Traffic Control - Definition, Classification, and Outlook

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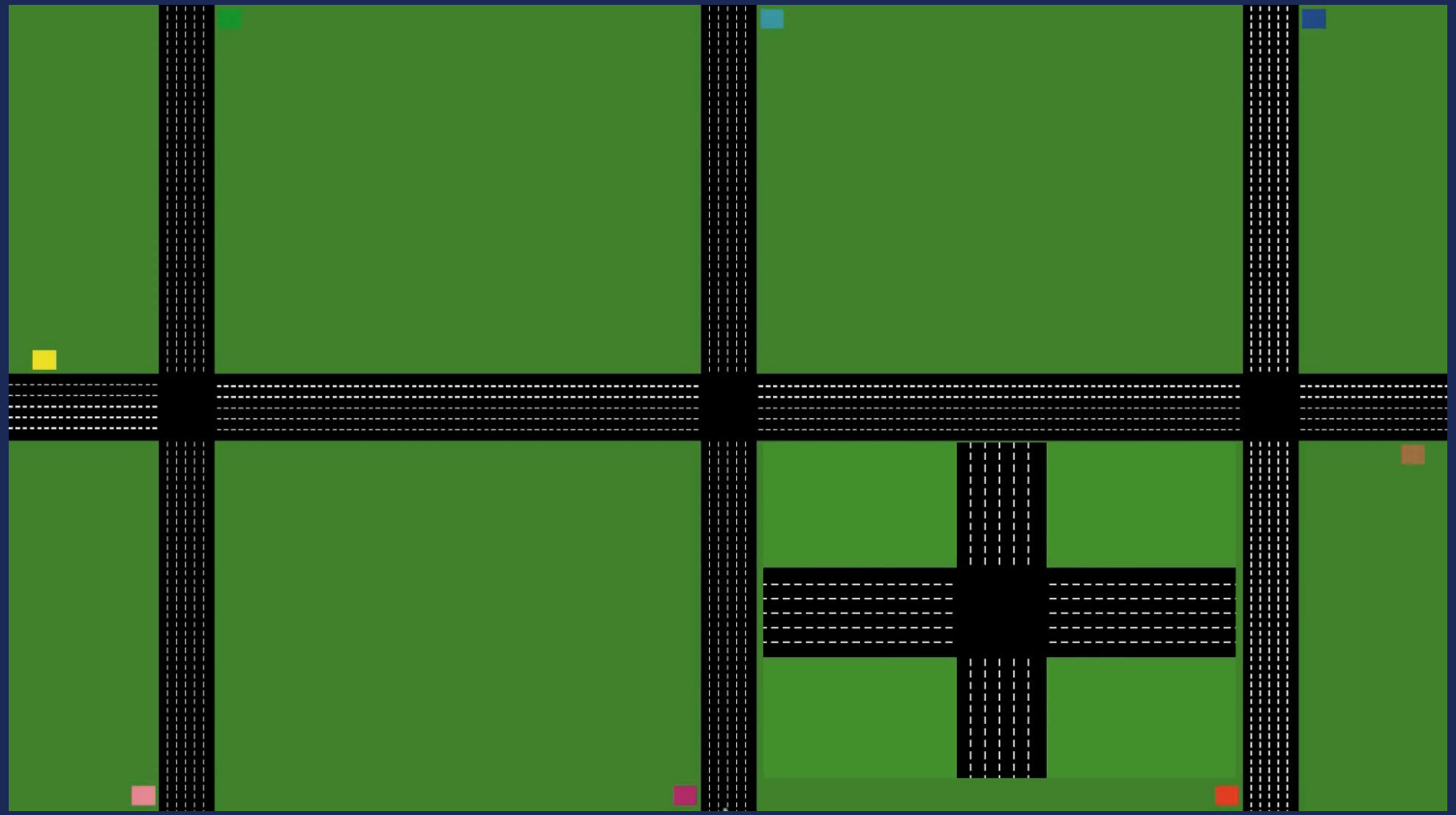
Transportation Engineering & Safety Conference
PennState, December 13, 2019

CADLARIC - https://youtu.be/RXSwJKqBQtM

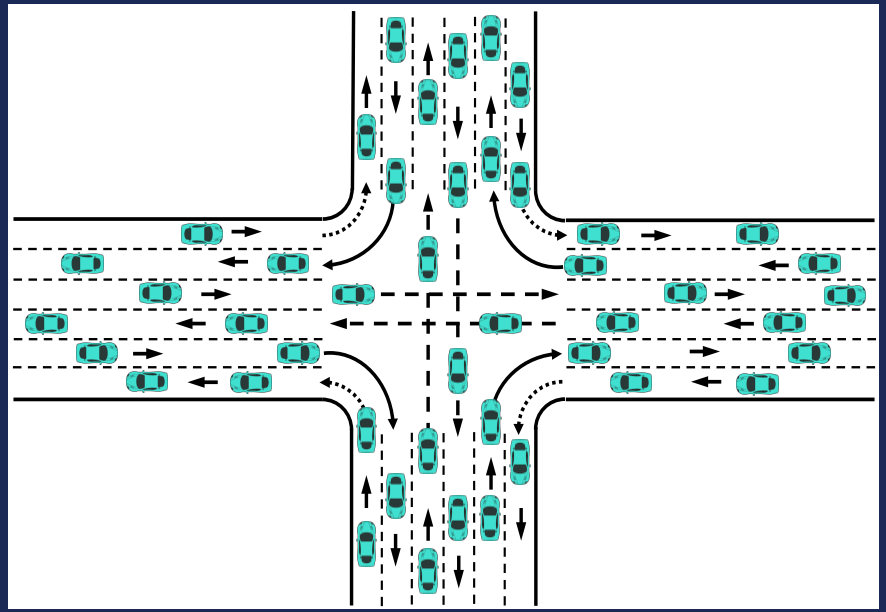


CADLARIC - Combined Alternate-Direction Lane Assignment and Reservation-based Intersection Control

CADLARIC – New Rules of the Road

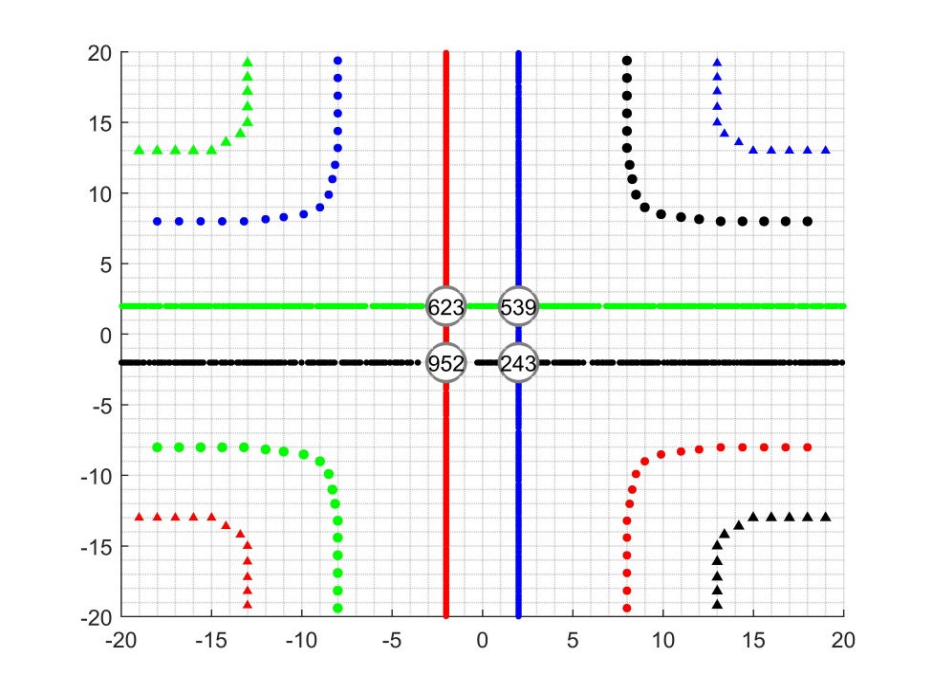
- At least 6 lanes – one per each enter & exit turn type
- The most left lane – for exiting left turns
- Next to the most left lane – for receiving right turns
- Two middle lanes – through movements
- Next to the most right lane – for exiting right turns
- The most right lane – for receiving left turns

CADLARIC - Combined Alternate-Direction Lane Assignment and Reservation-based Intersection Control

