

Beyond Beckmann, McGuire and Winsten's *Studies in the Economics of Transportation*

Hani Mahmassani

Maryland Transportation Initiative
University of Maryland

*50th Annual North American Meeting of the
Regional Science Association International
Philadelphia, November 2003*



OUTLINE

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

STABILITY and USER ADJUSTMENT PROCESSES

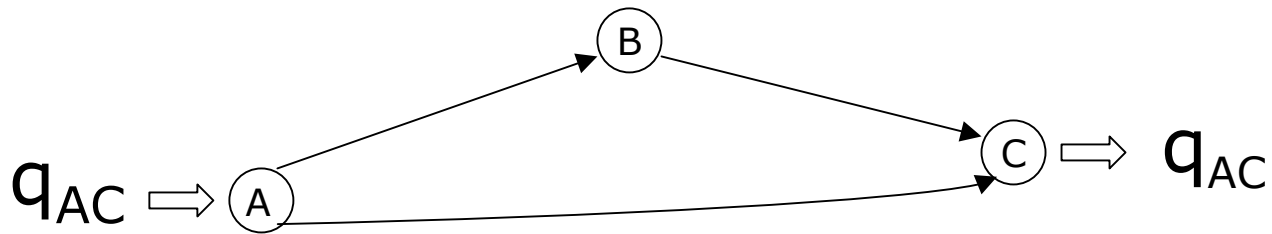
- *An equilibrium would be just an extreme state of rare occurrence if it were not stable– that is, if there were no forces which tended to restore equilibrium as soon as small deviations from it occurred.*
- *Besides this stability “in the small” one may consider stability “in the large”– that is, the 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

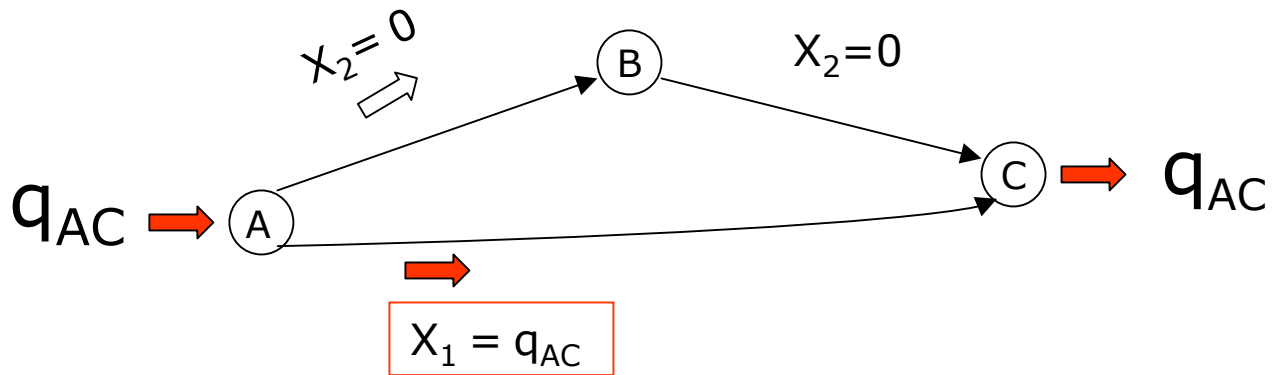


Consider simple network; known link performance functions;

