THE FUTURE OF MOBILITY THROUGH INNOVATIONS IN INTELLIGENT TRANSPORTATION INFRASTRUCTURE

George J. Pappas
University of Pennsylvania

AAAS 2018: Advancing Science Discovery to Application
February 16, 2018

CCC
Computing Community Consortium
Catalyst

CCC INFRASTRUCTURE WHITEPAPERS

MOBILITY21: Strategic Investments for Transportation Infrastructure & Technology

Rahul Mangharam
University of Pennsylvania

Megan S. Ryerson
University of Pennsylvania

Steve Viscelli
University of Pennsylvania

Hamsa Balakrishanan
MIT

Alexandre Bayen
UC Berkeley, ITS

Surabh Amin
MIT

Leslie Richards
PennDOT

Leo Bagley
PennDOT

George Pappas
University of Pennsylvania

FUTURE MOBILITY WILL IMPACT SAFETY, EFFICIENCY QUALITY OF LIFE

SAFETY

94
PERCENT
of U.S. crashes involve human error. [1]

1.2
MILLION
deaths worldwide due to vehicle crashes in 2013. [2]

37,461
ROAD DEATHS
in the U.S. in 2016 and 2.4 million injuries in 2015. [3]

2
OUT OF 3
people will be involved in a drunk driving crash in their lifetime. [4]

SOCIETY

$594
BILLION
in harm from loss of life and injury each year. [5]

$277
BILLION
in annual economic costs. [6]

$160
BILLION
in gas burned and time lost each year. [7]

MOBILITY AND QUALITY OF LIFE

3
MILLION
Americans age 40 and older are blind or have low vision. [8]

79
PERCENT
of seniors age 65 and older living in car-dependent communities. [9]

42
HOURS
wasted in traffic each year per person. [7]

On the road to fully self-driving, Waymo Safety Report, October 2017

FUTURE MOBILITY WILL IMPACT ECONOMY

STRATEGY ANALYTICS
Research, Experts, and Analytics

Autonomous Vehicle Service

Accelerating the Future: The Economic Impact of the Emerging Passenger Economy

Autonomous Vehi

Report Snapshot

Intel has engaged Strategy Analytics as a partner in the preparatio
report to validate the hypothesis that a "Passenger Economy" base
pilotless vehicles is on the horizon and that it holds massive econo
potential. In assessing this opportunity, Strategy Analytics and Intel
start a conversation that explores the catalysts for change, frames
or economic opportunity, and begins to build use cases that can en
business decision makers to explore and develop actionable chang
strategies.

Automotive

Tel: +

STRATEGY ANALYTICS
Research, Experts, and Analytics

Autonomous Vehicle Service

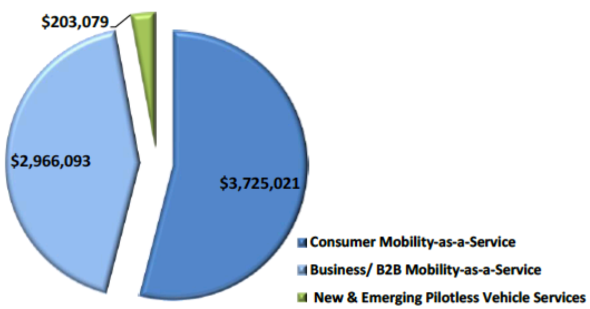
2. Key Findings

The Passenger Economy represents a US$7 trillion global opportunity in 2050.

The Passenger Economy will stimulate value creation from the adoption of Mobility-as-a-Service and other new mobility services as well as emerging new applications and services as well as from savings in time and money associated with vehicle use and from the resulting freedom of movement.

Our research finds that autonomous driving technology will enable a new Passenger Economy worth US$7 trillion in 2050. It will drive change across a range of industries, displacing vehicle ownership with Mobility-as-a-Service, and defining a new landscape of concierge and ride-hailing services, as well as pilotless vehicle options for businesses in industries like package delivery and long-haul transportation.

Passenger Economy: Global Revenue from Services 2050 (US$, Millions)



Source: Strategy Analytics

US$7 Trillion Opportunity

Autonomous driving technology will enable a new "Passenger Economy" worth US$7 trillion – more than the projected 2017 GDPs of Japan and Brazil combined.

