An Analysis of Traffic Breakdown Phenomena Using a Platoon-based Traffic Flow Model

Kyoto University Yasuhiro SHIOMI
Contents of my talk

1. The reason why I choose Kitamura sensei

2. Current research related to Kitamura sensei
   - Research of my colleagues
   - My PhD studies

3. The influence and teach of Kitamura sensei
Self Introduction

Apr, 2000  Kyoto University
Apr, 2001  First meeting with Kitamura sensei
           (in the class, “Statistics”)
Oct, 2002  Second meeting with Sensei
           (in the class, “Traffic Engineering”, co-organized by Prof. Iida)
Apr, 2003  Join “Kitamura Lab.”
Apr, 2004  Graduate school of Engineering, Kyoto University
Sep, 2008  Doctor of Engineering, Kyoto University
           (Supervised by Kitamura sensei)
Oct, 2008- Assistant Professor, Kyoto University (ITS Lab.)
Why I choose “Kitamura Lab”? 

Because ...

“I was interested in urban problems, especially in transportation system.”

“I knew Kitamura sensei and Kikuchi sensei, who was assistant professor in Kitamura lab.”

Inspiration

(Choosing Kitamura lab is the best decision I have ever made.)
A study for the amusement activities in the public realm by the suburbs residence (2001)

Kei Maeda
A study for the amusement activities in the public realm by the suburbs residence

- What makes our life “true” well-being?
- The death of suburban residential area.
- The necessity of “Oldenburg’s the third place”

**Hypothesis**

Suburbs, where “Oldenburg’s the third place” are lacked, are not attractive place for resident.

- Analyzing Keihanshin area-PT data (1990)
- Questionnaire for customers of “Izakaya (pubs)” in urban and suburban area.

**Conclusion**

1. Some “Oldenburg’s third place” could be found also in suburban area.
2. In reality, suburban residence had less amusement activities due to time constraint.
A study on the perception of the public space in the city (2003)

Risa Koi
A study on the perception of the public space in the city

In typical suburban areas, some public spaces where the community and social welfare can mature were equipped. There are fewer social welfare and community in suburban areas.

**Hypothesis**
People never aware the “public” feelings in the suburban areas.

“Public” = Diversity in (people + faculty + activity) + History

Questionnaire asking which factors affect the cognition of “public” feeling.

Typical suburban area

Typical urban area
A study on the perception of the public space in the city

Hypothesis

People never aware the “public” feelings in the suburban areas.

Conclusion

1. Residence in urban area tend to perceive urban space as “public”, whereas residence in suburban area tend to perceive suburban area as “public”.
2. Residence in suburban area were less sociable than in urban area.
Worldviews, lifestyle and sustainability: A search for a primordial determinant of environmental friendliness (2005)

Kyotaro Sakamoto
Worldviews, lifestyle and sustainability: A search for a primordial determinant of environmental friendliness

An individual’s way of thinking and attitude, which have strong influence to the social recognition and behavior

<table>
<thead>
<tr>
<th>Worldviews</th>
<th>Egalitarian</th>
<th>Hierarchist</th>
<th>Fatalist</th>
</tr>
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<tbody>
<tr>
<td>Individuals</td>
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Questionnaire about worldviews and attitude towards transportation, environment, residential area and society was done in some areas

Conclusion

1. Strong relationship between individuals’ worldviews and attitudes towards residential area.
2. The utility of market research for public works based on the worldviews was discussed.
Platoon-based Traffic Flow Model to Estimate Traffic Breakdown Probability on Freeway Bottlenecks

Kyoto University Yasuhiro SHIOMI
Kyoto University Toshio YOSHII
Kyoto University Ryuichi KITAMURA

9/24/2008 at Kitamura sensei’s office
Background (i)-Traffic Capacity

**“Traffic Capacity”** has played important roles in...

**Planning**  
**Design**  
**Operation**

**“Traffic Capacity”** is defined as the maximum number of vehicles that can pass a point per unit of time.

In this concept, traffic congestion occurs only when traffic demand exceeds the maximum flow rate.

In reality, this is not so simple issue....
"Traffic Breakdown" occurs stochastically to the traffic volume.

Transition from non-congested state to congested state

Background(iii)-Stochastic Capacity

The concept of “stochastic capacity/breakdown probability” have been suggested. (Brilon et al. (2005), Kuhne (2007) and so on...)
The concept of “stochastic capacity/breakdown probability” was suggested. (Brilon et al. (2005), Kuhne (2007) and so on...)

To establish the traffic flow model that represents traffic breakdown stochastically.

To investigate new freeway operation schemes based on the concept of stochastic capacity.
Viewpoint of this study (i) - Heterogeneity

- Why does traffic phenomena have stochastic nature???
  - Heterogeneity of vehicles in traffic flow

- Desired speeds vary among vehicles.
  - Trucks or sports cars
  - Young drivers or senior drivers
  - With time limit or without time limit

Desired Speed: the speed a driver would choose for a certain section without any obstacles.
Due to the desired speed distribution, platoons are formed in stochastic manner.

A platoon of four vehicles
It is pointed out that platoons cause traffic breakdown (e.g. Koshi, 1986)

**Small Platoons**  
Deceleration wave will not propagate upstream.

**Large Platoons**  
Deceleration wave can propagate upstream, which causes traffic breakdown.

CONJECTURE  
Each platoon has breakdown probability, influenced by its platoon size.
Frameworks of this study

**INPUTS**
- Road structural condition
- Traffic inflow rate
- **Desired speed distribution**

**OUTPUTS**
Stochastic capacity
Traffic Inflow Rate vs Breakdown Probability

Platoon condition at bottlenecks
- Platoon size
- The speed of a lead vehicle

Platoon behavior model
Platoon-breakdown probability
Summary of the result

- Desired speed distribution was estimated in unbiased way.
- Breakdown probability to the traffic inflow rate was defined.
  - The relationship between traffic flow rate and breakdown probability could be explained by desired speed distribution.
  - **Reducing the variance of DSD** and **installing pace cars** are effective way to reduce breakdown probability.

