Next Generation Intelligent Transportation Solutions for Smart Cities

Dr. Raj Bridgelall & Dr. Denver Tolliver

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The Pace of Technology Adoption Quickeens

Trending Now – Smart Cities
Convergence of Information and Transportation Technologies
(The “Internet-of-Everything”)

A City that Embraces Rapid Innovation

- World’s fastest growing city
  - 20% of the world’s cranes\(^a\)
  - Six visitors per resident\(^a\)
  - Compare: NYC has 0.6 visitors/resident

- Hosting a World’s Fair
  - Expo 2020 (25M visitors)
  - Theme: “connecting minds, creating the future: sustainability, mobility, opportunity”

- The first true Smart City?

\(^a\)Source: MasterCard Global Destination Cities Index (2015)

View of Sheikh Zayed Road

Source: Al Mawakeb Schools (2016)
Transportation Research is Multidisciplinary

ITS: Brains at the intersection, helping us to manage complex interdependencies.

Innovation tends to occur with interdisciplinary approaches.
Rapid Innovations in Every Category

Transportation Demand
- Work trip grows
- Personal trip grows
- Tourism increases
- Service types needed
  - Short- vs Long-haul
  - Overseas
  - Time-sensitive
  - High-value & Commodity

Measures & Assessments

Policy & Planning
- Safety
- Security
- Privacy concerns
- Land-use
- Equity
- Environment

Usage
- Wireless activity
- Cameras & Lasers
- Magnetic sensors
- Weight sensors ...

Transportation Supply

Infrastructure
- Flow control
- Message signs
- Managed lanes ...

Vehicles
- Electrified
- Connected
- Automated
- Sharing services
- High-speed (rail, pods)

Condition
- NDE (LiDAR, GPR ...)
- Remote sensing
- Infrastructure sensors

NDSU National Plan Transport Institute
Congestion is a growing threat for many cities ...

• **Good news**
  – Each vehicle is the movement of people, goods, & waste
  – Symptom of a robust economy

• **Bad news**
  – Squanders critical resources (time and fuel)
  – Creates anxiety, stress, and loss of productivity
  – Amplifies safety and security challenges
  – Pollutes the air we breathe (smog)
The Cost of Congestion

- **Cost factors (annual average)**
  - Lost productivity (time wasted)
  - Wasted fuel
  - Environmental effects that are undesirable
  - Price increases for transportation services

- **Cost equivalents (U.S.)**
  - Federal Govt: double the annual spending on highways
  - Person: $1700 tax plus 40 hours of lost time in traffic

*Source: Center for Economics and Business Research (2014)*
What’s the solution? Simply adding more lanes?

Demand (Derived)

- GDP
- Population

Larger & Heavier Trucks

Demand (Induced)

- Add Roads (+Cost)
- Maintain Roads (+Cost)

Supply Response

- Trucks Haul 70% of the U.S. Gross Tonnage

Deterioration

- In 10 Years, Truck Miles Increased 50%
- But Miles of Road Increased only 5%

Congestion
The Vision for Smart Cities

• **Zero** congestion
  – Travel time decreases
  – Travel time becomes more reliability
  – Direct and indirect costs decrease

• **Zero** traffic fatalities
  – Crashes kill 38,300 and injures 2M annually\(^a\)
    • Deaths equivalent to weekly Jumbo Jet explosions
  – 94% of causes faults the human driver

• **Zero** pollution
  – Outdoor air pollution kills 3.2M annually (world)\(^b\)
  – CO\(_2\) emissions create green-house warming effects

• **Zero** stress ("sustainability, mobility, opportunity")
  – Beautiful and enjoyable outdoor spaces
  – Accessible, affordable, and lovable public transit
  – Walkable and bike-able communities
  – Safe, secure, and healthy environments

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\(^a\)National Highway Traffic Safety Administration (2015)