FUTURE TRENDS

1. AUTONOMOUS PLATFORMS
2. CONNECTIVITY
3. CITY-SCALE DATA
4. USER-AUTONOMY INTERACTION

1. AUTONOMOUS PLATFORMS



CCC
Computing Community Consortium
Catalyst

24 year old dies on the spot

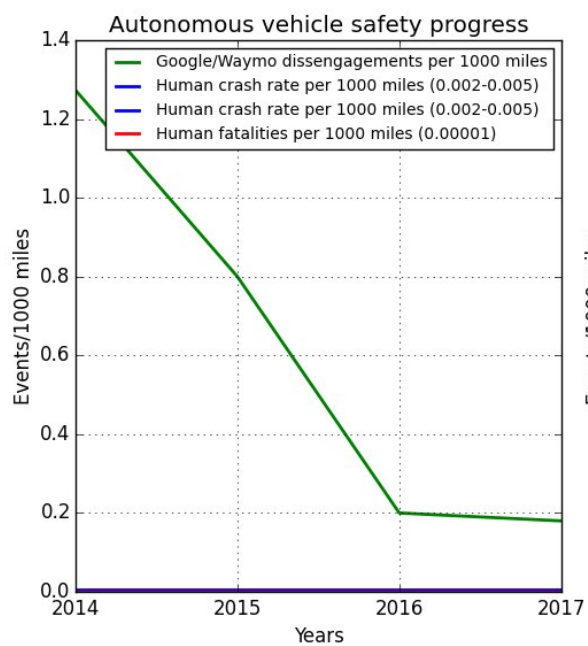
CHALLENGE–SAFE AUTONOMY

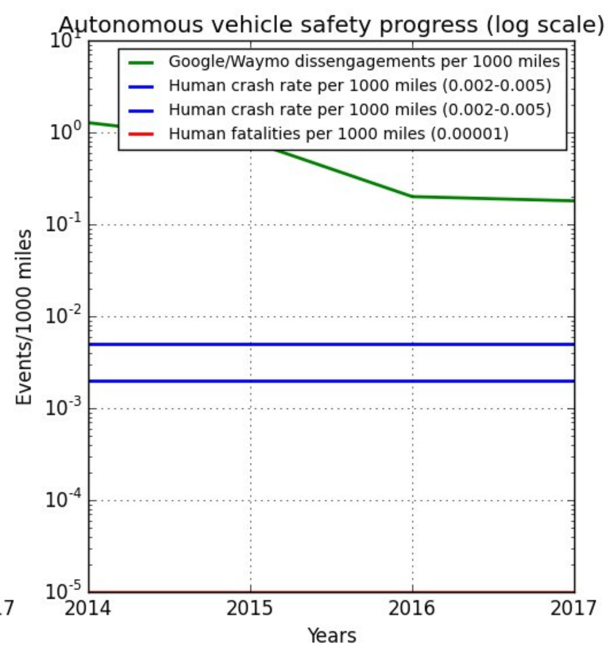
Cars That Think | Transportation | Self-Driving

2 Feb 2018 | 14:24 GMT

Have Self-Driving Cars Stopped Getting Better

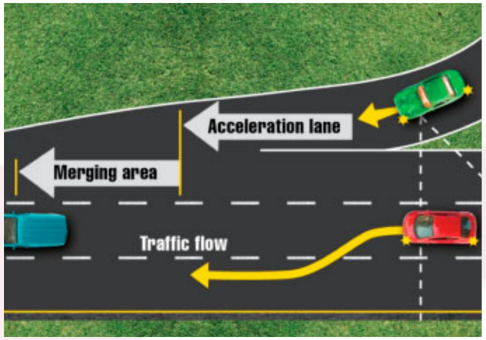
New reports from California suggest limits to autonomous vehicle performance





