Beyond Equilibrium: User Adjustment Processes and Day-to-Day Dynamics

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OUTLINE

- Stability and User Adjustment Processes
- Dynamic Equilibrium
- Did They Miss Anything??
- Where to Now?

STABILITY and USER ADJUSTMENT PROCESSES

- *An equilibrium would be just an extreme state of rare occurrence if it were not stable– that is, if there were no forces which tended to restore equilibrium as soon as small deviations from it occurred.*

- *Besides this stability "in the small" one may consider stability "in the large"– that is, the ability of the system to reach an equilibrium from any initial position.*

- *This latter type of stability is interesting not only because it concerns the capacity of the system to reach a new equilibrium position after some big change, but also because* ***one may want to use an analogue of the adjustment process as a method of computing an equilibrium solution by successive approximations.***

from page 70, section 3.3. Stability

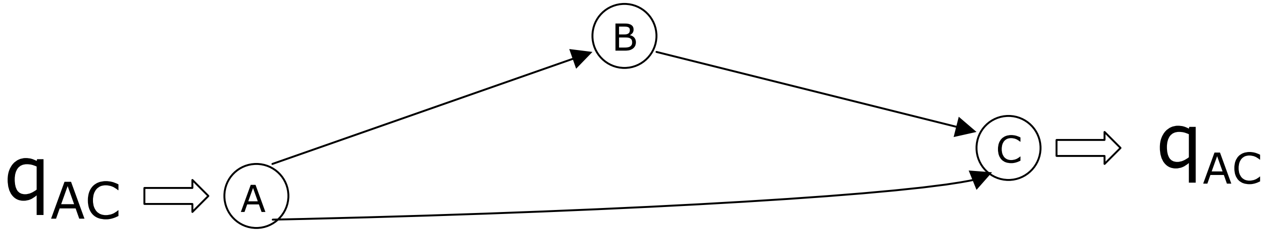
USER ADJUSTMENT PROCESSES

- *The study of stability hinges ultimately on the question of how road users adjust themselves to changes– that is, how they adapt the extent of their travel by road and their choice of routes to varying traffic conditions.* ***This, however, is one of the big unknowns of road-user behavior****, so at the present stage only conjectures are possible.*

- *Through a simple and plausible model one can get a rough picture of the minimum of conditions that must be met in order that the adjustment process should converge.*

- *These road users who have or can obtain adequate knowledge of the traffic conditions , even if not by first-hand experience, choose a route which is optimal at the transportation cost of the last period and set their demand for transportation at levels corresponding to the average costs of trips during the last period.*

from page 70, section 3.3.1 Adjustments of Road Users

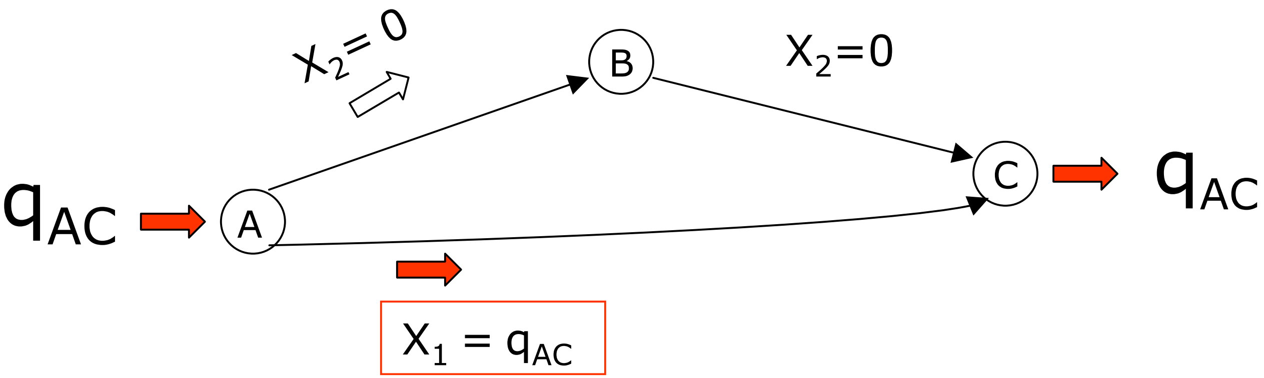


Consider simple network; known link performance functions;