\(^b\)World Health Organization (2015)
Challenges To Build Smart Cities

• **Access to a trained workforce**
  – New job descriptions (new skills)
  – Both IT and transportation savvy
  – Policy and planning interdependencies
  – Context sensitive solutions (environment, culture)

• **Forecast how cities will transform**
  – Impacts of technology
  – Travel behavior changes
  – Land use changes
  – Mindset towards public transit
  – Value and utility of walking and biking facilities

• **Leverage big data and connected things**
  – Rise of real-time data-driven applications
  – New sources of data
    • Crowd-sourcing, smart grid, RFID, M2M, IoT
  – Integrate with personal mobile devices
  – Security issues and privacy concerns

*Source 1: UCL Institute (2016)*
Disruptive Innovations: Opportunities & Challenges

- **Connected vehicles (V2V, V2I, V2X)**
  - IT platform on wheels (IoT)
  - Collision avoidance (40% fewer crashes)\(^1\)
  - Vehicle platoons increase capacity
  - Adaptive flow control (sustain mobility)
  - Enhance work-zone safety & throughput
  - Rapid incident clearance

- **Driverless vehicles**
  - Reduce crashes by 94%
  - Reclaim lost productivity (40 hours)
  - Reclaim city spaces (remote self-park)

- **Mobility-as-a-service (MaaS)**
  - Ride/vehicle share (Uber, Lyft, ZipCar)
  - Travel personalization (cloud)
    - Sync smartphone, office, home, car systems
  - Network-level traffic flow optimization

\(^{1}\) Source 1: Insurance Institute for Highway Safety (2016)

Source 2: ECNmag (2014)

Source 3: UCL Institute (2016)
The Race to Driverless Vehicles

The race to deliver driverless vehicles is fierce...

- **Google**: Started in 2009, has 1.3M miles driverless
- **Ford Joint Venture (2016)**
- **Formed Team (Jan 2016)**
- **Formed Team (Jan 2013)**
- **Mercedes-Benz**: Formed Team (1995)
- **Many Others**: JV with Navteq, For Sale Now (Limited Facilities)

2020
Why are IT companies in the race?

• Information technology companies
  – Huge market for “the brains”
  – Forming key partnerships
  – Piloting prototypes now
  – Market ready by 2020

• Regulatory framework coming
  – Government backing
    • USDOT commits $4 Billion
    • United Kingdom awarded £100+ Million
    • NHTSA (USA) clarifies regulatory definitions (2/2016)¹
  – Cities still lagging, but
    • Smart City Challenge ignited action (77 cities)
    • Winner gets $50M in June 2016 to prototype

¹NHTSA: Considers the artificial intelligence in the vehicle as the ‘driver’ for regulatory purposes (February 2016)
Disruptive Innovation – Vehicle Sharing Services

Sharing, not growing

Worldwide forecast

Adoption (early research)
- 5% use it daily
- 50% never tried it
- Service doubles/6-mo
- 40% fewer car owners

Trips (early research)
- 3.1 miles on average
- 67% social/leisure
- 16% work
- 39% shift from Taxi
- 24% shift from bus
- Parking time reduced

Uber case study
- Largest market share
- 13% less than cab fare
- 2X revenue growth
- Surpassed Taxis (2015)
- 4X trip growth in NYC
- 3X trip growth in SF

Lyft case study
- 35% less than cab fare
- 30% market share

Source: Via Economist.com (2016)

Factors Driving Demand for Ride Sharing Services

- **Convenience**
  - Smartphone app based
  - Door-to-door service
- **Price transparency**
  - Real-time quotes
  - No tipping
- **High visibility service**
  - See your vehicle as it approaches
  - Waiting time estimate and count down
  - Travel time estimate and count down
- **Self-policing enhances service & security**
  - Riders and drivers rate each other
  - Bad riders and drivers economically forced out
- **Accessible to non-driver population**
  - Young adults (fewer are driving; smartphone addicts)
  - Elderly and disabled (baby boomers)
  - First and last mile connectivity (e.g. to transit)

