Information Technology and Intelligent Transportation: A Marriage Made in Heaven

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The Problem

• Safety:
  – 43,000 deaths per year in the USA;
  – 3 million+ accidents;
  – $250+ billion cost to the economy

• Congestion:
  – 2.9 billion gals of fuel wasted per year;
  – $78 billion cost to the economy;
  – 4.2 billion hours extra travel every year

• Environmental:
  – > 50% of hazardous air pollutants in U.S.,
  – up to 90% of the carbon monoxide in urban air
Motorization Growth: Road Vehicle Populations by Region, 1996 and 2020

Source: EIA, International Energy Outlook 1999
Traditional approach to address problem

- construct more highways/roadways
- Greater investment in public “mass” transit.
Information Technology impact on society

• Impact on economy
  – Financial industry
  – Insurance industry
  – Entertainment industry (games)
  – Utilities

• Impact on science and engineering
  – Biology (bioinformatics, human genome project)
  – Environmental science (weather prediction)
  – High energy physics
  – CAD/CAM
  – Operations research
  – Mathematics
IT impact on Transportation

- Car navigation systems, web-routing
IT impact on Transportation

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- Traffic information systems
IT impact on Transportation

• Car navigation systems, web-routing
• Traffic information systems
• Autonomous/assisted driving
  – sponsored by military
  – Successful in areas W/O traffic
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- Fleet management software
Why?

- Distributed/mobile system of unprecedented scale
- Incentive mechanisms / business models
Outline

• Introduction – the problem

• Vehicular Infrastructure Integration (VII) Initiative

• Graduate Program in Computational Transportation Science

• Conductive IT trends
Intelligent Transportation Systems

- Increase transportation system
  - Safety
  - Efficiency
- With the use of
  - electronics and sensors
  - communications
  - information systems
Vehicle Infrastructure Integration (VII): A Federal Initiative

• Vision
  – Information about all roads, all the time
    • To control center
    • To individual vehicles
  – To enable a broad range of safety and mobility services

• Approach: Convene a “VII Coalition”—
  – auto manufacturers,
  – state transportation authorities,
  – USDOT
Application examples

• Safety
  – Vehicle in front has a malfunctioning brake light
  – Vehicle is about to run a red light
  – Patch of ice at milepost 305
  – Vehicle 100 meters ahead has suddenly stopped
Application examples (cont.)

- Improve efficiency/convenience/mobility:
  - What is the average speed a mile ahead of me?
  - Are there any accidents ahead?
  - What parking slots are available around me?
  - Taxi cab: what customers around me need service?
  - Customer: What Taxi cabs are available around me?
  - Cab/ride sharing opportunities
  - During the past year, how many times was bus#5 late by more than 10 minutes at station 20, or at some station
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IGERT Ph.D. program in Computational Transportation Science

- Funded by the National Science Foundation ($3M+)
- Will train about 30 Scientists
  - Will develop novel classes of applications
- Colleges: engineering, business, urban planning
VII +

– Traveler/pedestrian focus
  • What Taxi cabs are available around me? (pedestrian)

– Non real-time issues
  • Query-language: During the past year, how many times was a bus on route #5 late by more than 10 minutes at some station (given gps traces)
  • Visualize accident based on sensors

– Data Management issues (above communication)
  • Parking slots (discovery, auctions)
Sample Research Problems

Platform to develop VII applications

Traffic simulations from perspective of computer science – computational problems, complexity, parallelization

Realistic/practical simulation testbed for purpose of evaluating VII algorithms

Discovery of novel VII applications

Human/social aspects of VII deployment

Integrating methodologies from the 2 fields

Human Computer Interaction – driving simulators
Research Issues in Data Management and Communication

- Data modeling and Uncertainty Management
- Data mining
- Wireless Networking
- Mobile P2P
- Security
Data Modeling

– Basic construct **trajectory**: location = f(time)
– Novel built-in mechanisms for
  • trajectory approximation
  • trajectory matching
  • trajectory aggregation
  • compression of spatial-temporal information
  • aging of spatial-temporal information
  • Location prediction
– Encapsulate in a trajectory data-blade
Uncertainty/imprecision Management

• Innovative approach: Optimize the tradeoff cost/imprecision

• Linguistic approach:
  – retrieve the average speed with 30% confidence
Research Thrusts

• Data Management and communication

• Software tools and services

• Human factors and sociological issues
  – Human-computer interaction (multimodal)
  – Privacy (particularly location information)
  – Socio-economic issues (e.g. air-quality implications of adaptive speed limits)
Prototype
ITA

• Intelligent traveler assistant —
  — on handheld computers

  — networked to
    • Traffic information center
    • Neighboring vehicles

  — plan multi-modal routes for its user
ITA modes

• Multi-modal trip planning
  – Possible optimization criteria: cost, time, predictability