One O-D pair, connected by two paths

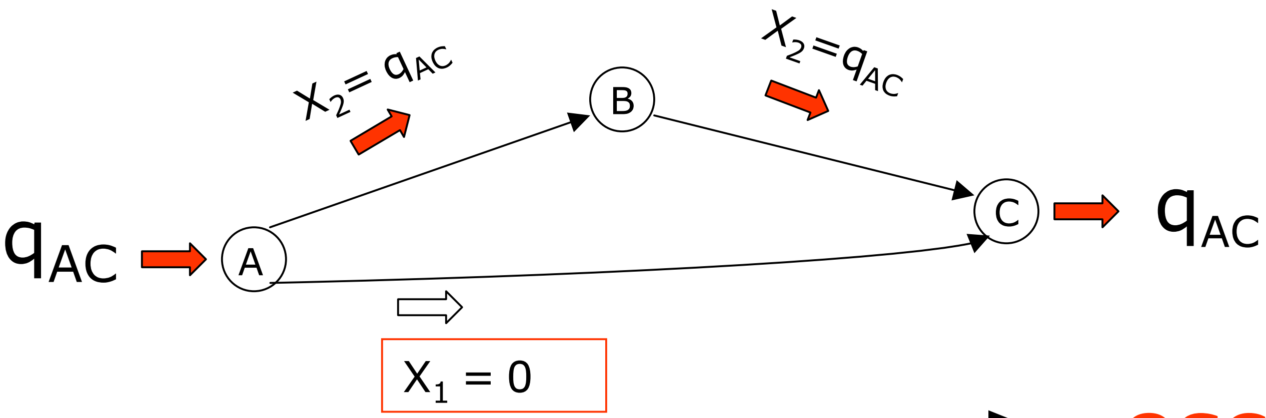
Known constant demand rate q_{AC}

Day 1



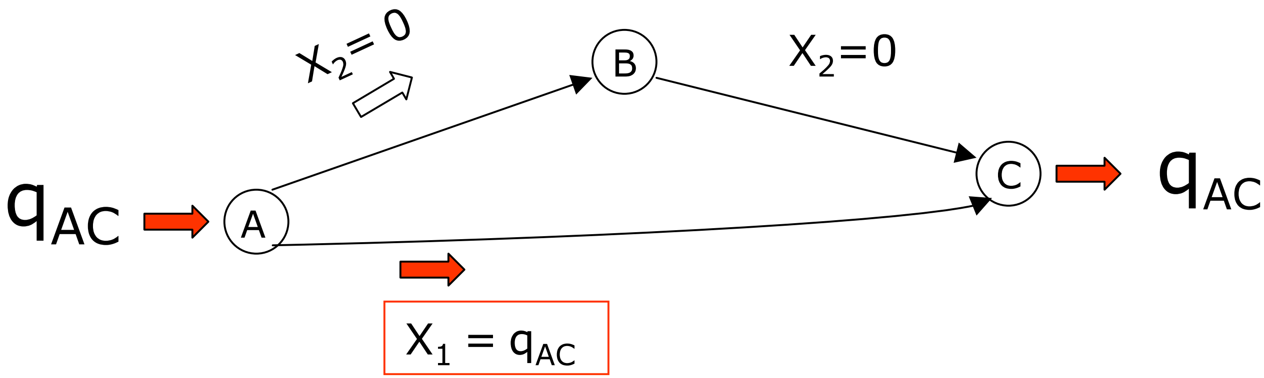
Day 2

Assume users act on day t+1
according to costs prevailing on day t



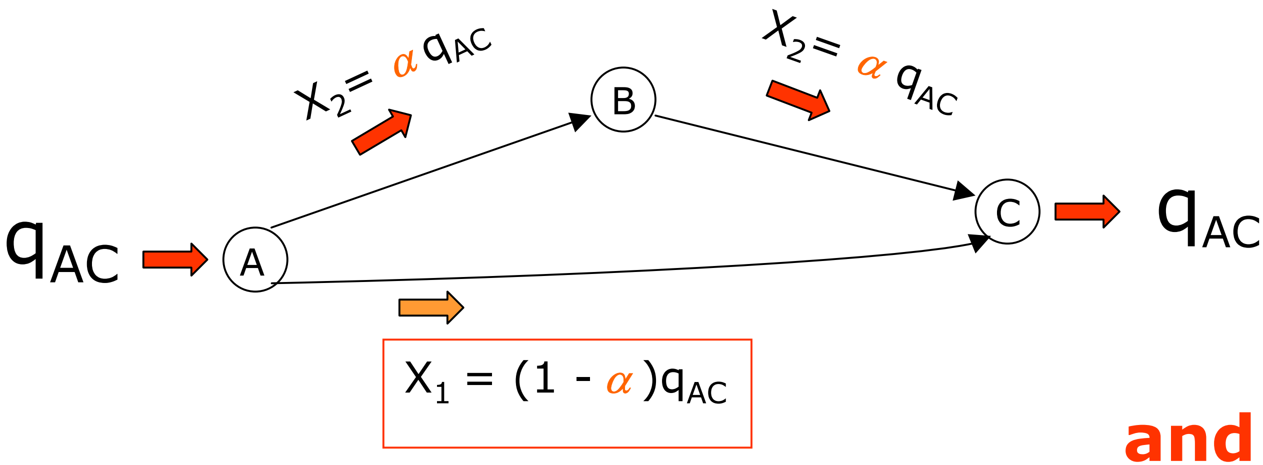
⟹ **OSCILLATIONS…**

Day 1



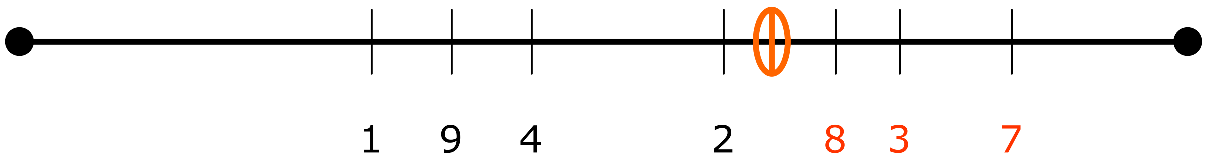
Day 2

Assume ***only fraction α of users*** act on day t+1 according to costs prevailing on day t



and so on...

Using α = 1/5



Solution may diverge, oscillate, or possibly approach convergence, depending on parameters of the problem and fraction α. Relates problem to classical cobweb pattern in supply-demand equilibration.

BMW discuss intuitively how equilibrium might be approached, with α decreasing as difference in route costs narrows; adaptive behavior.

USER ADJUSTMENT PROCESSES

- Suggest concept for ***day-to-day learning model***; instead of Markovian assumption (knowledge only of previous day's experience),

  …*some weight may be given to experience of the more remote past, especially where oscillations have already been experienced. (p. 75)*

This work has influenced, directly and indirectly, a fascinating body of work on adjustment processes, day-to-day dynamics and associated system properties, disequilibrium and tatonnement approaches, including:

Horowitz (1984); Mahmassani, Herman and coworkers (1985-2003); Cantarella and Cascetta (1993, several); Friesz, et al. (1993); Nagurney and Zhang (1993, several); Watling (1999);Peeta (2002), Chen and Mahmassani (2004)…