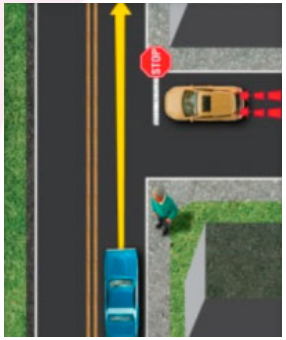
RESEARCH CHALLENGE : SAFE AUTONOMY

For vehicle model, & safety requirements specified over time

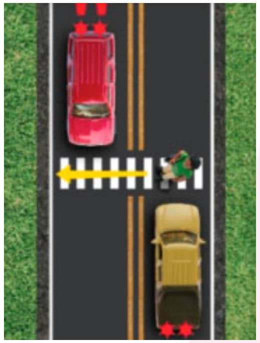


Lane merge

Roundabout

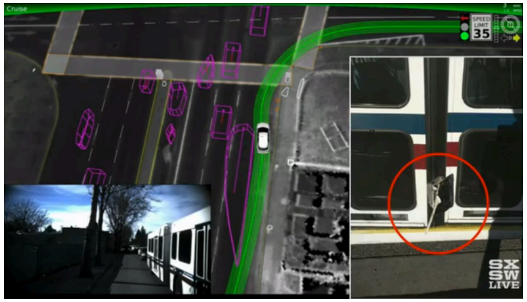


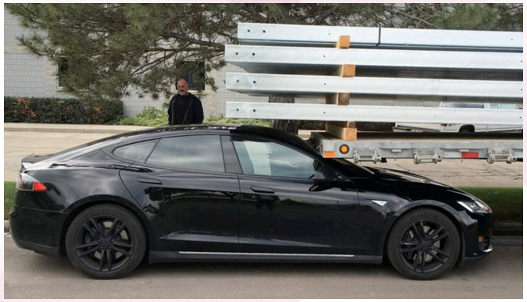
Stop signs



Pedestrians

Provide safety guarantees for integration of controller, sensor, computing, learning





Who is responsible when autonomous cars crash with human-driven cars?

CCC
Computing Community Consortium
Catalyst

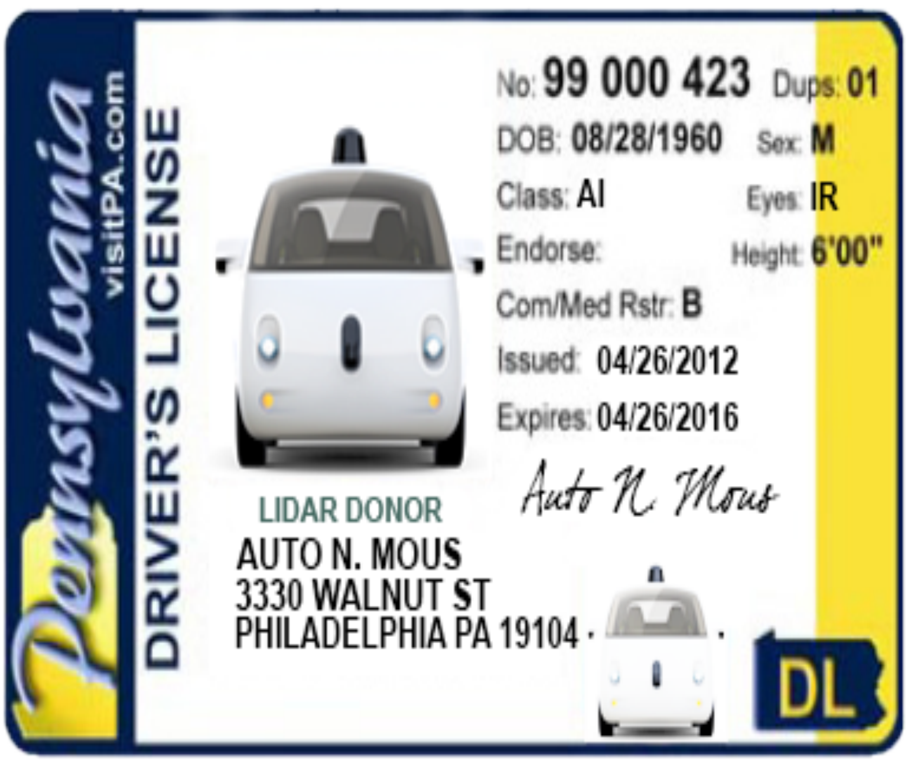
Technologies for Safe and Efficient Transportation