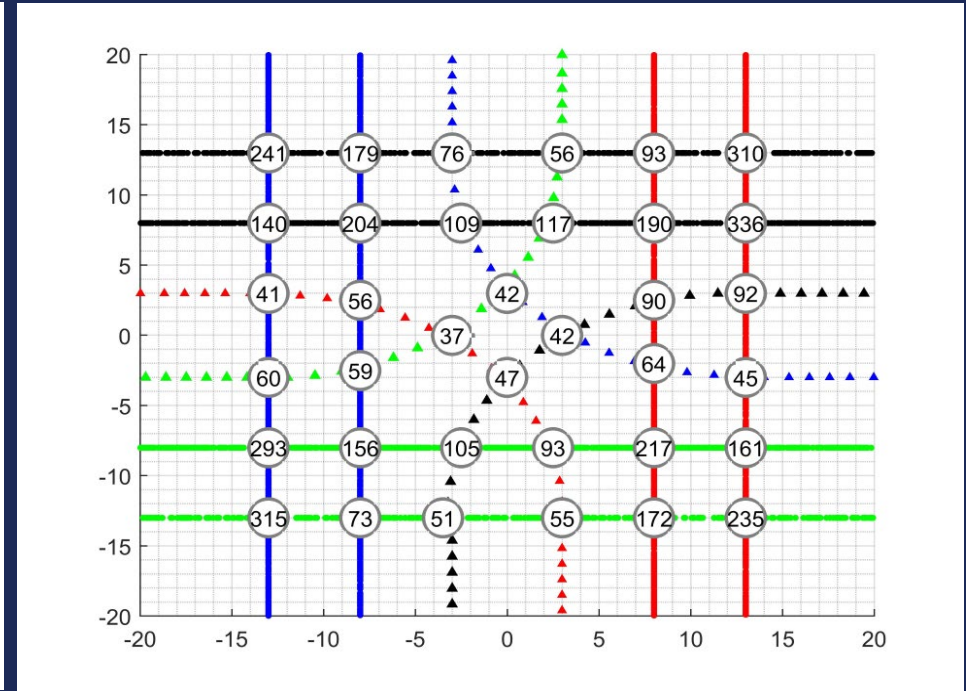


Cells with Intersection Crossing Conflicts

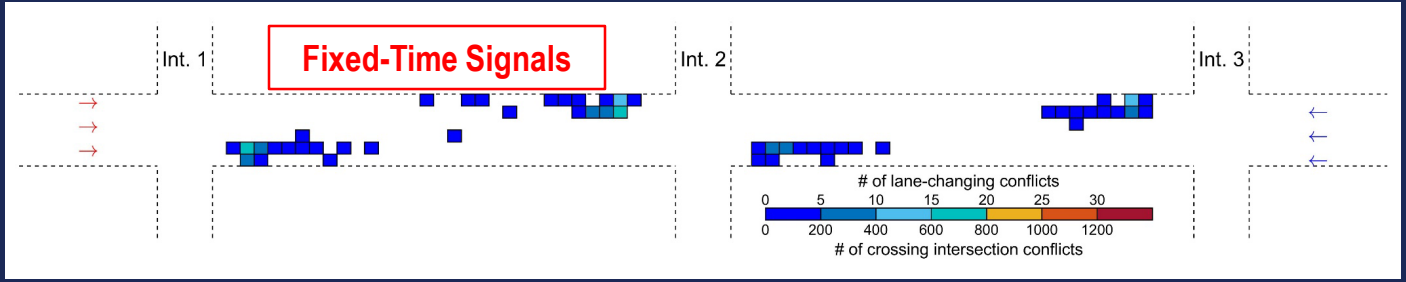
CADLARIC

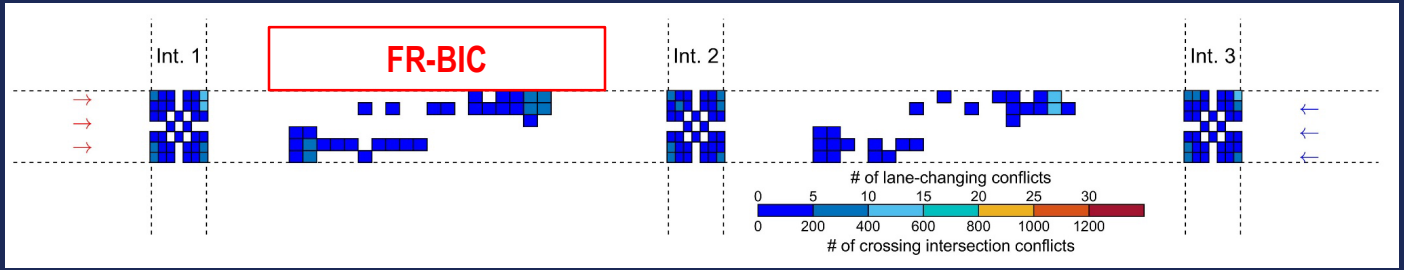


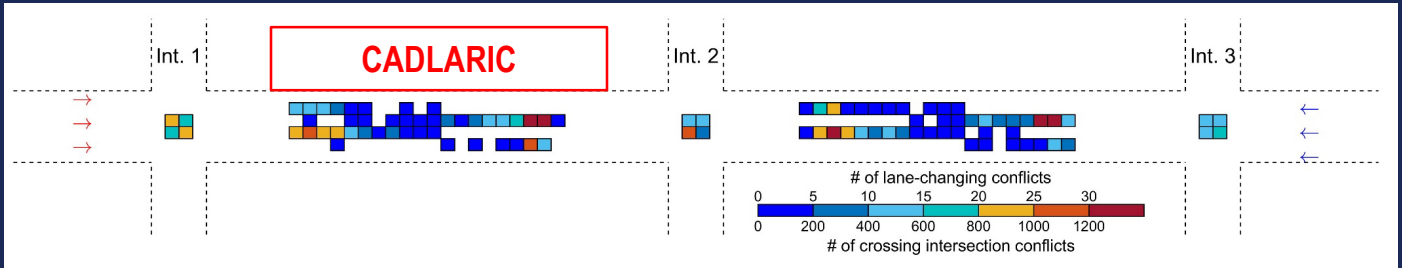
Fully Reserved Intersection Control



Spatial Distribution of Conflicts – LOS D

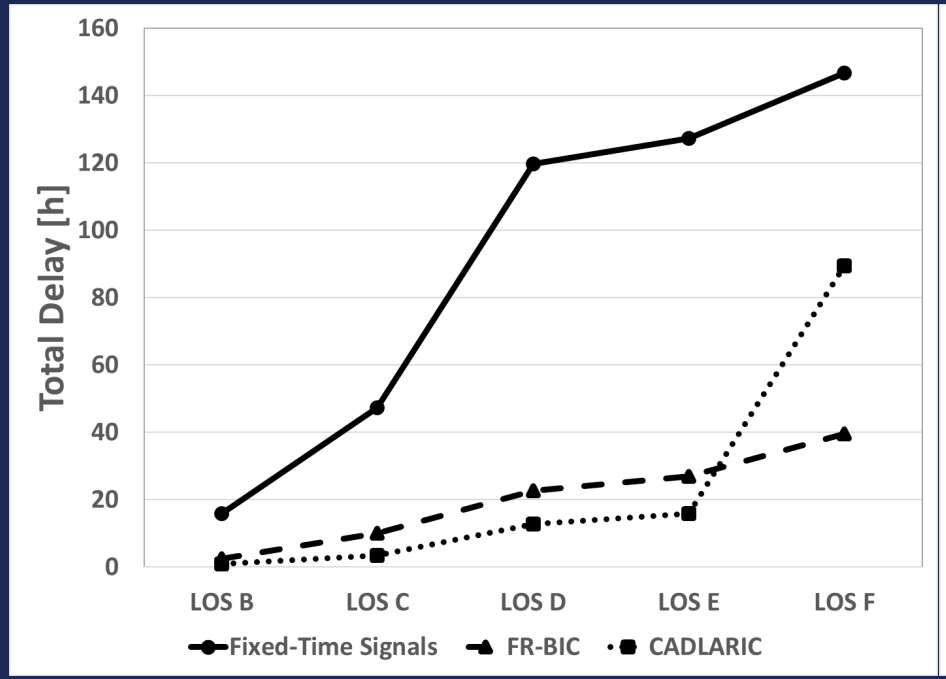




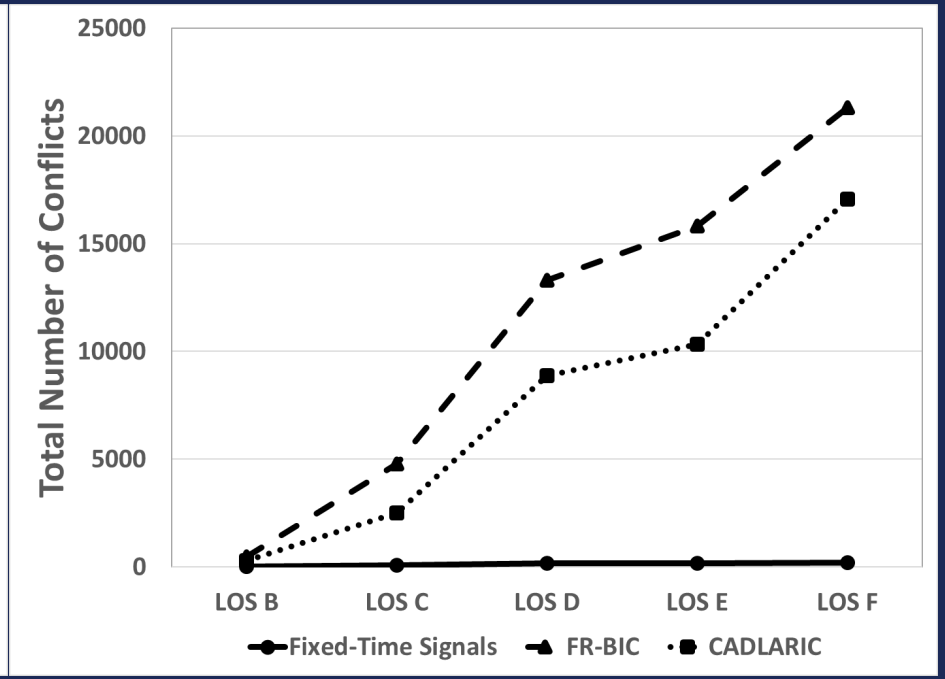


Efficiency & Safety of Three Scenarios

Total Delay [h]



Total Number of Resolved Conflicts



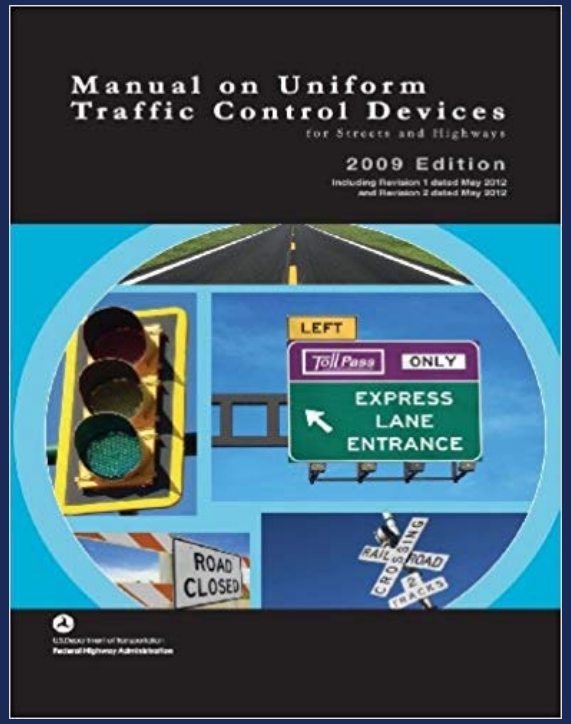
TRAFFIC CONTROL - DEFINITION

What is Roadway Traffic Control?

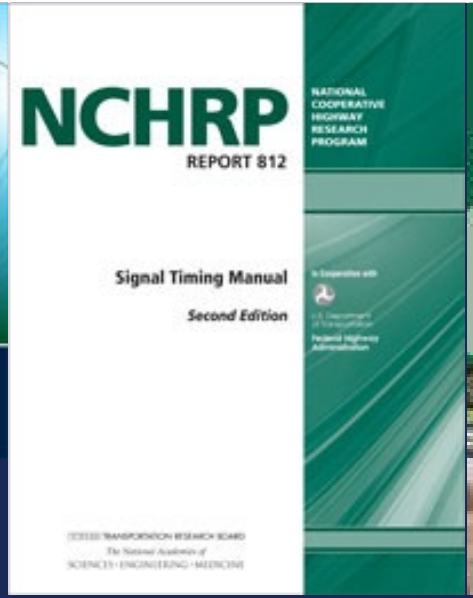
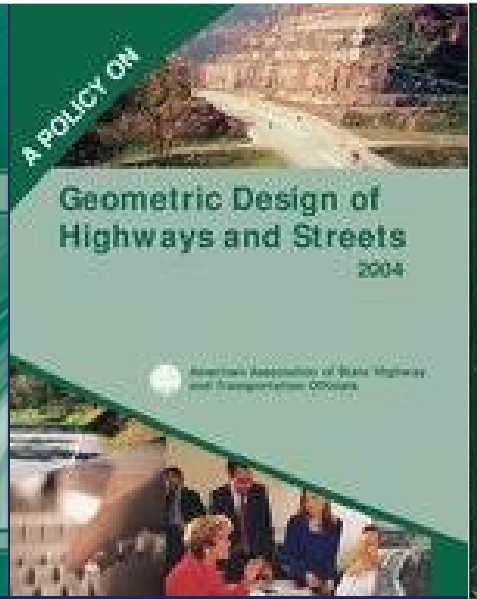
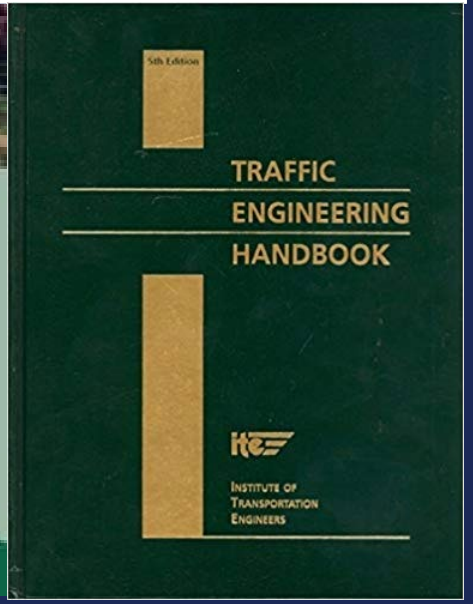
- It applies to all control devices – it can be signals, signs, or pavement markings
- It can be executed by humans or computers
- It can be applied at intersections or road segments
- It includes cars, pedestrians, public transport (with passengers), etc.
- Vehicles can be strictly governed or advised
- It applies to work zones, special events, or regular conditions
- Directions can be communicated visually (HIL) or wirelessly (C2C)
- Movements can be fully halted or adjusted
- Users can be processed in groups or individually