⟹ Many important results and properties, valuable insight

USER ADJUSTMENT PROCESSES

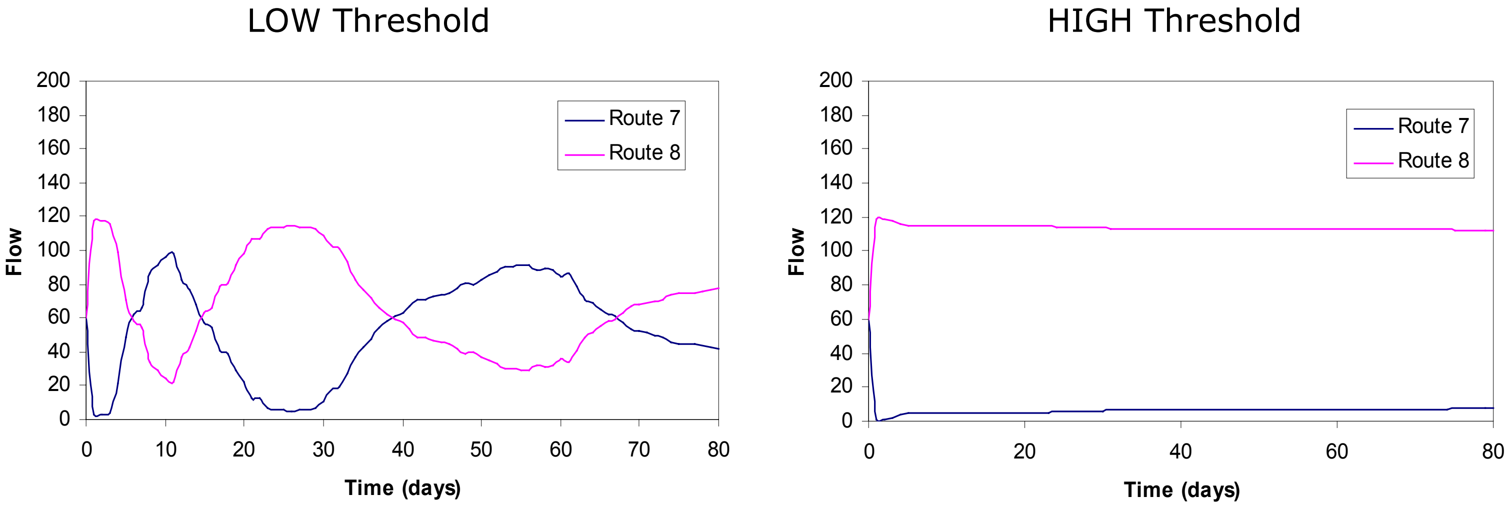
- R. Chen and Mahmassani (2004)

Bayesian framework for updating travel time perceptions

Trigger Mechanisms: travel time difference threshold vs. periodic

Stopping Rules: based on user confidence (perceived travel time variance)

Heterogeneous Users: selectivity, information



USER ADJUSTMENT PROCESSES

- *The study of stability hinges ultimately on the question of how road users adjust themselves to changes– that is, how they adapt the extent of their travel by road and their choice of routes to varying traffic conditions.* ***This, however, is one of the big unknowns of road-user behavior****, so at the present stage only conjectures are possible. (p.70)*

- NEED FOR EMPIRICAL BASIS FOR THESE MODELS OF USER BEHAVIOR

- LARGE AND GROWING BODY OF LABORATORY EXPERIMENTS; focus on experimental study of system dynamics and user decision processes; early experiments of Mahmassani and Herman (1984-1989); Iida et al. (1990)

- CONSIDERABLE INTEREST FROM *ITS* COMMUNITY and EXPERIMENTAL ECONOMISTS (e.g. 2001 workshop on route choice dynamics organized by Prof. R. Selten in Bonn; Schrekenburg; Helbing…)

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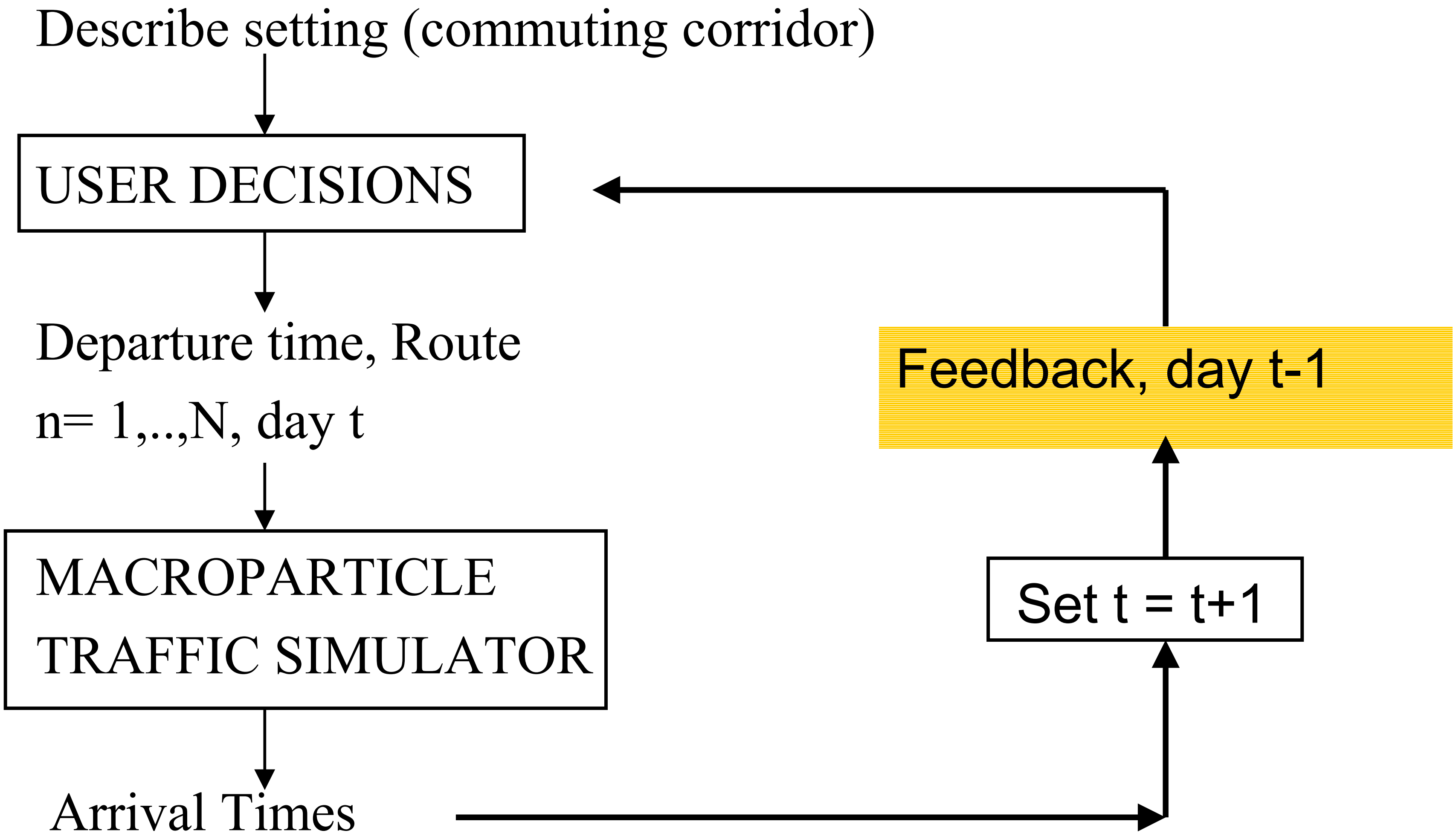
THE EARLY EXPERIMENTS:

Mahmassani, Herman, Chang, Tong, Stephan, Jayakrishnan…

Interaction of user decisions and traffic system dynamics

1984-1989

GENERAL EXPERIMENTAL PROCEDURE



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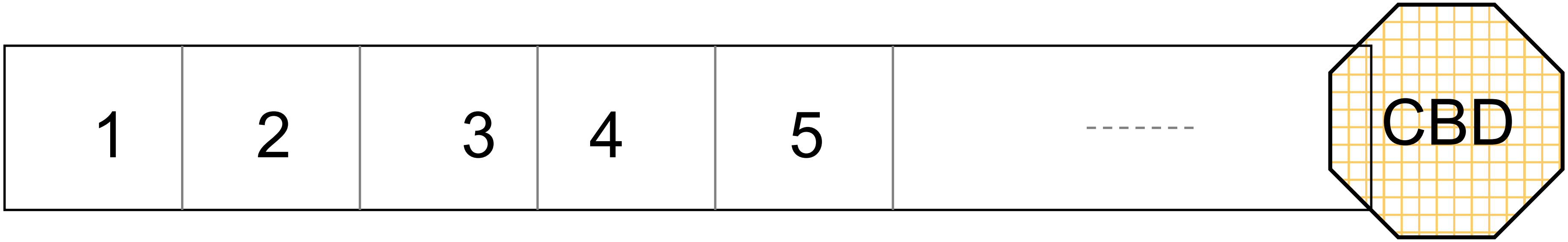
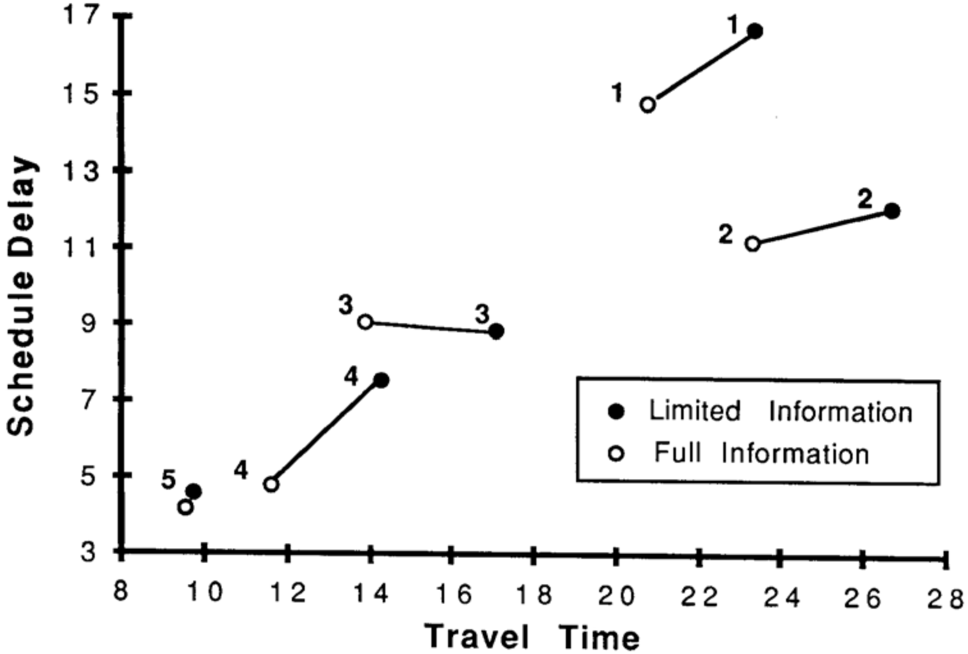
COMMUTING CONTEXT



THE EXPERIMENTS

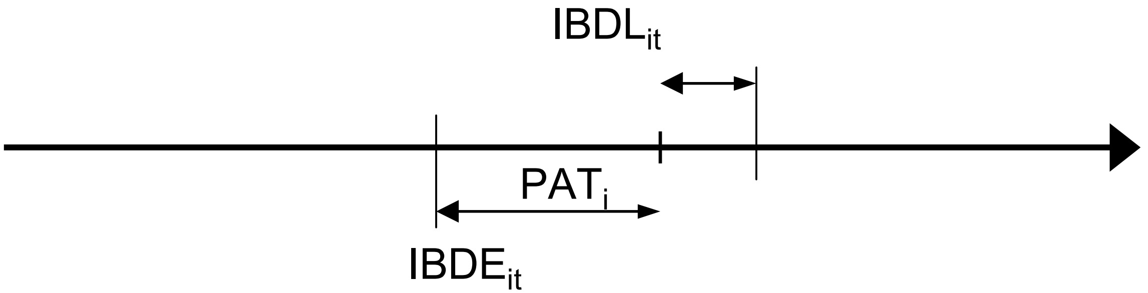
- Experiment 1: 100 subjects
  - Single route corridor → departure time only;
  - Feedback: individual perf. only (limited info)
- Experiment 2: 100 subjects
  - Same as 1; feedback on overall system performance (full info)
- Experiment 3: 200 subjects
  - Two routes: not identical
  - Two information availability groups: *full* vs. *limited*
  - More congestion



Comparison of Average Performance of the Two Information Availability Groups at the Final State (average over last four days) in Each Sector in the Third Experiment.

It was also noted that FULL INFO group in Experiment 3 was switching less (on average) than LIMITED INFO group..

