Integrated Data System Structure for Active Traffic Management - Planning and Operation

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Outlines

- Integrated Corridor Management (ICM)
- Active Traffic Management (ATM)
- Towards Integrated Traffic Data Systems
Integrated Corridor Management (ICM)

• Integrated Corridor Management
  – Larger Scale Corridor
  – All Roads
  – All Modes
  – All the Times

• Active Traffic Management System
  – Corridor Wide Road Network Traffic
  – Demand Manage
  – Capacity manage
  – Network Traffic Flow Manage
  – Data Supporting System
Active Traffic Management

- TRB Definition of ATM
- Lesson Learned in Traditional Traffic Management
- Traffic Characteristics
- Overall Picture of ATM
- Demand Manage
- Capacity Management
- Freeway Traffic Control
- Bottleneck Detection and Handling
- Traffic Control Assistance Measures
- Coordination between Freeway and Arterial Traffic Control
TRB Definition of ATM

- TRB Active Traffic Management Subcommittee (2009)
  - Active Traffic Management (ATM) can be defined as the concept of dynamically managing and controlling traffic demand and available capacity of transportation facilities. By continuously monitoring system performance and related real time data, strategies would be employed based on prevailing and anticipated conditions to optimize the effectiveness, efficiency and safety of the transportation network.
• Maximizing utility of available
  – Highway infrastructure
  – Sensor, communication and information technologies
  – Control system technologies
• Improved safety
• Improved mobility
• Minimized pollution – noise and emission
Lesson Learned in Traditional Traffic Management

- Operation locally
- Operation only divide traffic into two state: free-flow or congested
- Corresponding traffic control was trying to bring congested traffic into free-flow, which is not always possible if demand is too high
- Freeway traffic and arterial traffic managed separately
- Demand partially managed passively through driver information
- Capacity is not properly managed
- Inadequate attention on traffic data quality
- Current traffic data systems do not support ATM
- Traffic control (mainly ramp metering) performance rather low
Traffic Characteristics

- Traffic system cannot be treated a closed system: Dynamic interactions exist between subsystems of all levels
  - Freeways
  - Freeway and arterials
  - Arterials, local surface street, driveway
- Highly stochastic
  - Demand uncertainty
    - Variety of sinks and sources
    - Complex network connection
    - Special event
    - OD table is not available
  - Large variance in driver behavior
    - Mode and rout choices: based on experiences and current perception
    - Driving behavior
Traffic Characteristics

• **Uncertainty directly affecting traffic flow**
  – Driver behavior: time headway, speed, acceleration/deceleration
  – Weather condition
  – Road geometry: available lanes, curvature, grade,
  – Visibility
  – Vehicle differences

• **Non-recurrent bottleneck challenge**
  – Quick automatic detection and estimation of bottleneck capacity flow
  – Traffic control response
  – Incident/accident clearance

• **Traffic control strategy for multiple bottleneck along a corridor**
Overall Picture of ATM

Demand manage

Capacity Manage

Combined VSL & CRM for mainstream traffic control

Bottleneck detection and management

Traffic Control Assistance Measures
Overall Picture of ATM

Traveler’s info for trip planning & routing

Demand manage

Capacity Manage

Combined VSL & CRM for integrated mainstream and arterial traffic control

Bottleneck detection and management

Traffic Control Assistance Measures

Driver advice or mandate on: speed limit, lane use limit, lane changing assistance/limit, dynamic shoulder use, HOV/HOT dynamic use, merging assistance, gap etc
Overall Picture of ATM

Traffic assignment for individual veh. routing

Trip planning & mode use selection

Demand Manage

Capacity Manage

Combined VSL & CRM for integrated mainstream and arterial traffic control

Bottleneck detection and management

Traffic Control Assistance Measures

Driver advice or mandate on: speed limit, lane use limit, lane changing assistance/limit, dynamic shoulder use, HOV/HOT dynamic use, merging assistance, gap etc
Demand Manage