THE NATIONAL USDOT UNIVERSITY TRANSPORTATION CENTER FOR SAFETY

UNIVERSITY of PENNSYLVANIA

Carnegie Mellon University

A Driver’s License Test for Autonomous Vehicles



Prof. Rahul Mangharam
Penn Director, Mobility21 DoT UTC
University of Pennsylvania
rahulm@seas.upenn.edu

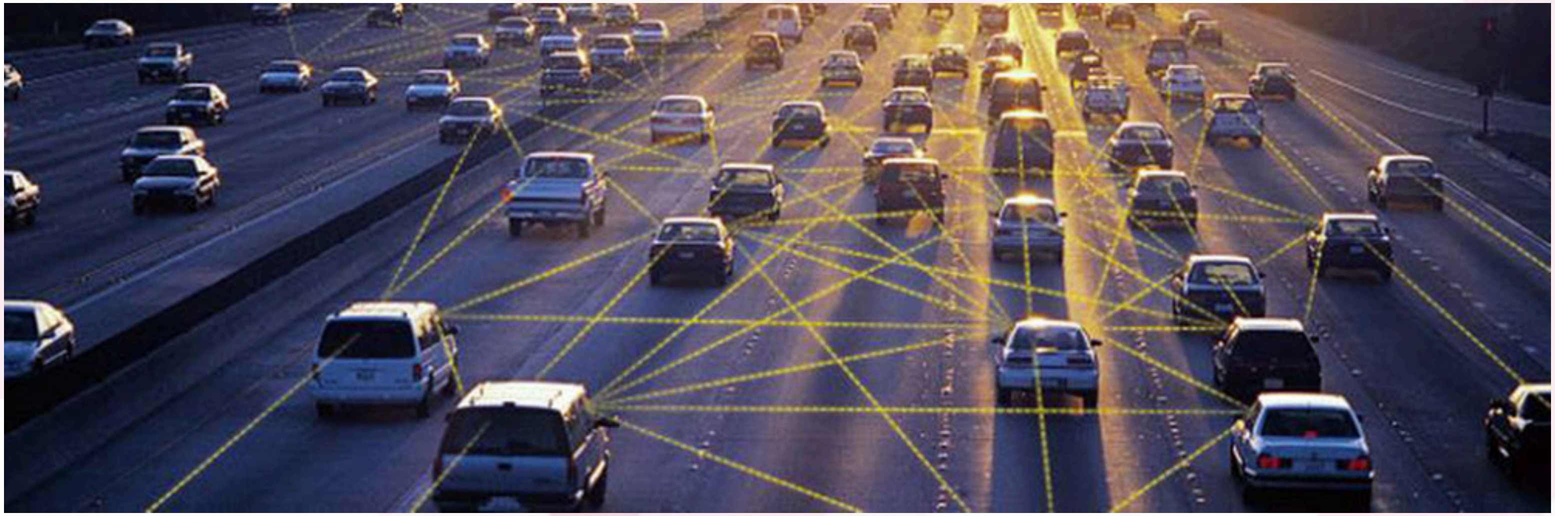
RESERCH CHALLENGE : AUTOMOTIVE SECURITY

ANDY GREENBERG SECURITY 08.10.16 4:29 PM

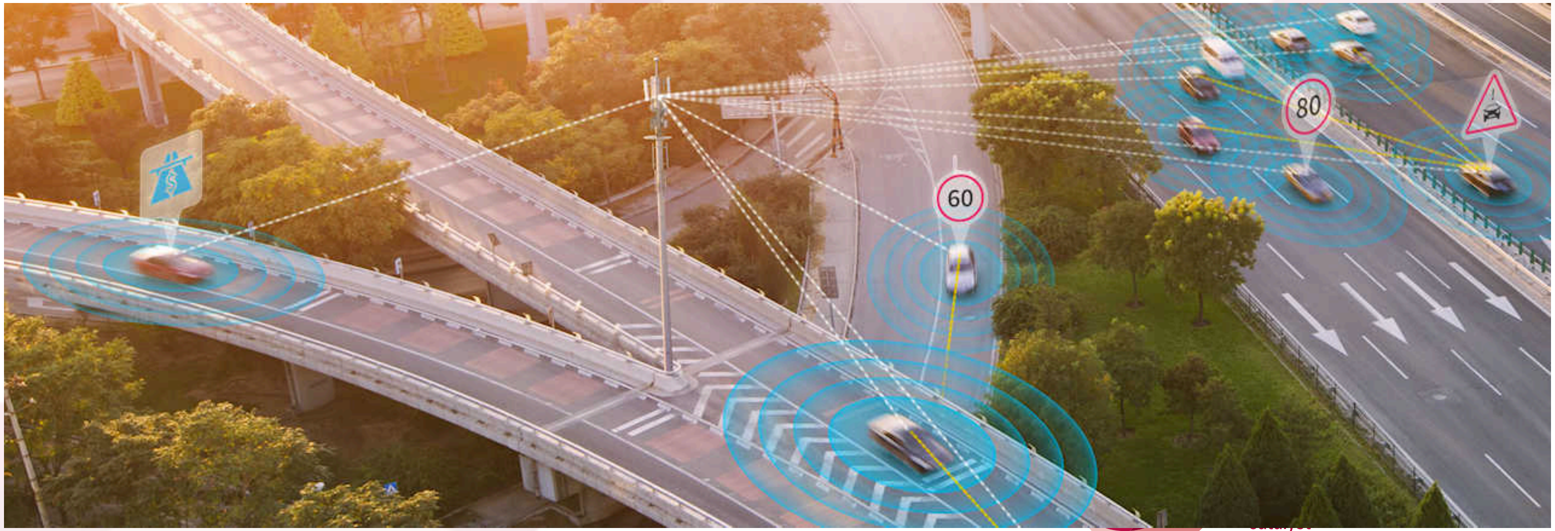