Manual on Uniform Traffic Control Devices (2009)

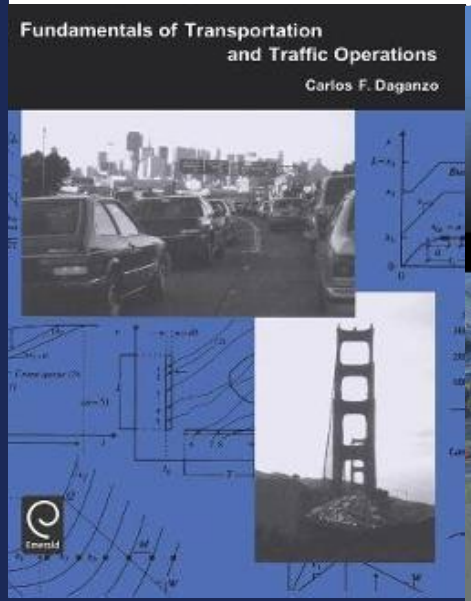
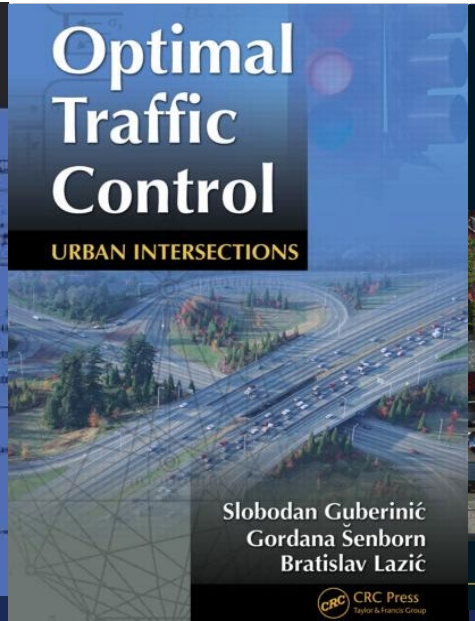
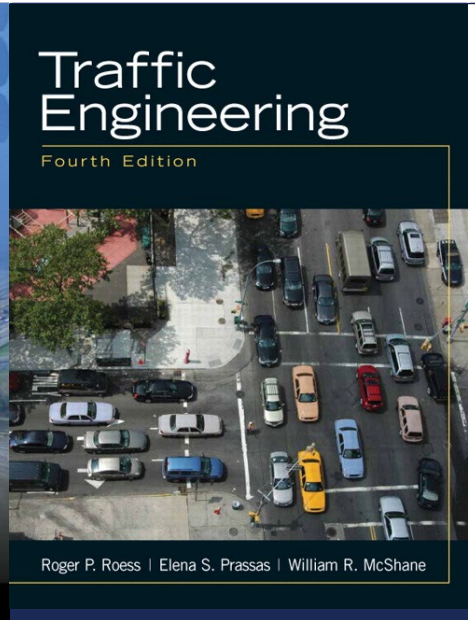
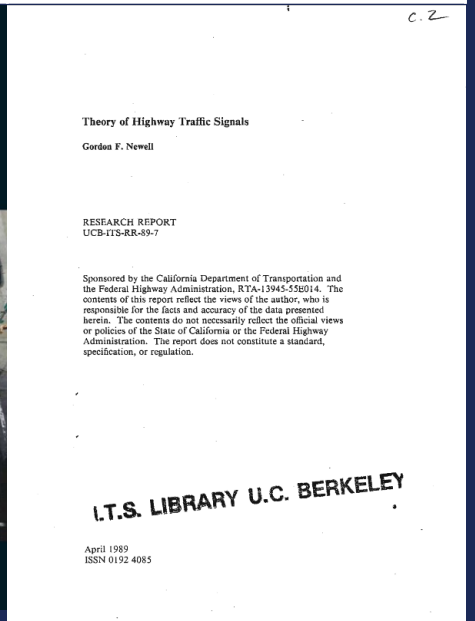
- Traffic control device and traffic control signal are defined
- Traffic control (as a process) is not defined



No Definition of Traffic Control

Highway Capacity Manual (2016)	Signal Timing Manual	Geometric Design of Highways and Streets	ITE Traffic Engineer. Handbook
			

No Definition of Traffic Control – Cont.

Fundamentals of Transportation and Traffic Operations – Carlos Daganzo	Optimal Traffic Control – Slobodan Guberinic, Gordana Senborn, Bratislav Lazic	Traffic Engineering – Roess, Prassas, McShane	Theory of Highway Traffic Signals – G.F. Newell
			

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Theory of Highway Traffic Signals

Gordon F. Newell

RESEARCH REPORT
UCB-ITS-RR-89-7

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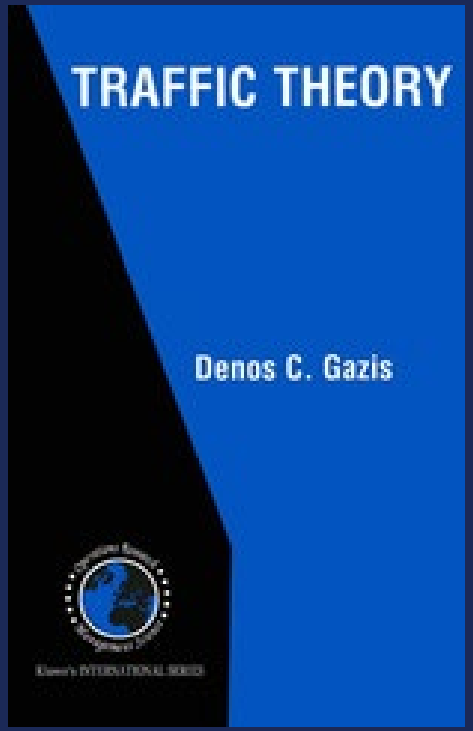
April 1989
ISSN 0192 4085

Traffic Control – Online Sources

Encyclopedia Britannica	Wikipedia
Paul P. Jovanis & F.D. Hobbs	NA
Traffic control, supervision of the movement of people, goods, or vehicles to ensure efficiency and safety.	*Road traffic control involves directing vehicular and pedestrian traffic around a construction zone, accident or other road disruption, thus ensuring the safety of emergency response teams, construction workers and the general public.*

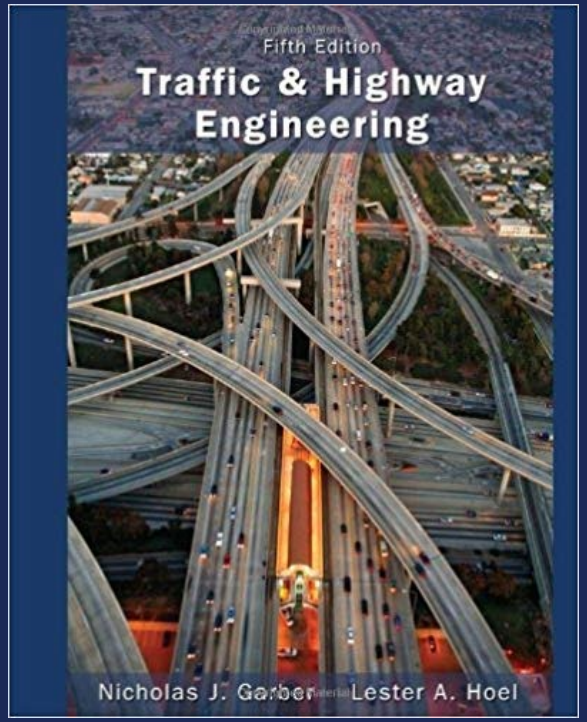
Traffic Theory – Denos Gazis

Traffic control came about mostly for reasons of safety, to avoid coincidence of two cars in space at the same time. The evolution was intended to accomplish something beyond safety, namely, to reduce unnecessary stops by individual cars and consequently reduce delays and the overall travel time required for a trip.



Traffic and Highway Engineering – Garber & Hoel

The purpose of traffic control is to assign the right-of-way to drivers and thus to facilitate highway safety and efficiency by ensuring the orderly and predictable movement of all users of the roadway systems, including highways, streets, and bikeways.



What is Roadway Traffic Control?

Roadway Traffic Control is a process of managing movements of transportation system users to ensure conflict-less passages along their intended paths.

