Transportation system monitoring method by using probe vehicles that observe other vehicles

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Introduction

Transportation system monitoring

Transportation system

A system where travelers are traveling

- Automotive road network
- Pedestrian space
- City

Monitoring

Acquiring information on a transportation system's dynamics

- State
  - Flow
  - Speed
- Behavior
  - Macroscopic behavior of travelers
    - System model
  - Microscopic behavior of a traveler
    - Destination/route choice (strategic)
    - Interaction between travelers (tactical, operational)

Methods for monitoring

Eulerian observation

Observe a system's dynamics from fixed points in the system

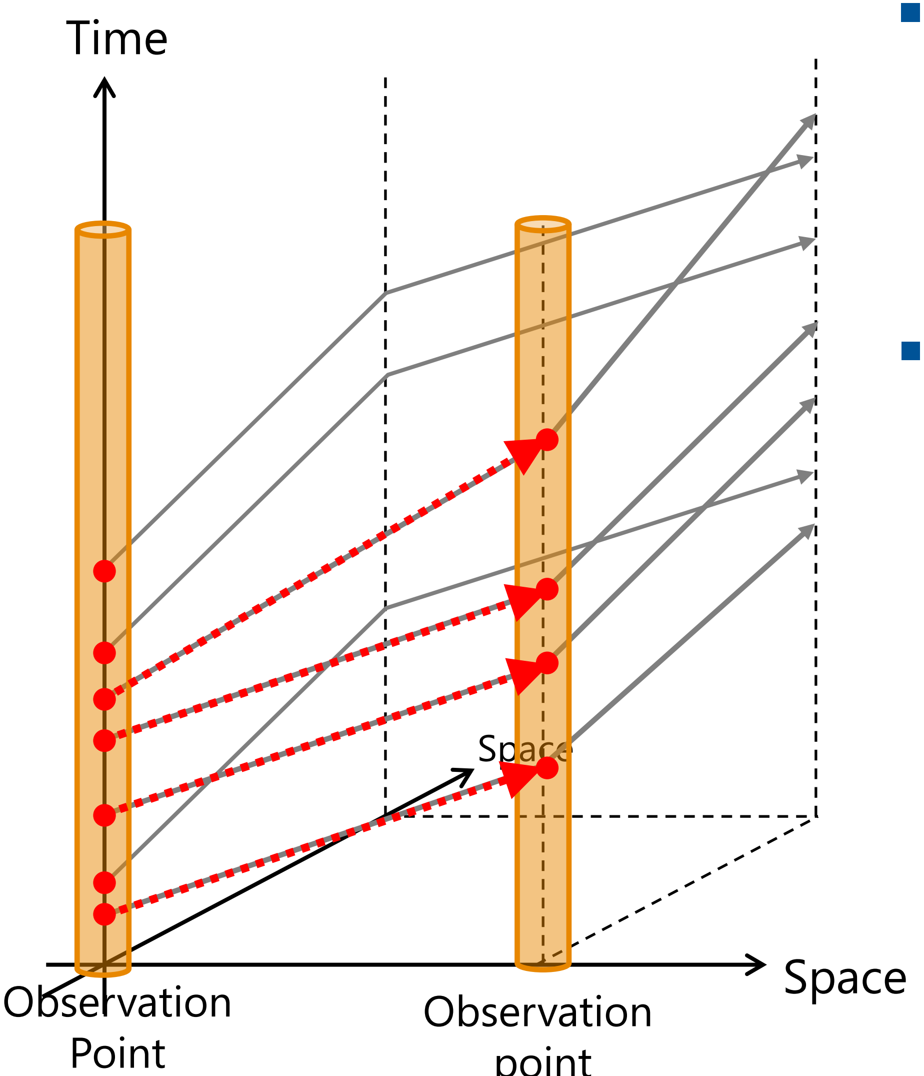
- Traffic detectors
- Cameras
- Ticket transaction data

Lagrangian observation (probe)

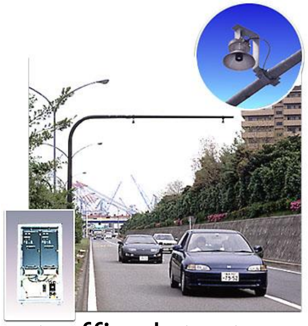
Observe a system's dynamics from floating points that move along with travelers