Behavioral Mechanism



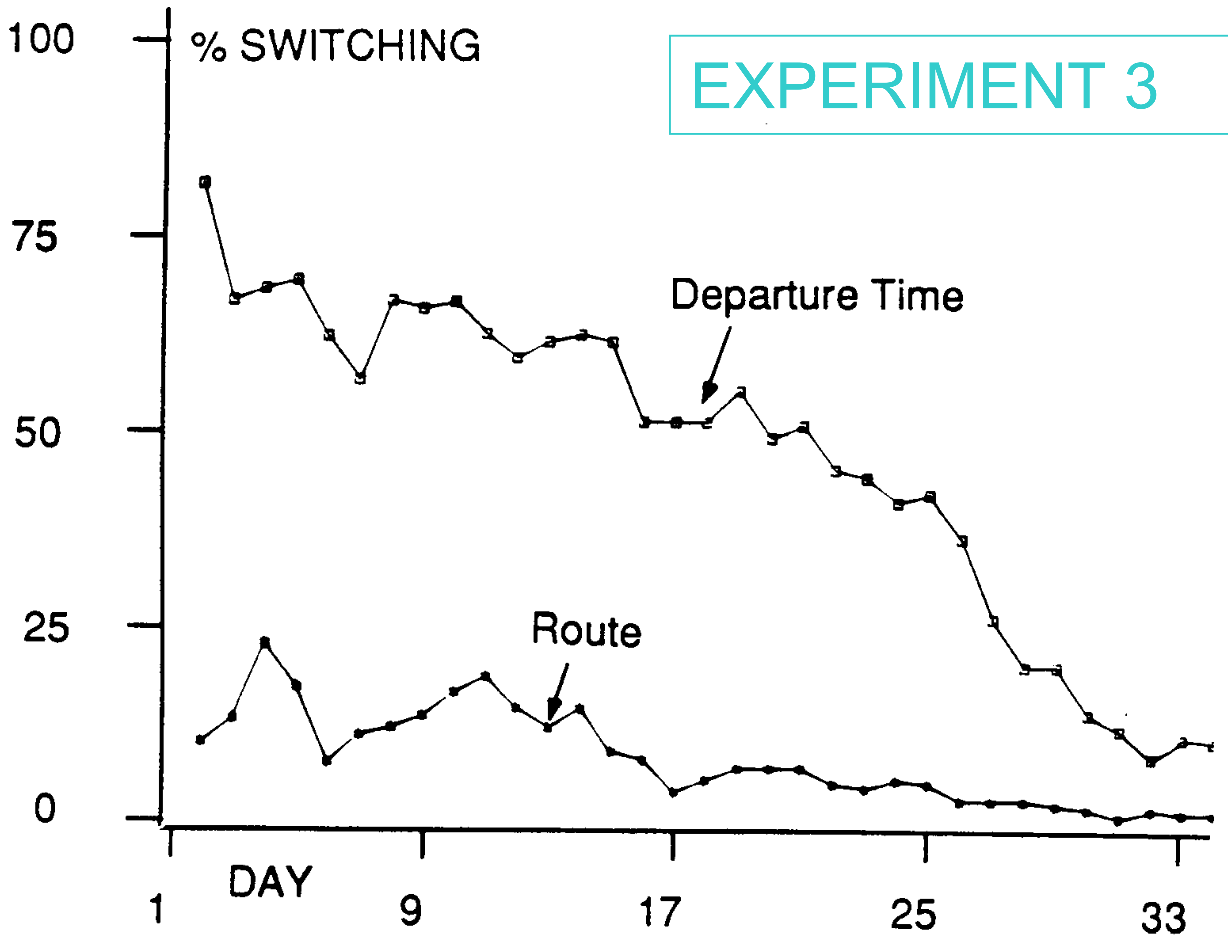
Day-to-day Switching of Departure Time

Boundedly-rational search for acceptable arrival time

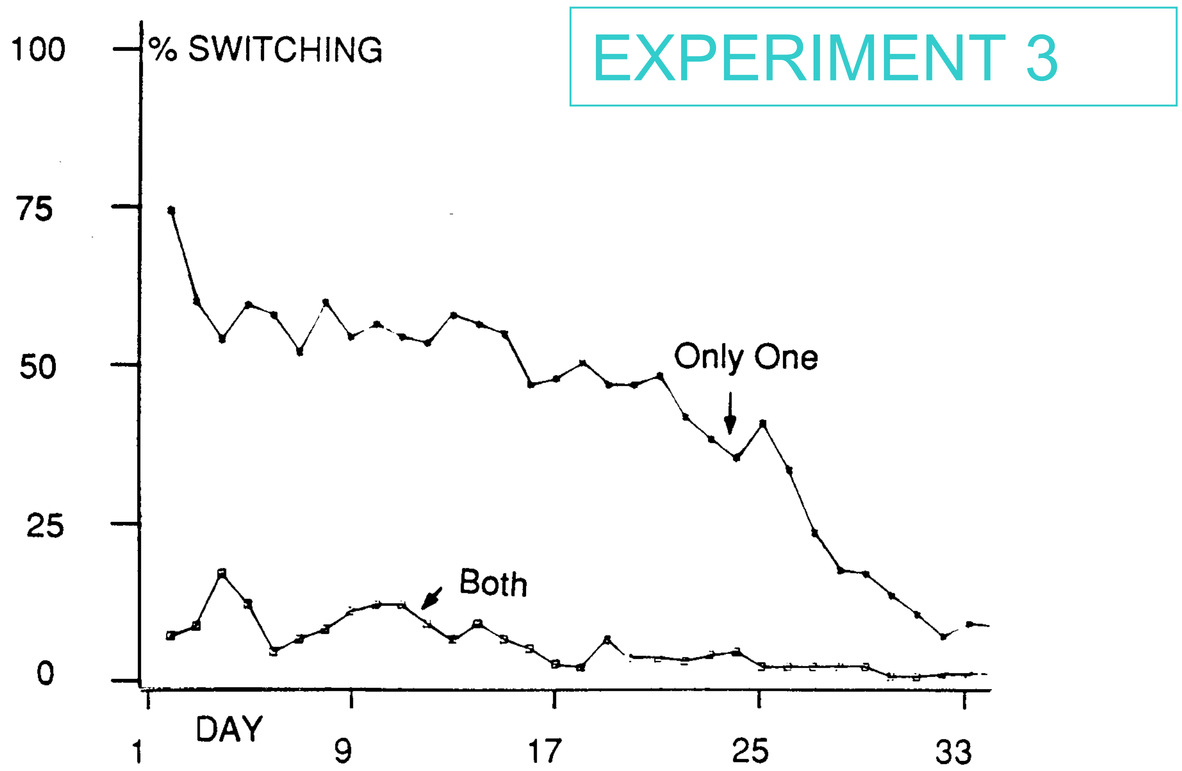
Indifference Band for Schedule Delay (viz PAT)

