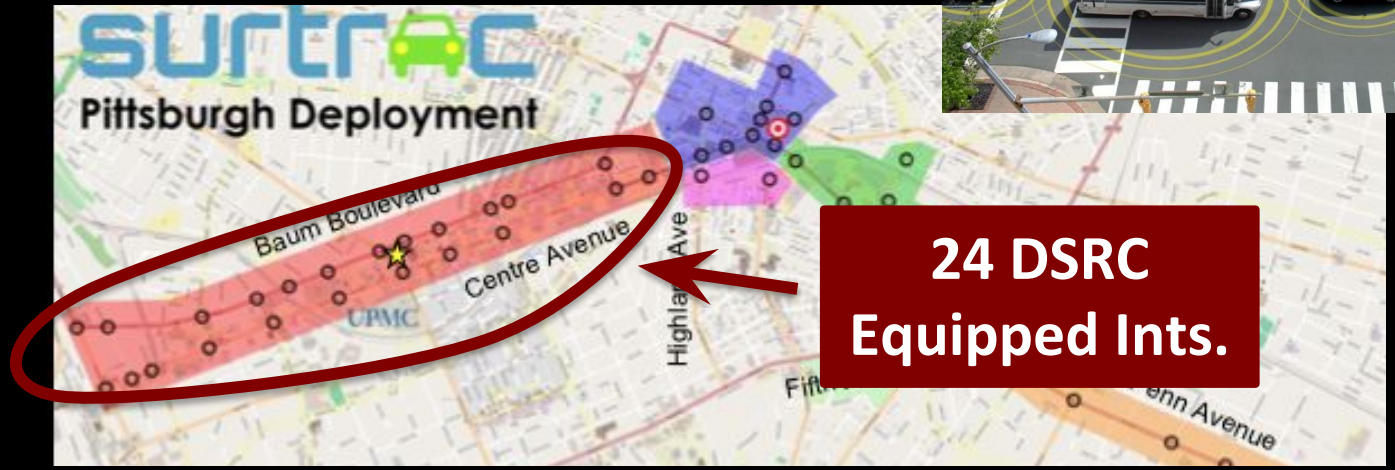
Future Directions

Smart Infrastructure for Future Urban Mobility

- Opportunities and Research Directions
  - Connected and Autonomous Vehicles
  - Ubiquitous Sensing
  - Multi-modal trip planning
  - Integrated municipal services (traffic signals, snow removal, emergency vehicles, etc.)
  - Sustainable infrastructure
  - … (What are some other suggestions here)

Integration of Signal Control with Connected Vehicle Technology

- Better sensing
- Use of mode, route information
- Incident detection and real-time re-routing



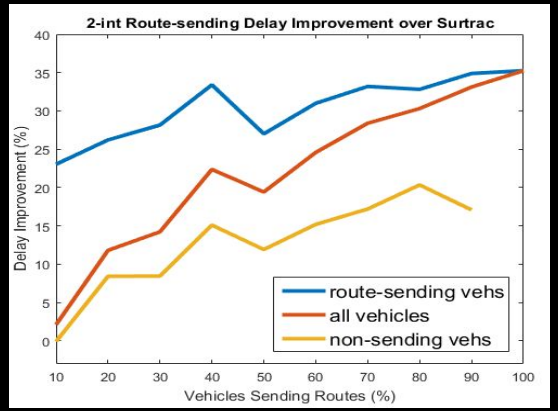
Enhanced Mobility

Real-time Bus Information

- Equip Port Authority buses with DSRC
- Signal system uses info. to better predict bus arrivals and provide smart transit priority

Sharing Vehicle Routes

- Connected Vehicle (CV) shares its route with the network
- Intersections incorporate this info. into local optimization

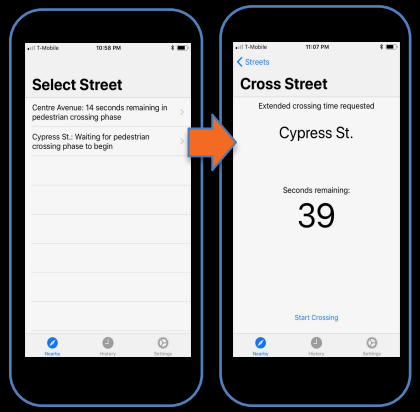


Safe Intersection Crossing for Pedestrians with Disabilities

Concept: *A smartphone app that allows pedestrians to interact directly with a smart signal control system*

Capabilities:

- Personalized crossing time
- Active monitoring and dynamic extension
- Anticipation of arrival time to streamline crossing



PHAENON Sensor Networks

- Measure real-time traffic conditions for:
  - Incident detection
  - Congestion due to cruising for parking
  - ...

Low-cost automatic vehicle identification (AVI) sensors

Dense, ubiquitous sensor network deployments

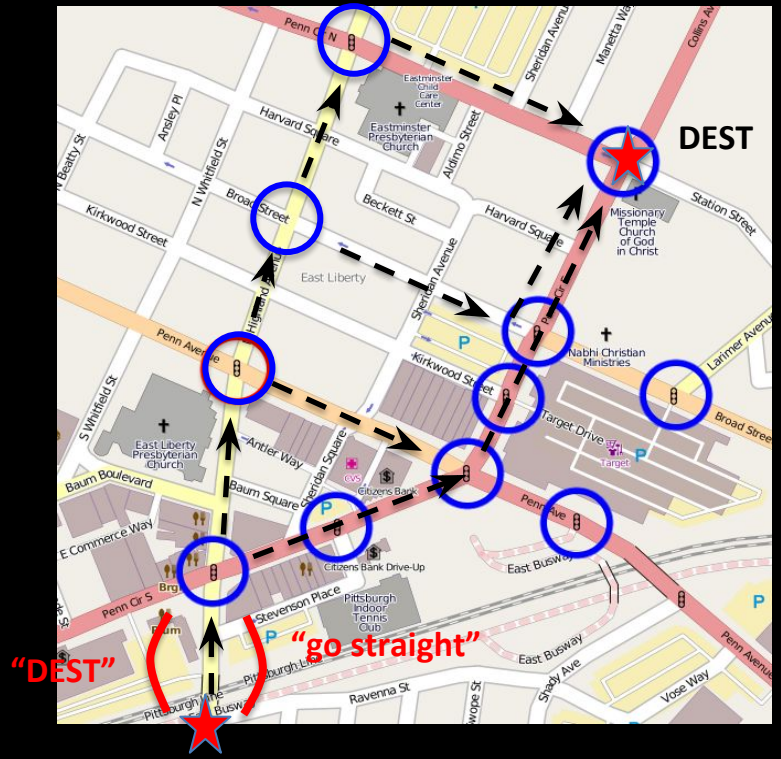
Reconstructed vehicle routes

Real-Time Vehicle (Re-)Routing

Concept: *Exploit network-level schedule to provide real-time routing guidance*

Approach

- Distributed computation of shortest path using most recently generated plans at each intersection
- Fall back on historical delay information when planning horizon is exceeded



Broader Vision

- As X2I communication proliferates, the signal network will become the gateway for real-time information
- Self-driving cars in urban environments will depend just as heavily on this information
- Connectivity and smart signals can also enhance sustainability
- Smart infrastructure is key to future urban mobility