- GPS

Eulerian observation



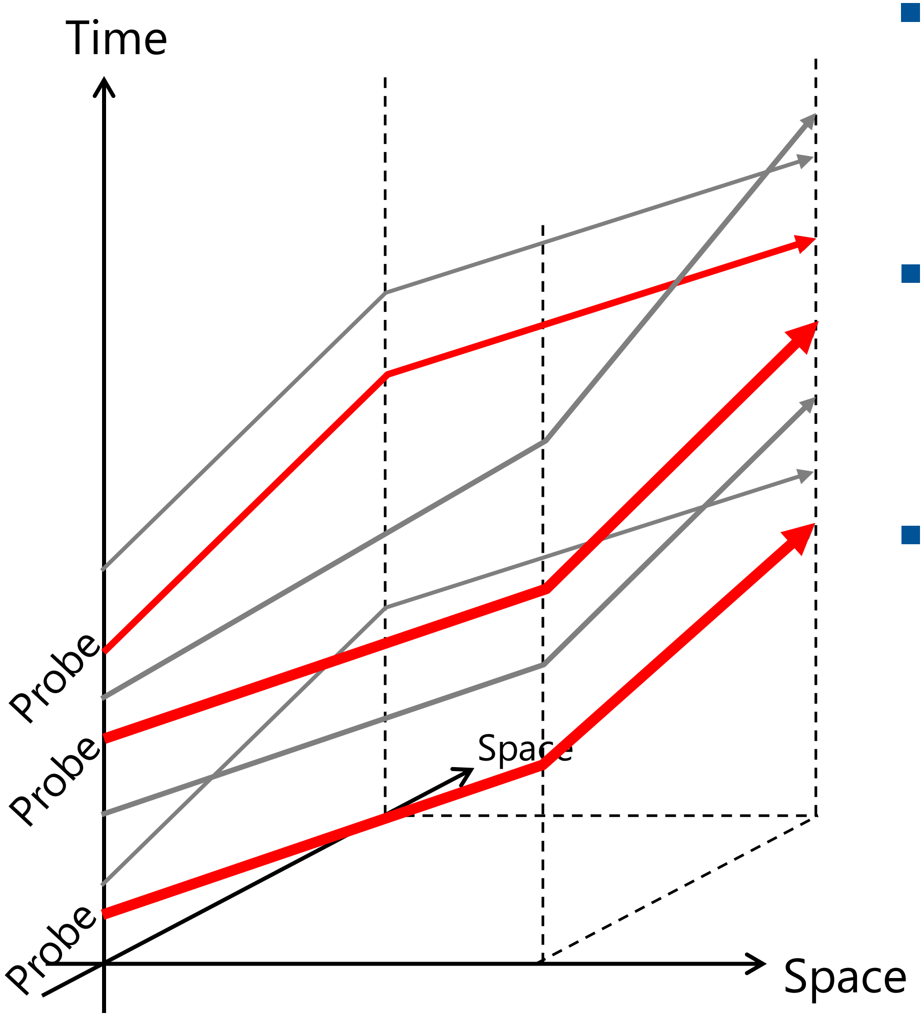
- **Rich information** at the sensor's installed points can be acquired
- **Wide-ranging** observation is difficult due to the **cost** of the observation



traffic detector

fixed camera

Lagrangian observation (probe) 6



- Information over **wide-ranging** space can be acquired
- Passive observation can acquire information **cost-efficiently**
- **Volume-related information** can not be estimated from these sampled trajectories

GPS-equipped probe vehicle

BCALs (Hato 2010)

smartphone

Summary of current monitoring methods

Eulerian observation

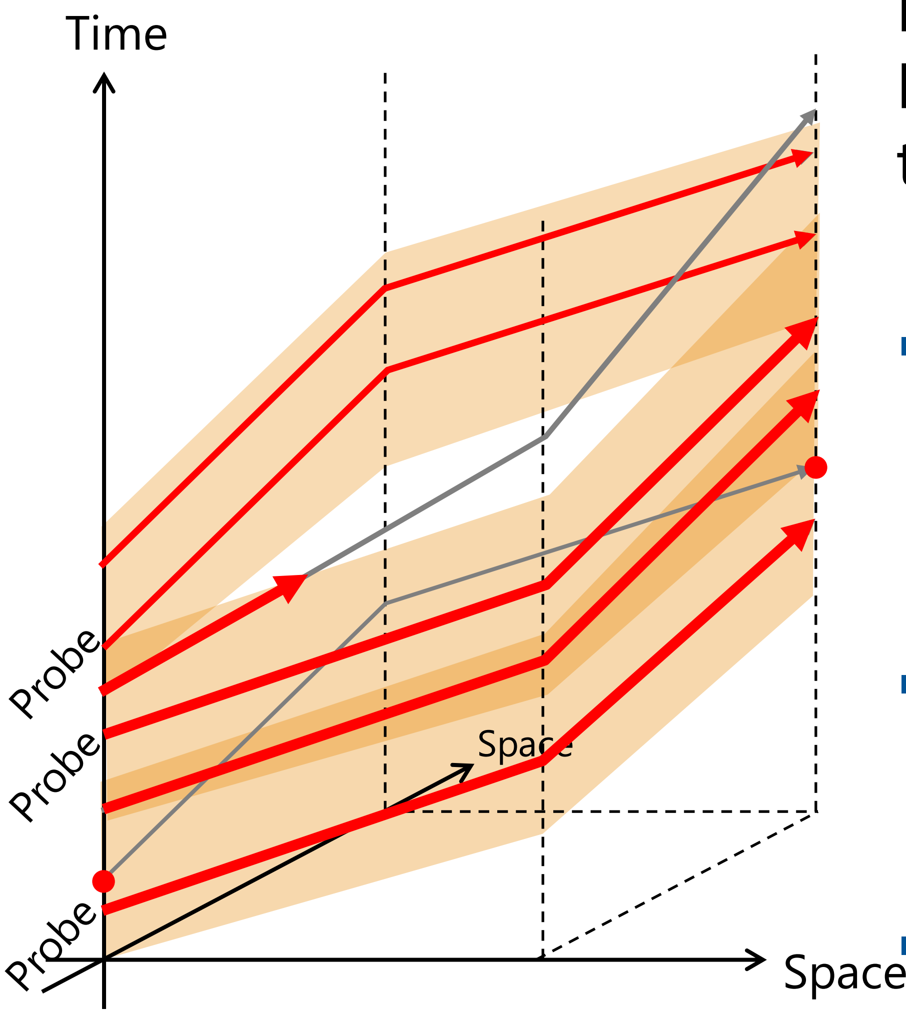
- Can acquire
  - Volume-related info. (flow, density)
  - Quality-related info. (speed, reliability)
- Can not acquire
  - Wide-ranging info. (for time and space)

Lagrangian observation (probe)

- Can acquire
  - Quality-related info.
  - Wide-ranging info.
- Can not acquire
  - Volume-related info.

