Perpetual Virtual Motion: Transportation Systems Research for the Age of Wireless Telecommunications

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CHALLENGES IN TRANSPORTATION - TELECOMMUNICATION INTERACTIONS

- Effect of telecoms and information on travel behavior and the demand for transportation

- Application of information and telecommunication technologies to improve the operational performance of transportation systems and facilities: ITS

- Information as policy tool to influence traveler behavior in the short run as well as over time
Intelligent Transportation Systems
Telematics

• Convergence of location, telecommunication and automotive technologies for better transportation system safety, efficiency, and user convenience

• Envisioned mobility as tied to the vehicle, and the vehicle as extension of home and office

• Delivery of services via transponders, using some air interface technology; receivers “built in” vehicles; largely left design of telecom infrastructure out of the picture

• Two-way communication also allows system-level operational efficiencies of the transport system
Capacity Explosion

• Moore’s Law: Semiconductor performance
  (2 x MHz every 18 mos.)

• Optical bandwidth: Wavelength division multiplexing
  2 x capacity (megabits per sec.) delivered at given
  price every 9 mos.

Optical equipment has driven down price of moving a
bit of information over long distances to 0.006% of
what it was in 1996. “If BMW could do that, you could
buy a new BMW for $2.50” (D. Huber, CEO, Corvis)
Operators Have Choices:
Voice vs. Data Comparison™
(10MHz)

2 WCDMA (5 MHz) Carriers
or
7 1x (1.25 MHz) Carriers

Assumptions
1. No Tx Diversity
2. Environment and Channel Model™
Macrocellular with
50% ITU Pedestrian (A)
50% ITU Vehicular (A)

* Theoretical channel models used for comparison purposes only
+ channel model, as per assumptions, may not be applicable
# average values for erlang and data throughput from sources 2, 3 and 4 are used
Society demands and expects, and service providers are delivering

**Online All-the-time Broadband Access**
- at fixed locations/wireline
- mobile wireless (3G)

➤ **TELEMOBILITY**: VIRTUAL MOBILITY, relaxes temporal and spatial constraints on activity participation and social/economic transactions
Wireless Paradigm Shifts
(C. Levine, Sprint PCS, 2001)

• From *luxury* to *necessity*

• From *person to person* to *anywhere access to information*
Implications of pervasive wireless mobility (Third Generation telecom services):

- **Location-specific services**, delivered at place of query, including navigation, ATIS, marketing, ...

- **Location-independence** of activity patterns, as work, entertainment, virtual communities constantly accessible remotely
End Users Benefit More... as Data Rates Increase
Wireless providing value-addition & differentiation for ANY product
TRANSPORTATION: PHYSICAL MOBILITY OVER SPACE

• Limited growth in capacity, and in output (compared to information –voice and data--traffic)

• Social expectations and public policy: *diminished expectations* of curtailed access, limited over time and space

• Subject to considerable inefficiencies, high congestion, arbitrary rules for allocation and use of capacity
INFORMATION AND TELECOMMUNICATION TECHNOLOGY (ICT)

• Permeating the world of Transportation Systems through:
  
  – Adoption as tool for better system management (ATMS, Fleet Management…)
  
  – Ubiquitous availability of mobile information devices to users
ITS and Telematic Capabilities through Communication in the Highway Environment

Infrastructure $\leftrightarrow$ vehicle
- Automated highways, safety warnings, navigation

System Operator $\leftrightarrow$ vehicle
- Traffic management, fleet operation

Third party $\leftrightarrow$ vehicle: ATIS

Vehicle $\leftrightarrow$ vehicle: Automated highways, ????
• Detectors, sensors of traffic activity
  ➔ State measurement

• Transaction logs: AVI, EDI

• Convergence of voice and data, location (GPS) and wireless telecom devices (CDMA, GSM): handsets and PDA’s as probes or diaries

• Internet transaction records: activity participation, e- and m-commerce

  ➔ Explosion of real-time information on system state
Wireless telecommunication provides an *acceleration* in the rate, ubiquity, location-specificity, nature and quality of real-time information on individual particles system state
### CONVENTIONAL WORLD

- Steady - state
- **Equilibrium**
- Static
- **Data poor**
- Uncertainty about past/current events
- **Component level**
- Long lead time between solution and implementation
- **Limited “accountability” of decisions**
- “A priori” solutions

### ITS ENVIRONMENT

- Time varying
- **Evolutionary paths**
- Dynamic
- **Data rich**
- Known past/current events (to varying degrees)
- **System level**
- Immediate action
- **Performance monitoring and feedback**
- Real-time adaptive strategies
FUNDAMENTAL OR CHALLENGES IN ITS