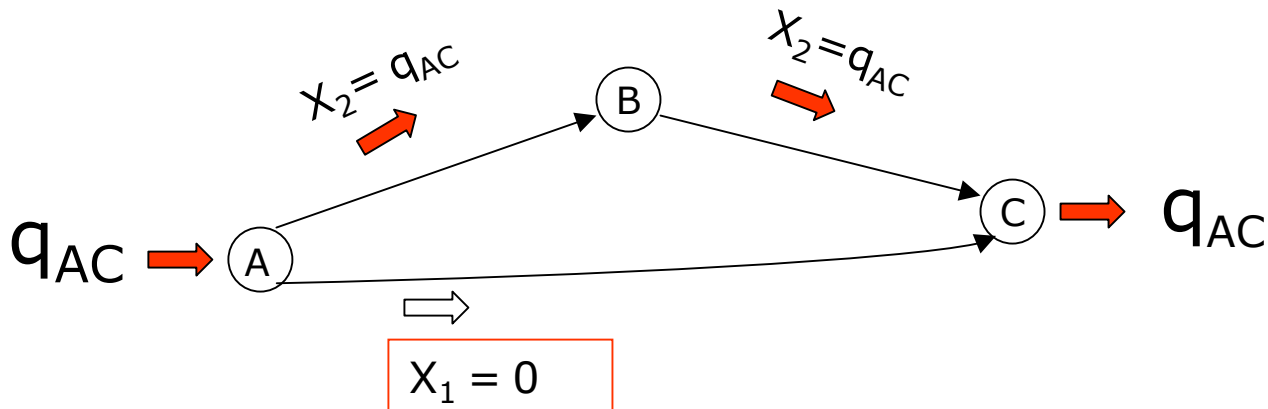
One O-D pair, connected by two paths

Known constant demand rate q_{AC}

Day 1



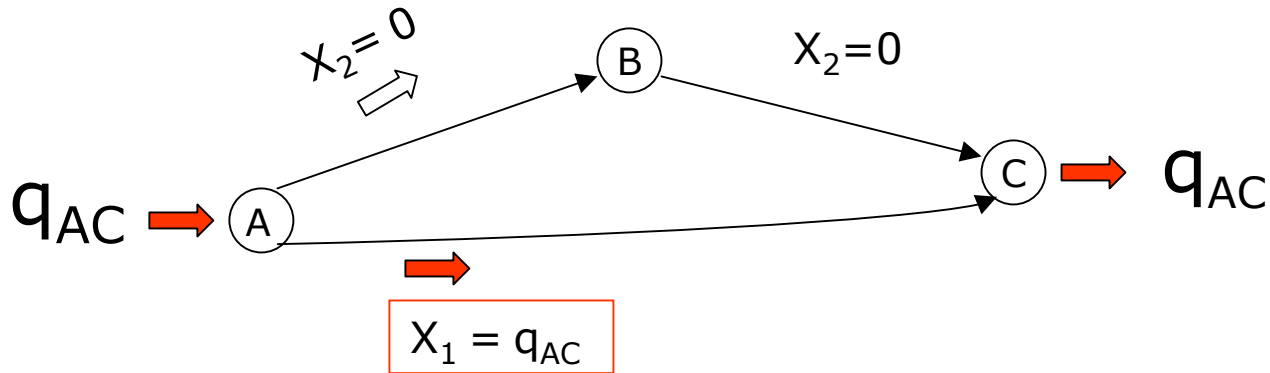
Day 2



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

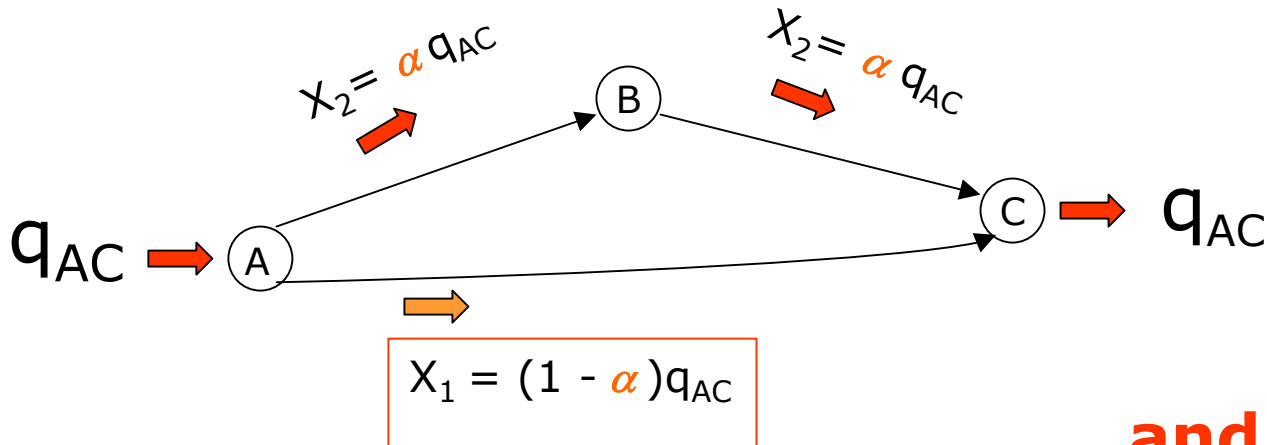
➡ **OSCILLATIONS...**

Day 1



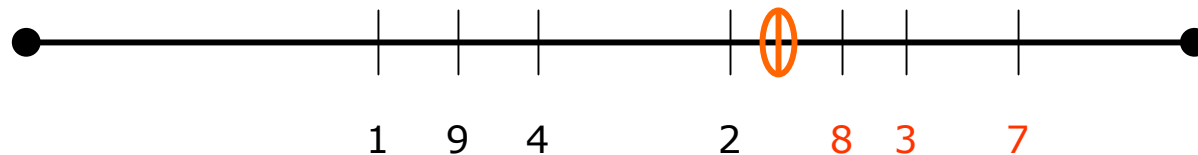
Day 2

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



and so on...

Using $\alpha = 1/5$



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.

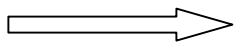
BMW discuss intuitively how equilibrium might be approached, with α decreasing as difference in route costs narrows; adaptive behavior.

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)...



Many important results and properties, valuable insight

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...)