Problem: How we can acquire volume-related info over a wide range?

A solution

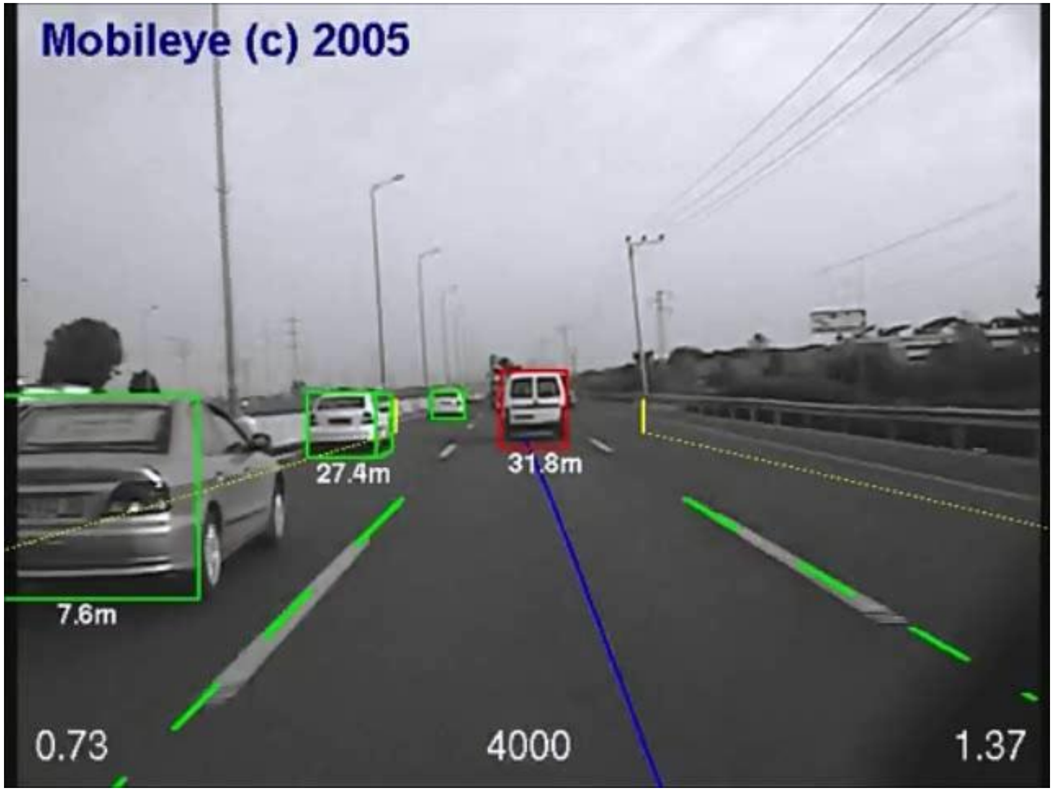


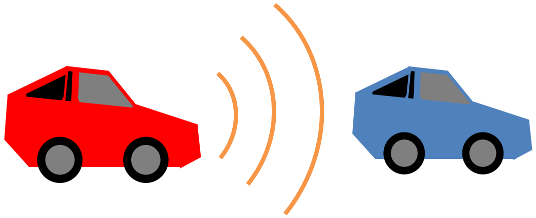
New Lagrangian observation:
Probe travelers that observe other travelers

- **Volume-related information** can be estimated, since local density is available
- Information over **wide-ranging** space can be acquired
- Can be **efficient** in traffic flow monitoring in the near future

Spacing measurement technologies

- Technologies of recognizing surrounding environment of a vehicle from an on-vehicle equipment were developed
  - Radar, Laser scanner, Monoeye/stereo camera
  - Other vehicles, road alignment



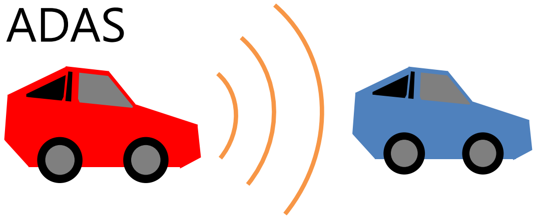


Movie source: Stein et al. (2005)