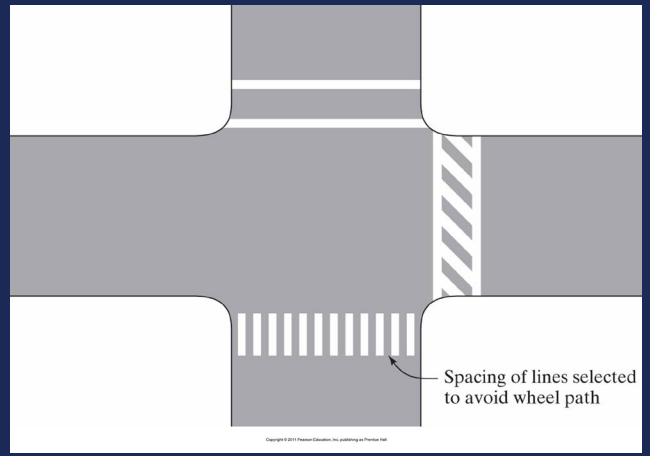
- It applies to all control devices – it can be signals, signs, or pavement markings
- It can be executed by humans or computers
- It can be applied at intersections or road segments
- It includes cars, pedestrians, public transport (with passengers), etc.
- Vehicles can be strictly governed or advised
- It applies to work zones, special events, or regular conditions
- Directions can be communicated visually (HIL) or wirelessly (C2C)
- Movements can be fully halted or adjusted
- Users can be processed in groups or individually

TRAFFIC CONTROL - CLASSIFICATION

Traffic Control Devices (MUTCD)

- Media for communication with drivers
- Three major categories
  - Traffic markings
  - Traffic signs
  - Traffic signals
- Proper communication a critical for safe and efficient traffic operations
- Messages must be uncomplicated and clear

Markings, Signs, and Signals



Traffic Engineering – Roess, Prassas, McShane

http://www.mbssigns.com/traffic-signs/

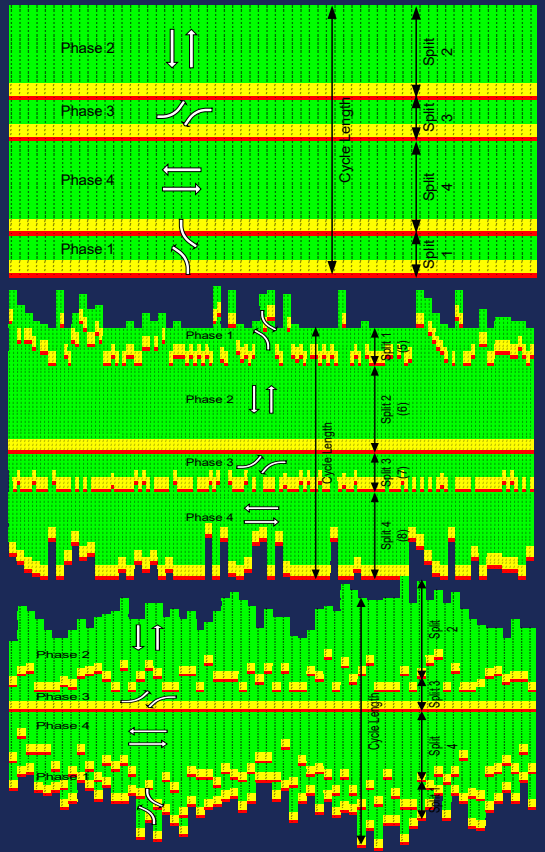
https://ingmarschumacher.files.wordpress.com/2015/10/the-traffic-signal-tree.jpg

Traffic Signals

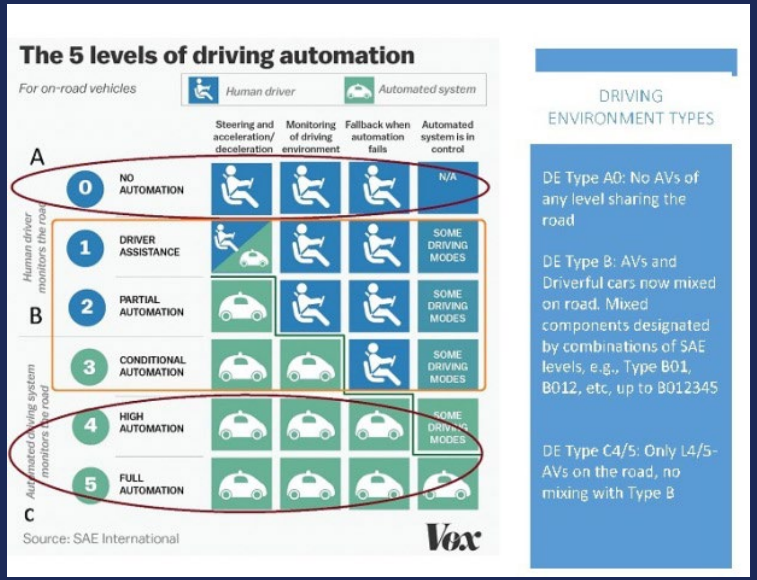
1. Traffic control signals
2. Pedestrian signals
3. Emergency vehicle traffic control signals
4. Traffic control signals for one-way two-lane facilities
5. Traffic control signals for freeway entrance ramps
6. Traffic control signals for movable bridges
7. Lane-use control signals
8. Flashing beacons
9. In-roadway lights

Traffic Signal Timings by Degree of Variation

Control Type	Traffic Demand	What is modified?
Fixed	Diurnal Traffic Patterns	Plans
Actuated	Diurnal Traffic Patterns and Short-term Fluctuations	Plans, Splits within a plan
Adaptive	All changes in traffic demand (short-, and long-term)	(Plans), Splits, Offsets, Cycle Length



Traffic control in CAVs environment?



https://www.vox.com/2016/9/19/12966680/department-of-transportation-automated-vehicles

https://www.digitaltrends.com/cars/denso-v2v-connected-car-technology/

New Traffic Control Framework

- Controlling Environment
  - How is traffic organized (spatially and temporally)?
  - Where does control occur?
- Controlling Process
  - 4D (Detect, Decide, Disseminate, Deploy)

Controlling Environment

- How is traffic organized spatially?
  - In 3D space
  - On surface
    - Unidirectional
    - Bidirectional
      - Grouped Lanes
        - » Fixed
        - » Reversible
      - Flexible Lanes
      - Other
- How permanent is this organization?
  - Constant
  - Variable by Time of Day (TOD)
  - Dynamic (based on various factors)

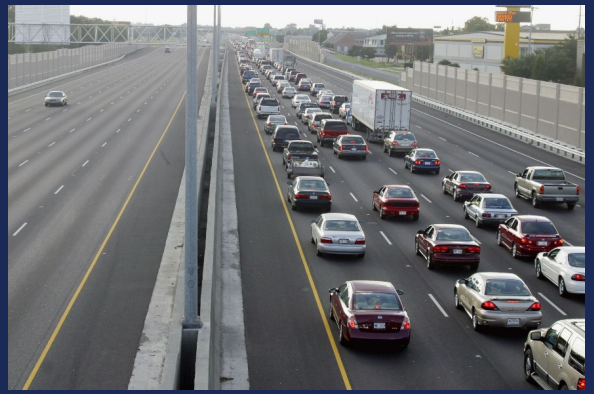
Moving & Environment

http://humanfoodproject.com/hunter-gatherers-namibia/#comment-690

https://thumbs.dreamstime.com/z/moving-crowd-dalian-china-28908860.jpg

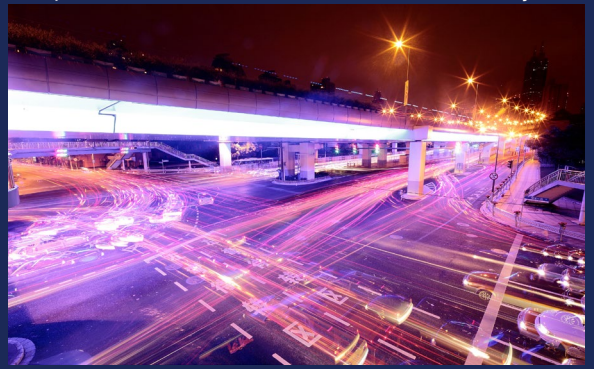
http://blog.mazurw.com/2008/06/

We define how and where agents move

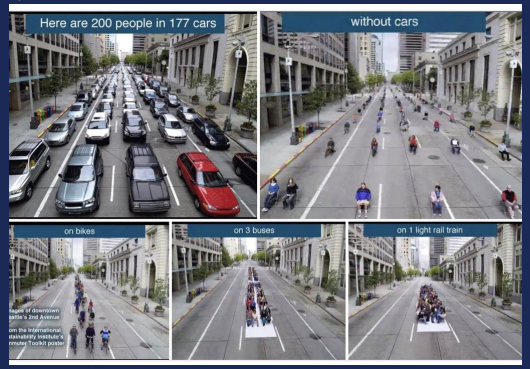


https://www.vox.com/2014/11/24/7276027/traffic-jam

https://www.businessinsider.com/5-ways-to-solve-the-nations-worsening-traffic-problem-2015-6?IR=T



http://onboarddefence.com/

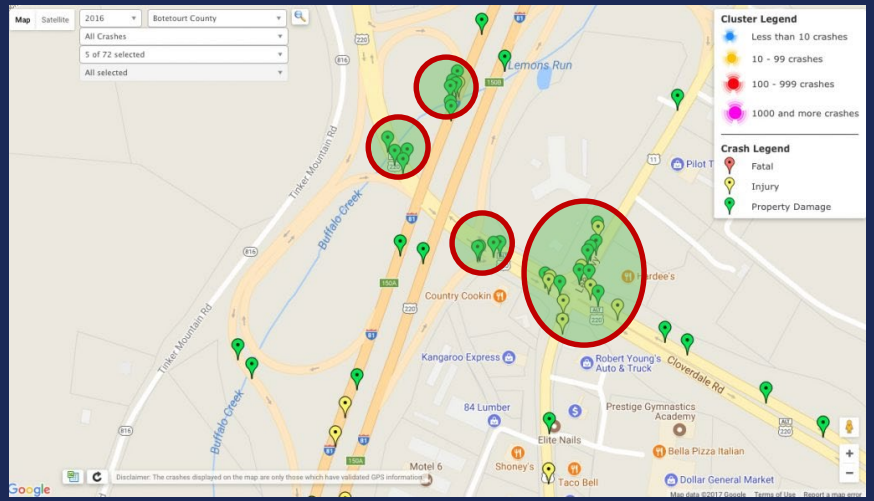


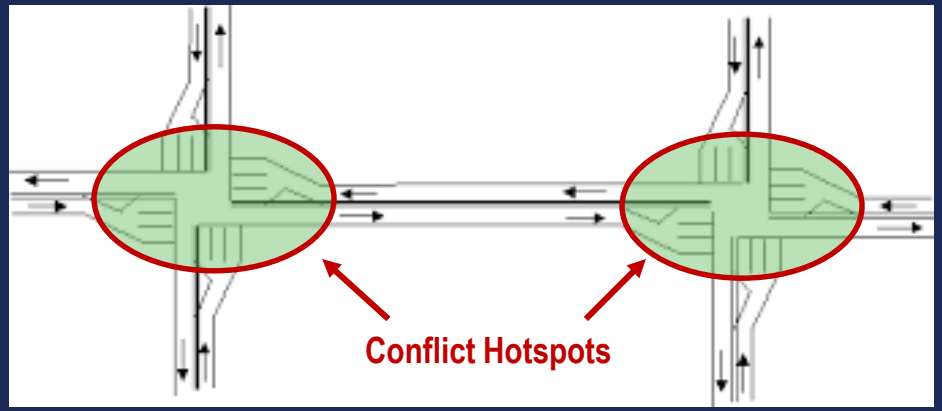
https://twitter.com/faisal7455/status/945642429289521152

Where Does Traffic Control Happen?

