INTELLIGENT TRANSPORTATION SYSTEMS

Lecture 2:
Advanced Traffic Management System (ATMS)

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Economic Growth and High Rate of Urbanization in Recent Century

Congestion and its consequences; pressing issue of modern societies.

Problems such as economic impacts, greenhouse emissions, accidents, time spent, and health damages.
Solutions?

- More roads to accommodate more cars
- Use the full capacity of the current network to improve efficiency, decrease travel time and optimize routes.

Causes of urban traffic

- Bottlenecks are responsible for 40% of the overall traffic congestion
- traffic incidents with 25%,
- bad weather conditions with 15%,
- work zones with 10%, and
- poor traffic signal timing and special events with 5%.

ATMS aims to minimize traffic congestion and its negative effects.
Advanced Traffic Management Systems (ATMS) are composed of a set of applications and management tools to integrate communication, sensing, and processing technologies.

- **Collect** traffic-related data.
- **Aggregate** and **exploit** data in the Traffic Management Center (TMC), in data center.
- **Extract** intelligent measures for **identifying** traffic hazards.
- **Control** traffic flow, increase mobility **efficiency**, and **maintain** and improve **safety**.
ATMS Requirements

Traffic Information
- Sensors
- Communication
- Data Processing

Control Mechanisms
- Traffic Messages
- Traffic Lights
- Ramp Meters

Traffic Management Center
- Advanced Algorithms & Analytics
  - Traffic Assignment
  - Traffic Prediction
  - Decision Support
Traffic Information

Traffic information is a unit for **handling data collection and transmission** from different data sources to understand traffic situations, manage traffic, or avoid incidents based on data observation.
Methods to collect traffic information

- Automatic
  - Point Detectors
  - Interval Detectors
- Manual
  - Survey
  - Manual Counting
Methods to obtain traffic information

Traffic Information

Automatic
- Point Detectors
- Interval Detectors

Manual
- Survey
- Manual Counting

- Tally sheets,
- Mechanical counting,
- Electronic counting boards
Methods to obtain traffic information

- **Automatic**
  - Point Detectors
  - Interval Detectors

- **Manual**
  - Survey
  - Manual Counting

**Traffic Information**

- Household surveys
- Roadside interviews
- Origin-Destination surveys

- Not feasible on a large scale
- Costly
Methods to obtain traffic information

- **Automatic**
  - Point Detectors
  - Interval Detectors

- **Manual**
  - Survey
  - Manual Counting

Located at fixed points of the street and record traffic information at these specific points.
- Costly, need periodic maintenance
- Replaced by video cameras
Methods to obtain traffic information

- Automatic
  - Point Detectors
  - Interval Detectors
- Manual
  - Survey
  - Manual Counting

- Inductive loops
- Floating cars or probe vehicles
  - GPS-based
  - Cellular-based
Data Collection Technologies: Inductive Loops

Inductive loops are electromagnetic detection systems, based on alternating current to induce a magnetic field.

The sensing of vehicles is performed by computing the change caused by the vehicle disturbing the loop magnetic field.
Data Collection Technologies: Inductive Loops

Functionalities:

- Counting and classifying vehicles.
- Velocity measurements.

Magnetic profiles of the selected vehicle classes:

1. passenger vehicles,
2. delivery vehicles,
3. buses,
4. heavy goods vehicles.

Data Collection Technologies: Cameras

Functionalities:
- Detecting and tracking moving objects
- Movement interpretation

Capable of:
- Adapting to dynamics of the real world
- Operating independently of human operators
- Easy to set up
- Performance in real-time
- Making decisions (AI)
Some of the basic techniques:

- Model-based detection
- Active contour-based detection
- Feature-based detection
- Background subtraction
- Temporal differencing
- Optical flow
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Recovering trajectories and models for a small number of vehicles

Weakness:
- Not reliable with geometric details
- Not realistic (hard to have all the designs of all the vehicles)

Some of the basic techniques:

- Model-based detection
- Active contour-based detection
- Feature-based detection
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- Temporal differencing
- Optical flow

Objects are represented in bounding contours and keeping updated dynamically. Computational complexity is not very high.