- Demand manage - Semi-global (corridor or network) range – dynamically assigning traffic according to *predicted demand* and *practical capacity*
  - Routing
    - Network wide - highway selection
    - Routing through arterial/surface street (using alternate onramp and off-ramp)
  - Diverging (using alternate onramp and off-ramp)
  - Integrated manage for freeway connections
Capacity Manage

- Real-time operation (practical) capacity estimation
- Mainline capacity flow is determined by bottleneck capacity flow
- Capacity of a corridor with multiple bottlenecks is determined by the bottleneck with the minimum capacity unless diverging road is available
- Planning: revise recurrent bottleneck to improve physical capacity
- Operation: maximally use capacity for highest mobility
  - Active (dynamic or temporary) shoulder use if necessary
  - Active (dynamic or temporary) HOV/HOT lane manage
Freeway Traffic Control - Coordinated VSL and RM

- **RM:**
  - Local traffic responsive RM directly control average density for the immediate downstream
  - Corridor wide Coordinated RM control balances the main lane flow and demands from onramps
  - Only indirectly affecting speed passively

- **VSL:**
  - To control driver behavior in mainline
  - To reduce speed variance in the same lane and between lanes
  - To smooth traffic and delay/avoid shock wave including *Stop&Go*
  - To control mainline traffic flow when RM switched off due to onramp length limit and/or equity issues
Freeway Traffic Control - Coordinated VSL and RM

- Combined VSL & CRM
  - To control traffic in different aspects and complementary
  - To control main line traffic to a large extent for given demand, capacity and current traffic situation
  - To homogenize/stabilize traffic flow
  - To control density distribution
  - To achieve higher density (thus flow) for the same speed
  - To delay congestion start time
  - To achieve maximum possible flow (not necessarily free-flow) under congested condition
  - Two legs of a person
Freeway Traffic Control – Other Measures

- **Local Active Traffic Management to smooth traffic**
  - Merging manage – assisting onramp merging
    - Macroscopic
    - Microscopic – zipper-like approach
  - Weaving manage
    - Planning – removing weaving section
    - Operation – similar to merging assistance + lane use limit
  - Maximizing off-ramp flow
    - Avoid spill-back to block off-ramp in traffic control strategy
    - Coordinate with local traffic signal
  - Lane Manage
    - Lane change limit/advice
    - Dynamic lane marker – lane use limit
    - TOD (Time of Day) Lane Use
Bottleneck Detection and Handling

• Needs traffic data immediate upstream as well as within the bottleneck

• Recurrent bottleneck caused by
  – Demand over capacity–lane drop due to geometry or road work zone
    • Diversion/routing if possible
    • Maximizing bottleneck flow by controlling upstream flow
    • Reduce shockwave caused by bottleneck
  – Off-ramp spills back: case-by-case based on traffic & road geometry
    • Can be quickly detected if sensor installed properly
    • Temporary use of hard shoulder if available
    • Coordinate with arterials/surface-street intersection
    • Diversion – using off-ramp upstream or downstream if available
    • Active lane manage to confine waiting vehicle on curbside lane if not hard shoulder
Example: Data Needs for Bottleneck Traffic Control, I-80W
Bottleneck Detection and Handling

– Onramp high demand
  • Can be detected if sensor installed properly
  • Coordination of freeway traffic control & arterial traffic signaling
  • Discouraging short freeway user by metering short and long freeway users separately
  • Enforcement is more effective than advice
  • Dynamic lane manage

– Avoid road design flaws
Bottleneck Detection and Handling

- **Non-recurrent – detection and assessment are crucial**
  - Incident/accident:
    - Automatic detection is indispensible
    - Need high sensor density
    - Incorporate driver report and automatic detection
  - Driver behavior or slow vehicle: moving bottleneck
    - Lane use and lane-wise VSL
    - Post both minimum and maximum speed
    - Lane use limit by ground sign or VMS
  - Off-ramp spill back
Bottleneck Detection and Handling