- Asymmetric: early vs. late
- Varies across users (socio-demographics)
- Dynamically varying
  - - with experience: short-term vs. long term
  - - with information availability

EXPERIMENT 3



Day-to-day Evolution of Percent of Users Switching Departure Time and Percent Switching Route



Day-to-day Evolution of Percent of Users Switching Both Route and Departure Time and Percent Switching Only One

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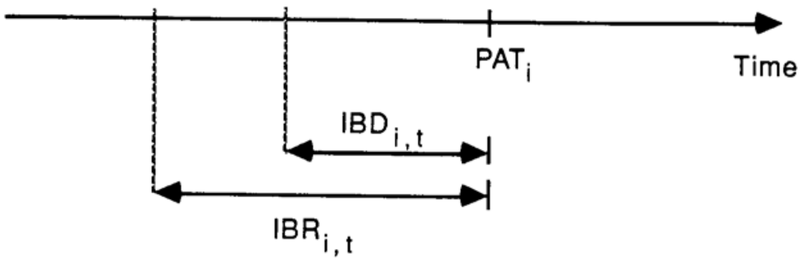

If $SD_{i,t} \leq IBD_{i,t}$ $\Rightarrow$ Keep both $DT_{i,t}$ and $R_{i,t}$

If $IBD_{i,t} < SD_{i,t} \leq IBR_{i,t}$ $\Rightarrow$ Switch $DT_{i,t}$ only

If $SD_{i,t} > IBR_{i,t}$ $\Rightarrow$ Switch both $DT_{i,t}$ and $R_{i,t}$

Note: $SD_{i,t}$ is the schedule delay of user i on day t.

Relation Between Indifference Bands of Departure Time and for Route Switching for Early Arrivals.

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ROLE OF EXPERIMENTS

- **Develop insights into behavioral processes**
- **Develop model specifications**
- **Learn about**
  - Direction (sign) of effects of different attributes
  - Significance of main effects and interactions
  - Relative magnitudes

CONCERN

- **External validity**
  - Previous experience suggests very good potential to transfer *insights*, *specification* and *relative magnitudes* to real world
  - However, actual *parameter values* may vary (site specific)

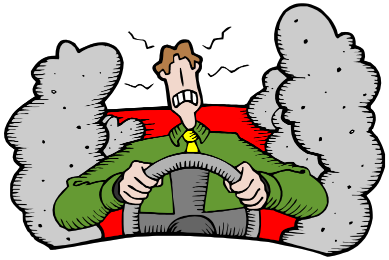
Role of operational tests, in tandem with laboratory experiments, to develop more definitive basis of behavioral knowledge to support ATIS design and deployment.

return

MOTIVATION

Importance of modeling and understanding tripmaker behavior under real-time information

- ATIS design, deployment and evaluation
- ITS impacts assessment (e.g. congestion alleviation)
- Demand modeling and forecasting applications
- Critical for network performance analysis and state prediction



•THE ATIS SIMULATOR EXPERIMENTS:

Mahmassani, P. Chen, Srinivasan, Liu, Kraan

Role and effect of real-time information on individual decision processes and system dynamics

1995-2001

Objectives

- Propose a methodology to model behavior under real-time information
- Develop a framework to observe/measure trip-maker behavior dynamics
- Investigate structural effects in trip-maker behavior
  - dynamics
  - heterogeneity
- Analyze choice dimensions: route & departure time switching, compliance
  - role of ATIS information quality, strategies
  - effect of network supply conditions
- Examine decision processes underlying observed behavior

OVERVIEW OF RESEARCH METHODOLOGY

Observational Framework

- Dynamic interactive multi-user travel behavior simulator

Empirical Analysis

- Perform quasi-experimental design to investigate factors of interest
- Conduct large scale experiments with actual commuters
- Build mathematical models of observed choices

Modeling Framework

- Dynamic Kernel Logit (DKL) formulation / MNP formulation
- Calibration by iterative Monte-Carlo simulation and non-linear optimization

return

ROUTE CHOICE (SELECTION) BEHAVIOR MECHANISMS

Inertia vs. Compliance Effects

- **Inertial Effect: Propensity to chose current path (CP)**
  - Represents resistance to switching
  - Rationale: lower cognitive, information search and processing costs, switching costs, habit persistence, familiarity
  - Reflected in utility of current path

- **Compliance: tendency to follow the 'best path' (BP)**
  - Rationale: efficient alternatives, trip-time savings, congestion avoidance, schedule delay consideration
  - Reflected in utility of best path

return

COGNITIVE DECISION PROCESSES
UNDERLYING COMMUTER BEHAVIOR DYNAMICS

- **Learning**
  - discriminative and trial and error learning
  - role of memory
  - attentional factors
- **Perception and attitudinal factors**
  - margin (12%) added to accommodate uncertainty
  - attitudes towards trip time savings and congestion affect choice
- **Judgment of information quality**
  - predicted - highest, random - lowest
- **Updating perceptions**
  - reported information weighted more than past perception in random treatment
  - weights: 2/3 (sequential case) to 8/9 (random evolution)

return

DYNAMIC EQUILIBRIUM MODELS

- *The notion of a static equilibrium of flow in a network may be thought somewhat limited because of the noted periodicity of traffic during the day, week, year and perhaps the business cycle. While the equilibrium mechanism is operative during the relatively short periods of constant load,* ***one would like to see a more comprehensive model which contributes to our understanding of the time pattern itself.***

- *The generation and the economics of traffic peaks are subjects for further inquiry.*