Weakness:

- The detection is unreliable in occlusion cases.
Some of the basic techniques:
- Model-based detection
- Active contour-based detection
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- Optical flow

Focus on detecting sub-features present on the vehicles.
The performance relies on the motion and addition of common motion constraints.
Some of the basic techniques:

- Model-based detection
- Active contour-based detection
- Feature-based detection
- Background subtraction
- Temporal differencing
- Optical flow

Frames are compared to a reference background frame, pixel by pixel.

Weakness:

- Sensitive to background changes
- Suitable for a static environment.
Some of the basic techniques:

- Model-based detection
- Active contour-based detection
- Feature-based detection
- Background subtraction
- **Temporal differencing**
- Optical flow

Identifies the intensity changes of moving objects, by checking consecutive frames.

Weakness:

- Difficult to extract all relevant features
- Number of frames affect the performance
Data Collection Technologies: Cameras

Some of the basic techniques:
- Model-based detection
- Active contour-based detection
- Feature-based detection
- Background subtraction
- Temporal differencing
- Optical flow

Identifies the characteristics of the flow vector of the moving objects over time.

Weakness:
- Too slow for real-time application

Reference: https://nanonets.com/blog/optical-flow/
Data Collection Technologies: RADAR
(RAdio Detection and Ranging system)

Functionalities:
- Detecting the speed of vehicles on the road.
- Detecting moving objects.

High accuracy, Speed measurement, Robust in weather conditions

Weakness:
- Limited range
- Unable to distinguish multiple objects
Data Collection Technologies: GPS

- In mid-1990s, researchers began to explore the possibility of obtaining trip data from GPS data.
- Combined with a web-based diary system or a Geographic Information System (GIS), gives additional and confirmation information of transportation modes and trip purposes.

Average speed on the track is symbolized with a rainbow color scale.

Data Collection Technologies: Cellular Network

- Increasingly informative database, collected by the mobile operators for billing purposes.
- Each time a mobile terminal is used for a call or for sending an SMS, the operator records call features, including the timestamp, base station's identifier to which the user is connected, and quantitative data (call duration, volume of data exchanged).
Data to Traffic Metrics
Main variables to measure a traffic stream:

**Flow** is the number of vehicles passing a reference point per unit of time (vehicles per hour).

**Density** is the number of vehicles per unit length of the roadway (vehicles per kilometer).
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**Time mean speed** is the average speed of all vehicles passing a reference point over a duration of time. It is the simple average of spot speed. Time mean speed $v_t$ is given by

$$v_t = \frac{1}{n} \sum_{i=1}^{n} v_i$$

$v_i$ is the spot speed of $i$th vehicle, and $n$ is the number of vehicles passing the fixed point.
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**Space mean speed** is measured over a roadway segment. $n$ represents the number of vehicles passing the roadway segment of length $l$.

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Exercise;

You are in a vehicle traveling a total of 10 kilometers.

- first 5 kilometers you travel at 40 km/h
- next 5 kilometers you travel at exactly 60 km/h

What is your average speed?
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What is your average speed?

Time per section:
First: 5 kilometers / 40 km/h = 7.5 minutes
Second: 5 kilometers / 60 km/h = 5 minutes

Average Speed = \( \frac{10}{7.5 + 5} \times 60 = 48 \text{ km/h} \)
Exercise;

Suppose you have five vehicles over a given 1-kilometer section. It takes 1.0, 1.2, 1.5, 0.75, and 1.0 minutes respectively, to travel the section for the cars. What is the space mean speed?
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What is the space mean speed?

Average travel time $\frac{5.45}{5} = 1.09$ minutes $= 0.0182$ hours.