- Onramp high demand
- Weather/visibility

**Challenge:**
- To quickly identify the type of bottleneck, its location
- To quantitatively estimate/predict its impact on traffic
  - Queue length upstream
  - Potentiality of blocking off-ramp
  - Time needed to clean up
- To determine
  - traffic control strategy
  - upstream traveler information for feedback
Coordination between Freeway and Arterial Traffic Control

- **Objectives:**
  - To relieve the conflict between high demand to freeway and traffic congestion in arterials to optimize the traffic systematically.
  - To avoid/minimize traffic spills back into arterial/surface street
  - Balance the efficiency of moving in peak hours
- **The problem: subsystems interact with each other needs coordination**
  - **Arterial traffic control**
    - Tends to maximize the flow into freeway
    - Vehicle moving in platoons
  - **Freeway Traffic Control**
    - To maximize mainline flow, may reduce flow into the freeway if mainline demand/density
    - To avoid/reduce onramp queue
    - To spread out (breaking platoon) vehicle entry into freeway
Coordination between Freeway and Arterial Traffic Control

- **Possible solution: systematic coordination**
  - Optimize w. r. t. an integrated system performance measure
  - Slow down arterial multiple intersection traffic flow if necessary
  - Diversion to adjacent street if necessary

- **Planning:**
  - Onramp length for adequate storage capacity for peak hours
  - Smart road geometry design

- **Issues for integration**
  - Equity among multiple onramps subject to length limit
  - Technical
    - Require integrated data system (data format, timing, …)
    - Communication systems and protocol
    - Coordination between control system – priority issues
  - Institutional: close cooperation of state DOT, county & city
Towards Integrated Traffic Data Systems

• Data Requirement for ATM
• Current Traffic Data Systems Structure
• New Technologies and Information Available
• Next Step Data Systems Structure
• Data Quality and ATM Performance
• Function of VII
• Data System Examples
• Systematic Sensor Fault Detection and Management
• Developing Reliable Communication Systems
• How to Maximally Use Current Data System
• Integrated Traffic Data System for Planning and Operation
Data Requirement for ATM

- **Low Goal for local traffic responsive or coordinated RM**
  - Distance mean speed
  - Average density
  - Data aggregation level:
    - **Time:** 30~60s
    - **Space:** 150~200m

- **High Goal: Accurate and reliable traffic state parameter estimation over time and space**
  - Spatial-temporal (distance mean) speed estimation
  - Spatial-temporal density distribution
  - Traffic prediction over certain period of time
  - Data aggregation level:
    - **Time:** 10 ~ 20s
    - **Space:** ~ 150m
Data Requirement for ATM

• **OD for a given set of modes:**
  – Only possible if
    • **VII is available for individual vehicle**
    • **Traffic assignment conducted network wide**
    • **Dynamic rerouting in case of incident/accident**

• **VSL and RM have to be coordinated instead of local**
  – **Real-time capacity estimation**
    • **Recurrent bottleneck: influence zone**
    • **Non-recurrent bottleneck: influence zone**
  – **Integration with arterial and surface street traffic control**
  – **Dynamic reconfiguration through wireless or cable**
Data Requirement for ATM

• Coordinated RM Needs:
  – Minimum Requirement
    • Onramp queue length measure
    • Off-ramp flow
  – Medium Goal: in addition
    • Density distribution
    • Synchronized data along a corridor
  – High Goal: in addition for merging assistance
    • Individual vehicle movement

• VSL Needs:
  – Spatial-temporal speed estimation
  – Spatial-temporal density estimation
Example: Traffic Drop probability and flow Contour
Example: Traffic Drop probability and flow Contour

I80W @ Station: 6; 25(vpm) < Density

Density (vpm)

Speed (mph)
Current Traffic Data Systems Structure

(a) Current Model of Traffic Data System

PeMS / TMC

Operation Applications
Data Processing
Planning Application

Classified Database:
Raw and/or Processed Data

Long Range Comm. passing raw data

Local data use:
Traffic Management

Sensor systems of Freeway Network:
Real-time synchronized traffic Data
New Technologies and Information Available