- *While it is not difficult, by attaching time subscripts to the flow variables, to write down formally the equilibrium conditions of Chapter 4 for a dynamic model, this merely makes the analysis more complicated without explaining much that is new.* ***An understanding of the dynamic aspects of traffic really depends on an understanding of demand substitution over time.***

from page 107, section 5.4 Dynamic Equilibrium Models (in Chapter 5: Some Unsolved Problems)

DYNAMIC EQUILIBRIUM MODELS

- Two main categories of contributions (with many variants) in this area:

  1. The generation and the economics of traffic peaks: Dynamic User Equilibrium (DUE) models, which incorporate trip timing in addition to route choice decisions in response to congestion

  2. Assignment of time-dependent demand to a traffic network (where flows and travel time are allowed to vary)– DYNAMIC TRAFFIC ASSIGNMENT

DYNAMIC EQUILIBRIUM MODELS

1. *The generation and the economics of traffic peaks:*

Dynamic User Equilibrium (DUE) models, which incorporate trip timing in addition to route choice decisions in response to congestion

Extends Wardrop conditions to where no user can improve utility by unilaterally changing route or departure time

Seminal contribution by Vickrey (1969), though not initially recognized;very large body of work on "the bottleneck problem", e.g. Hendrickson and Kocur (1981); Fargier (1983); Mahmassani and Herman (1984); dePalma et al. (1983--); Newell (1987); Arnott, Lyndsey (several); many more…

Several natural extensions consider congestion pricing.

Is there anything left to learn from the bottleneck model?

DYNAMIC TRAFFIC ASSIGNMENT PROBLEMS

Model evolution of traffic flows in a given network, given time-varying trip desires (within-day), under various traffic management strategies (including real-time information to users).

- Strategic and operational planning
- Evaluation
- Prediction
- Real-time operation
- Route guidance/information supply

Dynamic Traffic Assignment

- **Seminal contribution: Merchant & Nemhauser (‘76)**
  - Formulated key elements of the problem
  - Provided starting point for identifying limitations and challenges

Main Limitations:

- Traffic Model Complexity ("flow propagation")
- Single Destination
- System Optimum (SO)

- Limited progress/no major breakthroughs in solving fundamental difficulties in analytical formulations of the problem that would lead to solution algorithms for realistic networks

Some contributions to Dynamic Traffic Assignment Theory and Analytic Formulations:

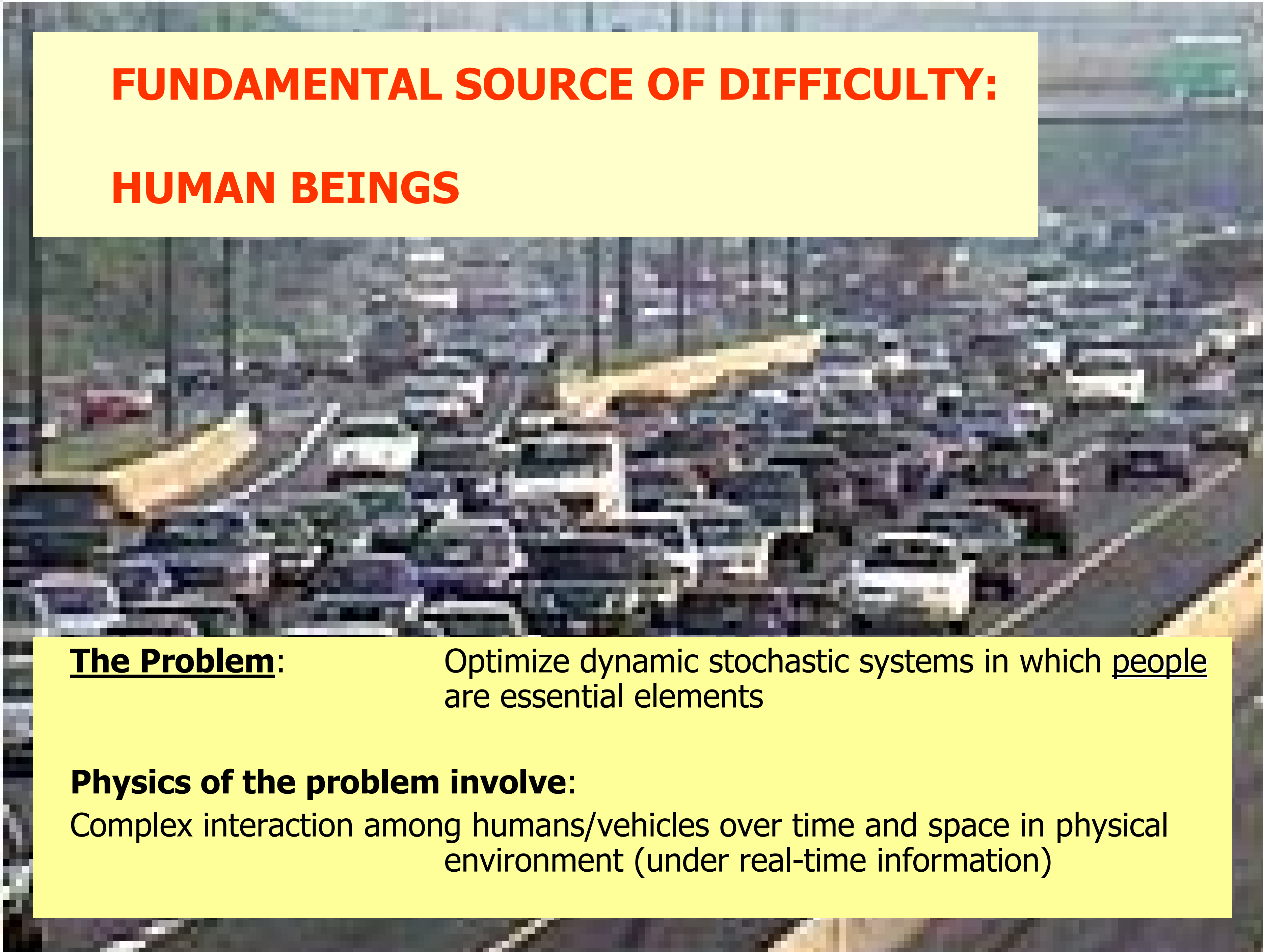
- M. J. Smith, Smith & Ghali
- Friesz, Bernstein, Tobin, Wie
- Carey
- Ran (& Shimazaki, & Boyce)
- Cascetta and Cantarella
- Heydecker
- Wu & Florian
- Barcelo

And the list is growing…

DID THEY MISS ANYTHING??

