Next Generation Intelligent Transportation

Solutions for Smart Cities

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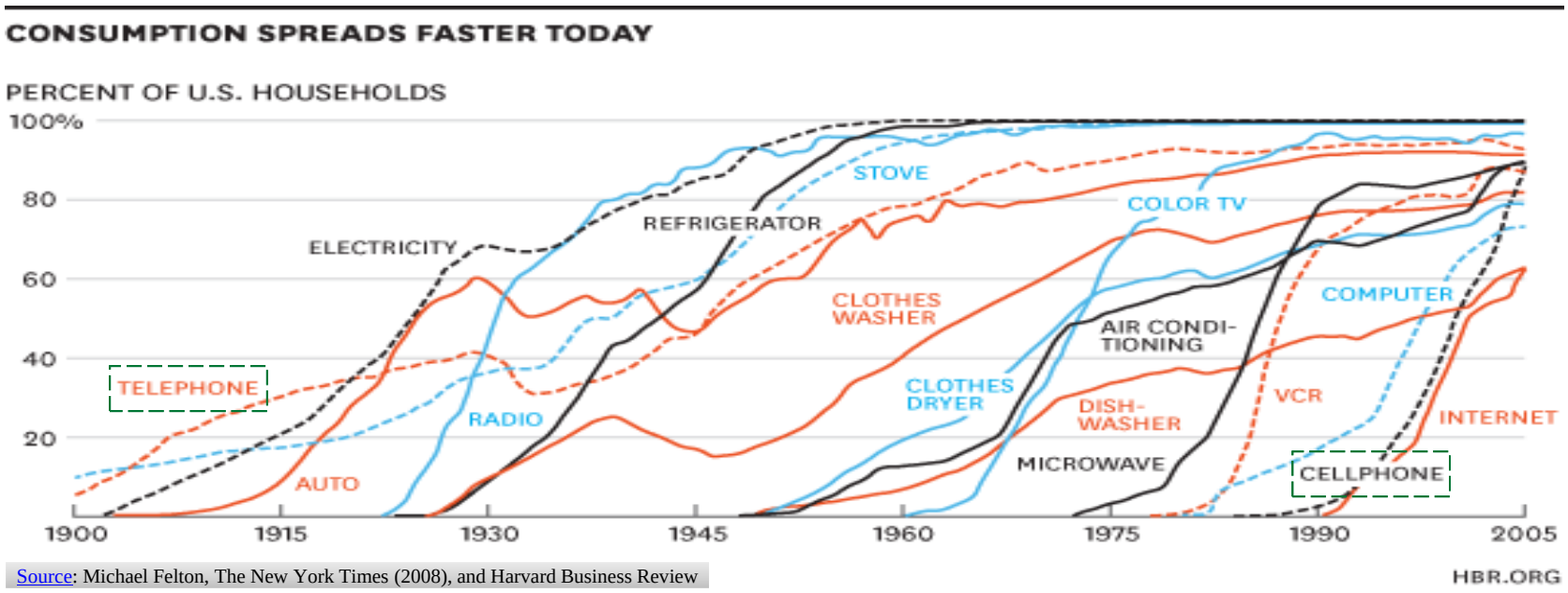
NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

The Pace of Technology Adoption Quickens



Trending Now – Smart Cities

Convergence of Information and Transportation Technologies
(The "Internet-of-Everything")