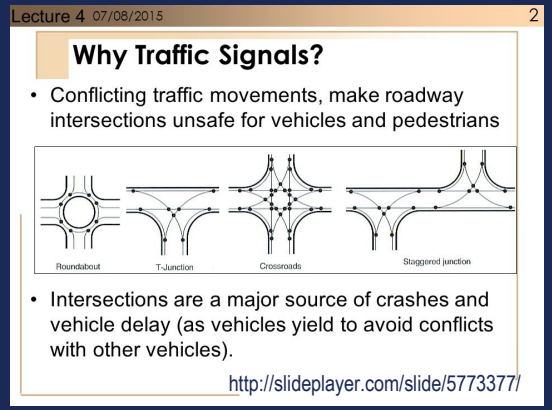
- At crossroads only
  - (e.g. 4-leg intersections, roundabouts)
- At multiple points between crossroads
  - (DLTs, RCUTs, MUTs, etc.)
- Everywhere between crossroads
  - (Continuous conflict avoidance ‘systems’)

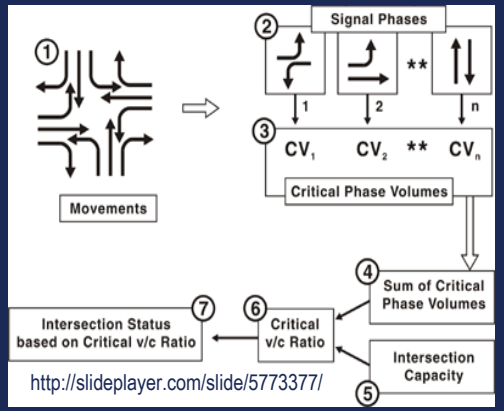
Intersections as Crash/Conflict Hotspots





We decide where, when & how we treat conflicts

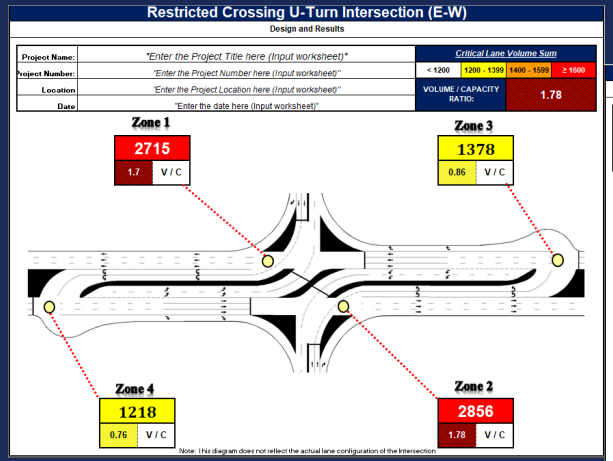


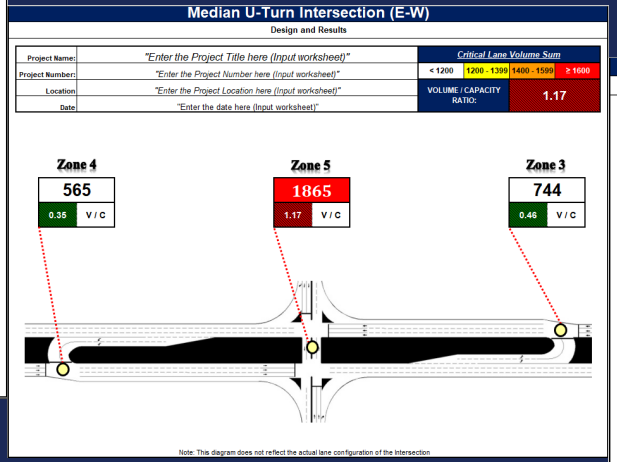


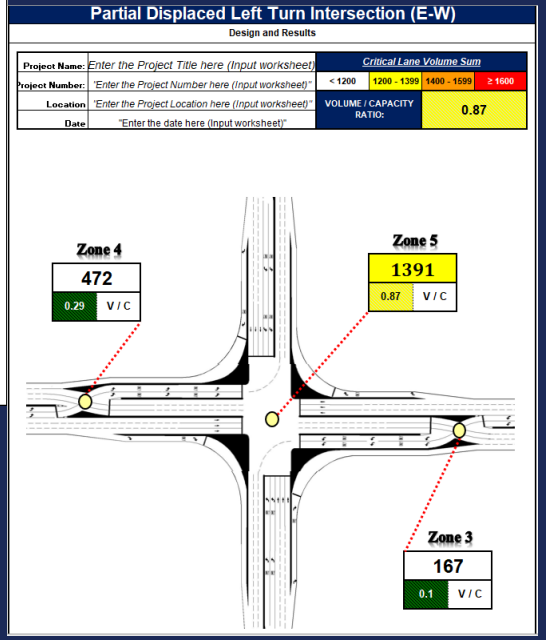
http://www.condemnation-law.com/wp-content/uploads/2014/11/roundabouts-eminent-domain.jpg

http://accesswdun.com/article/2017/5/536295/go-with-the-flow-continuous-flow-intersection-opens-monday-night-in-dawson-co

Examples of Distributed Conflict Resolutions

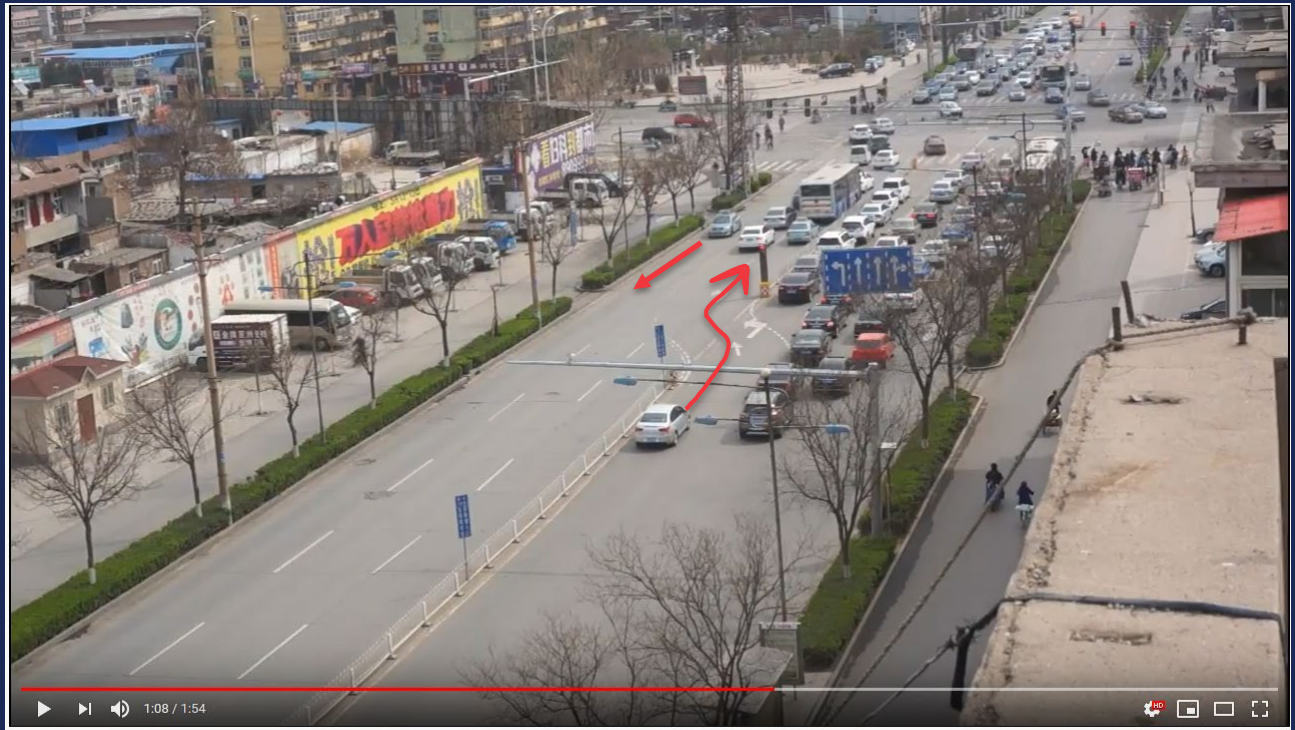






Alternative Intersections/Interchanges: Informational Report (AIIR) Publication Number: FHWA-HRT-09-060
FHWA Capacity Analysis for Planning of Junctions (CAP-X)_FINAL.xlsx

Contraflow Left-turn Intersection



Contraflow Left Turn Intersection from China

https://www.youtube.com/watch?v=xb5cvAAbuIQ

Control Process - Entities

- Who is controlling – jurisdiction perspective?
  - An external authority
  - Self
- Who is controlling – entity type?
  - Human
  - Machine
- Who is being controlled?
  - Human
  - Machine

Who is Controlling (Effectively)?

- Entity Type
  - Human (policeman, work-zone road worker, etc.)
  - Machine (local controller, computer @ TMC, cloud server)
- Jurisdiction
  - External authority (government, another participant)
  - Self (permissive, yield, conflict-resolution negotiation)

Who is being Controlled (Effectively)?

- Entity Type
  - Human (driver, pedestrian, bicyclist, passenger)
  - Machine (in-vehicle computer, drone, a robot, etc.)
- Control Aggregation Level
  - Individual entities (CAVs in AIM, trains, buses)
  - Groups of entities (cars, pedestrians, buses, bicycles)

4D Controlling Process

- Detect
- Decide
- Disseminate (Information/Decision)
- Deploy (Implement Decision)

Detection

- No immediate detection (control based on historic data)
- Point-based
  - Individual (high-resolution data from individual ‘loops’)
  - Group (multiple loops connected in a single channel)
- Trajectory
  - Individual (follow a trajectory of a single entity)
    - Segment-based
    - Path-based
  - Group (fusion of multiple trajectories)

Detection Technologies

- Inductive loops
- Magnetic radars
- Video imaging
- Acoustic
- Global Positioning System (GPS)
- Direct Short-Range Communications (DSRC)
- Global System for Mobile (GSM) Communications

Decide

- Where? When? Who? Why? How?
- Where and who – already addressed
- How and when – closely correlated
- Why?
  - Safety (avoid conflicts, reduce harmful emissions)
  - Efficiency (reduce delay or energy consumption)
  - Comfort (provide level of service – e.g. pedestrians)

