Dynamic Analyses on Network Traffic Flow

-Applications of Queueing Models-

Institute of Industrial Science,
University of Tokyo
Masao Kuwahara

1. Cumulative Figures for **Point** Queues & **Physical** Queues
(A relationship between the cumulative figures and the time-space diagram)

2. Dynamic Assignment
   - DUO (Dynamic User Optimal)
   - DUE (Dynamic User Equilibrium)
   - DSO (Dynamic System Optimum)

3. Departure Time Choice
   Overview of recent studies

4. Future Perspective
Static Assignment
Wardrop Principles

Beckmann Type Formulation

Point Queue vs. Physical Queue
3-dim Representation of Traffic Flow
3-dim Representation of Traffic Flow

Cumulative Trips

Departure Curve

Arrival Curve

time

Flow

space

Applications of Physical Queues

Freeway

On-Ramp

(a)

Bottleneck

Arterial

(b)

Grid-Lock

(c)

(d)
Kinematic Wave Theory

- Flow, Forward Wave Speed \( f(x,t) \)
- Backward Wave Speed, Density, \( k(x,t) \)
- Forward Wave
- Backward Wave
- Shock Wave
- Characteristic Curve

Vehicle Trajectories and Waves

- Cumulative Trips
- Forward Wave
- Shock Wave
- Backward Wave

Applications to Network Analysis:
Dynamic Assignment, Signal Control, etc.
Dynamic Assignment

Assignment Principles

DUO (Dynamic User Optimal )
DUE (Dynamic User Equilibrium )
DSO (Dynamic System Optimal )

Constraints

1. Flow Conservation
2. First In First Out discipline
3. Non-Negativity of Traffic Flows

DUO (Dynamic User Optimal )

Route Choice based on present and past information (“Reactive” assignment)
This principle becomes realistic by use of ITS instruments.

Point Queue
Many-to-Many OD Formulation
Solution Algorithm
(Decomposition with respect to the current time.)

Physical Queue
Many-to-Many OD + Physical Queues
**DUE (Dynamic User Equilibrium)**

Route Choice is “Predictive”: more difficult than DUO

Point Queue
- Many-to-One (One-to-Many) OD
  - Decomposition with respect to departure(arrival) time at the single origin(destination).


Physical Queue
- Many-to-One (One-to-Many) OD
  - Formulation and Solution Algorithm (OK)

**Research Needs on DUE**

Extension to Many-to-Many OD

1. Combination of Many-to-One Problems

(2) Conversion to Mathematical Problems
- Non-linear Complementary Problem
- Fixed Point Problem
- Variational Inequality Problem
  - (using Route Variables)
DSO (Dynamic System Optimal)

**Point Queue**
- Easy Formulation

Min : Total Travel Cost  
s.t. : 1. Flow Conservation  
      2. First In First Out  
      3. Non-Negativity

Non-unique solutions due to FIFO constraints.

- LP Formulation for Many-to-One (One-to-Many) OD  
  by Daganzo, Ziliaskopoulos

**Physical Queue**
- Inclusion of Physical Queues would be possible  
  : use of traffic simulations

Research Needs on DSO

A Solution Algorithm for Many-to-Many OD  
: How efficiently find the global optimal

**Basic Strategy:** Equilibrate Dynamic Marginal Costs

**Dynamic Marginal Cost** = Present Cost Change  
+ Future Cost Change

Kuwahara, Yoshii, and Kumagai: Strategies for Dynamic System Optimum  
and the Ramp Control Application-A fundamental theory on a simple network –  
Submitted to Transp. Res. B

Kuwahara: A Theoretical Analysis on Dynamic Marginal Cost Pricing,  
TRANSPORTATION PLANNING AND MANAGEMENT IN THE 21st  
CENTURY, Proceedings of the Sixth Conference of Hong Kong Society for  
Transportation Studies, pp.28-39
Departure Time Choice Problem

Mainly for Commute Trips on Highways which have clear Time Constraints

Late 1960s: Analysis by Economists
Vickrey, Henderson, etc.

Late 1970s: Single Bottleneck Analysis:
Hurdle, Hendrickson, Smith, Daganzo
Uniqueness and Existence of the Solution

Late 1980s: Several Extensions
Many Bottlenecks (Kuwahara, Depalma, etc.)
Non-Identical Travelers (Newell)
Stochastic Models (Ben-Akiva, Mahmassani, etc.)

Single Bottleneck Analysis

Residential Area \[\xrightarrow{\text{Cumulative Trips}}\] Queueing Delay \[\xrightarrow{\text{Equilibrium Arrival}}\] Work Starting Time \[\xrightarrow{\text{Schedule Delay}}\] Desired Departure Time from a Bottleneck

Bottleneck Work Places

Work Starting Time = Desired Departure Time from a Bottleneck
1. Many Bottleneck Problem

2. Non-identical Travelers (time value variation) by Newell

3. Stochastic Analysis (random utility) by Ben-Akiva, Mahmassani etc.
**Simultaneous Analysis**

- Route
- Departure Time
- Mode

**Control**

- DUO
- DUE
- DSO

Road Pricing, Flex Time, Staggered Commuting
Ramp Control, Travel Information, Signal Control

**Human Behavior**

- Human Response to Information, Pricing
- Route Choice & Departure Time Choice behavior

**Data Diversity**

- Sensing Technology

**Needs Diversity**

- Various Output
- Requirement

**Dynamic Analysis**

- Spatially+Temporally

**Interdisciplinary**

- Traffic Engineering
- Transportation Planning
- Economics
- Electric Engineering
- Mechanic Engineering

**Simulation**

- Modelling
  - Choice Behavior
  - Vehicle Motion
- Verification
  - Validation
- Application
- Interpretation

**Theoretical Analysis**

- Discovery of General Rules
- Construction of Model Structure
- Preparation of Theoretical Solution
  - Uniqueness/Existence
  - Qualitative Consequences
- Output Interpretation
  - Sensitivity Analysis (IN→OUT)