A City that Embraces Rapid Innovation

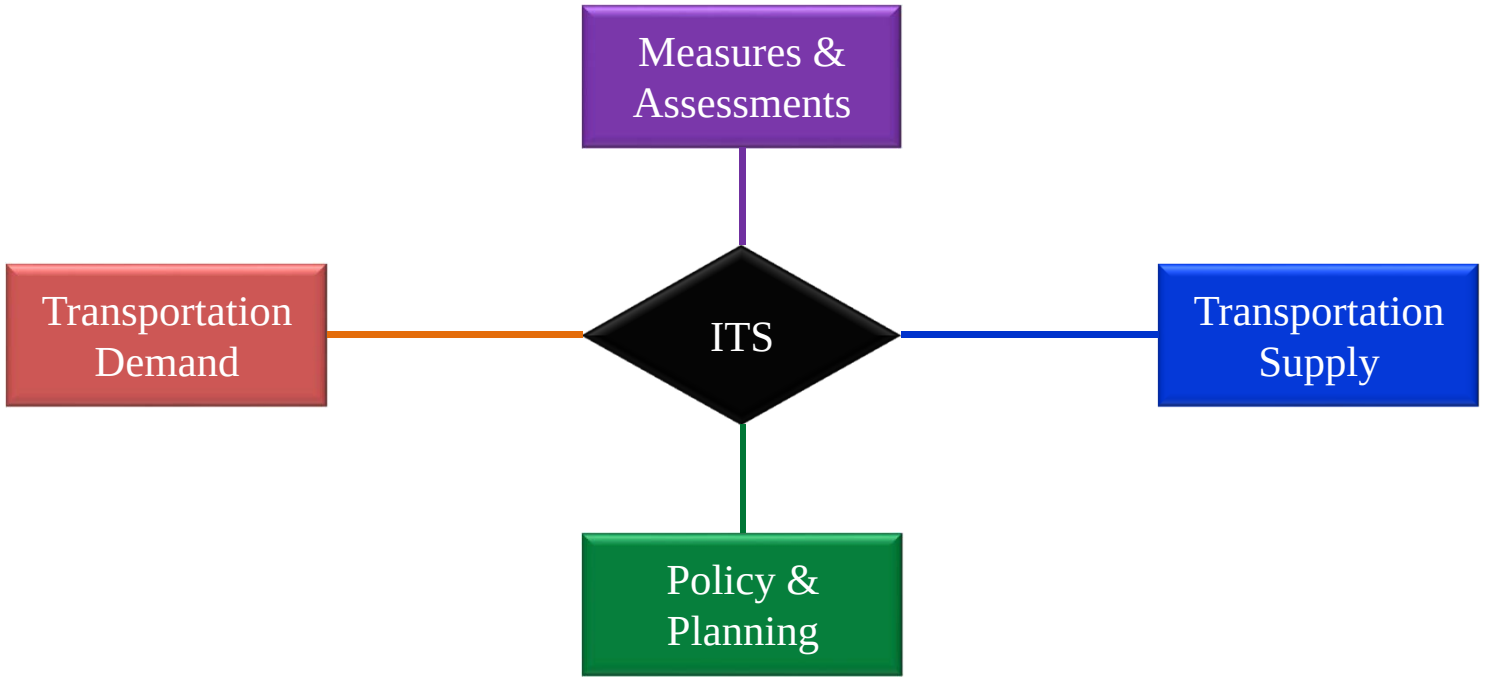
- World's fastest growing city
  - 20% of the world's cranes[a]
  - Six visitors per resident[a]
    - Compare: NYC has 0.6 visitors/resident
- Hosting a World's Fair
  - Expo 2020 (25M visitors)
  - Theme: "*connecting minds, creating the future: sustainability, mobility, opportunity*"
- The first true Smart City?

[a]Source: MasterCard Global Destination Cities Index (2015)

View of Sheikh Zayed Road

Source: Al Mawakeb Schools (2016)