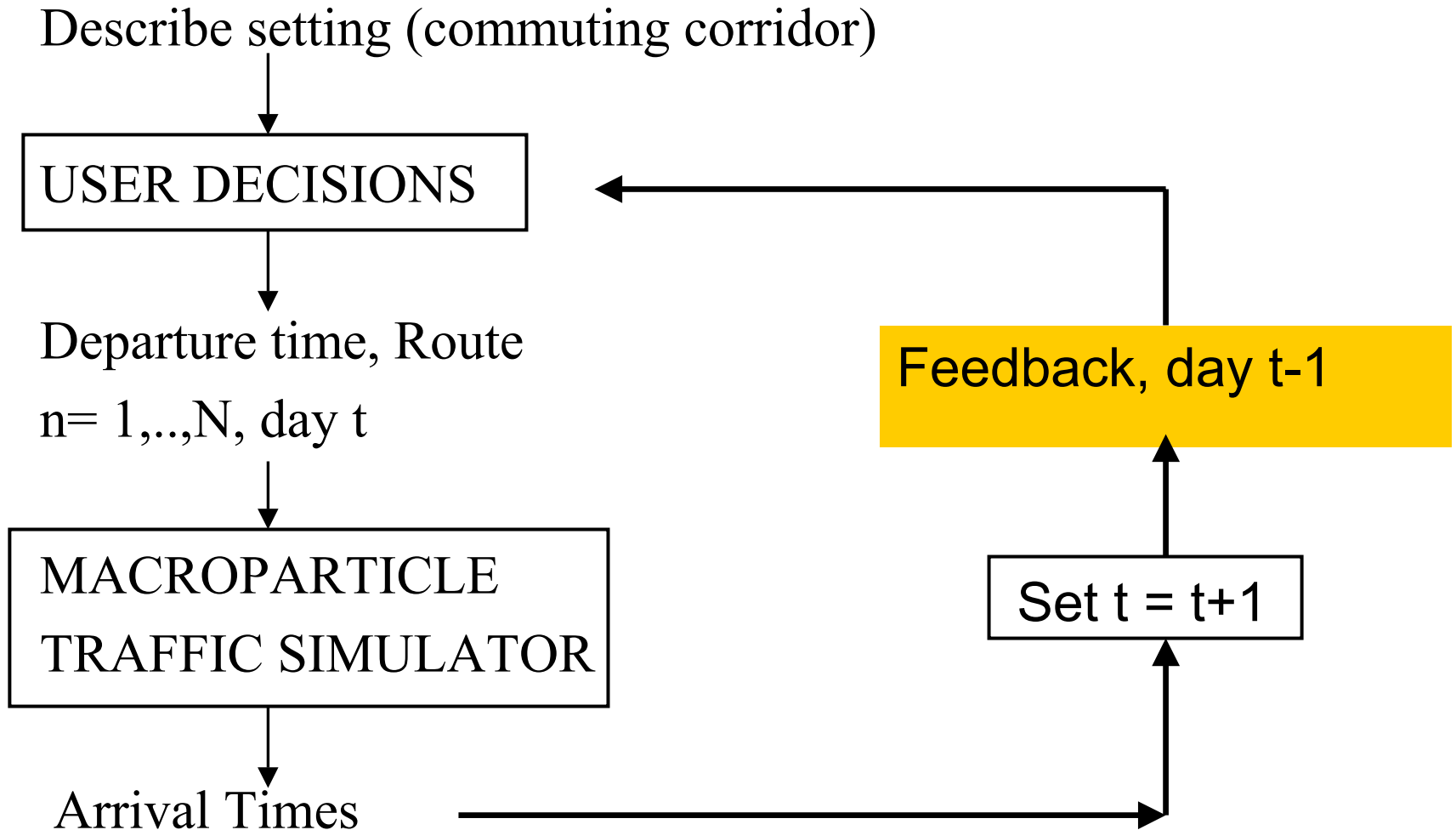
THE EARLY EXPERIMENTS:

Mahmassani, Herman, Chang, Tong,
Stephan, Jayakrishnan...

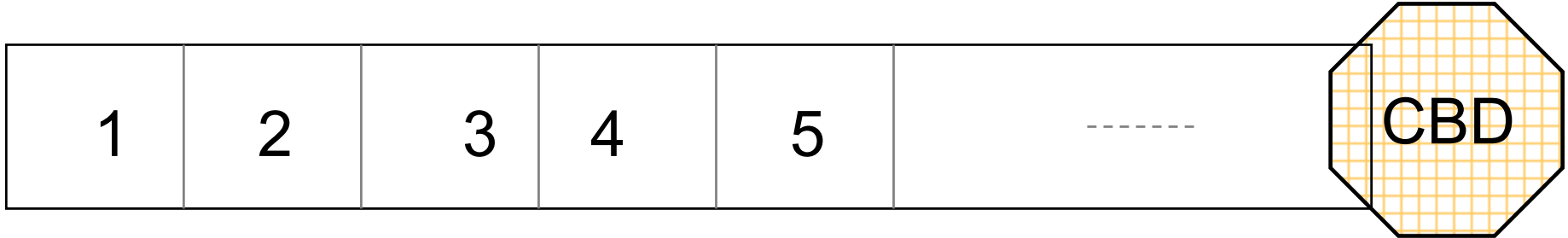
Interaction of user decisions and
traffic system dynamics

1984-1989

GENERAL EXPERIMENTAL PROCEDURE



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

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...

CONGESTION PRICING

- *There is, however, one particular aspect of this freedom of choice which does the totality of road users more harm than good: the choice of route—once a trip is decided on—is quite naturally made so as to minimize cost...to the individual driver..., without reference to delays caused to other users ...as a result of his choice.*

(from the Introduction, page xiv.)