- *While it is not difficult, by attaching time subscripts to the flow variables, to write down formally the equilibrium conditions of Chapter 4 for a dynamic model….*

It turns out the equations governing flow propagation in actual networks do not lend themselves readily to analytical treatment (and still result in well-behaved models…).



FUNDAMENTAL SOURCE OF DIFFICULTY:

HUMAN BEINGS

<u>The Problem</u>: Optimize dynamic stochastic systems in which <u>people</u> are essential elements

Physics of the problem involve:
Complex interaction among humans/vehicles over time and space in physical environment (under real-time information)

Still major limitations in traffic modeling (flow propagation) for DTA models:

- Mostly approximate algorithms for general road networks based on analytical theoretical formulations

- Key obstacles:
  - Junctions, especially signalized
  - FIFO (not only for links taken individually)

- Theoretical developments have generally established/confirmed the difficulty of the problem rather than solved them.

Major role for simulation-based network procedures for dynamic traffic assignment and dynamic network equilibrium modeling for both offline (planning) and online (traffic management) applications

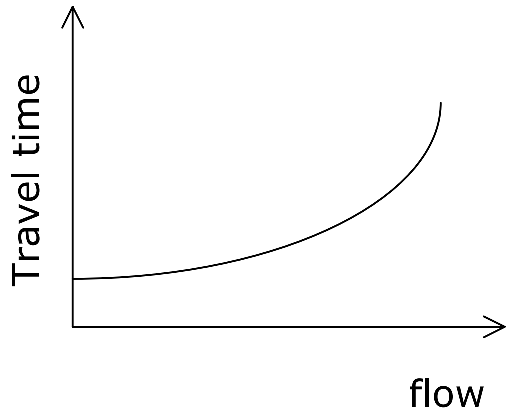
DYNASMART-P

Intelligent Transportation Network Planning Tool

DYNASMART-X

REAL TIME DYNAMIC TRAFFIC ASSIGNMENT SYSTEM

DID THEY MISS ANYTHING??

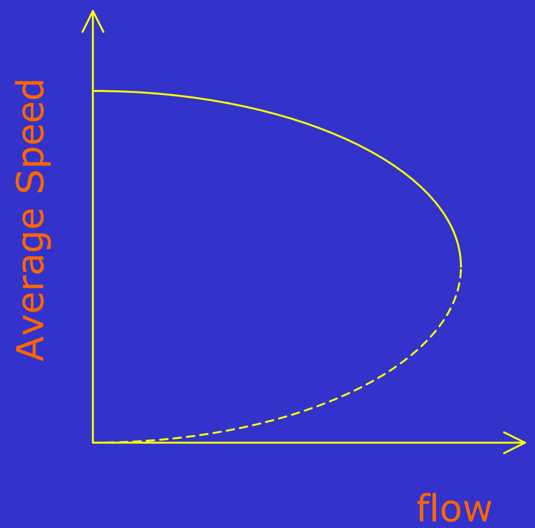


LINK PERFORMANCE FUNCTIONS (volume-delay curves)

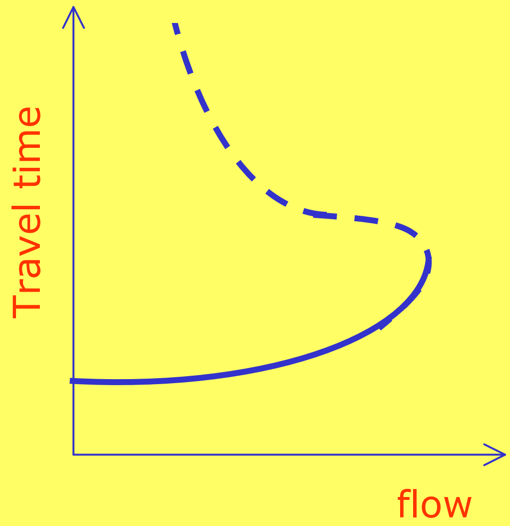
- Representation of traffic flow processes on roadway facilities (incl. junctions)
- Bone of contention between economists and traffic scientists
- Limited appreciation in both camps of interpretation

DID THEY MISS ANYTHING??

Traffic Science
(fundamental diagram)



Backward-bending curve



DID THEY MISS ANYTHING??

Importance of appropriate length of observation interval over which the averages are taken in specifying and calibrating link performance functions: over sufficiently long intervals, backward-bending portion of the curve (mostly transient and highly unstable operating points) is averaged away.

Importance of appropriate definition of time scales over which equilibrium models are applied; equilibrium models not suitable for traffic operations applications over short horizons.

WHERE TO NOW?

- *Beckmann, McGuire and Winsten's study laid the intellectual and economic-science foundation for transportation systems analysis, planning and evaluation for the rest of the 20th century, and beyond*
- *The ideas and concepts are fundamental in nature, and unlikely to change in the foreseeable future*
- *While considerable progress has been made on many of the problems insightfully identified in that seminal work, many remain active areas of investigation; only recently have observational methods become practical to provide empirical support for the theories and methods addressed in that work*
- *The main areas where potentially significant departures from the principles and methods of that text lie in the contribution of technology to our ability to manage traffic systems, and, more fundamentally, in the kinds of socio-technical changes that pervasive availability of real-time information and ubiquitous access to the internet (e.g. 3G wireless broadband)*
- *Equilibrium provides convenient reference point for comparative evaluation of contemplated future alternatives. What do we make of day-to-day evolution, disequilibrium, etc…? Will political decision processes in Transportation sector be able to profitably exploit improved understanding of system dynamics for better planning? Will new insights in day-to-day user behavior be leveraged to design more effective policies to improve system performance?*
- ***Have we left the next generation a contribution that is as far-reaching and insightful as what Beckmann, McGuire and Winsten have given us?***