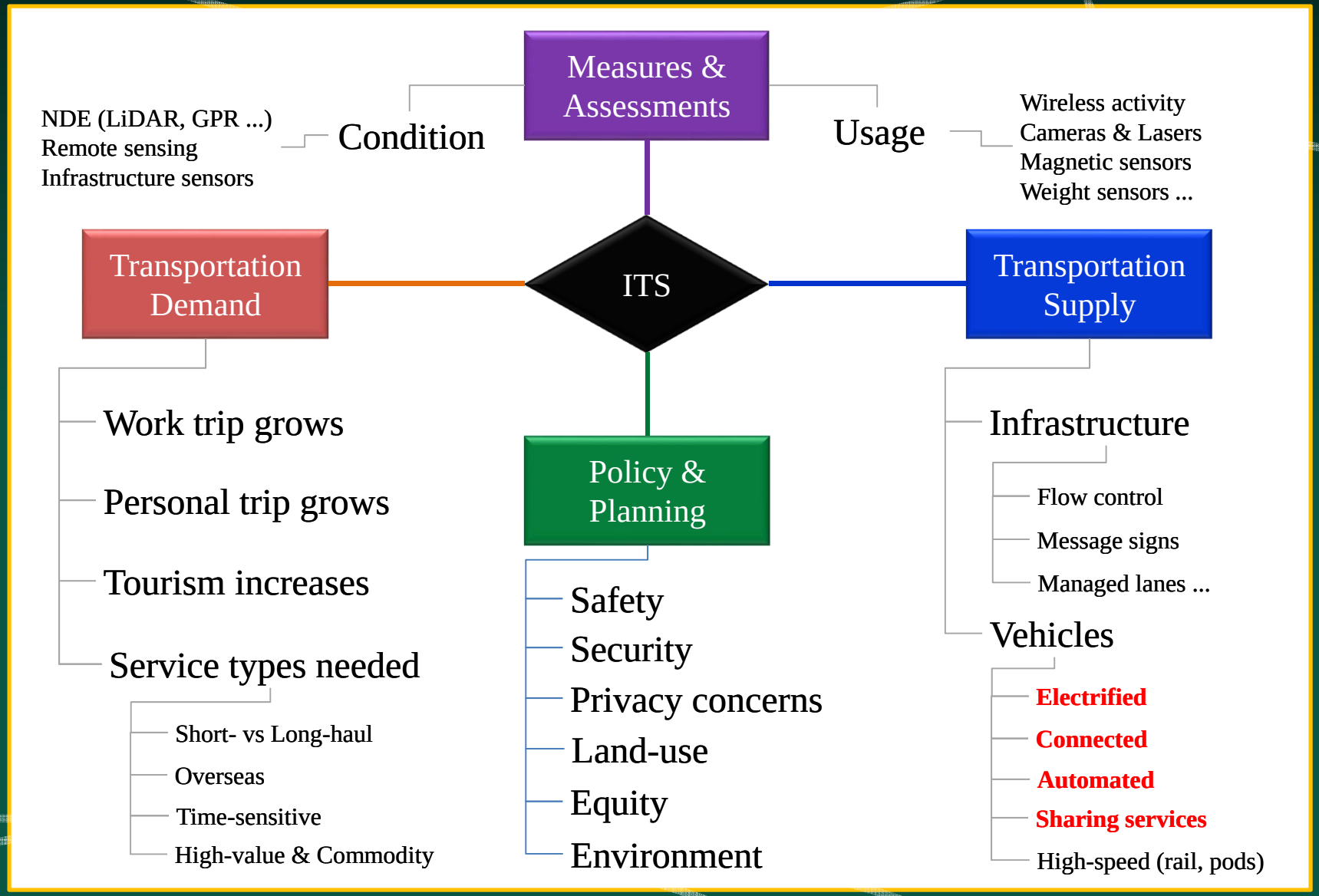
Transportation Research is Multidisciplinary



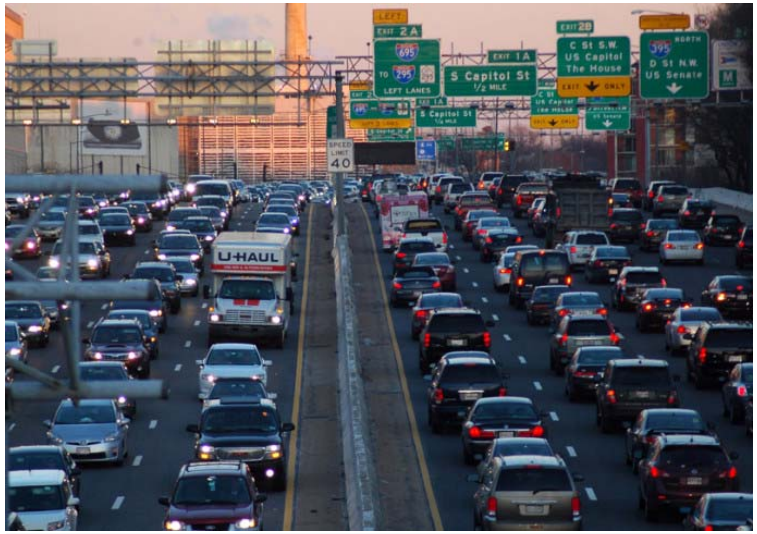
ITS: Brains at the intersection, helping us to manage complex interdependencies.

