Traffic Control in Action

Prof. Markos Papageorgiou
Dynamic Systems and Simulation Laboratory,
Technical University of Crete, Chania, Greece
1. INTRODUCTION

Man has reached to the moon but ...

... even ants were taught by evolution to address their transportation problems more efficiently, see I.D. Couzin and N.R. Franks: “Self-organized lane formation and optimized traffic flow in army ants”, Proc. R. Soc. Lond. B (2003) 270, 139–146
Minimization of Total Time Spent

⇔

Maximization of (Early) Exit Flows
Simple Queuing Systems

- Demand > Capacity ⇒ Queuing
- Capacity ≠ f (Queuing)
⇒ Delay depends on D–C only!

Water Systems

More Inflow ⇒ Higher Pressure ⇒ Higher Outflow
Traffic Networks

- Congestion degrades the infrastructure (capacity)
  Local link demand exceeds local capacity
  ⇒ Local congestion degrades local capacity

\[\text{Accelerated increase of congestion} \rightarrow \text{Further capacity degradation} \rightarrow \ldots \text{until generalized network congestion} \]

although
Demand $\ll$ Nominal network capacity
Ile-de-France Expressway Network

12 January 2011, 8:14 am
Conclusion: Generalized traffic congestion is not only due to high demand.

Congested Traffic Networks: Expensive infrastructure capacity not fully available at the **only** time it is actually needed, i.e. the peak periods!

Goal: Operate traffic networks optimally (as a **controllable** system)
Basic elements of an automatic control system
2. RAMP METERING
Why Ramp Metering?

1st Answer
2nd Answer

\[
\frac{\gamma}{1-\gamma} (q_{cap} - d)
\]

**Note:** On-ramp queue should not interfere with surface street traffic.
Local Control Issues

\[ r(k) = q_{\text{cap}} - q_{\text{in}}(k - 1) \]

Note: \( o_{cr} \) is less sensitive than \( q_{\text{cap}} \) (e.g. under adverse weather conditions).
Sample from Glasgow Implementation of ALINEA
HERO Feedback Coordination

- ALINEA Activation?  Master Ramp
- HERO hires gradually (upstream) Slave Ramps
- Cluster: Master + Slaves
- HERO MIMO Feedback: Balance relative ramp queues in Cluster (create 1 super-ramp)
- Cluster de-activation logic
HERO Implementation at the Monash Freeway, Melbourne, Australia

- Test pilot: 6 consecutive ramps
- Significant improvements in all PI: Productivity, Speed Variation, Reliability
- 11 days payback period!
AM PEAK Typical day (Fixed Time)

<table>
<thead>
<tr>
<th>Time</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:00</td>
<td></td>
</tr>
<tr>
<td>5:15</td>
<td></td>
</tr>
<tr>
<td>5:30</td>
<td></td>
</tr>
<tr>
<td>5:45</td>
<td></td>
</tr>
<tr>
<td>6:00</td>
<td></td>
</tr>
<tr>
<td>6:15</td>
<td></td>
</tr>
<tr>
<td>6:30</td>
<td></td>
</tr>
<tr>
<td>6:45</td>
<td></td>
</tr>
<tr>
<td>7:00</td>
<td></td>
</tr>
<tr>
<td>7:15</td>
<td></td>
</tr>
<tr>
<td>7:30</td>
<td></td>
</tr>
<tr>
<td>7:45</td>
<td></td>
</tr>
<tr>
<td>8:00</td>
<td></td>
</tr>
<tr>
<td>8:15</td>
<td></td>
</tr>
<tr>
<td>8:30</td>
<td></td>
</tr>
<tr>
<td>8:45</td>
<td></td>
</tr>
<tr>
<td>9:00</td>
<td></td>
</tr>
<tr>
<td>9:15</td>
<td></td>
</tr>
<tr>
<td>9:30</td>
<td></td>
</tr>
<tr>
<td>9:45</td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td></td>
</tr>
<tr>
<td>10:15</td>
<td></td>
</tr>
<tr>
<td>10:30</td>
<td></td>
</tr>
<tr>
<td>10:45</td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td></td>
</tr>
<tr>
<td>11:15</td>
<td></td>
</tr>
<tr>
<td>11:30</td>
<td></td>
</tr>
</tbody>
</table>

Bottleneck created due to large number of lane changing
AM PEAK Typical day (ALINEA/HERO)

Bottleneck cleared
PM PEAK Typical day (No RM)

