Traffic Control - Definition, Classification, and Outlook

Aleksandar Stevanovic, Ph.D., P.E.,
Associate Professor, University of Pittsburgh

Transportation Engineering & Safety Conference
PennState, December 13, 2019
CADLARIC - Combined Alternate-Direction Lane Assignment and Reservation-based Intersection Control

CADLARIC - https://youtu.be/RXSwJKqBQtM
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

Fixed-Time Signals

FR-BIC

CADLARIC
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

- 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.**

<table>
<thead>
<tr>
<th>Book Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamentals of Transportation and Traffic Operations – Carlos Daganzo</td>
<td>Carlos F. Daganzo</td>
</tr>
<tr>
<td>Optimal Traffic Control – Slobodan Guberinic, Gordana Senborn, Bratislav Lazic</td>
<td>Slobodan Guberinic, Gordana Senborn, Bratislav Lazic</td>
</tr>
<tr>
<td>Traffic Engineering – Roess, Prassas, McShane</td>
<td>Roess, Prassas, McShane</td>
</tr>
</tbody>
</table>

Theoretical foundations and practical applications of traffic control.
Traffic Control – Online Sources

<table>
<thead>
<tr>
<th>Encyclopedia Britannica</th>
<th>Wikipedia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paul P. Jovanis &amp; F.D. Hobbs</td>
<td>NA</td>
</tr>
</tbody>
</table>

*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 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.
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

Spacing of lines selected to avoid wheel path

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

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


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

Why Traffic Signals?
- Conflicting traffic movements, make roadway intersections unsafe for vehicles and pedestrians
- Intersections are a major source of crashes and vehicle delay (as vehicles yield to avoid conflicts with other vehicles)


Examples of Distributed Conflict Resolutions

FHWA Capacity Analysis for Planning of Junctions (CAP-X)_FINAL.xlsx
Contraflow Left-turn Intersection

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 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

Audio Signal (16-2K Hz)  DSRC Signal (~5.9 GHz)  Visual Signal (380-750 THz)

https://twitter.com/swedishpm/status/99925634587335056
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