Spacing measurement technologies

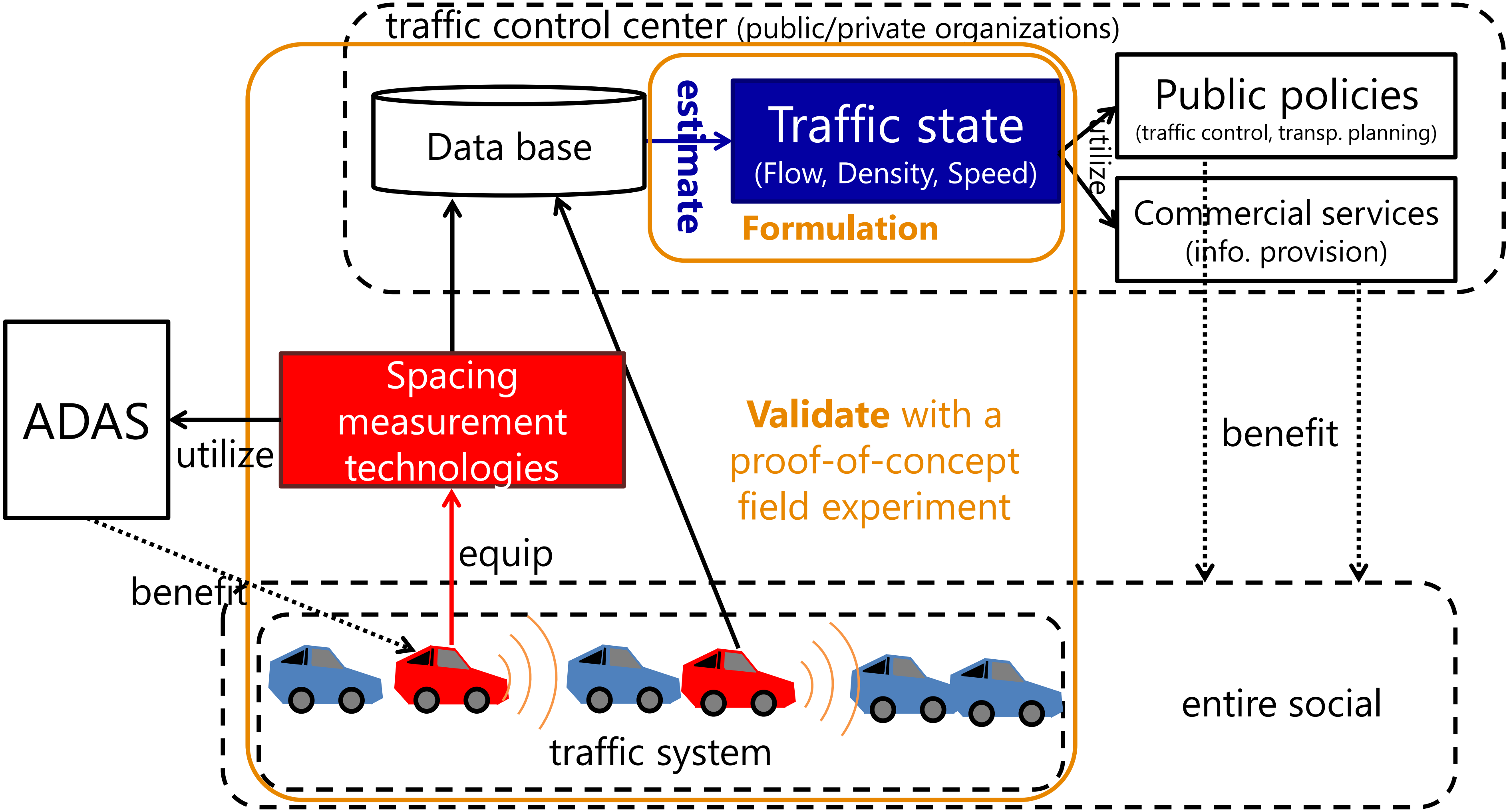
Advanced driver assistance systems (ADAS)

- record driving
- warn the driver
- semi-automation (ACC)
- full-automation (autonomous car)



- Vehicle-to-vehicle distance (≃spacing) must be measured in order to achieve traffic safety
- ADAS-equipped probe vehicle data can be utilized for estimation of the volume-related variables, since spacing is inverse of local density

Supposed future traffic system



- Some drivers will gain benefit from ADAS by equipping the SMT
- Entire social will gain benefit from policies and services based on the collected probe vehicle data

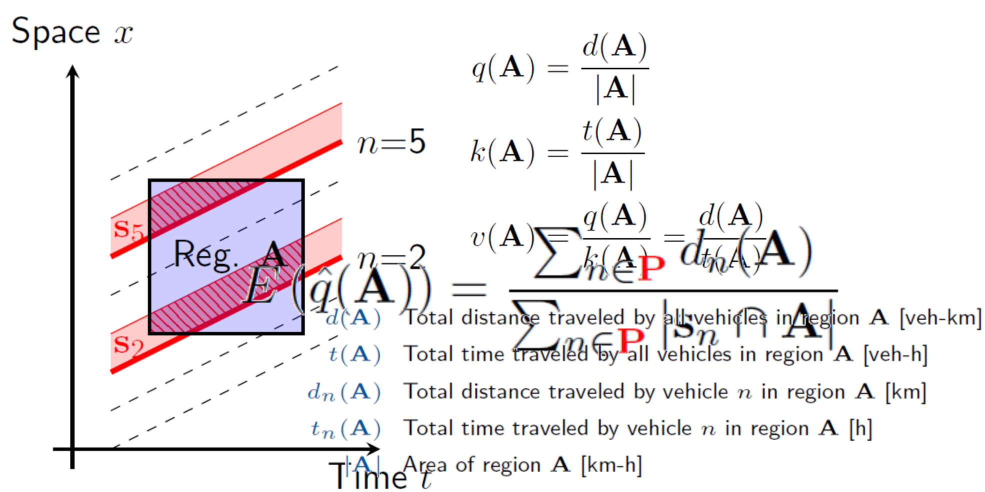
Motivations and Objective

Motivations

- Transportation managements will be significantly improved if it is monitored by using Lagrangian observation only
  - arterial roads, developing courtiers
- Current probe vehicles can not acquire volume-related information
- Spacing measurement technologies were practically implemented; and have potential to spread to the world in order to enable ADAS