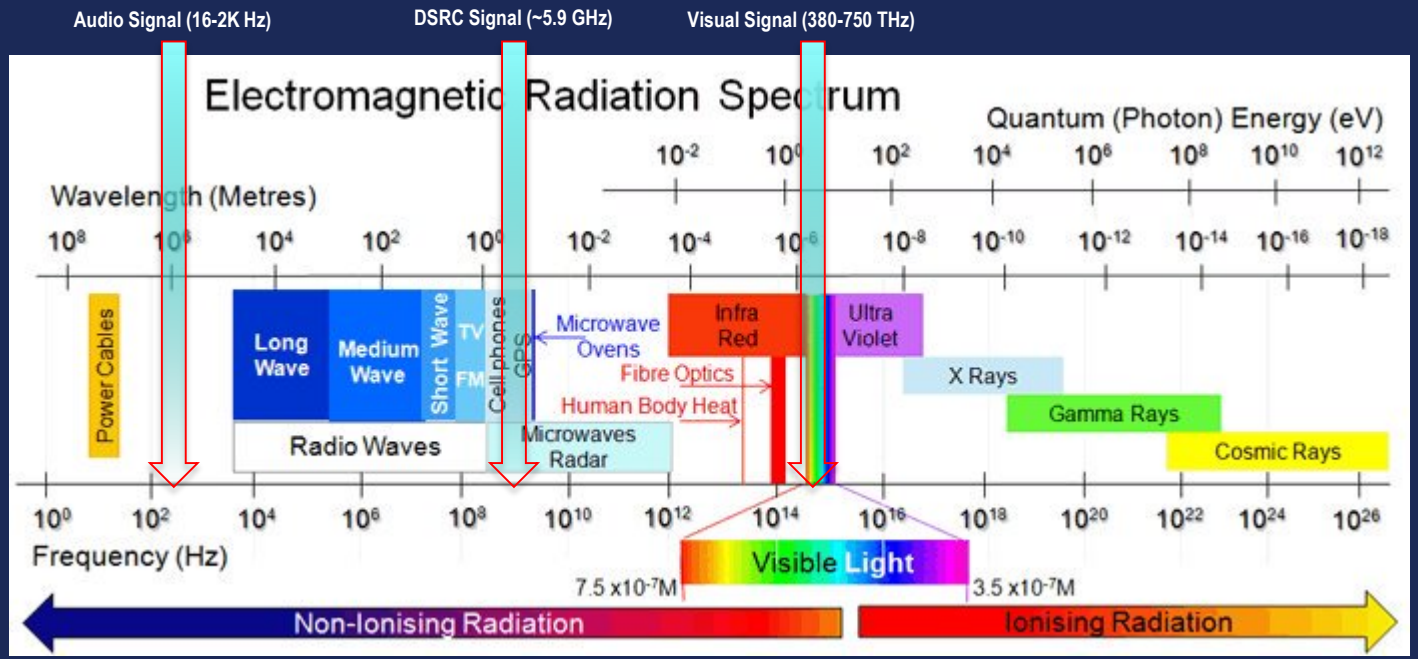
Decide – How and When?

- How?
  - Historic data as input (stop sign, pedestrian X-ing, fixed-time signal, etc.)
  - Open loop (speed warning flasher, actuated signals, etc.)
  - Closed loop (Nth generation of adaptive control, ATSPM, etc.)
- When?
  - Continuously (e.g. Automated Intersection Management, CADLARIC)
  - At discrete intervals (within a signal cycle, within 15-min, within an hour, within a peak period, within a day, within a season, in few years)

Disseminate Decision

- How? (always wirelessly)
  - Visual Signals, Audio (e.g. blind pedestrians), DSRC, etc.
- What infrastructure is used?
  - Signs, markings, signal heads/lamps
- When? (Immediately or later?)
  - Adaptive - same or next cycle, ATSPM - in the next two months, a new sign - when the road is reconstructed

Wireless Communication with Traffic Signals



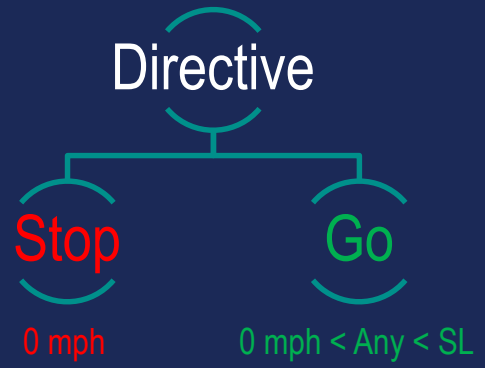
https://twitter.com/swedishpm/status/999256345873350656

Deploy

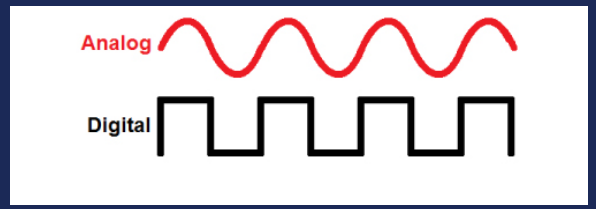
- Entity Type
  - Human (driver, pedestrian, bicyclist, passenger)
  - Machine (in-vehicle computer, drone, a robot, etc.)
- Control Acceptance Level
  - Fully accepted
  - Partially accepted
  - Rejected
- Control Output
  - Binary
  - Nonbinary

Current vs. Future Traffic Control

- Binary vs. Nonbinary Control

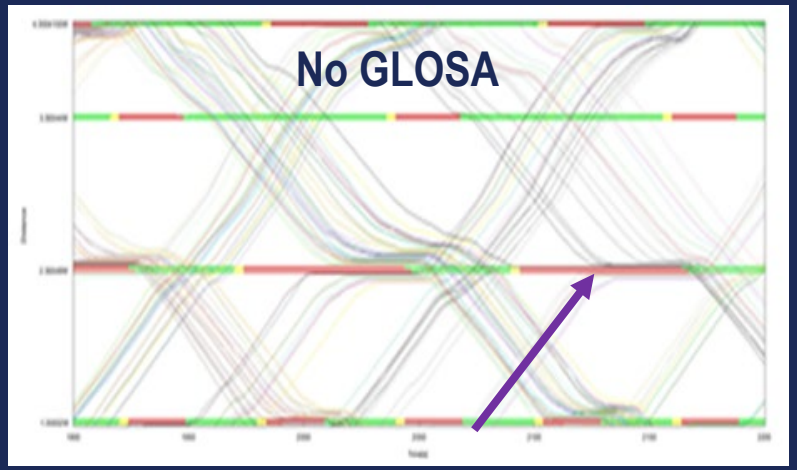


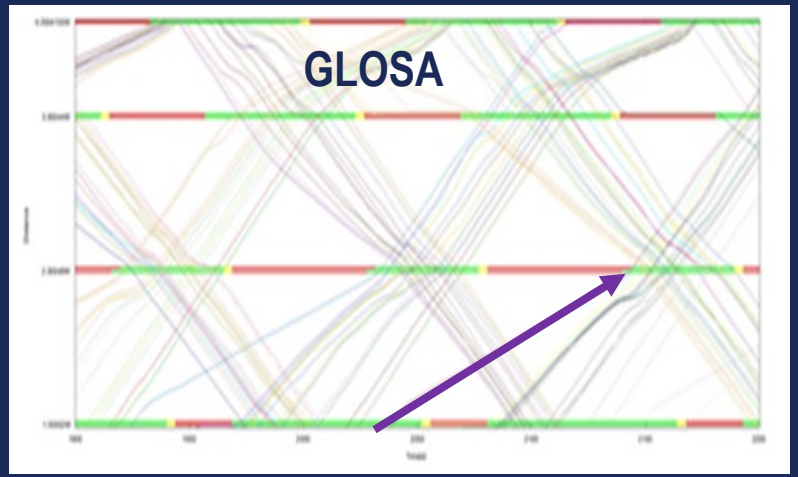
- Digital vs. Analog Signal



Green Light Optimized Speed Advisory (GLOSA)

- Vehicles reduce approach speed to avoid being stopped at downstream intersection
- Communications exist between intelligence (e.g. traffic signal) and each vehicle
- Assumed that each vehicle complies with the suggested speed





Urban Traffic Control – Classification (start)

Type of Urban Traffic Control	Signal Timings	Vehicles	Lane Utilization	Conflict Resolution
Stop Signs	No signals	Unmanaged	Conventional	At intersection
Fixed-time Signals	Fixed	Unmanaged	Conventional	At intersection
Advanced Signal Control	Modified	Unmanaged	Conventional	At intersection
Roundabout (common)	No signals	Unmanaged	Conventional^	At intersection
Roundabout with signals	Modified	Unmanaged	Conventional^	At intersection
Alternative Geometry	Modified	Unmanaged	Unconventional - Fixed	Multiple points
Reversible Lanes	Modified	Unmanaged	Unconventional - TBS	At intersection
Best GLOSA	Fixed	Managed	Conventional	At intersection
Common GLOSA	Modified	Managed	Conventional	At intersection
Reservat.-based Control	Modified	Managed	Conventional	At intersection
CADLARIC & Similar	Modified	Managed	Unconventional - Fixed	Everywhere
Dynamic CADLARIC	Modified	Managed	Unconvention. - Dynamic	Everywhere

Urban Traffic Control – Classification (WIP)

Control Category	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Possible Codes
Controlling Environment Domain	3D	2D						(2)/(3).
		Unidirectional	Bidirectional					(U)/(B).
			Grouped lanes		Flexible lanes	Other		(G)/(F)/(O).
				Fixed				(F)/(R).
				Reversible				
Permanency of Environment	Constant	Variable by TOD	Dynamic (various factors)					(C)/(T)/(D).
Place of Control	Intersections	Multiple points along road	Everywhere					(I)/(M)/(E).
Controlling Entity - Jurisdiction	External	Self						(E)/(S).
Controlling Entity - Type	Human	Machine						(H)/(M).
Controlled Entity - Type	Human	Machine						(H)/(M).
Control Aggregation Level	Individual	Groups						(I)/(G).
Detection Coverage	No detection	Point-based	Trajectory					(N)/(P)/(T).
Detection Technology	Inductive loops	Magnetic radars	Video imaging	Acoustic	GPS	DSRC	GSM	(I)/(R)/(V)/(A)/(G)/(D)/(M).
Decision - Feedback	Historic	Open loop	Closed loop					(H)/(O)/(C).
Decision - Time	Continuously	Cycle	15-minutes	Hour	Peak	Day	Season (Year)	(C)/(L)/(15)/(H)/(P)/(D)/(S)/(Y).
Dissemination - Media	Visual	Audio	DSRC	GSM				(V)/(A)/(D)/(M).
Dissemination - Infrastructure	Sign	Marking	Signal	Other				(S)/(M)/(L)/(O).
Dissemination - Time	Continuously	Next cycle	Next 15 min	Few months	Redesign	Other		(C)/(L)/(15)/(M)/(R)/(O).
Deploying Entity	Human	Machine						(H)/(M).
Control Expectation	Mandatory	Permissive	Optional					(M)/(P)/(O).
Control Output	Binary	Nonbinary						(B)/(N).
Conflict Type	Crossing	Lane-changing	Merging	Diverging	Rear-end	Side	Various	(C)/(L)/(M)/(D)/(R)/ (S)/(V).

Examples of Traffic Control Nomenclature Strings

Control Type	Traffic Control Nomenclature String (TCNS)	QR Code
Fixed-time signal	2.B.G.F.C.I.E.M.H.G.N.X.H.Y.V.L.O.H.M.B.R	
Roundabout	2.B.G.F.C.I.E.H.H.G.N.X.H.Y.V.S.R.H.P.N.M	
Stop Sign (4-way)	2.B.G.F.C.I.E.H.H.G.N.X.H.Y.V.S.R.H.M.B.V	
Actuated (Coord.)	2.B.G.F.C.I.E.M.H.G.P.V.O.C.V.L.O.H.M.B.R	
GLOSA Actuated	2.B.G.F.C.E.E.M.M.I.T.D.C.C.D.O.C.M.M.N.R	
Adaptive signal	2.B.G.F.C.I.E.M.H.G.P.I.C.C.V.L.C.H.M.B.R	
AIM (Reservation)	2.B.G.F.C.I.E.M.M.I.T.M.C.C.M.O.C.M.M.N.V	
CADLARIC	2.B.F.X.D.E.E.M.M.I.T.M.C.C.M.O.C.M.M.N.V	

TRAFFIC CONTROL - OUTLOOK

Why is classifying of traffic control important?

