Transportation: Computing Opportunities & Challenges

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Spatial Databases: Representative Projects

- Parallelize Range Queries
- Evacuation Route Planning
  Sustainable Transportation for Disasters
  - Reception Center located at OSSEO JUNIOR HIGH SCHOOL 10223 93rd Avenue North Osseo, Minnesota
  - Orange: only in old plan
  - Green: Only in new plan
  - Blue: In both plans

- Shortest Paths
- Storing graphs in disk blocks
Spatial Data Mining: Representative Projects

**Location prediction: nesting sites**
- Nest locations
- Distance to open water
- Vegetation durability
- Water depth

**Spatial outliers: sensor (#9) on I-35**
- Average Traffic Volume (Time v.s. Station)

**Co-location Patterns**

**Tele connections**

- Apr
- El-Nino
- R: higher than normal
- D: lower than normal

- W: higher than normal
- R: lower than normal
Outline

• My Background: Spatial Computing
• Transportation Science
• Transportation & Energy Independence
• Eco-Routing
• Summary
Transportation Questions

• Traveler, Commuter
  – What will be the travel time on a route?
  – Will I make to destination in time for a meeting?
  – Where are the incident and events?

• Transportation Manager
  – How the freeway system performed yesterday?
  – Which locations are worst performers?

• Traffic Engineering
  – Which loop detection are not working properly?
  – Where are the congestion (in time and space)?
  – How congestion start and spread?

• Planner and Researchers
  – What will be travel demand in future?
  – What will be the effect of hybrid cars?
  – What are future bottlenecks? Where should capacity be added?

• Policy
  – What is an appropriate congestion-pricing function?
  – Road user charges: How much more should trucks pay relative to cars?
Theories in Transportation Domain

• Physics
  • Traffic: Fluid flow models (e.g. reduce turbulence), control theory
  • How to reduce icing on pavements?
• Chemistry
  • Environmental impact (e.g. salt, incomplete combustion)
• Biology
  • How to reduce crash-injury severity?
  • Effect of age, sleep deprivation, toxins, …
• Psychology
  • Human factors: design of highway signage, vehicle dashboard
  • Activity and agent based models
• Sociology
  • Household decisions, Homophily and social networks
  • Lack of trust => aggressive driving
• Economics, Game Theory
  • Incentive mechanisms
  • Wardrop equilibrium among commuters
    • Ex. All comparable paths have same travel time!
Limitations of Transportation Theories

- **Multi-disciplinary questions:**
  - Will hybrid cars reduce environmental impact of transportation?
  - Extreme events – evacuation, conventions, …
  - Impact of context – weather, climate, economy, politics, crime, police cars, …

- **Mono-disciplinary questions**
  - Non-equilibrium phenomena, e.g. location, time and path
  - Critical places & moments: Accident hotspots (hot-moments)? Why?
  - Normality & anomalies: e.g. traffic flow discontinuities – location, cause
  - Regional difference: effectiveness of Ramp meters across places & time-periods

- What are the **options** to complement theory based approaches?
Data-Intensive Scientific Discovery

- Classical Approach
  - Travel diaries, NHTS survey (OD matrix), Lab. (mpg rating)
  - Hypothesis driven data collection, Statistical hypothesis testing

- Emerging Data-Intensive Approach
  - Secondary Data: Engine computer, gps, cell-phones, face-book, VGI,
  - Exploratory data analysis for hypothesis generation
  - Ex. Data Mining and Knowledge Discovery
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Transportation: A Major Energy Consumer

- **Energy Consumption**
  - 20 to 30% in transportation
  - $\geq 20,000$ TWh
  - Growing car ownership

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<thead>
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<tbody>
<tr>
<td></td>
<td>TWh</td>
<td>%</td>
<td>TWh</td>
<td>%</td>
</tr>
<tr>
<td>Industry</td>
<td>21,733</td>
<td>27.5%</td>
<td>27,273</td>
<td>27.8%</td>
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<tr>
<td>Transport</td>
<td>22,563</td>
<td>27.5%</td>
<td>26,742</td>
<td>27.3%</td>
</tr>
<tr>
<td>Residential and service</td>
<td>30,555</td>
<td>37.3%</td>
<td>35,319</td>
<td>36.0%</td>
</tr>
<tr>
<td>Non-energy use</td>
<td>7,119</td>
<td>8.7%</td>
<td>8,688</td>
<td>8.9%</td>
</tr>
<tr>
<td>Total*</td>
<td>81,970</td>
<td>100%</td>
<td>98,022</td>
<td>100%</td>
</tr>
</tbody>
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Source: IEA 2010, Total is calculated from the given sectors
Numbers are the end use of energy
Total world energy supply (2008) 143,851 TWh
Transportation Energy Source = Petroleum!