Objective

- To develop and validate a methodology of estimating traffic state using probe vehicles with spacing measurement equipment

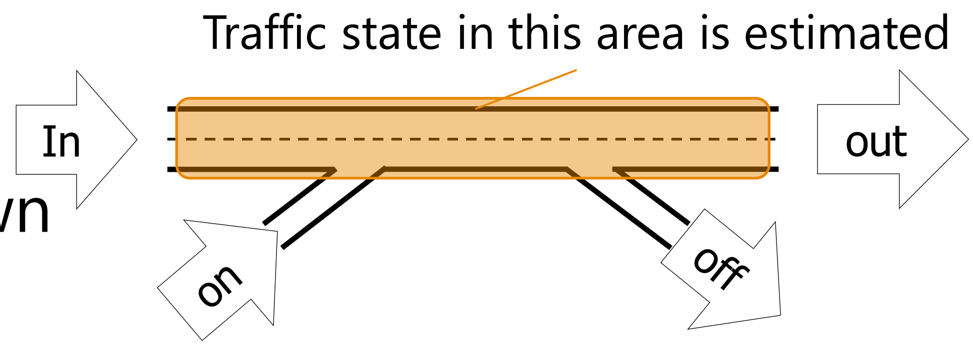


Traffic State Estimation method

Supposed situations

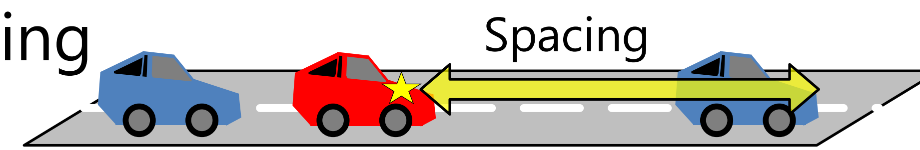
Target road

- One-way
- The schematics are known



Probe vehicles

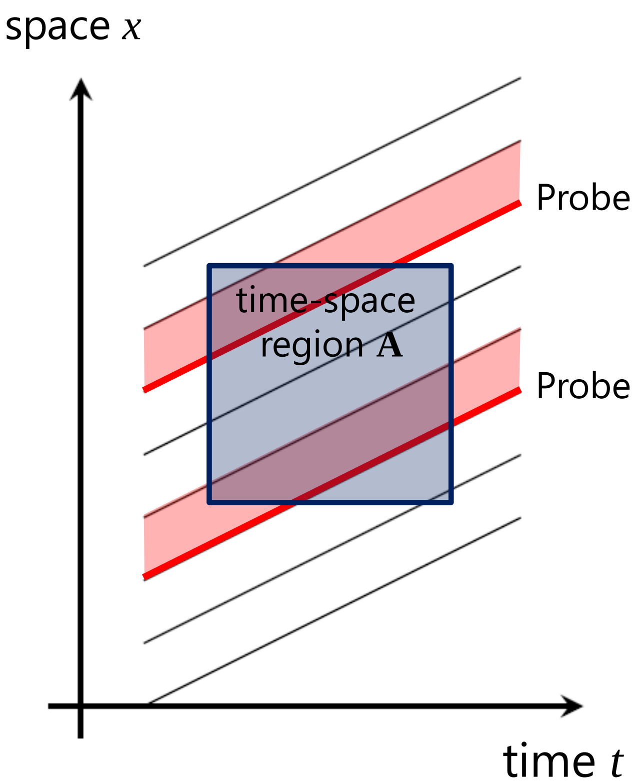
- randomly distributed in the traffic at a certain penetration rate
- measure its position and spacing
- no measurement errors
- their characteristics and driving behavior are the same as the rest of traffic



Target of estimation

- Traffic state (flow, density, speed) with a certain time space resolution

Estimation method



- Traffic flow represented as a time-space diagram
  - vertical axis: space
  - horizontal axis: time
  - curves: vehicle trajectories
- The probe vehicle acquire its own trajectory and its leading vehicle's one
- Traffic state in any closed region **A** can be estimated from the probe vehicles'
  - distance traveled
  - time traveled
  - area of region between the probe and its leading vehicle