• Trip execution (plan adjustment)
  – taxi/ride-sharing opportunities
Trip execution experiment

• 20 vehicles with ITA’s receiving sensor information in real-time

• demonstrate simple query processing in a mobile environment
Main differences from other transportation centers

• Focus on Computer Science and IT

• Focus on traveler rather than vehicular technology

• Focus on applications above communication layer
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IT trends => Transportation

• Wireless networking
• Mobile computing
  – Fault tolerance, connectivity, longevity
  – Resource management
  – Programming paradigms (randomization)
• Information systems:
  – Spatial-temporal data management
  – Moving object databases
• Sensor networks
• Positioning technologies (GPS, cellular, anchor/less)
• Computer vision
  – Scene understanding (what the operator sees, and doesn’t)
IT trends => Transportation (cont.)

- Context awareness
  - Computer is aware of profile, location, activity, biometric information of user

- GIS

- Human-computer interaction
  - Speech processing
  - Natural language processing
  - Effectiveness (present only information operator does not already know)
  - Multimodal interface

- Security, privacy, trust management
  - Maliciously creating havoc, self serving information
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Wireless networking

- Technologies differ in
  - Bandwidth, range/license, power consumption
- Long range: licensed spectrum
  - Cellular (4G, WiMAX)
- Short range: unlicensed spectrum
  - Wi-fi (100-200meters, up to 54mbps)
  - Bluetooth (2-10meters, 2Mbps)
  - Zigbee (low power, .25Mbps)
  - Ultra-Wide-Band (675Mbps)
Wireless networking architectures

- Infrastructure-based

- Ad hoc networks
  - Mobile ad hoc networks (MANET’s)
  - Vehicular ad hoc networks (VANET’s)

- Mesh networks – involving both, static and mobile nodes
Mobile Ad Hoc Networks

Network nodes are routers – **dynamic topology**

Short-range wireless technologies

Energy considerations

Main investor: dod
Vehicular Ad Hoc Networks

- Vehicles within transmission range can communicate
- Uses variants of 802.11 (Wi-fi)
- Dynamic topology, but constrained to road network
- No energy constraints
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Mobile computing

• Resource constraints on nodes (devices)
  – Power
  – Bandwidth
  – Memory
  – Small screen
  – Small keyboard
Mobile computing models

• Centralized information system
  • User interface
  • Minimizing communication
  • Data broadcasting
  • Disconnection

• Local Information system
  • Small footprint
  • Wireless update of local databases (disconnected operation)
  • Example: Real-time traffic updates of car navigation system

• Mobile P2P information system
  – Computing and data management in MANET/VANET without a central control point.
Centralized/Hierarchical model

Location Area $A$

$A - 1$

1. MSS
2. MSS
3. MSS

Central Database
$a - A$
Mobile P2P network
Technical Problems in Mobile P2P

• Data modeling –
  – lack of a common schema and naming conventions
  – sensor- and human-generated information
  – Semantic-web concepts (e.g. ontologies) become relevant

• Participation incentives for brokers
  – to achieve reasonable coverage

• Dynamic and adaptive use of fixed infrastructure

• Managing Heterogeneity
Mp2p vs. client-server

• Mp2p advantages
  – Zero cost
    • Unregulated communication
    • No central database to maintain
  – Independent of infrastructure
  – Higher reliability
  – Privacy preservation
  – Often higher speed

• Mp2p disadvantages
  – Weaker answer-completeness guarantees
  – Density requirements
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Spatio-temporal data management

Initially database systems managed symbolic information (inventory)

Spatio-temporal databases handle discrete and continuous changes

Moving Objects Databases: continuous change in location
Moving Objects Database Technology

Query/trigger examples:
- Send me message when helicopter in a given geographic area
- Trucks that will reach destination within 20 minutes
- Where is the closest ATM/restaurant/hospital
- Bus on line #5 late

Basis for:
- Infrastructure provided location-based-services
- Fleet management
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Sensor networks

– **Vehicular sensors:**
  - speed,
  - fuel,
  - cameras,
  - airbag,
  - anti-lock brakes

– **Infrastructure sensors:**
  - speed detectors on road,
  - parking slots,
  - traffic lights,
  - toll booth
• Sensor information processing
  – Mostly static sensors
  – Sensor fusion (ladar and camera)
  – Protocols for sensor networks
  – Detection/classification/tracking of phenomena (trajectory of a vehicle going through a sensor net; sensors detect, assemble trajectory)
  – Distributed control and actuation
That’s all Folks

- Transportation has big problems
- Small IT impact
- Vehicle Infrastructure integration
- Computational Transportation Science
- Enabling IT trends
  - Wireless networking
  - Mobile computing
  - Information systems:
  - Sensor networks
  - Other trends (computer vision, HCI, positioning)