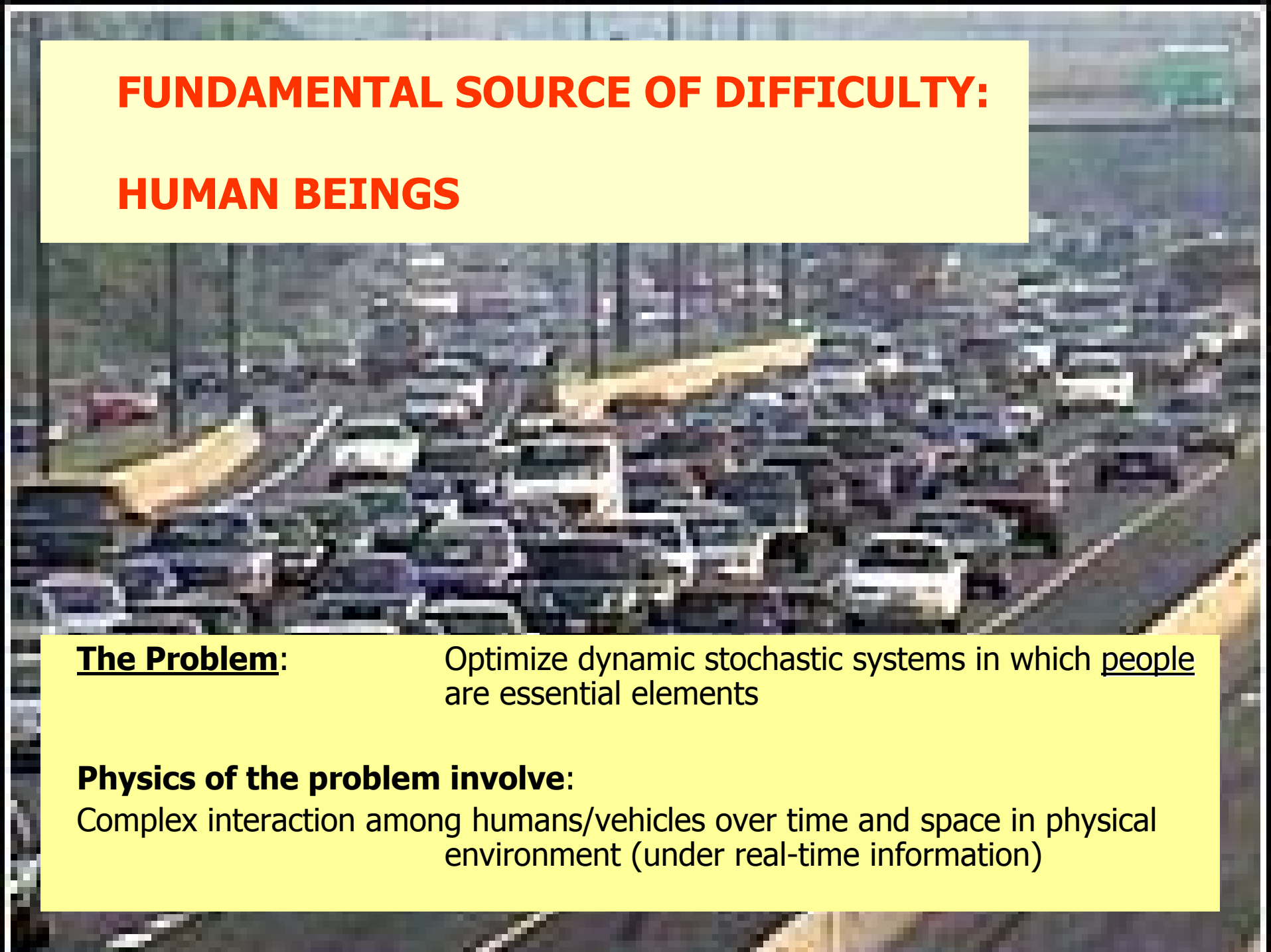
- *If there were a way to collect tolls from the users of congested roads at rates that would measure the cost to others caused by the average road user, a better use of the highway system would be obtained.*
- *Chapter 4 analyzes **as a hypothetical proposition** how such "efficiency toll rates" could be determined.*

(from the Introduction, page xv.)