Innovation tends to occur with interdisciplinary approaches.

Rapid Innovations in Every Category



Congestion is a growing threat for many cities …

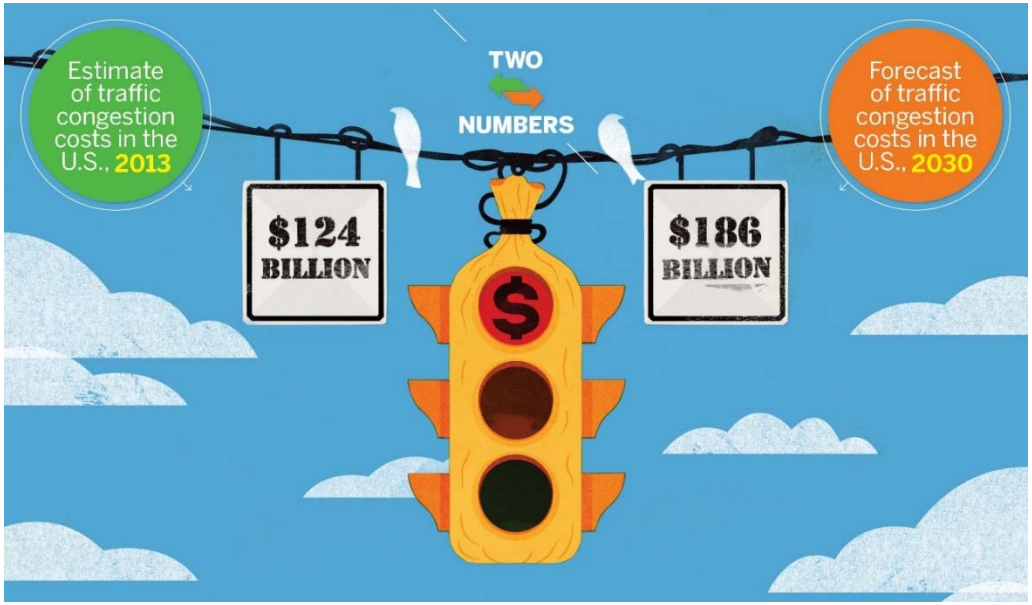


Source: Washington's Top News (WTOP, 2016)

Source: Emirates 24|7 (2016)

- 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 breath (smog)

The Cost of Congestion

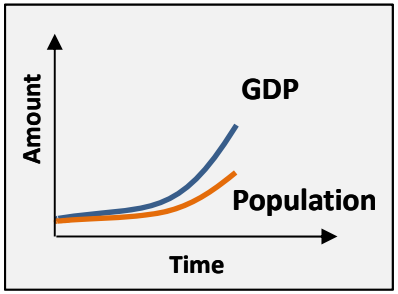


- Cost factors (annual average)
  - Lost productivity (time wasted)
  - Wasted fuel
  - Environmental effects that are undesirable
  - Price increases for transportation services
- Cost equivalents (U.S.)
  - Federal Govt: double the annual spending on highways
  - Person: $1700 tax plus 40 hours of lost time in traffic

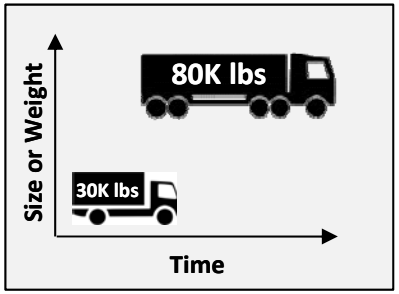
Source: Center for Economics and Business Research (2014)

What's the solution? Simply adding more lanes?