- A connected-automated vehicle approaching (in series) a regular traffic signal and then a smart (DSRC) signal
- A regular traffic signal having to serve both regular and DSRC vehicles
- A CAV passing through regular, then GLOSA, then AIM, then CADLARIC zone
- It could be a mess…
- …or we could wait forever to ‘standardize operations’

How is this applicable in heterogenous conditions?

https://www.media.volvocars.com/us/en-us/media/photos/49886

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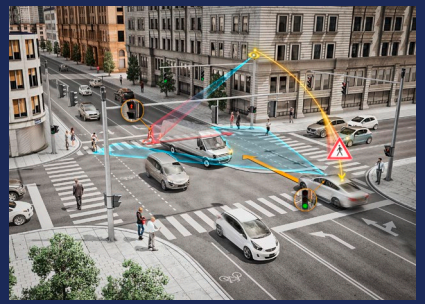

https://www.continental.com/en/press/press-releases/2018-12-17-ces-2019-smart-cities-156184

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https://www.treetopproducts.com/flash-alert-solar-stop-sign

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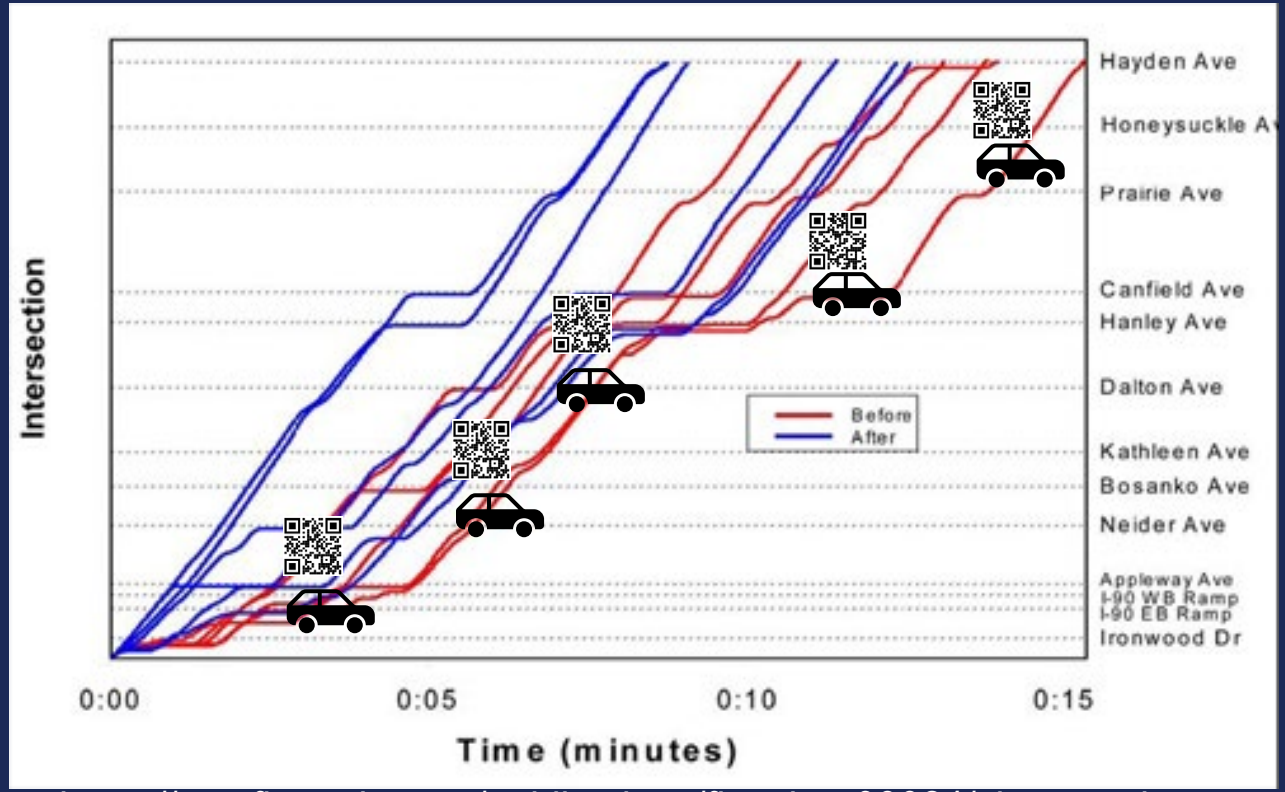
https://www.digitaltrends.com/cars/ford-intersection-priority-management-connected-car-v2v-experiment/

?

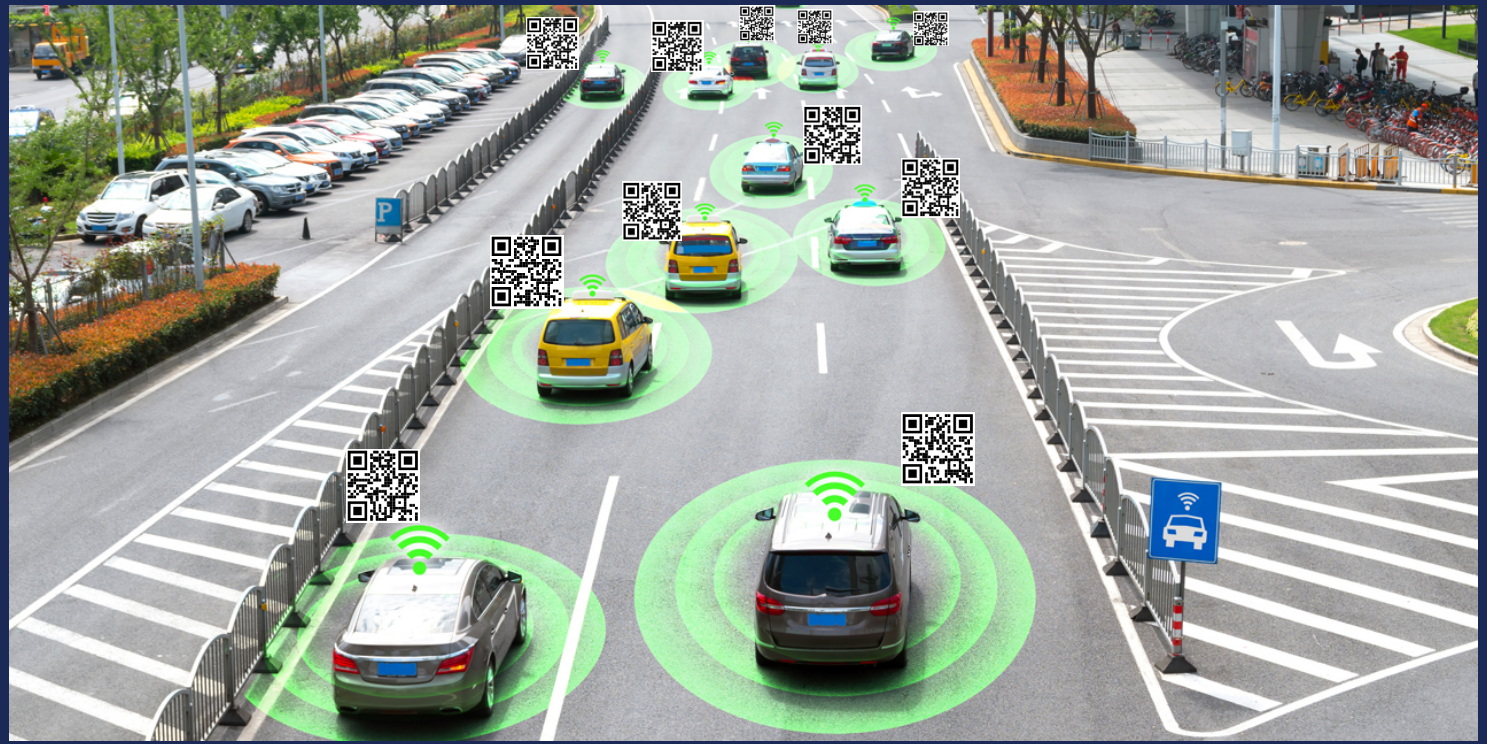
If a corridor has multiple traffic control types which code to use?

Continuous Awareness of Traffic Control



https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter7.htm

New Paradigm for Traffic Control



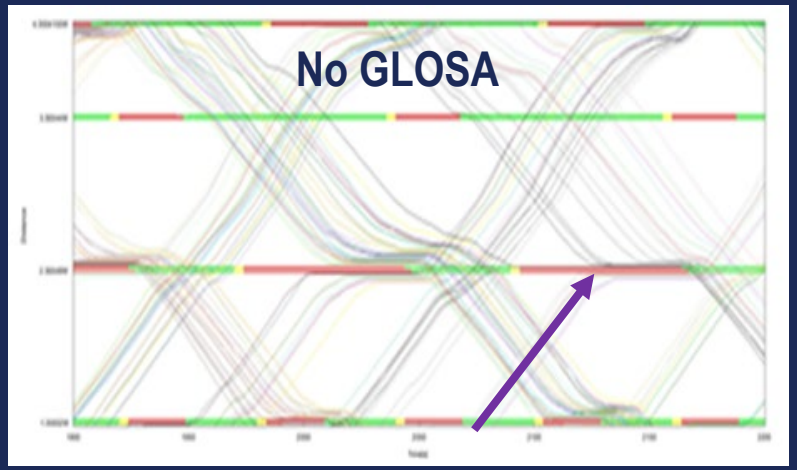
Traffic Control as a vehicle-centered tempo-spatial characteristic of interactions with other agents in the network

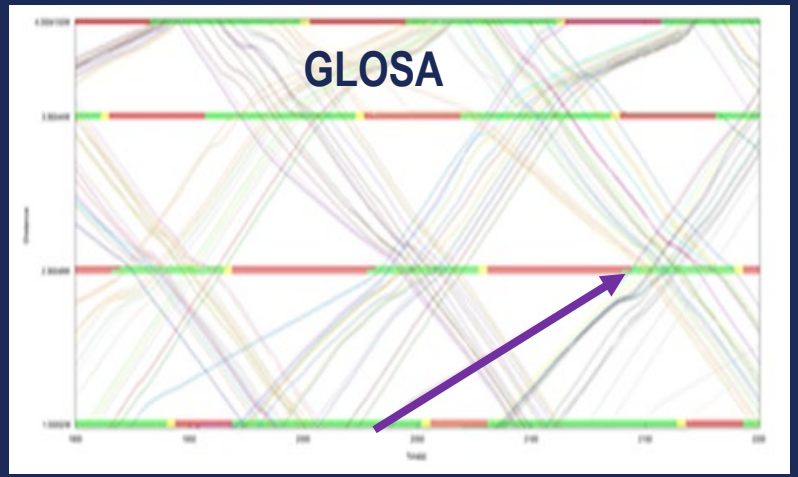
* Needs to be appended to include vehicular characteristics

https://tiaonline.org/industry-priorities/internet-of-things/intelligent-transportation/