Source: BBC News (2015)
Mixed Reaction Worldwide

• Competing interests
  – Taxi companies protesting
  – Users petition for adoption

• Regulatory challenges
  – Smartphone apps
    • connects riders to drivers
  – Private vehicles
    • drivers share them

• Potential macro benefits
  – Vehicle utilization increases
  – Ownership decreases

• Uncertainties
  – Safety and security
  – Taxes
  – Insurance
  – Fairness

• Driver-less vehicle sharing (coming soon)
Transitional Challenges for Smart Cities

- **Policy & planning related challenges**
  - Normalize regulations (autonomous vs. regular vehicles)
  - Set new standards or fix fragmented standards
  - Handle public expectations and confusions
  - Work with Transportation Network Companies (TNCs)
  - Manage uncertain impacts on mode choice

- **Vehicle related challenges**
  - Robots and human drivers share roads
  - Varied technology capabilities
  - Interoperability (trucks, transit, car)
  - Service facilities and requirements

- **Infrastructure related challenges**
  - Synchronizing messages/signs with robots
  - People versus robot traffic signaling
  - Intermodal facilities accommodate
    - Last mile links to transit (TNCs)
    - Freight and port facilities (truck platoons)

Data Driven Decision-Making

- Total Vehicle miles traveled (VMT)
- Annual Average Daily Traffic (AADT)
- Peak Hour Factor (PHF)
- Average Travel Time
- Intersection Throughput
- Flow Density (e.g. vehicles per mile per lane)
- Flow Volume (e.g. vehicles per hour)
- Freight Cost Per Ton-Mile
- Passengers per Hour
- Trains per Day
- Crash statistics
- Emission levels (e.g. metric tons of CO₂)
- Many more ...
BIG DATA Analytics

Data Source Variety
- Embedded Sensors
- Crowd-sourcing
- Remote sensing
- Social media
- Many more ...

Machine Intelligence
- Statistical Modeling
- Neural Networks
- Decision-Trees
- Pattern recognition

Decision-Support
- Data Visualization
- Scenario Analysis
- Simulations
- Public Feedback
- Autonomous vehicles

Autonomous vehicles

Many more ...
Some Applications of Big Data Analytics

• Real-time traffic analysis
  – Optimized operations and management
  – Both local and system-wide
  – Pre-trip guidance

• Long-term Planning
  – Trip demand forecasting
    • Micro-level GPS activity enhances accuracy
  – Mode shift analysis
    • Ride-sharing vs. Transit (where to invest?)
  – Land use changes (parking, sprawling)
  – Crash cause statistics (vehicle probe data)

• Optimize maintenance strategies
Research Questions?

Lots

?
Research Questions (Benefits and Costs)

• **Benefits Analysis**
  – Congestion reduction
  – Crash reduction
  – Pollution reduction

• **Cost Analysis**
  – Technology acquisition and deployment
  – Training to deploy new technologies
  – Multimodal facility modifications
  – Intermodal facility modifications

• **Economic impacts**
  – Enhanced trucking capacity
  – Enhanced rail capacity
  – Vehicle electrification
Research Questions (Qualitative Impacts)

• **Travel demand changes?**
  – More people traveling (blind, unlicensed, disabilities)
  – Longer travel distances?
  – Cases for/against more congestion?

• **Parking demand changes?**
  – If cars self-park in distant lots
  – Currently 31% of land devoted to parking in urban cores

• **Will urbanization accelerate or slow down?**
  – People move to cities (no parking issues) or
  – People live further (more productive during commute)
  – Evaluation of cost, speed, and mode choice

• **Traffic laws and enforcement changes?**
  – What are the implications?