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

The Problem:

Optimize dynamic stochastic systems in which people 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.

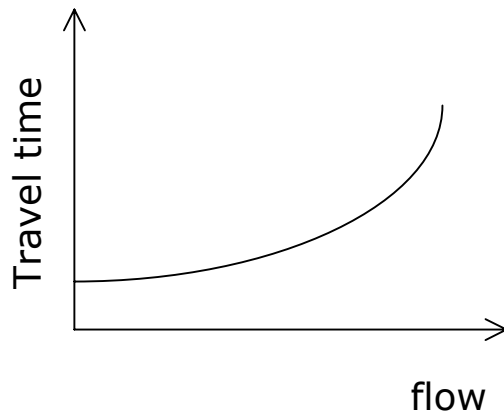
Major role for simulation-based network procedures for dynamic traffic assignment and dynamic network equilibrium modeling for both offline (planning) and online (traffic management) applications



DYNASmart-X

REAL TIME DYNAMIC TRAFFIC ASSIGNMENT SYSTEM

DID THEY MISS ANYTHING??

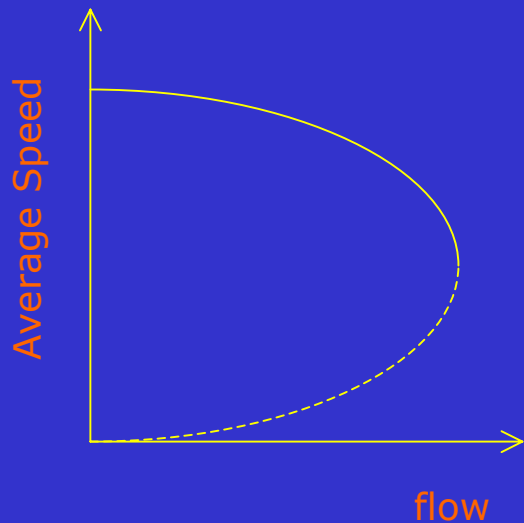


LINK PERFORMANCE FUNCTIONS (volume-delay curves)

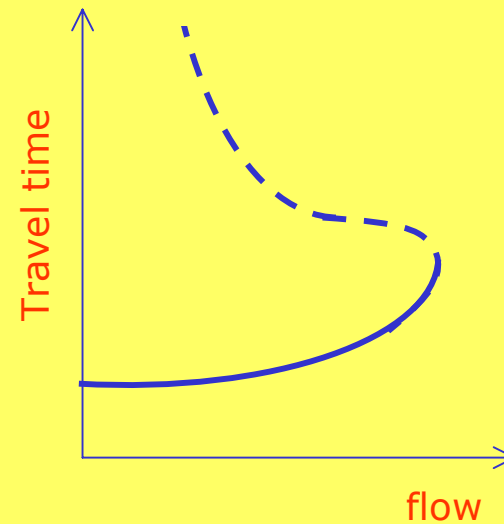
- Representation of traffic flow processes on roadway facilities (incl. junctions)
- Bone of contention between economists and traffic scientists
- Limited appreciation in both camps of interpretation

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.

A touch of scholarly class...

In describing the network used in a numerical example (p. 73):

- *The parameters were chosen arbitrarily and any resemblance to an actual road network is accidental*

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)*
- ***Have we left the next generation a contribution that is as far-reaching and insightful as what Beckmann, McGuire and Winsten have given us?***

WHERE TO NOW?



With Robert Herman at the Award Ceremony

- ***Have we left the next generation a contribution that is as far-reaching and insightful as what Beckmann, McGuire and Winsten have given us?***