Advanced Modeling of Traffic Flow Dynamics and the Need for Wide Area Detection

Prof. Panos G. Michalopoulos
Univ. of Minnesota
- Modeling of traffic flow essential for high performance applications
- Consider Control of oversaturated intersections
- Queuing process
Figure 0: The cumulative input-output process
An optimal control problem in which:

- The system is the intersection
- Control objective: minimization of total delay
- State variables: queue lengths
- Control variables: the green times subject to Max. and Min. values
- Consider a two phase operation
MATHMATICAL FORMULATION:

1. MINIMIZE THE DELAY FUNCTION,

\[ \min D = \int_0^T (x_1 + x_2) \, dt \]

2. SUBJECT TO

\[ F_1 = \frac{dx_1}{dt} = g_1(t) - u \]
\[ F_2 = \frac{dx_2}{dt} = g_2(t) - s_2 (1 - \frac{1}{c})t + \frac{s_2}{s_1} u \]

\( u \) IS A BOUNDED CONTROL VARIABLE DEFINED AS:

\[ u = \frac{s_1g_1(t)}{c} \]

AND SUBJECT TO:

\[ \frac{s_1g_{\text{MIN}}(1)}{c} \leq u \leq u_{\text{MAX}} = \frac{s_1g_{\text{MAX}}(1)}{c} \]

3. THE QUEUES MUST SATISFY THE CONSTRAINTS

\[ 0 \leq x_i \leq \text{PREDETERMINED UPPER BOUND} \]

ALSO,

\[ x_1(0) = x_1(T) = 0 \quad i = 1, 2 \]
Optimal control is essentially bang-bang:

- Max.green on appr. Having max.capacity=>min. to the other appr.
- At switch over time reverse operation
- When queues reach max. value, cycle must vary and solution may not exit
- Co-ordination essential for system of over saturated intersections; conditions under which problem is impossible
Qualitative results plausible but implementation requires better modelling of traffic dynamics

- 2D vs 1D and compressibility
EQUATION OF CONTINUITY

\[ \frac{\partial}{\partial t} \left( \frac{\partial K}{\partial x} \right) - \frac{\partial Q}{\partial x} = 0 \]

WHERE:  
\( K \) = DENSITY  
\( Q \) = FLOW RATE = \( F(K) \)  
\( t \) = TIME  
\( x \) = DISTANCE ALONG THE ROADWAY

SOLUTION

\( K = \text{CONST. ALONG A FAMILY OF STRAIGHT LINES CALLED "CHARACTERISTICS" EMANATING FROM INITIAL AND BOUNDARY CONDITIONS} \)

SLOPE OF CHARACTERISTICS:

\[ \frac{DX}{DT} = F(K) + K F'(K) = \frac{DQ}{DR} \]
Formation and dissipation of queues in 2D (compressible medium)

- Shock waves at tail end of queue under simplifying assumptions
- More realistic assumptions require discretization in time and space (figures)
<table>
<thead>
<tr>
<th>ZONE</th>
<th>DENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 4</td>
<td>$K = K_1$</td>
</tr>
<tr>
<td>2</td>
<td>$K = K_a$</td>
</tr>
<tr>
<td>3</td>
<td>$K_1 \leq K \leq K_m$</td>
</tr>
</tbody>
</table>
Similar modeling applies to freeways

Real life complexities such as initial conditions, variable arrivals, non-equilibrium flow, q-k relationship, sinks and sources are treated numerically.

Real-time implementation requires measurement of initial and boundary conditions.