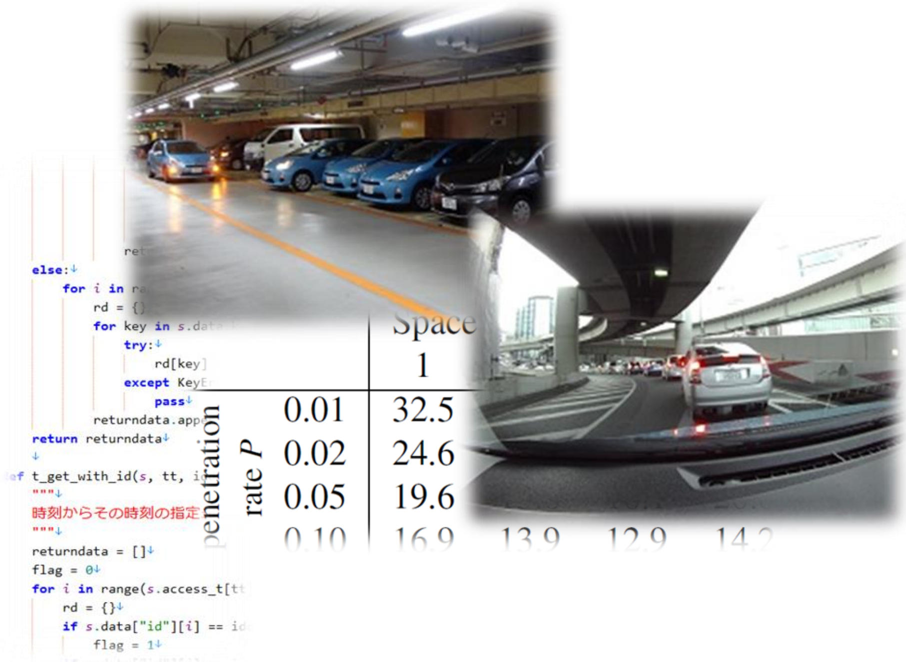
  based on Edie's generalized definition (1963)

Characteristics of the method

- The method can estimate traffic state including the volume-related variables from Lagrangian observation data only

- The method can estimate traffic state with an arbitrary time space resolution
  - 1 min-100 m traffic state
  - hourly traffic volume of a link
  - macroscopic fundamental diagram

- The method relies on few exogenous assumptions: Data oriented approach
  - It can be utilized for estimating behaviors in system (BinN?)

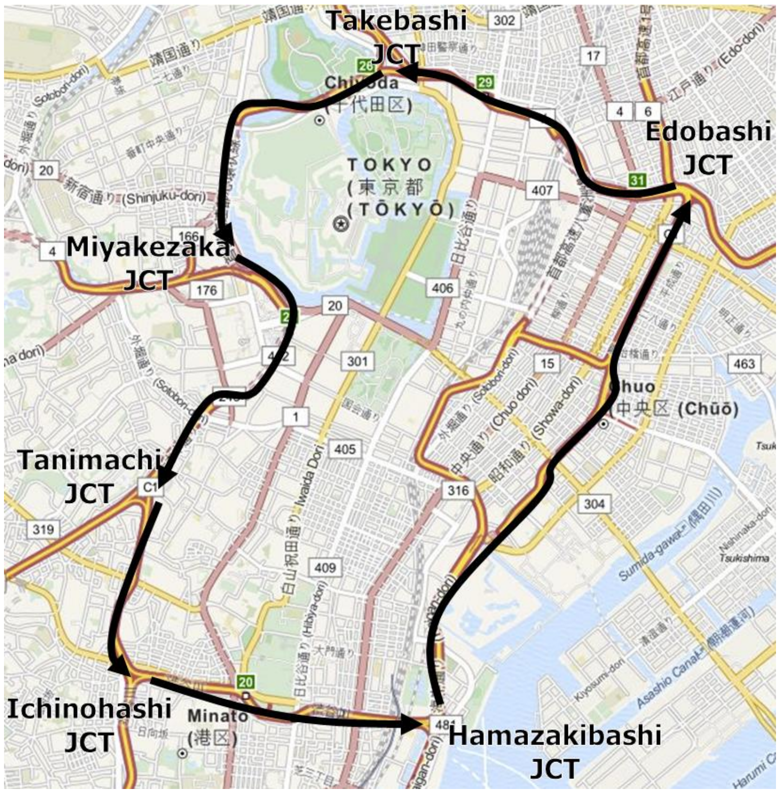


Validation with a Field Experiment

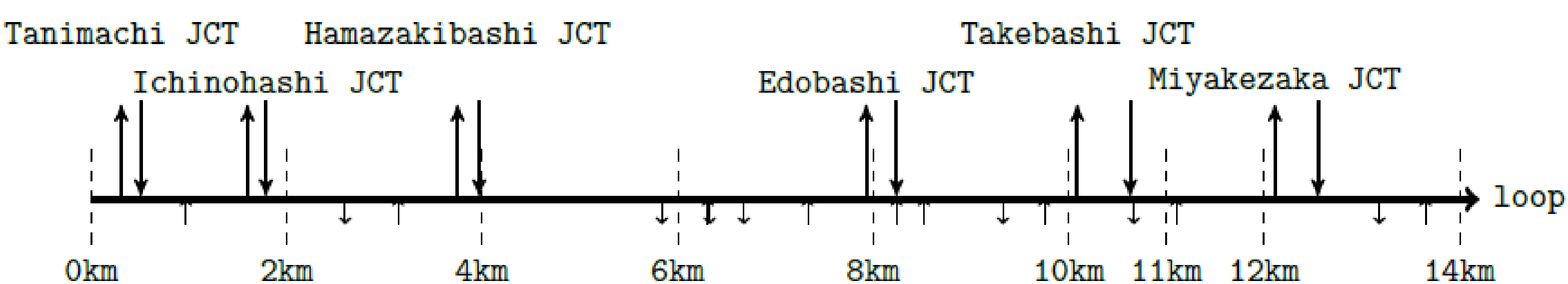
Field experiment at Tokyo

- Date/time: Sep. 24, 2013 (Fri.), 15:00 – 16:00
- Location: Cruising lane, Inner Circular Route (counterclockwise), Tokyo, Japan
- Number of probe vehicles: 20 (=3.5% penetration rate)
- Measurement devices: GPS logger and Mono-eye camera

