Towards Proactive Traffic Management
- The MIDAS-CPS Project

**MIDAS Team:** Pitu Mirchandani*, B. Li*, D. Huang*, Y. Yin* (U Florida), Xuesong Zhou, Pengfei Li, K. Demirtras, Z. Zhou, P. Chandakkar, Y. Deng, Y. Wang, V. Potluri

**Supported by:** NSF Grant 1239396

School of Computing, Informatics and Decision Systems Engineering
Arizona State University

***: Principal Investigator & Co-PIs
Preliminaries (1)

KEYWORDS (for MIDAS Concepts)

- Proactive versus Reactive
- Streaming data collection
- Big Data and cloud computing
- Predictive Data Analytics
- Real-time Joint Optimization of Controls and Driver Decisions
- Lane-Based management of vehicles, peds, travelers,…

What’s MIDAS?

- Managing Interacting Demands and Supplies?
Preliminaries (2) on Traffic Management

“Supplies” in Transportation?
Transportation Infrastructure (network, bridges, etc.),
Traffic Signals, Ramp Meters, Variable Traffic Signs, Travel Advisories, Traveler Information, etc.
TRAFFIC SUPPLY MANAGEMENT DEALS WITH OPERATING THIS SUPPLY
(with assumed stationary loads) - focus on the infrastructure and technology actions

“Demands” in Transportation?
Commuters, trucks, emergency vehicles, pedestrians, bicycles, ..
that use the above supplies and “load” the transportation supply.
TRAFFIC DEMAND MANAGEMENT DEALS WITH CONTROLLING LOADS
(with time-of-day shifts, work staggering, travel advisories/information, pricing, incentives, telecommuting) – focus on activities and travel behavior changes

When supply and demand loads are stationary,
After a awhile, after people keep changing routes over time, mostly from day to day,
they move towards equilibrium, where available routes have nearly equal travel times.

BUT …
Towards the future: Proactive Traffic Management

• We are hardly at an equilibrium given accidents, incidents, weather, major events, fluctuating demand, etc.

• Current (TOD Supply Management):
  Set “supply parameters and forget it” is a poor way to manage traffic especially given our state of technology.

• Recently and Soon:
  Use sensors and observe traffic conditions – and then with a predictive engine use feedback control to proactively change controls and make traffic management decisions.

  PREDICTION is key to Proactive Management

• A little later:
  Working with data streaming from the sensors, to a bank of servers in a cloud, do the above to end up with the Cyber-physical System MIDAS.
MIDAS Preview

BIG DATA (from sensors and historical)

REAL-TIME ALGORITHMS (Learning and Optimization)

MIDAS

PROACTIVE DEMAND/SUPPLY TRAFFIC MANAGEMENT

CLOUD COMPUTING (handing and processing Big Data)
MIDAS CONCEPT OF OPERATIONS

Cloud Infrastructure

Local controller

Local controller

Local controller
**MIDAS Broad Objectives**

- Explicitly consider **demand-supply interactions** in the design of a new traffic management system
- Enhance **mobility** (reduce travel time, increase safety, etc.)
- Reduce driver and traveler **stress**
- Help **sustainability** objectives (eco-driving, less emissions, less energy use, …)
- **Do not increase infrastructure** footprint substantially (i.e., _use current technological and service infrastructure_, if possible)
- **MIDAS** will be a **service system**: Providing **mobility service** to traveler, to manual car, to driverless car, to CV, to trucks, … those that request and/or pay for it
Framework For Proactive Real-time Decision Systems

Real-world data flow:

- Equipment
- Data Processing
- State Estimation
- Decision Systems

Feedback & decisions:

Sensors

Sensor media
Major Performance Criterion of an “Responsive” Control System?

**Responsiveness:**
How fast does it respond to changes in traffic conditions? (including incidents and special events)

Does it respond to current situation? **Reactive control**

Does it respond to anticipated situation? **Proactive control**
"Open-loop", "Reactive" & "Proactive" (Illustration in following a trajectory)

Position

- Reactive (after the fact)
- Proactive (anticipatory)
- Open Loop (stationary assumption)
General Proactive Control Architecture

- Estimator/Predictor
- Model
- Exogenous inputs
- Decisions/Controls
- Real-World Systems
- Sensors
- Measurement noise
- Output states of the system.