Bottleneck created due to merge at Forster ramp
PM PEAK Typical day (ALINEA/HERO)
Currently: HERO extension to 65 ramps, i.e. whole freeway, 75 km, both directions
3. VARIABLE SPEED LIMITS
- Many application stretches in many counties
- Impact: “homogenisation” of traffic flow
  - Traffic safety: –20-30% accidents
  - Travel times: questionable impact of existing systems
- Simplistic control strategies
Switching plan

Speed indications at subsequent VSL-stations
Parameter estimation at one particular location

\[ A = 0.42 \]
\[ E = 3.16 \]

leading to capacity increase by 8\%
Other location

A = 0.7
E = 1.9
no capacity increase!
4. ROUTE INFORMATION AND GUIDANCE

- Multi-origin, multi-destination, multi-route per O-D pair
- Fixed direction signs: shortest path in absence of congestion
- Rush hours
- Changing demands, weather conditions, exceptional events, incidents
  - underutilisation of infrastructure
  - congestion, delays, reduced safety, increased fuel consumption, environmental pollution
VMS (Variable Message Signs) or two-way communication with equipped vehicles

- **Real-time information:**
  - Drivers’ knowledge
  - Message length
  - Decision efficiency
  - System controllability
  - Travel time or queue length: drivers’ stress (e.g. BP in Paris) but also basis for route choice
  - Instantaneous (estimation) or predicted information

- **Route guidance**
  - Control strategy
Issues

- Modelling: micro, meso, macro
- Integrated Optimal Control: AMOC
- User vs. System Optimum
- Instantaneous vs. Experienced travel times
- Algorithms: feedback vs. predictive feedback vs. iterative
Automatic Control of VMS in Aalborg, Denmark

Aalborg network with VMS positions indicated. Bold black lines represent detector equipped segments.

VMS control modes:
Delay information (a) and route guidance (b).
Automatic Control of VMS in the Interurban Scottish Highway Network
5. TRAFFIC SIGNAL CONTROL

- Original reason for traffic lights: safe crossing of antagonistic streams of vehicles and pedestrians
- Once they exist, they can be set in different ways. Which is best? → Optimisation problem
- Difficulties:
  - Binary variables
  - Large dimensions
  - Many disturbances
  - Difficult measurements
  - Real-time constraints
- Many control strategies, both heuristic and systematic
“2-D Fundamental Diagram” for urban networks
(PhD-Thesis by Geroliminis, 2007; Fahri, 2008)

Caution: Different underlying phenomena than on link – FD
Real-time Signal Control Strategies/Systems

- **Isolated**
  - Traffic actuation, MOVA

- **Network-wide**
  - Plan selection
  - SCOOT, SCATS, UTOPIA, MOTION, OPAC, ...
    (partially strong communication requirements)

- **Saturated traffic conditions**
- Store-and-forward based strategies
  - TUC and variations
  - Cycle-to-cycle changes
  - Low communication requirements
- Perimeter gating control
Replication R2

(a) TTS non-gated
(b) actual flow
(c) TTD non-gated
(d) TTS gated
(e) set value
(f) TTD gated
6. PUBLIC TRANSPORT PRIORITY

- Refers to all types of public transport vehicles (buses, trams, trains, etc. and even emergency vehicles)

- Technological implications
  - special detection technologies
  - programmable controllers
  - sec-by-sec communication with the controllers

- Implications for the road traffic
  - Frequent disturbances of signal control may lead to significant negative implications to road traffic
  - Recovery methods may not be sufficient to avoid negative implications
Multiple approaches: Included in signal control strategies

- Easier: one PT vehicle at a time
- More challenging: multiple PT vehicles!
- Good improvements reported
7. MERGING TRAFFIC CONTROL

Merging traffic infrastructures ($M \rightarrow \mu$ lanes)
- Merging of two highways
- Motorway on-ramps
- Toll plazas
- Motorway work zones
- Tunnels.

Structure and Elements

Merging traffic control to restore capacity flow

Diagram:
- Arriving flow
- Exiting flow
- Queuing area
- Merge area
- Control devices
- Control algorithm
- Real-time measurements
Simulation Example: Toll plaza
San Francisco-Oakland Bay Bridge

\[ M = 15 \]

\[ \mu = 5; \quad q_{\text{cap}} = 10,500 \text{veh/h} \]
Work Zone Control

\[ M = 3 \]

\[ \mu = 1; \quad q_{cap} = 2,300 \text{veh/h} \]
Different layout (now using PI-ALI NEA)
WZ Control video
8. Conclusions

- Traffic flow can be substantially improved (in some cases -50% travel times) via traffic control
- Technological giants with a baby brain
- Methodological zombies
- Nothing is more practical than a good theory
- As simple as possible as complex as necessary
- General applicability, high efficiency
- Field applications needed