<table>
<thead>
<tr>
<th>Type of Urban Traffic Control</th>
<th>Signal Timings</th>
<th>Vehicles</th>
<th>Lane Utilization</th>
<th>Conflict Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop Signs</td>
<td>No signals</td>
<td>Unmanaged</td>
<td>Conventional</td>
<td>At intersection</td>
</tr>
<tr>
<td>Fixed-time Signals</td>
<td>Fixed</td>
<td>Unmanaged</td>
<td>Conventional</td>
<td>At intersection</td>
</tr>
<tr>
<td>Advanced Signal Control</td>
<td>Modified</td>
<td>Unmanaged</td>
<td>Conventional</td>
<td>At intersection</td>
</tr>
<tr>
<td>Roundabout (common)</td>
<td>No signals</td>
<td>Unmanaged</td>
<td>Conventional(^)</td>
<td>At intersection</td>
</tr>
<tr>
<td>Roundabout with signals</td>
<td>Modified</td>
<td>Unmanaged</td>
<td>Conventional(^)</td>
<td>At intersection</td>
</tr>
<tr>
<td>Alternative Geometry</td>
<td>Modified</td>
<td>Unmanaged</td>
<td>Unconventional - Fixed</td>
<td>Multiple points</td>
</tr>
<tr>
<td>Reversible Lanes</td>
<td>Modified</td>
<td>Unmanaged</td>
<td>Unconventional - TBS</td>
<td>At intersection</td>
</tr>
<tr>
<td>Best GLOSA</td>
<td>Fixed</td>
<td>Managed</td>
<td>Conventional</td>
<td>At intersection</td>
</tr>
<tr>
<td>Common GLOSA</td>
<td>Modified</td>
<td>Managed</td>
<td>Conventional</td>
<td>At intersection</td>
</tr>
<tr>
<td>Reservat.-based Control</td>
<td>Modified</td>
<td>Managed</td>
<td>Conventional</td>
<td>At intersection</td>
</tr>
<tr>
<td>CADLARIC &amp; Similar</td>
<td>Modified</td>
<td>Managed</td>
<td>Unconventional - Fixed</td>
<td>Everywhere</td>
</tr>
<tr>
<td>Dynamic CADLARIC</td>
<td>Modified</td>
<td>Managed</td>
<td>Unconvention. - Dynamic</td>
<td>Everywhere</td>
</tr>
<tr>
<td>Control Category</td>
<td>Option 1</td>
<td>Option 2</td>
<td>Option 3</td>
<td>Option 4</td>
</tr>
<tr>
<td>------------------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>Controlling Environment Domain</td>
<td>3D</td>
<td>2D</td>
<td>Bidirectional</td>
<td>Flexible lanes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unidirectional</td>
<td>Grouped lanes</td>
<td>Fixed</td>
</tr>
<tr>
<td>Permanency of Environment</td>
<td>Constant</td>
<td>Variable by TOD</td>
<td>Dynamic (various factors)</td>
<td>Everywhere</td>
</tr>
<tr>
<td>Place of Control</td>
<td>Intersections</td>
<td>Multiple points along road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controlling Entity - Jurisdiction</td>
<td>External</td>
<td>Self</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controlling Entity - Type</td>
<td>Human</td>
<td>Machine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controlled Entity - Type</td>
<td>Human</td>
<td>Machine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Aggregation Level</td>
<td>Individual</td>
<td>Groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection Coverage</td>
<td>No detection</td>
<td>Point-based</td>
<td>Trajectory</td>
<td></td>
</tr>
<tr>
<td>Detection Technology</td>
<td>Inductive loops</td>
<td>Magnetic radars</td>
<td>Video imaging</td>
<td>Acoustic</td>
</tr>
<tr>
<td>Decision - Feedback</td>
<td>Historic</td>
<td>Open loop</td>
<td>Closed loop</td>
<td></td>
</tr>
<tr>
<td>Decision - Time</td>
<td>Continuously</td>
<td>Cycle</td>
<td>15-minutes</td>
<td>Hour</td>
</tr>
<tr>
<td>Dissemination - Infrastructure</td>
<td>Sign</td>
<td>Marking</td>
<td>Signal</td>
<td>Other</td>
</tr>
<tr>
<td>Dissemination - Time</td>
<td>Continuously</td>
<td>Next cycle</td>
<td>Next 15 min</td>
<td>Few months</td>
</tr>
<tr>
<td>Deploying Entity</td>
<td>Human</td>
<td>Machine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Expectation</td>
<td>Mandatory</td>
<td>Permissive</td>
<td>Optional</td>
<td></td>
</tr>
<tr>
<td>Control Output</td>
<td>Binary</td>
<td>Nonbinary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conflict Type</td>
<td>Crossing</td>
<td>Lane-changing</td>
<td>Merging</td>
<td>Diverging</td>
</tr>
</tbody>
</table>
### Examples of Traffic Control Nomenclature Strings

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Traffic Control Nomenclature String (TCNS)</th>
<th>QR Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIM (Reservation)</td>
<td>2.B.G.F.C.I.E.M.M.I.T.M.C.C.M.O.C.M.M.N.V</td>
<td></td>
</tr>
<tr>
<td>CADLARIC</td>
<td>2.B.F.X.D.E.E.M.M.I.T.M.C.C.M.O.C.M.M.N.V</td>
<td></td>
</tr>
</tbody>
</table>
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?

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

GLOSA – 1\textsuperscript{st} 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

Dresner & Stone, 2004

We developed a new intersection control paradigm called AIM.

https://www.youtube.com/watch?v=4pbAl40dK0A
CADLARIC - Combined Alternate-Direction Lane Assignment and Reservation-based Intersection Control
Nth Gen. of Distributed Traffic Control
# Evolution of Traffic Control

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

stevanovic@pitt.edu