- Transportation energy source
  - Petroleum > 95%
  - Consumption > production
    - Large & growing import
    - From volatile regions

- Concerns
  - Economic
  - National Security

- Approaches
  - Long-term: Alternative fuel
  - Short-term: Reduce waste using big-data!

Source: http://www.ei.lehigh.edu/learners/energy/usenergy6.html
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Source: [http://www.ei.lehigh.edu/learners/energy/usenergy6.html](http://www.ei.lehigh.edu/learners/energy/usenergy6.html)
Big Data: Hope to reduce Fuel Waste

• Trajectories
  – GPS, cell-phone,
  – Automatic tolling transponder
  – Automatic Vehicle Location, …

• Other Datasets
  – Loop-detectors: traffic volume, density, occupancy, …
  – Traffic camera - videos
  – Reports on accidents, traffic law violation
  – Travel diaries and surveys
  – Traffic simulator (e.g. DYNASMART) outputs
  – Other sensors: bridge strain, visibility (in fog), ice, …
  – Yellow Pages, street addresses
Big Data: Trajectories

Growing popularity of smart-phones and in-vehicle navigation devices
These provide new trajectory datasets, which can help reduce gasoline waste!
Big Data: Real-time and Historic Travel-time
Big Data: Opportunity Size

McKinsey Global Institute

The study estimates that the use of personal location data could save consumers worldwide more than \$600 billion annually by 2020. Computers determine users’ whereabouts by tracking their mobile devices, like cellphones. The study cites smartphone location services including Foursquare and Loopt, for locating friends, and ones for finding nearby stores and restaurants.

But the biggest single consumer benefit, the study says, is going to come from time and fuel savings from location-based services — tapping into real-time traffic and weather data — that help drivers avoid congestion and suggest alternative routes. The location tracking, McKinsey says, will work either from drivers’ mobile phones or GPS systems in cars.

The New York Times

New Ways to Exploit Raw Data May Bring Surge of Innovation, a Study Says
Published: May 13, 2011
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Eco-Routing

The New York Times

U.P.S. Embraces High-Tech Delivery Methods (July 12, 2007)
By “The research at U.P.S. is paying off. ……— saving roughly three million gallons of fuel in good part by mapping routes that minimize left turns.”

• Minimize fuel consumption and GPG emission
  – rather than proxies, e.g. distance, travel-time
  – avoid congestion, idling at red-lights, turns and elevation changes, etc.
Eco-Routing Questions

• What are expected fuel saving from use of GPS devices with static roadmaps?
• What is the value-added by historical traffic and congestion information?
• How much additional value is added by real-time traffic information?
• What are the impacts of following on fuel savings and green house emissions?
  – traffic management systems (e.g. traffic light timing policies),
  – vehicles (e.g. weight, engine size, energy-source),
  – driver behavior (e.g. gentle acceleration/braking)
  – environment (e.g. weather)
• What is computational structure of the Eco-Routing problem?

Predictable Future

Unpredictable Future

Stationary ranking of alternate paths

Dijkstra’s, A*….

New Computer Science?
Representations of (Spatio-)temporal Networks

(1) **Snapshot Model** [Guting 04]

Node: $N_i$  
Edge: travel time

(2) **Time Expanded Graph (TEG)** [Ford 65]

- Attributes aggregated over edges and nodes.

(3) **Time Aggregated Graph (TAG)** [Our Approach]

- Attributes aggregated over edges and nodes.
Routing in ST Networks: Scalable Methods

![Diagram](image)

Predictable Future

- Stationary
  - Dijkstra’s, A*….

- Non-stationary
  - Special case (FIFO)
    - TEG: LP, Label-correcting
    - TAG: Transform to Stationary TAG

Unpredictable Future

- General Case

Travel times → arrival times at end node → Min. arrival time series

Non-stationary TAG

Stationary TAG
Revisit Shortest Path Problem

- **New Routing Questions**
  - Best start time to minimize time spend on network
  - Account for delays at signals, rush hour, etc.

- **Time-Variant Flow Network Questions**

<table>
<thead>
<tr>
<th>Static</th>
<th>Time-Variant</th>
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<tbody>
<tr>
<td>Which is the shortest travel time path from downtown Minneapolis to airport?</td>
<td>Which is the shortest travel time path from downtown Minneapolis to airport at different times of a work day?</td>
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<tr>
<td>What is the capacity of Twin-Cities freeway network to evacuate downtown Minneapolis ?</td>
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• New challenges for Transportation
  – Classical approaches are limited
    • Multi-disciplinary problems, e.g., energy independence
  – Computational Simulation & Data-Intensive Scientific Discovery
    • Complements classical approaches: Hypothesis generation

• Transportation is critical for Energy Independence
  – It accounts for 20% to 30% of energy consumption
  – It’s energy source is largely Petroleum
  – Eco-routing may save billions of gallons of fuel each year

• Time to give serious consideration to computational methods!