Inner Circular Route



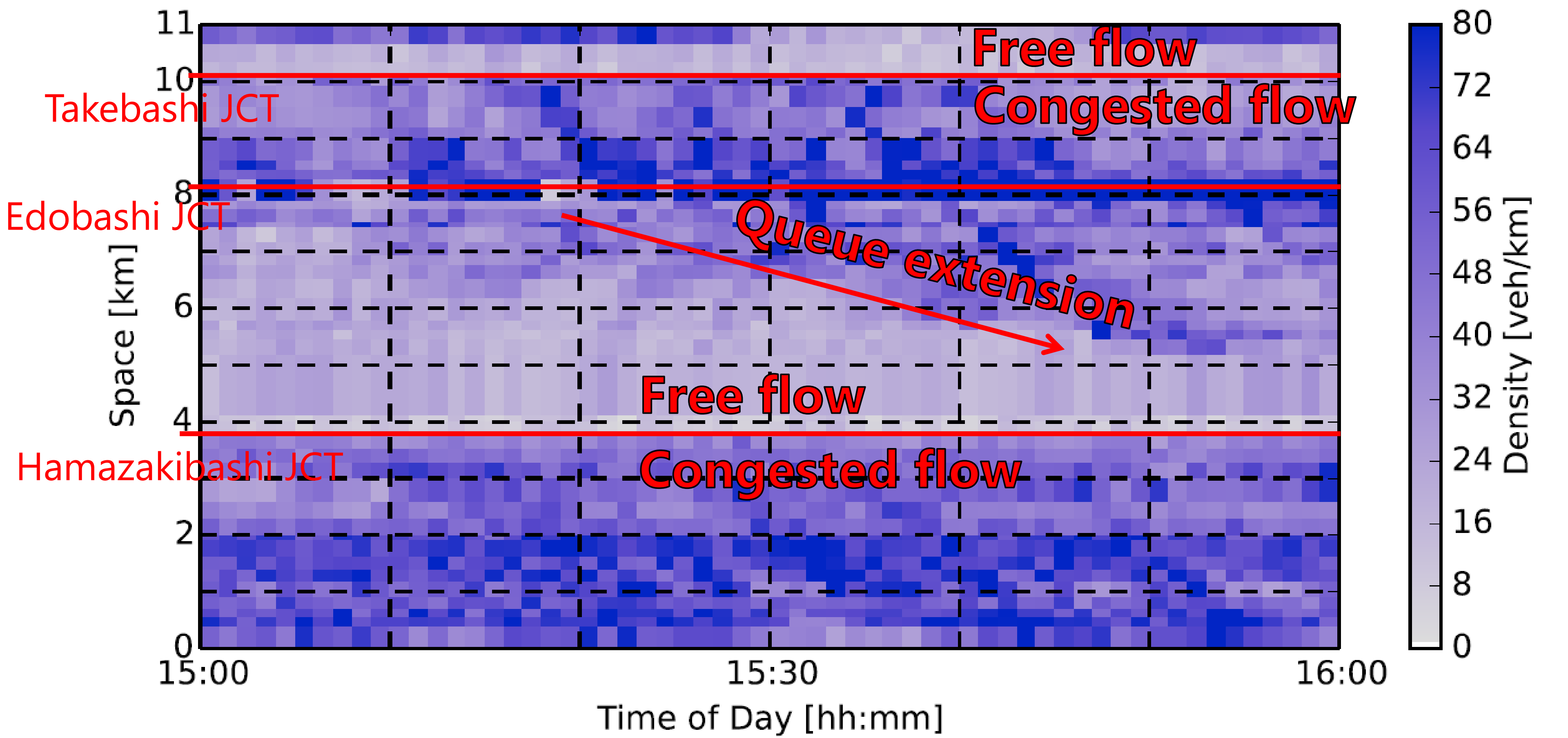
- Total section length: 14.2km
  - The survey area is cruising lane of 11km length section excluding tunnels
- Most of the section has two lanes and 50km/h speed limit
- It has complex traffic flow characteristic
  - curves, elevations, merging/diverging sections
- A lot of detectors are installed. Reliable ground truth data is available
  - time reso.: 1 min
  - space reso.: roughly 250m and per lane



Actual traffic state

Density as a time-space diagram

- plot color: density
- vertical axis: space
- horizontal axis: time



Probe vehicles

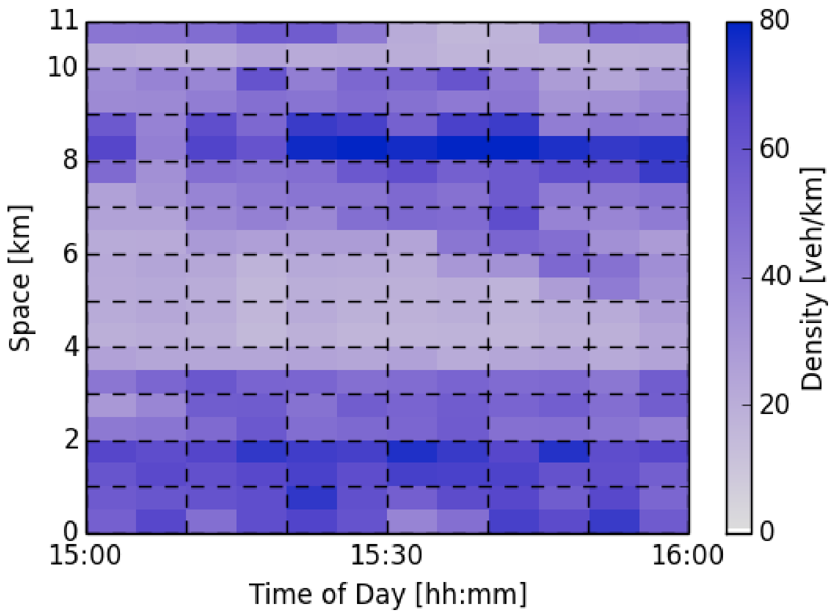
- 20 standard sized passenger vehicles driven by non-professional drivers were employed as probe vehicles
  - 44 laps were performed during 1 hour
  - It corresponds to 3.5% probe vehicle penetration rate