Demand (Derived)

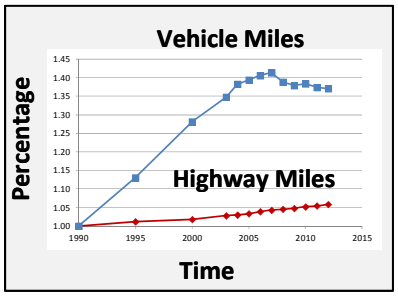


Larger & Heavier Trucks



Supply Response

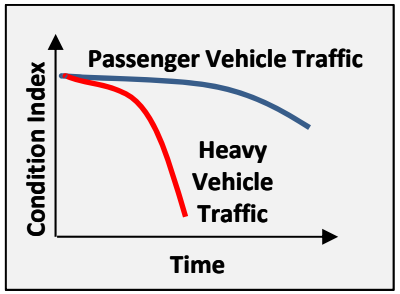
Trucks Haul 70% of the U.S. Gross Tonnage



Congestion

In 10 Years, Truck Miles Increased 50%

But Miles of Road Increased only 5%



Deterioration

Maintain Roads (+Cost)

Add Roads (+Cost)

Demand (Induced)

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

[a]National Highway Traffic Safety Administration (2015)

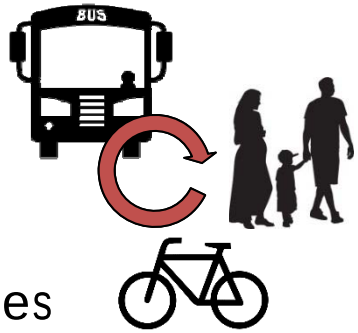
[b]World Health Organization

Source 1: Siradel (2016) Source 2: UT Austin (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



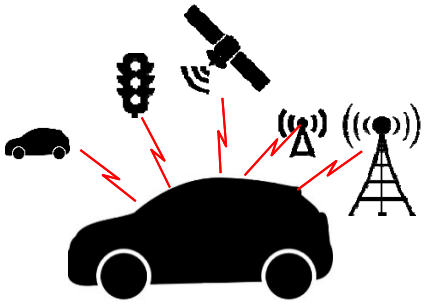
- Leverage big data and connected things
  - Rise of real-time data-driven applications
  - New sources of data
    - Crowd-sourcing, smart grid, RFID, M2M, IoT
  - Integrate with personal mobile devices
  - Security issues and privacy concerns

1

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



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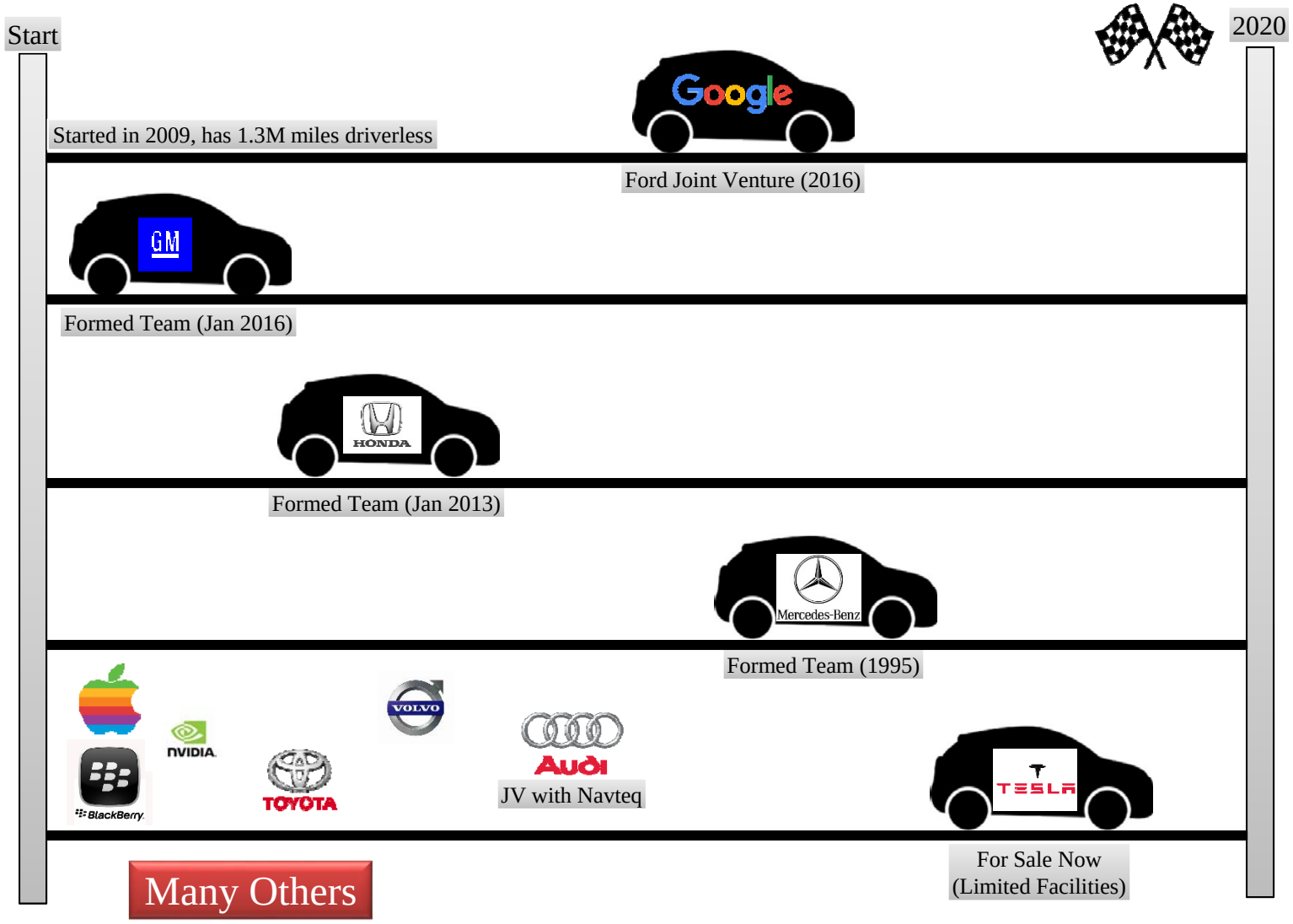
Source 1: Insurance Institute for Highway Safety (2016) Source 2: ECNmag (2014) Source 3: UCL Institute (2016)