• Computer technologies-miniature and used in almost all corners
• Road sensors: smart cards for inductive loops, magnetometer, lidar, microwave radar, digital video camera, infrared radar, acoustic sensor, piezoelectric (WIM), light beam, …
• Vehicle Information: J-Bus, onboard and remote Sensors, GPS, …
• Communication System
  – Wireless (GPRS, Cell-phone, DSRC – VII radio, WiFi, Bluetooth, )
  – Fiber-optics cable
  – Telephone line - DSL
• Information System
  – Internet, GIS, iPhone
  – Video, Radio
  – VMS, Traffic signs: Real-time feedback to the driver
  – Individual vehicle feedback
Immediate Next Step Data Systems Structure

(b) Next Step Model of Traffic Data System

PeMS / TMC

Operation
Higher level coordination

Data Processing

Planning

Classified Database:
Raw and Processed Data

Long Range Communication
passing raw data

Sensor systems of Freeway Network
Real-time synchronized traffic Data

Short/medium Range Comm.
passing raw data

Sensor systems of Arterial Network
Real-time synchronized traffic Data

Local data use: Active Traffic Management:
coordination between freeway traffic control and
arterial coordinated intersection traffic signaling
Function of VII in Active Traffic Management

- **VII Vehicle include**: probe vehicles; vehicle equipped with VII DSRC; vehicle equipped with combined cell-phone and GPS

- **VII Vehicle Info**:
  - Continuous measure over time
  - High market penetration of VII provides data continuous in both time and space
  - Single VII vehicle providing narrow moving distance-window measure
  - Certain percent of market penetration VII vehicles provide traffic measurement continuous over time and distance

- **Road sensor only provide point/short range measure**: heavily depends on sensor type, location, density, measurement accuracy, reliability, …
Function of VII in Active Traffic Management

• **Application:**
  – Traffic state estimation/prediction;
    • OD estimation
    • Spatial and temporal speed and density estimation
    • Retrieving microscopic traffic data
    • Refined RM, merging assistance,…
  – Congestion onset detection and management;
  – Active safety
    • Collision warning and avoidance
    • Intelligent intersection

• **Future Trend:**
  – VII data directly routed to control cabinet
  – Gradual merging/fusing point sensor data with VII data
Function of VII in Active Traffic Management

- Fusion of BHL loop & VII data for accurate speed and density estimation
Data System Examples: 1. PeMS

- **Data Source and Application:**
  - 30 second raw data
  - Lane by lane 5 minutes aggregated data: flow, occ., speed
  - Hourly and Longer Time LOS (A, B, C, D, E, F)
  - Speed/Occupancy plot
  - Bottleneck Information
  - Vehicle Hours of delay
  - CA Yearly VHT/VMT
  - Lost productivity (Lane-Mile-Hours)
  - Dynamic Maps/Google maps
  - AADT/Peak Hours
  - CHP Incidents Data
Data System Examples: 2. Netherlands NDW

• NDW – National Data Workhouse
  – the databank to collect, process, store and distribute all relevant traffic data of all motorway, major provincial and city roads
  – A network organization of municipalities, regions, provinces and the state

• Objectives:
  – Active Traffic Management for mobility and safety
  – Reduce congestion at 2020 to the level of 1992

• Data types
  – Real-time data – traffic flow, travel time, speed, traffic jam
  – Status data:
    • Actual and planned road work
    • Actual and planned availability of infrastructure
  – Historical data
Data System Examples: 2. Netherlands
Data System Examples: 3. Berkeley Highway Lab (BHL)
Data System Examples: 3. Berkeley Highway Lab (BHL)

- 8 dual loop stations in two directions
- Station distance: 500~2100 [ft]
- Update rate 1s with 60Hz information for loop ON/OFF time instant
- Traffic state parameter estimation at each station
- Detector health information
Data System Examples: 4. Microscopic - NGSIM Data

Frame number

Location in world coordinates

\[
\begin{bmatrix}
  x \\
  y
\end{bmatrix}
(i, t)
\]

Vehicle index & time
Data System Examples: 4. Microscopic - NGSIM Data

- For microscopic traffic analysis
- For driver behavior analysis and modeling
- For calibration of microscopic traffic simulation model
- For refined ATM strategy design and qualitative evaluation
Data Quality and ATM Performance