• **Insurance changes?**
  – Robots make decisions instead of people

• **Workforce changes?**
  – Job repurposing for drivers of taxis, buses, trucks, ferries, etc.
Research Questions (Quantitative Impacts)

- **Capacity of multimodal corridors**
  - Geometry changes
    - Narrower lanes
    - Median elimination
    - Shoulder narrowing
    - Reclamation of street parking
  - Managed lanes (HOV, HOT, reversible)
  - Truck-only platooning
  - Car-only platooning
  - Transit priority and emergency vehicle lanes
  - Mixed traffic platooning

- **Capacity of interrupted facilities**
  - Coordinated traffic signaling – collectors/arterials feeding highways
  - Adaptive traffic signaling
  - Adaptive ramp metering

- **Capacity of the Network**
  - Big Data and machine learning identifies derive optimal routes
  - Impact of ride-sharing technology penetration (Uber, Lyft, etc.)
  - Impact of shared vehicle ownership
  - Impact on mode shifting (will they take away from public transit?)

- Impacts on fuel and energy consumption
  - Supply and demand analysis
Research Questions (Scenario Studies)

• **Operations**
  – How would robots and humans share the road?
  – What are the new **safety and reliability testing** evaluations?
  – What infrastructure changes are needed?
  – What new technology and integration **standards** are needed?
  – What is the optimum distribution of power/charging stations?
  – **Vehicle hacking**: do we harden security or just plan for recovery?
  – Will users ‘flood’ the system with trivial errands? Congestion?
  – How to deal with a **system meltdown**?
    • Power grid? Communications grid?
  – Can big-data and **machine learning** address any of these issues?

• **Planning**
  – How must **incident management** and **emergency response** change?
  – What are new **vulnerabilities** of the evolving system?
  – How would we deal with public panic if the system fails?
  – How will **land-use** change? **Parking**? Sprawling?

• **Policy**
  – How must **traffic laws** and **enforcement** change?
  – How will the insurance industry change? Who is **liable** in a crash?
  – How do we educate diverse stakeholders? **Privacy** concerns?
    • Carmakers, technology firms, urban planners, governments, the public
  – Are user-based **fees** needed to help fund infrastructure maintenance?
  – How will we accommodate people who want to drive their own cars?
Research Questions (Field Implementation & Issues)

• Technology and **equipment**
  – Coexistence of legacy and new hardware
  – Safety analysis of vehicle retrofit devices
  – Evolution of data communication standards
  – Wireless spectrum harmonization

• **System deployment** issues
  – Specifications (what do all the numbers mean?)
  – Environmental impacts and considerations
  – Installation planning to minimize disruptions

• **Computing** framework
  – Accommodating cloud and edge computing
  – Structured and unstructured data housing
  – Handling velocity, volume, and variety
  – Sensor fusion techniques
  – Machine learning tools and techniques
Research Questions (Basic Technology and Issues)

• **Navigation learning**
  – GPS is accurate only to a few meters and subject to occlusions
  – Updating 3D maps of the environment in real-time
  – Currently speeds are typically low (<60 km/h)
  – Following faded lane markers

• **Challenges to technology** *(snow, heavy rain, night lights)*
  – Google & Nissan admitted that their vehicles must pull over in storms
  – Ford is addressing the issue using LiDAR maps

• **Human-Machine Interface**
  – Driver complacency in autopilot mode creates handoff issue
  – Diminished driver attention and reaction time

• **Policy, Protocols, and standards**
  – Infrastructure readiness and modifications
  – Uniformity of regulations
  – Insurance impacts
  – Crash liability

• **The public**
  – Privacy and security concerns
  – Top manufacturers will release models by 2020
  – Some analysts caution to add 5-years

Research Questions (Advanced Technology/Issues)

- **GIS system with real-time 3D mapping**
  - Map localization performance and issues
  - Path planning performance and issues

- **Cameras and Image Processing**
  - Object detection performance
  - Object classification performance
  - Object segmentation performance

- **See through fog and dark**
  - RADAR (proximity detection)
  - Ultrasonic (proximity detection)
  - LiDAR (360-degree vision)

- **Dedicated low-cost supercomputers**
  - NVIDIA DRIVE™ PX 2 capable of 24 Trillion ‘deep learning’ operations per second (equivalent of 150 MacBook Pros), supporting 12 simultaneous camera streams, plus LiDAR, RADAR, and Ultrasonic sensors [html] used by Audi, BMW, Daimler, Ford
  - Google, Apple, Blackberry, Samsung, etc.