The Race to Driverless Vehicles

Source: Harvard Business Review (2006)

The race to deliver driverless vehicles is fierce …



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

[1]NHTSA: Considers the artificial intelligence in the vehicle as the ‘driver’ for regulatory purposes (February 2016)

Disruptive Innovation – Vehicle Sharing Services

Source: Via Economist.com (2016)

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
- $2B (2015)
- 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

Study: Rayle, L, S. Shaheen, N. Chan, D. Dai, and R. Cervero. 2015. App-Based, On-Demand Ride Services: Comparing Taxi and Ridesourcing Trips and User Characteristics in San Francisco, TRB 2015

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)**

Source: BBC News (2016)

Source: Malaymail (2016)

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)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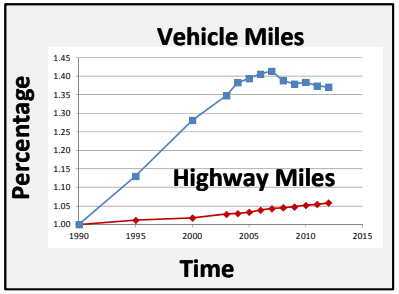
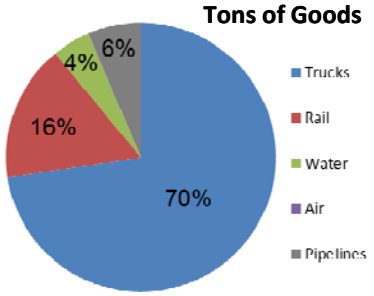
Source 1: The Telegraph (2015) Source 2: LA Times (2015)

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 CO_2)
- 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

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?

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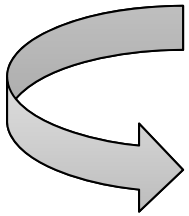
Lots



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

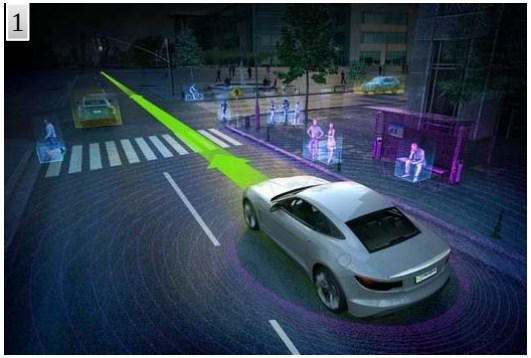
Research Questions (Basic Technology and Issues)

- 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 cautions to add 5-years

Source 1: ArabianBusiness.com (2015) Source 2: DailyMail.com (2016)