• Data quality determines traffic control performance
  • Most RM methods very simple; mostly determined by data quality
  • Quantitatively sensitivity analysis of the control system

• Data quality
  – Measurement noise and error (discrepancy)
  – Reliability
  – Time Delay
    • That from sensor
    • That from communication for data passing
    • That from data processing (such as aggregation)

• Improving data quality in different level
  • Microscopic (sensor reading) - essential
  • Mesoscopic – a section of freeway & arterial
  • Macroscopic – corridor level (PeMS/TMC)
Systematic Sensor Fault Detection and Management

• Faults mainly come from:
  – Sensor system fault
    • Component broken
    • Improper installation
    • Reliability with environmental including traffic conditions
    • Physical limit
    • Sensitivity selection
    • Mode selection (pulse or presence)
  – Communication system fault

• Sensor fault detection and data correction:
  – In different levels: macroscopic, mesoscopic and microscopic levels
  – Using historical data
  – Using threshold bound check
  – Using other faulty data analysis techniques
  – Using model based or statistical time series based prediction
Developing Reliable Communication Systems

• **Current Communication Systems:**
  
  – **Infrastructure:**
    • Fiber optics, Cell phone line, Old telephone line, GPRS Modem, CDPD Modem, WiFi, Bluetooth, others
  
  – **Communication protocol:**
    • TCP (acknowledgment of receiving; may resending)
    • UDP (no acknowledgment nor resending)

• **Recommendation:**
  
  – Using fiber optics, GPRS modem, telephone line with DSL
  
  – Protocol: Using TCP with resending and Automatic fault detection capability
Developing Reliable Communication Systems

- Professionals regularly checking/reporting sensor and communication faults
- Regular and in-time system maintenance
- Communication system reconfiguration capability
- Short/medium range communication:
  - Sensors, Control Cabinet ↔ Corridor Hub Computer & Database
- Long Range
  - Corridor ↔ TMC or PeMS
How to Maximally Use Current Data System

• Progressive improving in sensor density, data processing

• Maximally using current infrastructure with software modification

• Progressively incorporating VII with the increase of market penetration of VII vehicles: real-time routing to control cabinet

• Systematic plan for new sensor installation to complementary to previous sensors in location/density/function: single loop ➔ dual loop

• Cost effective; affordability; data security in a long run

• Towards integrated planning and operation data system
Integrated Traffic Data System for Planning and Operation

(c) Near Future Model of Traffic Data System

PeMS / TMC

- Coordination of Operation
- High Level Data Processing
- Planning Application

Classified Database: Processed Data

Long Range Comm. passing processed data (reduced)

Corridor Control Cabinet

Operation Applications
- Data Processing

Classified Database: Raw and Processed Data

Short/medium Range Comm. passing raw data

Sensor Systems of a Corridor: Freeway + Arterials

VII Data: Cell phone, DSRC (public and private)

Long Range Comm. passing processed data (reduced)

Corridor Control Cabinet

Operation Applications
- Data Processing

Classified Database: Raw and Processed Data

Short/medium Range Comm. passing raw data

Sensor Systems of a Corridor: Freeway + Arterials
Integrated Traffic Data System for Planning and Operation

- **Systems approach for supporting ATM**
  - Integrated and system wide performance measurement
  - Integrated freeway and arterial data system
  - Synchronized data in time and unified coordinate in space
  - Private and public data, from road-side and on-vehicle sensors
  - Optimal combination of sensor types and locations
- **Minimizing data storage and maximizing data utility**
  - Local data fusion and traffic parameter estimation for operation
  - ATM; ATIS; corridor level and system wide strategic planning
  - Processed and classified database at PeMS or TMC level
- **Improving data quality**
  - Systematic sensor fault detection, remedy and maintenance
  - Developing reliable communication systems for data passing
  - Adopting software for data correction and filtering in application
Thank You!

Please send questions and comments to: xylu@path.berkeley.edu