- **Machine learning software**
  - Accumulate more driving wisdom than humans over time
  - Never distract and never repeat a mistake ( unlike humans)
  - Sensor calibration, data synchronization, sensor fusion
  - Establish vehicle position relative to static and dynamic objects
  - Calculate optimal path for safe travel
  - ‘Deep’ neural network learning from successes, failures, and other vehicles
  - Shared learning network from effective driving behaviors

Source 1: NVIDIA (2016)
Research Questions (Autonomous Vehicles)

• What is the case for **driverless**?
  – Humans lack the reaction time to take over
  – Humans become too dependent on autopilots
  – Drivers will become less experienced over time
  – Situations requiring handover are likely too complex

• What is the case for **self-driving**?
  – Computers are not fail-safe
  – Computer cannot make good or moral decisions
  – Bad weather may hamper self-driving performance

• How long will full **adoption** take if ever?
  – Pew Research in 2015 found that
    • 50% won’t drive in one
    • 59% of college graduates will
    • 36% of rural residents will
Research Questions (Emerging Technologies)

• Emerging applications of s-UAVs (small drones)
  – Infrastructure inspections (roads, pipelines, bridges, rail)
  – Law enforcement
  – Emergency management
    • Fire access intelligence
    • Crash clearance intelligence
    • Disaster relief (e.g. flood management)
    • Search and rescue
  – Government operational missions (e.g. security)
  – Land surveillance
  – Traffic analysis
  – Lightweight package delivery (e.g. Amazon)

• Future applications of Hyperloops

• Implications to policy, regulations, standards
  – Regulations are country dependent
  – Sharing of frequency spectrum for communications
  – Privacy, safety, quality-of-life (noise, visual intrusion)
Curricula Overview for Basic ITS

Addressing Challenges of Mobility, Safety, Security, Sustainability

Advisory Systems
- Dynamic Message Signs
  - CCTV
  - Onboard Systems
  - Smartphone Apps
  - TBD

Traffic Flow Control
- Adaptive Signaling
  - Ramp Metering
  - Variable Speed Limits
  - Speed Warnings
  - Transit Signaling Priority

Electronic Payments
- Electronic Tolling Systems
  - Electronic Transit Cards
  - RFID
  - Smartphone Apps
  - Printed Codes

Preclearance Systems
- Vehicle Classification
  - Weigh-in-Motion
  - Wireless Inspections
  - Freight Scanners
  - Vehicle Identification & Data Mining

Managed Facilities
- High Occupancy Vehicles
  - High Occupancy Tolling
  - Dedicated Transit Lanes
  - Dedicated Truck Lanes
  - Lane Direction Reversal

Smart Parking
- Vehicle Occupancy Sensing
  - Parking Meters
  - Parking Reservation Systems
  - Parking Apps

Security & Privacy
- Case Studies of Physical Threats
- Case Studies of Cyber Threats
- Privacy Concerns
- Institutional Issues

How would you measure the performance of these systems?
What criteria do planners use to determine need?
What are the cost estimates per deployment?
## Curricula Overview for Advanced ITS

### Addressing Challenges of Mobility, Safety, Security, Sustainability

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**How would you measure the performance of these systems?**

**What criteria do planners use to determine need?**

**What are the cost estimates per deployment?**
Last Words

• **Rapid technology adoption**
  – Promising solutions (lower cost)
  – High uncertainty
  – Complex interactions
  – Multidisciplinary solutions

• **Plan ahead** *(often)*
  – Establish vision and goals
  – Formulate the key questions
  – Research the key questions
  – Anticipate change
  – Develop a **compatible workforce**
  – Plan collaboratively w/ stakeholders
  – Accommodate the changes