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



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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

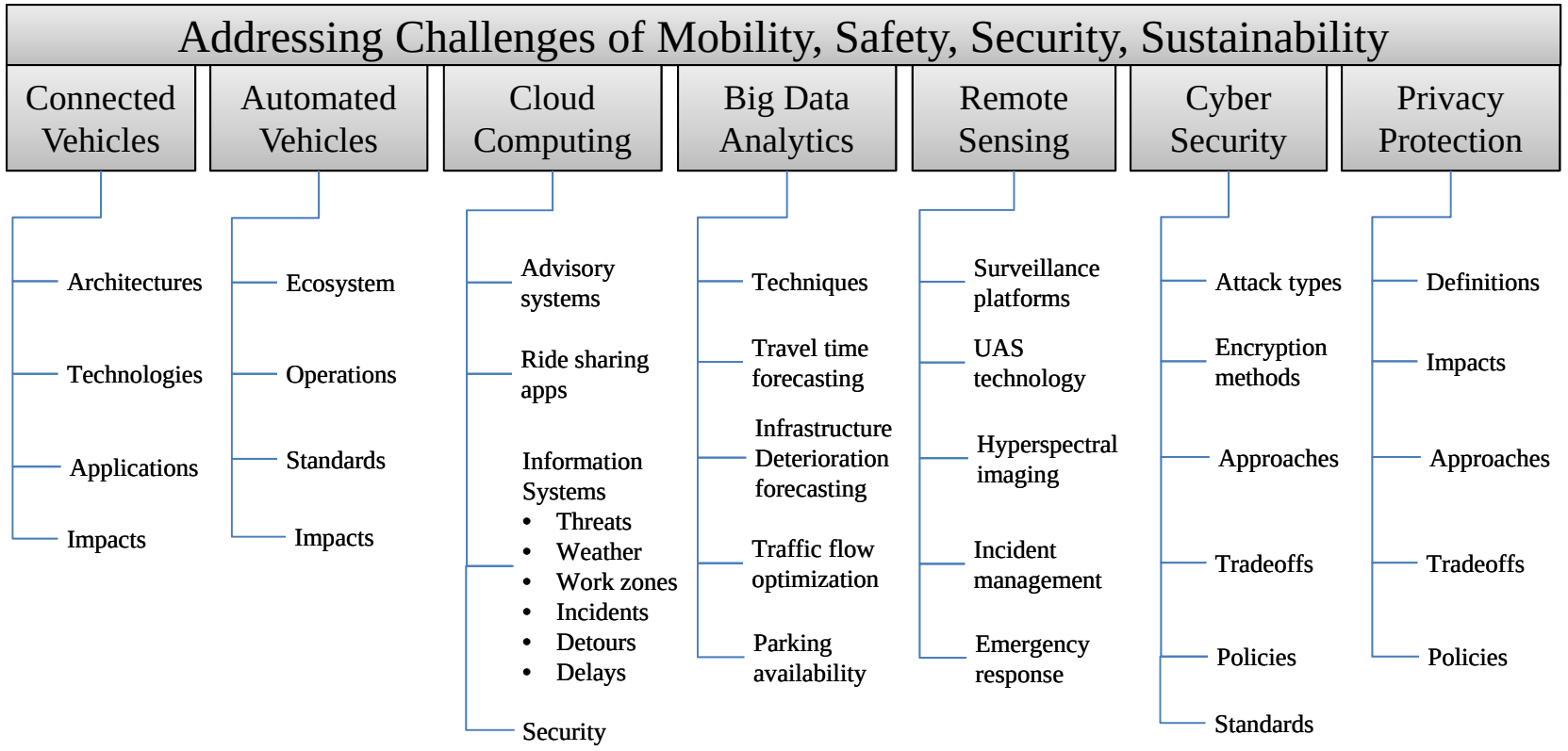
- **Advisory Systems**
  - Dynamic Message Signs
  - CCTV
  - Onboard Systems
  - Smartphone Apps
  - TBD
- **Traffic Flow Control**
  - Adaptive Signaling
  - Ramp Metering
  - Variable Speed Limits
  - Speed Warnings
  - Transit Signaling Priority
- **Electronic Payments**
  - Electronic Tolling Systems
  - 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



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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