- Decision/Control Algorithms
  (using desired objectives)

- Model
- Optimization

- Estimation/Prediction

- Preliminaries
- Proactive Control
- Sensing
- Computing
- Algorithms
- Conclusions
Example: “Proactive” Signal Control System

Prediction & Optimization ➔ Proactive Traffic Signal Control System

raw data

Feedback & decisions

Measurements: detectors & signals
Actuators: signals

Preliminaries  Proactive Control  Sensing  Computing  Algorithms  Conclusions
Hierarchical Architecture for “PROACTIVE” TRAFFIC MANAGEMENT

RHODES
Mirchandani et al. 1991-2005

+ NEW SENSORS
  Dash-camera & space-time trajectories

+ BIG DATA & PREDICTIVE ANALYTICS

+ DEMAND MANAGEMENT

+ CLOUD COMPUTING
At the highest level – Mesoscopic treatment
At the mid-level – Meso-Microscopic treatment
At the lowest-level – Microscopic treatment

Few Intersections in Tempe
INSIDE THE BOX: **MDAS** PREDICTION & CONTROL

- **PREDICT**
  - TURN RATIOS
  - TRAVEL TIMES
  - DISCHARGE RATES

- **CONTROL ALGORITHMS**
  - arrivals & queues

- **detectors**
- **state of traffic network**

**Sections:**
- Preliminaries
- Proactive Control
- Sensing
- Computing
- Algorithms
- Conclusions
And ... PREDICTIONS!

Next second

A little later

Tentatively Scheduled for demand management

Preliminaries  Proactive Control  Sensing  Computing  Algorithms  Conclusions
Components for MIDAS: Streaming Real-Time Data

Historical data & Traditional detectors
They give:
Traffic Counts
Speeds (approx.)

These are point detectors
called Eulerian Measurements

OTHER DETECTORS
• VIDEO DETECTORS
• SONAR DETECTORS
• RADAR DETECTORS

INDUCTIVE LOOP DETECTORS

MANUAL SURVEYS & COUNTS

Preliminaries  Proactive Control  Sensing  Computing  Algorithms  Conclusions
Components for MIDAS: Streaming Real-Time Data

Other recent point detectors to measure travel times

- Inductive Loop Detectors
- Other Detectors:
  - Video Detectors
  - Sonar Detectors
  - Radar Detectors
- Manual Surveys
- Vehicle IDs
- Blue-Tooth Signature
- Roadside Receiver for Connected Vehicles

Related topics:
- Preliminaries
- Proactive Control
- Sensing
- Computing
- Algorithms
- Conclusions
Components for MIDAS: Streaming Real-Time Data

The start of space-time (trajectory) detectors

These are Lagrangian Measurements

They give:
Travel times
Vehicle trajectories

REMOTE SENSORS

GPS-BASED LOCATOR

CELL PHONES

OTHER SENSORS
• TRAVEL PROBES
• 1G/2G TRAINGULATION
• 3G/4G TELEPHONY
Components for MIDAS: Streaming Real-Time Data

Given the technological state of practice, we have

1. 3G/4G mobile telephony data that provides streaming GPS data with quite accurate travel times and speeds

2. Engine sensors that monitor emissions

3. Streaming video and images
The objective (and challenge) is to get information from forward scenes dash-cam (such as motorists get).. This will allow us to detect densities, speeds, signal status, incidents, etc. We have developed the PICT (position-image-communication with time-stamps) Technology attempts to do that.
Components for MIDAS: Processing Real-Time Data

- Data Fusion
- Traffic Prediction
- Decision Systems
- Optimization
- Feedback & decisions

Streaming Sensor data

Real-world

Preliminaries  Proactive Control  Sensing  Computing  Algorithms  Conclusions
Components for MIDAS: Lane-Based Estimation/Prediction

For UNINTERRUPTED flow on freeways

- Traffic Flow Theory generally focuses on fluid flow through links

- Drivers are modeled as homogeneous active particles flowing through a pipe – Works of Pipes, Newell, LWR, Daganzo, Fundamental Diagram, and others (usually modeled as space-time partial dif. expressions)

- Also considered: physical characteristics of pipes (links), spatial queues
  Heterogeneous drivers and vehicles (stochastic models)
  Car following, lane changing, cooperative behaviors issues and models are implicit

In MIDAS FREEWAYS have permeable lanes.