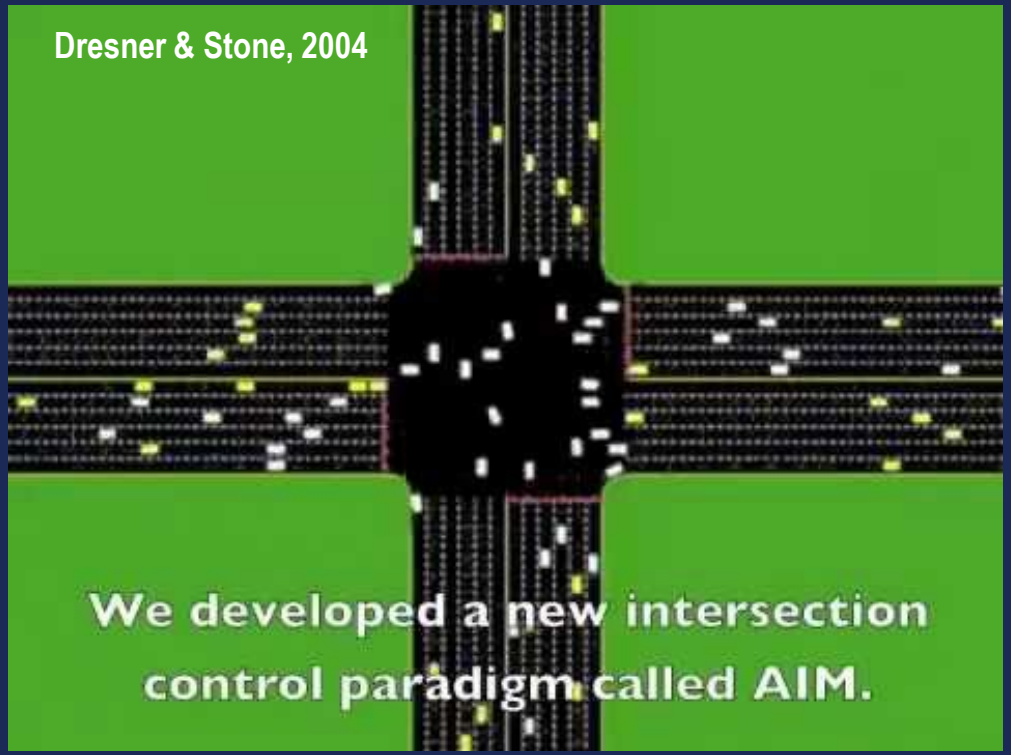
GLOSA – 1st Gen of Distributed Traffic Control

- Vehicles reduce approach speed to avoid being stopped at downstream intersection
- Communications exist between intelligence (e.g. traffic signal) and each vehicle
- Assumed that each vehicle complies with the suggested speed





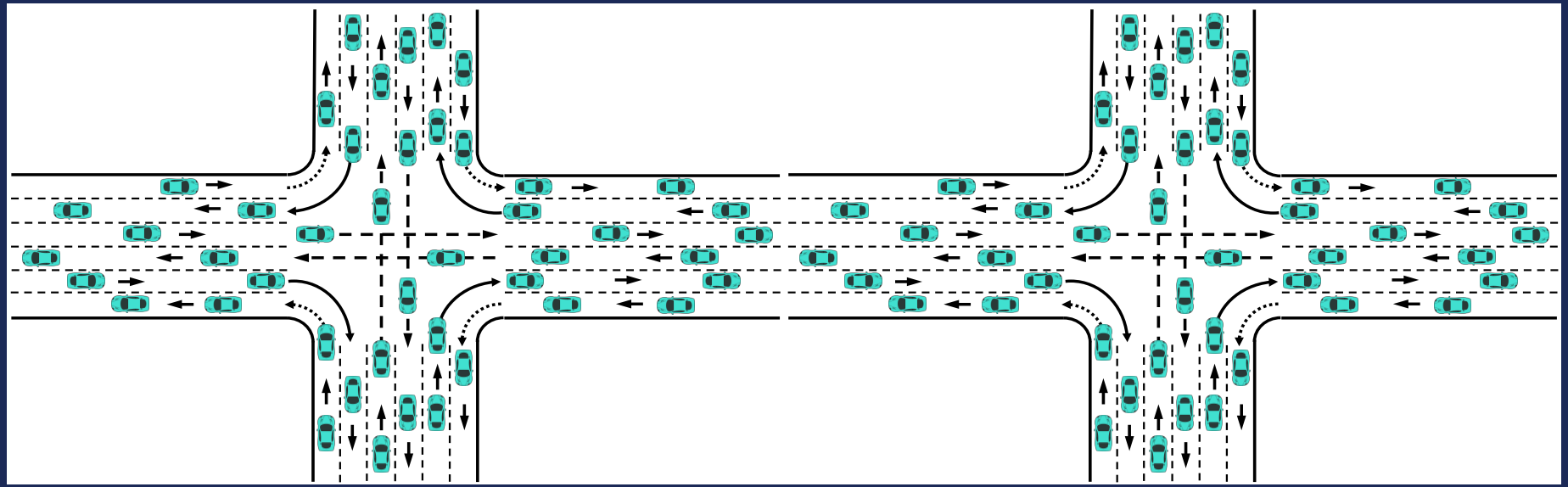
AIM – 2nd Gen of Distributed Traffic Control



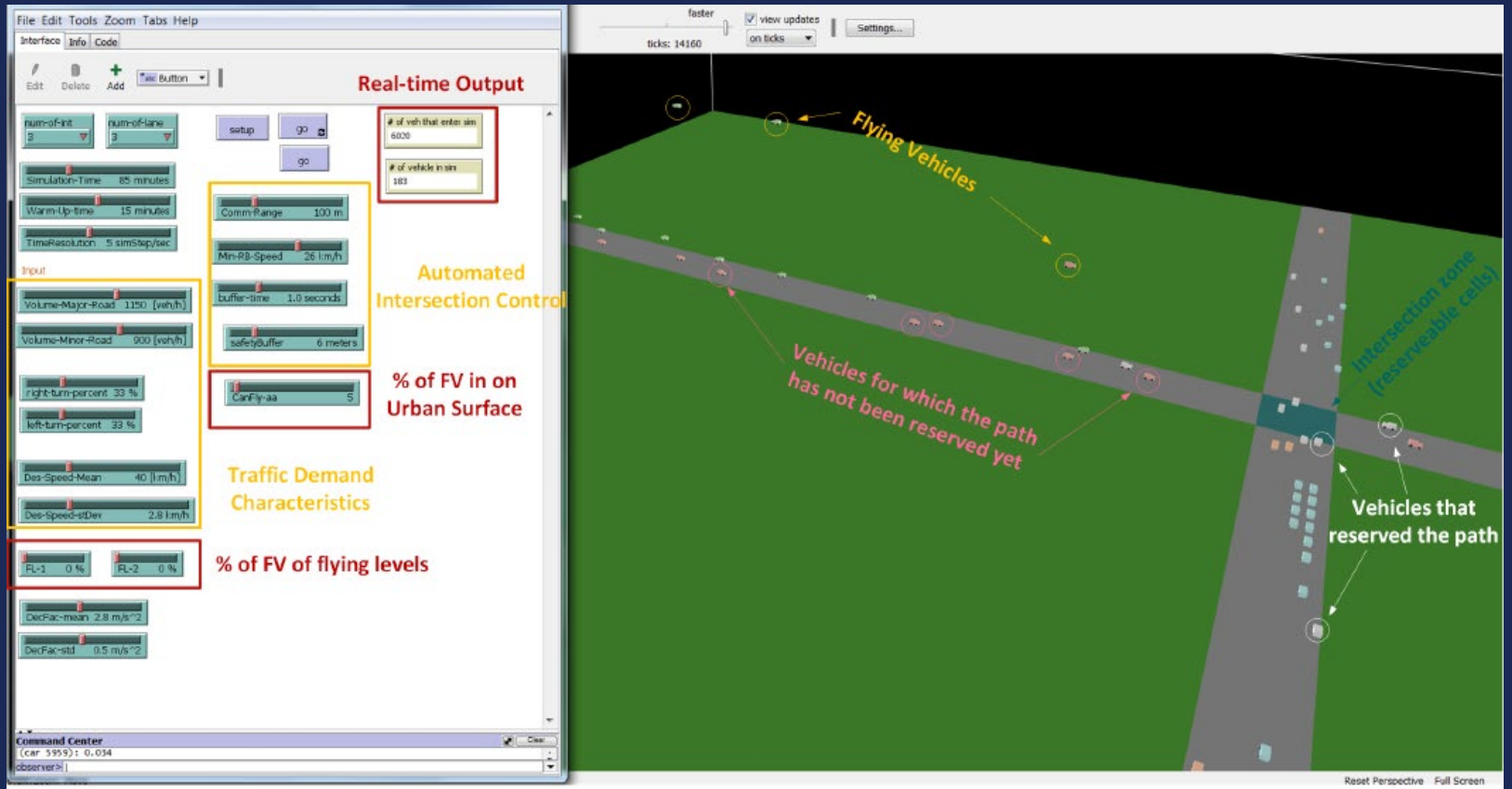
https://www.youtube.com/watch?v=4pbAI40dK0A

CADLARIC - 3rd Gen of Distributed Traffic Control

CADLARIC - Combined Alternate-Direction Lane Assignment and Reservation-based Intersection Control



Nth Gen. of Distributed Traffic Control



Evolution of Traffic Control

	Traditional	Contemporary	Future
Sensing Traffic	Collect traffic data (every few years)	Stationary sensors (near real time)	Moving sensors (real time)
Making Decision	No/little feedback; poor policy	Good feedback; poor policy	Good feedback; excellent policy
Control Model	One to many	One to many	Many to many
Implementing Control	0/1	0/1	0,0.1,0.2,…,1
Current Market Share	97%	2.99999%	0.00001%

Conclusions

- With additions of other ‘players’ in traffic control ‘game’ (e.g. smart cars, smart signals, new ways of communicating) controlling of traffic will be a much more complex and intensive process
- Not a ‘rocket science’ but more complex than sending the rockets in outer space
- We are moving into uncharted territory where the ‘rules of the game’ may change and we need to properly recognize various conditions and adjust the rules accordingly
- Future of traffic control is in regulation/handling of individual conflicts between traffic users in a distributed way
- Defining and classifying traffic control up to this point was not so important but it is becoming an issue which will need to be addressed in near future
- This framework presents one of the first attempts towards proper classification and context-sensitive utilization of ‘new traffic control’

Questions and comments?

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