- They measured their position and spacing with 15 s interval

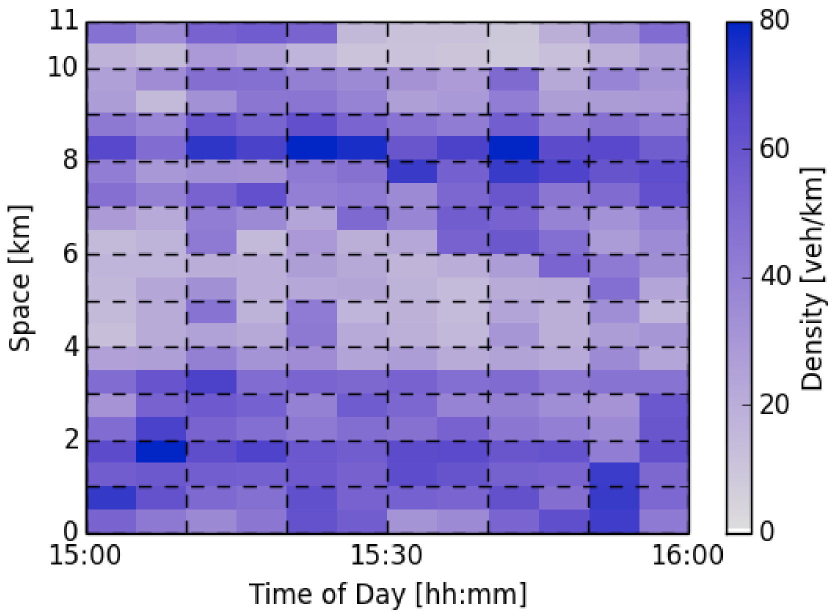
- The position was measured by the GPS logger

- The spacing was measured by analyzing images taken by the camera
  - width of the leading vehicle in the images
  - actual width of the leading vehicle
  - field of view of the camera

Estimation results



Detector data



Estimation result from the probe vehicle data

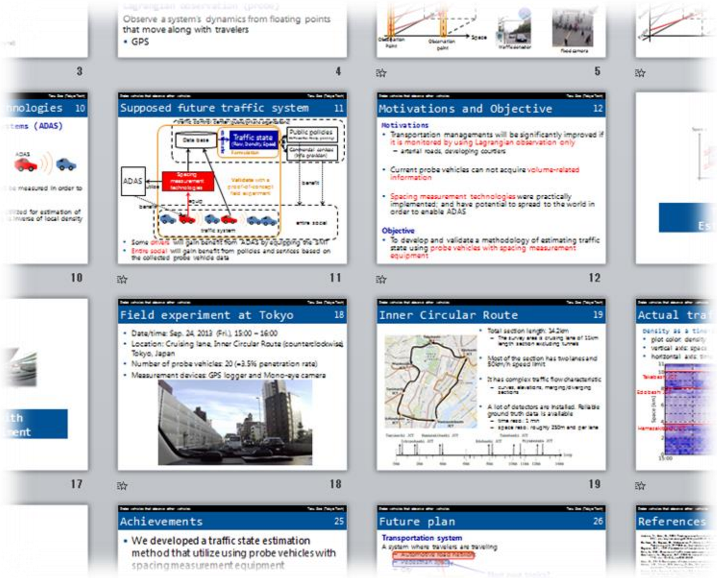
- Density as time-space diagrams
- penetration rate 3.5%, time resolution 5min, space resolution with 500m
- Dynamical features of the traffic flow were reproduced
  - free, congestion, queue extension

Estimation results

- Error indices of various estimation scenarios
  - root mean square percentage error (RMSPE)

penetration rate (probe per hour)	estimation target	error (RMSPE)
3.5% (42veh)	5min flow	14%
0.2% (2veh)	1hour flow	16%

- High resolution information can be acquired where enough number of probe vehicles exist
  - highway traffic managements
- Lower resolution information can be precisely acquired even if the penetration rate is low
  - transportation planning


Supposed future traffic system
Motivations and Objective
Field experiment at Tokyo
Inner Circular Route
Achievements
Future plan
References

Conclusion

Achievements

- We developed a traffic state estimation method that utilize using probe vehicles with spacing measurement equipment
- We validated the method under an actual traffic condition
- As result, the characteristics and performance of the method were clarified

Future plan

Transportation system

A system where travelers are traveling

- Automotive road network
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Current topics

Next next topics?

Monitoring

Next topics

Acquiring information on a transportation system's dynamics

- State
  - Flow
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  - Macroscopic behavior of travelers
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    - Destination/route choice (strategic)
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