Automated Vehicles
Connected Vehicles
Other Vehicles
Example of a **MIDAS** Decision-Making Algorithms

At the mid-level – Meso-Microscopic treatment to concurrently set signals and provide route guidance

**Concurrent**

**Routing/Loading** (i.e., Demand Management) and

**Traffic Signal Optimization** (i.e., Supply Management)

**Using Space-Phase-Time Hyper-networks.**

Example of **MIDAS** Visual Computing Algorithms

- Lane & vehicle detection from dashboard cameras

- Many modern automobiles are equipped with cameras and other active or passive ambient sensors.
  - Some driving-assistance features available only recently are based on such sensors.
Collision Mitigation Braking System
AcuraWatch Plus

To help reduce the likelihood or severity of a frontal impact, AcuraWatch Plus includes the Collision Mitigation Braking System™ (CMBS™), which uses both a radar system and a high-resolution forward camera to recognize hazards such as vehicles or pedestrians. The system can use up to 80% of full braking power to avoid or reduce impact with the detected object.

Source: Acura.com
Road Departure Mitigation (RDM) System

A camera mounted between the windshield and the rearview mirror determines if your vehicle begins to cross over detected lane markings while driving between 45 – 90 mph (72 – 145 km/h).

If you get too close to a detected lane line without using your turn signal, a message appears in the MID. Steering wheel torque and vibrations are applied to help your vehicle stay in the lane. Braking may also be applied if the lane lines are solid and continuous.
Many modern automobiles are equipped with cameras and other active or passive ambient sensors.

- Some driving-assistance features available only recently are based on such sensors, in particular cameras.

- Smart phones have become ubiquitous.

  - At any moment, there are many cameras in cars on the road.
  
  - We work on processing images/videos captured from a camera in/on a vehicle.

  - Current focus is for Intelligent Transportation Systems applications, considering mostly highway driving.
State-of-art ITS systems, e.g., HOT lanes

- Collect real-time traffic and vehicle information.
- Provide congestion pricing for cars entering and exiting the road.
- Generally, estimation of traffic flow and congestion is at a road-level.
  - HOT lane requires dedicated sensors for speed/flow estimation.
What more we may do?

Envisioned future:

- Capability for general lane-level traffic flow estimation and congestion modeling.
- Capability for modeling driving patterns in response to real-time traffic.

→ Enabling new applications:
- Pricing different lanes differently based on estimation of traffic/congestion (e.g., tiered HOT lanes).
- Providing (personalized) lane-level routing assistance.
- Improved situational awareness for drivers.
How on-vehicle cameras may help?

- Many of the envisioned features may be achieved *if we can utilize the many cameras in the cars driving on the road.*
Some Basic Computer Vision Tasks

- “Self-positioning” based on on-vehicle camera.
  - Identifying total number of lanes on the road.
  - Determining the index of the host lane.

- Detecting the number of vehicles on the road.
  - For each lane in the field of view.
    - "Local" traffic density.
  - Towards lane-level traffic flow estimation: relying on many cameras from many cars.
Some Basic Computer Vision Tasks
Some Related Work

- Self-positioning based on classification of the road terrain/surface in the field of view.
  - E.g., Use of spatial RAY features to solve a similar problem [Kuhnl et al., 2013].
    - Prediction accuracy decrease dramatically with more than 3 lanes at a time.
    - Low-traffic, good road and weather conditions.
Some Related Work

- Explicit lane detection:
  - Plethora of approaches have been developed:
    - Steerable filters for lane detection [McCall and Trivedi, 2006].
    - Hough transform + IPM [Cheng et al., 2006].
    - Bayesian approach to detecting lanes [Nieto et al., 2011].
    - Hierarchical Bipartite Graph Matching for lane detection [Nieto et al., 2008].
    - Patch-based learning approaches [McCall and Trivedi, 2006].
Some Related Work

• Vehicle Detection: Similarly many related efforts.
  • Mostly in the general field of object detection/recognition.