• Methodologies for Real-Time Decision Making Under Real-Time Information

  – Involves the following:
    • Information gathering
    • Information processing
    • Pattern recognition
    • Control Actions
    • Surveillance and feedback
FUNDAMENTAL OR CHALLENGES IN ITS

– Characteristics
  • Data rich environment
    => information overload?
  • Multiple information sources
  • Greater need for efficient context extraction
  • Uncertainty about future events
  • Opportunity for corrective action
Real-Time Info for Operational Decisions

Predictive Approaches:
Optimize for forecast demands

Real-time data → basis for prediction over next horizon
Real-Time Info for Operational Decisions

Reactive Approaches:
Optimize for realized, known demands
Real-Time Info for Operational Decisions

HYBRID APPROACHES:

- Optimize for Predicted Conditions
- React to deviations from forecast conditions

\[ \rightarrow \text{requires logic} \]

for checking, identifying deviations triggering action: plan modification, rapid response, etc…

APPLICATIONS:
Traffic network management – route guidance, traffic control
Real-time fleet operations – truck dispatching, load acceptance and assignment
REAL-TIME INFORMATION

OPERATORS/CONTROLLERS
- SYSTEM MANAGEMENT & CONTROL
- INFO SUPPLY

USERS

BETTER DECISIONS?
UNCOORDINATED DECISIONS, DESCRIPTIVE INFO

COMPOSITE BASED ON THEORETICAL ANALYSIS AND SIMULATION RESULTS

<table>
<thead>
<tr>
<th>Total Travel Time Savings</th>
<th>UNCOORDINATED DECISIONS, DESCRIPTIVE INFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20~40%</td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

% equipped (market penetration)
Some Issues in Real-Time Operational Decisions

1. Value of additional information: wait to know more about future loads, vs. act now with known demands
2. Value of prediction, and how to incorporate uncertain future conditions in objective function
3. Greedy (myopic, local) decisions vs. global solution quality under uncertain future demands
4. Robustness of current decisions vis-à-vis forecast errors
5. How good should current solution be for future forecast demands when recourse is available?
Issues in Real-Time Operational Decisions (ctd.)

6. Trade-off between effort to obtain optimal solution for uncertain predicted demands vs. more frequent updates
7. Decision to reject known demand to reserve capacity for higher-revenue future demand (yield management)
9. How important is user compliance?
Real-Time Data for Planning Decisions??

- Current Process

1973: Clean data
1987: Model dvpmt.
2010: Model application
Turning Real-Time Data into Historical Data to Support Strategic Decisions

ITS Data → Data Warehousing → Data Aging → Data Retrieval → Data Fusion → Data Mining → KNOWLEDGE EXTRACTION
How Useful is ITS Data for Planning?

• Combine ITS Data on system state with other sources, e.g.
  – Transaction logs
  – Passive and active activity diaries from location-telecom devices

→ New approaches to behavioral model development
→ Hybrid tools, integrating disciplines combining statistics/econometrics, with AI approaches
Challenges in Travel Behavior Research

• New classes of problems/decision situations, motivated by rapid penetration of telecommunications technologies:
  – Adoption of various information devices and services
  – Use of Internet (fixed and mobile)-based services for various activity purposes
  – Traveler responses to real-time information from multiple sources: short, medium and long-term effects
  – Opportunities lie in examining telecommunications and tripmaking jointly in an activity participation framework
Challenges in Travel Behavior Research

- Human factors questions pertaining to
  - Driver performance (attention, reaction times, etc..) while using wireless telecom devices on-board
  - Driver information processing
  - Driver performance in quasi-automated environment
  - User compliance under multiple information sources

- Data
  - novel survey approaches (technology-driven): Internet-based, electronic diaries, GPS
  - laboratory experiments now well established and accepted; extend to live tests via wireless telecoms
  - rich data sources from Internet and ITS (incl. Real-time data from various sources)
In Closing…..

• Natural complementarity between transportation and telecommunication systems; both complex dynamic spatial systems that involve non-linear interactions among human beings and advanced technologies in a network setting to deliver services that meet critical human needs

• Only the underlying physics are different, but system design and operational issues very similar

• Wireless telecommunication complements and enhances physical mobility
  ➔ Telemobility, or relaxation of space and time constraints in activity participation
  ➔ Convergence between telemobility and physical mobility
In Closing…..

- Wireless communication potential to become an integral element of transportation system operation, both as source of system state information (as input to management support tools) and delivery medium of expanded realm of control actions (including information)
- Opportunities for development of transportation-related content for 3G services (navigation and route guidance, infotainment)
- Research on
  - Design of wide array of products and services for the public and private transportation markets
  - Design for online methodologies for system optimization and user-level optimization
  - Design of analysis tools to evaluate performance of complex transport systems under different telecommunication capabilities and informational strategies
  - User behavior and human factors