Therefore, average speed over that distance $\frac{1 \text{ km}}{0.0182 \text{ hours}} = 55.05 \text{ km/h}$
Fundamental diagram of traffic flow (flow vs. density)

flow = speed $\times$ density

speed $v = \frac{\delta q}{\delta k}$
Traffic Metrics for Management and Control
Active Traffic Management

Active traffic management (ATM) is the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing and predicted traffic conditions.

- **Dynamic speed limits**: the dynamic change in speed limits based on road traffic and weather conditions.
- **Adaptive ramp metering**: the dynamic adjustment of traffic signals at ramp entrances to proactively manage vehicle flow from local-access roads.
- **Adaptive traffic signal control**: the optimization of signal timing plans based on prevailing conditions to increase throughput along an arterial.

Reference: [https://ops.fhwa.dot.gov/atdm/approaches/atm.htm](https://ops.fhwa.dot.gov/atdm/approaches/atm.htm)
ATMS Example;
Real-time merging traffic control
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Real-time merging traffic control

If $N > N_{cr}$ then the capacity drop is observed.

$N = \#\text{veh}$

$q_{\text{cap}}: 1000 \text{ veh/h}$
If $N > N_{cr}$ then the capacity drop is observed.

Another scenario: Use traffic control here.
ATMS Example;
Real-time merging traffic control

If $N > N_{cr}$ then the capacity drop is observed.

Another scenario: Use traffic control here.
Merging traffic: $M \rightarrow \mu$ lanes.

1. Merging of two highways.
2. Merging of on-ramps into mainstream.
3. Toll plaza infrastructure.
4. Freeway work zones.
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Control algorithm goal: maintaining the occupancy close to the critical occupancy

Merging traffic control helps to restore the capacity flow.
Control Devices in Merging Areas

- Traffic lights (with appropriate switching)
- Physical barriers (toll plaza)
- Variable speed limits
- Emerging vehicle-to-infrastructure technologies
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Control Algorithm:

- Feedback control for exit flow regulation:
  \[ q_k = q_{k-1} + K_R (\hat{o} - o_{k-1}), \quad k = 1, 2, \ldots \]
- Distribution of entering flow per lane
- Translation of control decision

\( q_k \): entering flow at time \( k \)
\( K_R \): regulator parameter
\( \hat{o} \): desired occupancy
\( o_{k-1} \): occupancy at time \( k \)
Bay Bridge Toll Plaza (San Francisco)

- Traffic Lights
- Detectors
- Merging Control: 20 lanes, 5 lanes
- No Control
- Toll Plaza
Bay Bridge Toll Plaza (San Francisco)

Different $\hat{N}$ values and 10 replications for each

Variable speed limit (VSL) as a tool for traffic management

- Applied in Germany, US, UK, Netherlands, Finland, ...
- Sometimes in peak hours set the speed limit to 20-30 km/h
- Impact on improving road traffic safety and congestion

Systematic studies about the effectiveness of VSL on traffic flow are limited.
Variable speed limit (VSL) as a tool for traffic management

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There are still open questions:

- Can we achieve higher capacity for highways with VSL?
- Can VSL increase the capacity of highways?
- Does VSL provide a more stable condition?

Systematic studies about the effectiveness of VSL on traffic flow are limited.
Feedback Structure for VSL and ramp metering
ATMS Future Challenges?
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  - tracking, managing, and identifying the high number of devices that will be involved in such integration.
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  - how to converge different information into a single traffic condition representation? How to identify hazards in real-time? Which information have more impact on the traffic?
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  - provide sophisticated mechanisms to fuse, aggregate, and exploit data to deal with different data types provided from heterogeneous sources.
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- Alternative route guidance;
  - how to provide a full scenario overview about the traffic condition to every vehicle to enable them to compute an efficient route without overloading the network.
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- Security and privacy;
  - in addition to inherent security problems in cloud computing, personal data and tracking people and vehicles.
THANK YOU FOR YOUR ATTENTION