• Typical challenges:
  – Photometric variations
  – Pose variations
  – Scale variations
  – Intra-class variations
  – Speed performance
A typical/baseline approach to vehicle detection: binary classification e.g. HOG + linear SVM
Proposed Approach

Stages in video-based self-positioning:

1. Pre-processing using guided filter [He et al., 2013].
2. Lane-width modeling.
3. Feature extraction.
4. Estimation of the road configuration.
5. Vehicle detection.

Use positions of detected vehicles to refine road configuration. Use the road configuration to constrain the search space for vehicle detection in the next frame. Repeat this process.
Proposed Approach

Guided filter works well in low-light and rainy conditions too.
Proposed Approach

- **Lane-width modeling:** Widths are approximately known and remain constant over large sections of freeways.

- Reduce noise in the feature space by extracting features only around dotted lines.
Proposed Approach

- **Vehicle detection in a closed-loop approach:**
  - Deformable Parts Model (DPM) for vehicle detection.
  - Bounding box proposal generation is constrained by the position of lane markers.
  - Constraints can be applied after any type of box proposal method – exhaustive, BING, edge box proposals etc.

These constrains reduce the proposals by a factor of 6 → reduces false positives

Use these detections again to refine the lane model.
Proposed Approach

- Vehicle detection: a little more detail

Scale Adaptive Deformable Part Model

- In DPM, an object is constructed by a hierarchy of parts; parameterized by the individual parts and the structural model maintaining the spatial relationship between the parts by using latent SVM;
- The latent SVM is formulated as:

\[ f_{\beta}(x) = \max \beta \hat{\phi}(x, z) \]

- The objective function is defined as:

\[ L_{D}(\beta) = \frac{1}{2}||\beta||^2 + C \sum_{i=1}^{n} \max(0, 1 - f_{\beta}(x_i)y_i) \]

- The distance \(d\) and the object size \(s\) can be estimated as:

\[ d \propto \frac{1}{\sqrt{s}} \]

- The match score is computed as:

\[ \sum_{x', y'} F(x', y') \hat{G}[x : x + x', y : y + y'] \]
Proposed Approach

- Vehicle detection: an example.

For details, see: P. Chandakkar, Y. Wang, B. Li, “Improving vision-based self-positioning in intelligent transportation systems via Integrated Lane and Vehicle detection”, IEEE Winter Conference on Applications of Computer Vision (WACV) 2015.
Concluding Remarks on **MIDAS CPS**

**Improvement in traffic performance:**
- Proactively responds to recurrent congestion
- Proactively responds to non-recurrent conditions and incidents (through “monitor”, “learn”, “predict” and optimally “respond” strategy)

**Potential fundamental contributions**
- **Real-time processing** of moving images
- **Lane-based traffic flow theory**
- Using **Lagrangian sensors**, to predict lane-based attributes
- **Lane based optimal controls**: Traffic signals; ramp metering; lane speed controls, lane changing control, …
Concluding Remarks on Future Vision

- **NEAR FUTURE:** Special vehicles will be identified via sensors, (e.g.: Emergency, Transit, HAZMAT, … ) using wireless communication (3G/4G).

- Traffic signals (and other controls) will provide **appropriate service by scheduling “green phase” service within the given time horizons**

- Other “Supplies” (*ramp meters, message signs, in-vehicle advisories*, etc.) will be operated and “Demands” will be influenced *(through information)* to improve service for these vehicles

- **LITTLE FURTHER FUTURE:** Each vehicles will come 3G/4G cards, opt-in vehicles will be tracked in the network and provided appropriate service and priorities from origins to destinations, using “supplies” outside and within vehicles