![Graph showing the relationship between breakdown probability and inflow rate with and without pace cars.](image)
Kitamura sensei’s teaching

Through the PhD research,

“what I was asked by Kitamura sensei” are...

“What is traffic capacity?”
“What is traffic congestion?”
“What is a platoon?”

In many cases, I could not answer correctly.

To think by myself is worth. Just “information” is meaningless.
Impressive talk of Kitamura sensei

At the end of his class, “traffic management engineering”, for before undergraduate 3rd year students, 2006.

Fortunately, I joined his class as a teaching assistant.

Kitamura sensei to the student in the class:

“In the future when you become a civil engineer and engage in land development, please keep this promise at least: don’t cut this existing tree.”

""
Thank you for your attention.
Assumptions in traffic flow

Platoon formation model

Each vehicle’s entrance time
Desired speed distribution

If the vehicle catches up with a front vehicle, it must follow at the same speed
The desired speed is given randomly

Inputs

Desired speed distribution

Freely driving vehicle
Following vehicle

A platoon

Trajectory

v1, v2, v3, v4, v5, v6

T1, T2, T3, T4, T5, T6

Exit

Entrance

L
Platoon Formation

This model outputs “lead vehicle speed and platoon-size distribution”

\[
\text{Prob}[v_i, k_i] = f(v | \hat{a}) \cdot p^{\text{lead}}(v) \cdot p_{k-1}(v)
\]

- \(f(v | \hat{a})\): PDF of desired speed distribution (parameter vector \(\beta\))
- \(p^{\text{lead}}(v)\): Probability that a vehicle with DS \(v\) becomes the lead
- \(p_{k-1}(v)\): Probability that \(k-1\) vehicles catch up with a vehicle at speed \(v\)

\[p^{\text{lead}}(v) = \prod_{k=1}^{\infty} \left\{ \int_{d_{i,i-k}(v)}^{\infty} f(u) du \right\} \]

\[p_{k-1}(v) = \prod_{j=1}^{k-1} \left\{ \int_{d_{i,j,i}(v)}^{\infty} f(u) du \right\} \]

\(d_{i,i-k}(v)\): Variable related to inflow rate and the bottleneck outflow rate
The parameter vector $\beta$ can be estimated by applying maximum likelihood estimation:

$$\hat{a}^* = \arg \max L(\hat{a}) = \prod_{i=1}^{N} \Phi \left[ \tilde{v}_i, \tilde{k}_i | \hat{a} \right].$$

- $N$: Observed number of platoons
- $\tilde{v}_i$: the speed of the lead vehicle of the observed platoon $i$
- $\tilde{k}_i$: the size of the observed platoon $i$
Assumptions in platoon flow

- Assumption 1: Speed transition within a platoon can be treated as Markov Chain

\[ v_{\text{top}}^{\text{2}}(v) = f(v_{\text{top}}^{\text{2}}(v)) \]

- Assumption 2: Traffic Breakdown under 40 km/h

\[
P = \begin{pmatrix}
1 & 0 & L & 0 \\
p_{S_iS_0} & p_{S_iS_i} & L & p_{S_iS_n} \\
M & M & O & M \\
p_{S_nS_0} & p_{S_nS_i} & L & p_{S_nS_n}
\end{pmatrix}
\]

Speed Transition Probability Matrix
Description of breakdown probability

• Breakdown probability at a bottleneck can be expressed as:

\[
P_{BD}(Q) = \Theta \sum_{i} \sum_{\nu_{top}} \sum_{4} \{ \frac{3}{3} \cdot \text{Prob}[\nu_{lead}, i | \nu_{top}] \}_{\text{plt}(0)}, T_{\nu_{top}(i), \text{plt}(1)} \}
\]

Q: given, β: inversely estimated, P: observed

Where,

\[
\mathbf{N} = \frac{Q}{\sum_{i} \sum_{\nu} \text{Prob}[\nu, i | \hat{\nu}, Q]}
\]

\[
t_{\text{plt}(\nu_{lead}, i), T_{\nu_{top}(i), \text{plt}(1)}} = \Phi 4.1 \quad 53.71 \quad T_{\nu_{top}(i), \text{plt}(1)}} = 1 \quad 0
\]

\[
\sum_{i} \sum_{\nu_{top}} \cdot \left( \sum_{\nu} \text{Prob}[\nu, i | \hat{\nu}, Q] \right)
\]

\[
\text{Prob}[\nu, i | \hat{\nu}, Q]
\]

\[
\text{Time of a platoon with (\nu_{lead}, i) to pass through a BN}
\]
Numerical example

- Single-lane section of 5km is considered.

Entrance

Breakdown probability

Pace car with 60km/h, one per ten vehicles

No pace car

Pace car with 70km/h, one per the vehicles

Improve the traffic breakdown

Inflow rate[veh/h]

1

0.75

0.5

0.25

0

1500

1600

1700

1800
Conclusion

- Single-lane section of 5km is considered.

![Diagram showing traffic breakdown probability against inflow rate with and without pace cars.]

- No pace car
- Pace car with 60km/h, one per ten vehicles
- Pace car with 70km/h, one per the vehicles

*Improve the traffic breakdown*