- i.e. flow and speed or concentration for every $\Delta x$
Fig 4 Space discretization of a complex arterial link
PROBLEM

◆ Lack of instrumentation for taking measurements
◆ Reliability and accuracy of existing equipment questionable
◆ Existing equipment:
  ● Loops
    ◆ High cost
    ◆ Maintenance problems
    ◆ Point measurements
    ◆ Cannot measure queues, concentration, etc.
  ● Detection weakest link for advanced surveillance and control
Solution

SOLUTION:
- Wide Area Detection
- Space + Time

TECHNOLOGY:
- Video Imaging

PROCESS:
- Video camera overlooking roadway
- Select detection area & detection type
- Specialized hardware and software for analyzing images and extracting required data
ADVANTAGES

- Wireless Detection (low maintenance)
- Simple Installation (no disruptions)
- Wide Area Detection (first real life field implementations, large scale too)
- Multi-function Capabilities
  - Detection, surveillance, Control.....
ADVANTAGES

◆ Key to New Solutions for Urban Traffic

Congestion and Safety:
- Next generation adaptive control
- Automatic incident detection
- Large-scale data collection
- Accident reconstruction

◆ Can quickly change/reconfigure detector placement at no cost
HISTORICAL

◆ U of M

- Feasibility Study 1985
- Breadboard fabrication testing 1986
- Artifact treatment 1987
- First real-time working prototype 1987
- Field implementation and testing 1989
- Technology transfer to industry 1991
- First large-scale real-time installation 1992
- First European installation 1992
INITIAL APPLICATIONS

◆ Adaptive Control
  - 28 intersections in Troy, Michigan (1992)
  - Expanded to 800 intersections
◆ Automatic incident detection
◆ Others (tunnels, wrong way movements, queue measurements, freeway management)
Video-based Freeway Incident Detection Options

- Shock wave from incident
- Stopped Vehicle
- Queues
- Vehicle Presence
- Wrong way vehicles
- Congestion
- Slow Traffic
- Slow Vehicles
- Large, Over Speed Vehicle (high speed arterials)
- User defined events programmed through GUI
AIDA Results
Initial 4-Month Test

- Detected 14 of 18 reported incidents (80%)
  - 4 did not affect flow and thus no shock wave produced
- 73 Alarms in 4 months
  - Alarm rate 0.6 alarms/day
  - 14 from reported incidents
  - 23 very likely incidents
  - Cause of remaining alarms unknown
- Detected incidents up to 2.5 km (1.5 mi) away
- AIDA handles gradual congestion buildup
- Weather reducing capacity does not trigger alarm
Incident Occurrence & Verification at I-35W 26th Street Installation

A = AIDA Match
C = Conventional Match

? 1/16/92 C Unreported Location
Time to Detect vs. Distance from Camera for Verified Incidents

Time to Detect vs. Distance from Camera for Verified Incidents (Dec 91-Mar 92)

- Time to Detect Rel. to TMC Log (min)
- Distance from Camera (miles)

- AIDA Algorithm
- Linear Fit

Graph shows a positive correlation between time to detect and distance from camera.
Accident Recording and traffic Data Collection

- Collect detailed traffic measurements at highest accident location in Minnesota
- Continuous coverage of road section
- Record accidents on video
- Analyze accident mechanics
- Determine correlation between accident occurrence and traffic conditions prior to accident
- 1 km long section of “Commons” area of Junction of I-94 and I-35W in Minneapolis
Accident Recording and Traffic Data Collection
Portable Surveillance Device
For Video Recording and Wireless Transmission

- Portable wireless surveillance for:
  - Event Monitoring
  - Threat/Problem Area Monitoring
  - Previewing Potential New Installations
  - Rooftop Monitoring
  - Building and Construction Monitoring

- Rapid Deployment
  - 15 Minutes or Less
  - Single Person Installation / De-installation
  - Light Weight Components

- Standalone Operation
  - Up to 280 hours

- Video Recording plus Wireless Transmission
  - Internet Access/Monitoring
  - Local or remote recording
  - Robust design

- Remote Control and Programming

- Low Cost / Re-usable

- Artificial vision add-ons for alarms and data
Basic Configuration

- Quick deployment removable cart
- Non-intrusive single person setup
Proposed Surveillance Approach: Portable, On Demand Low Cost Deployment

PORTABLE
- Camera
- Mast
- DVR

Multi-Use Deployment System
- Mobile
- Non-Intrusive
- Wireless
- Integrated
- Secure

Control Room
- Streaming
- Recording
- Playback
- Incident Detection

No Server
Automated Detection

WIFI
3G
THANK YOU!