A NEW WIRELESS HACK CAN UNLOCK 100 MILLION VOLKSWAGENS

2. CONNECTIVITY

V2V

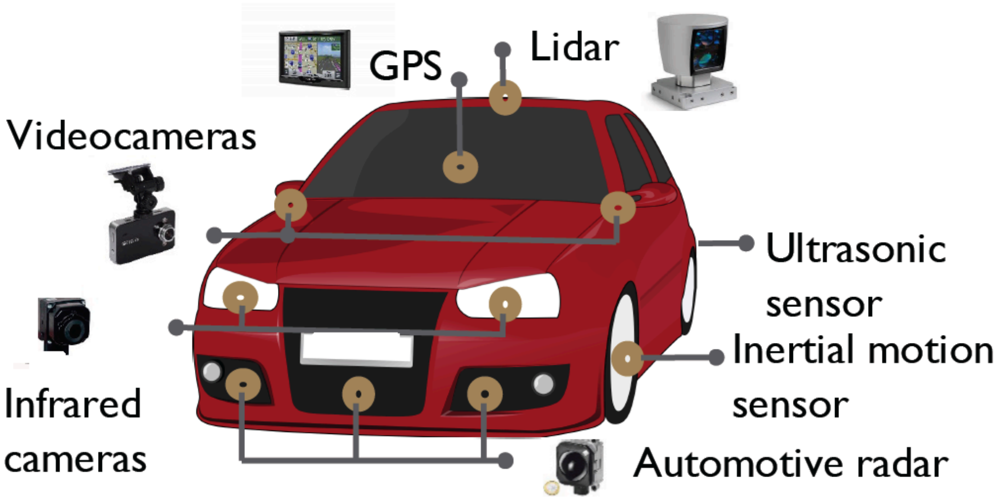


V2I



BIG MOBILE DATA

Massive data rates from sensors



Each sensor generates data

+

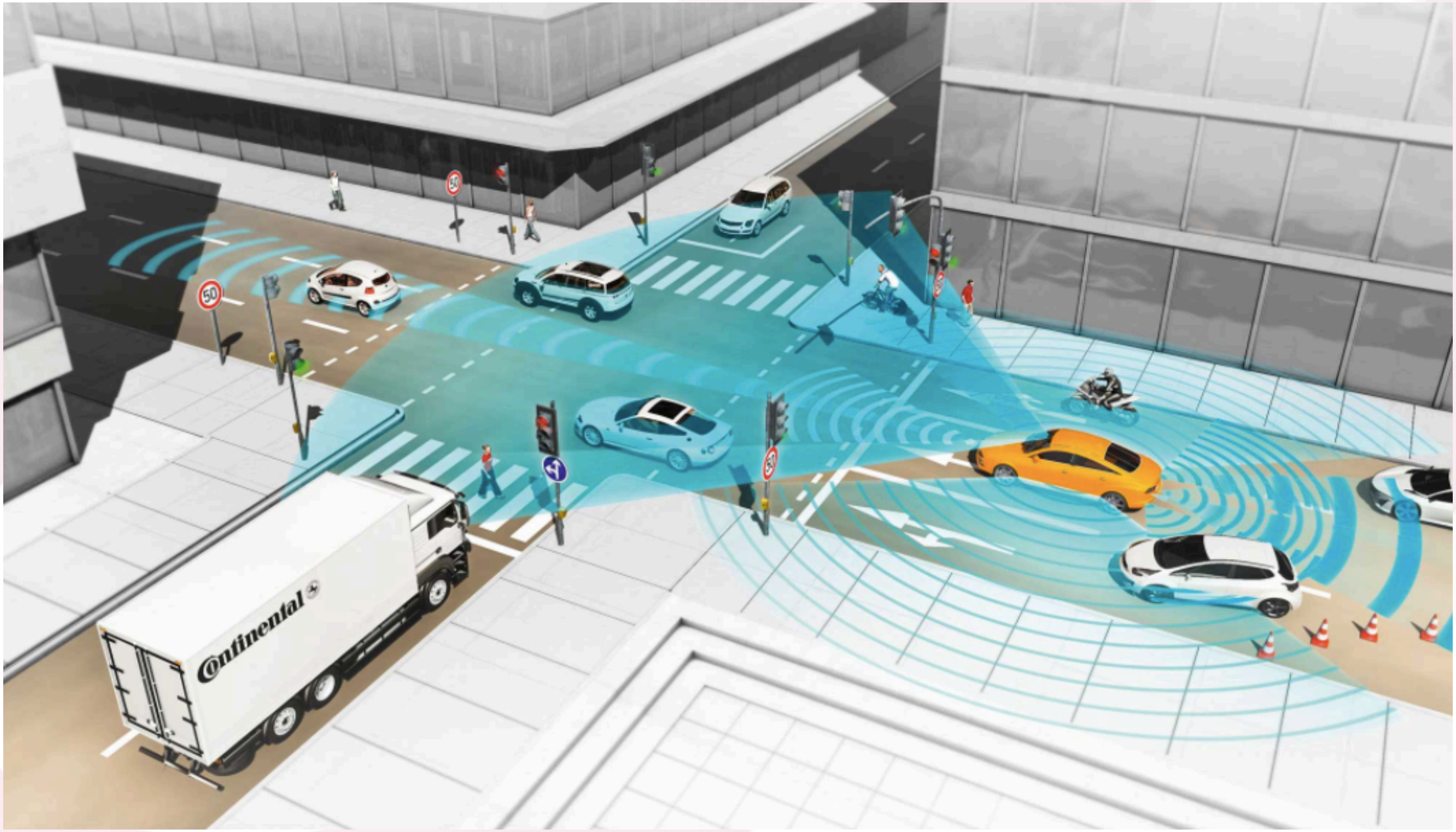
Lots of sensors in a vehicle

=

Massive amount of data per vehicle

Vehicles connected to the cloud generate 1.5GB monthly data
Autonomous vehicles can generate up to a 1TB real-time data per trip!
There are one billion cars in the world that are increasingly sensor-rich
Internet of mobile autonomous platforms
Instrumented cars serve as infrastructure sensors

RESEARCH CHALLENGE – VERY HIGH DATA RATES



Networking with very high data rates for see-through buildings intersection (mm-wave)

CCC
Computing Community Consortium
Catalyst

RESEARCH CHALLENGE – LOW-LATENCY WIRELESS

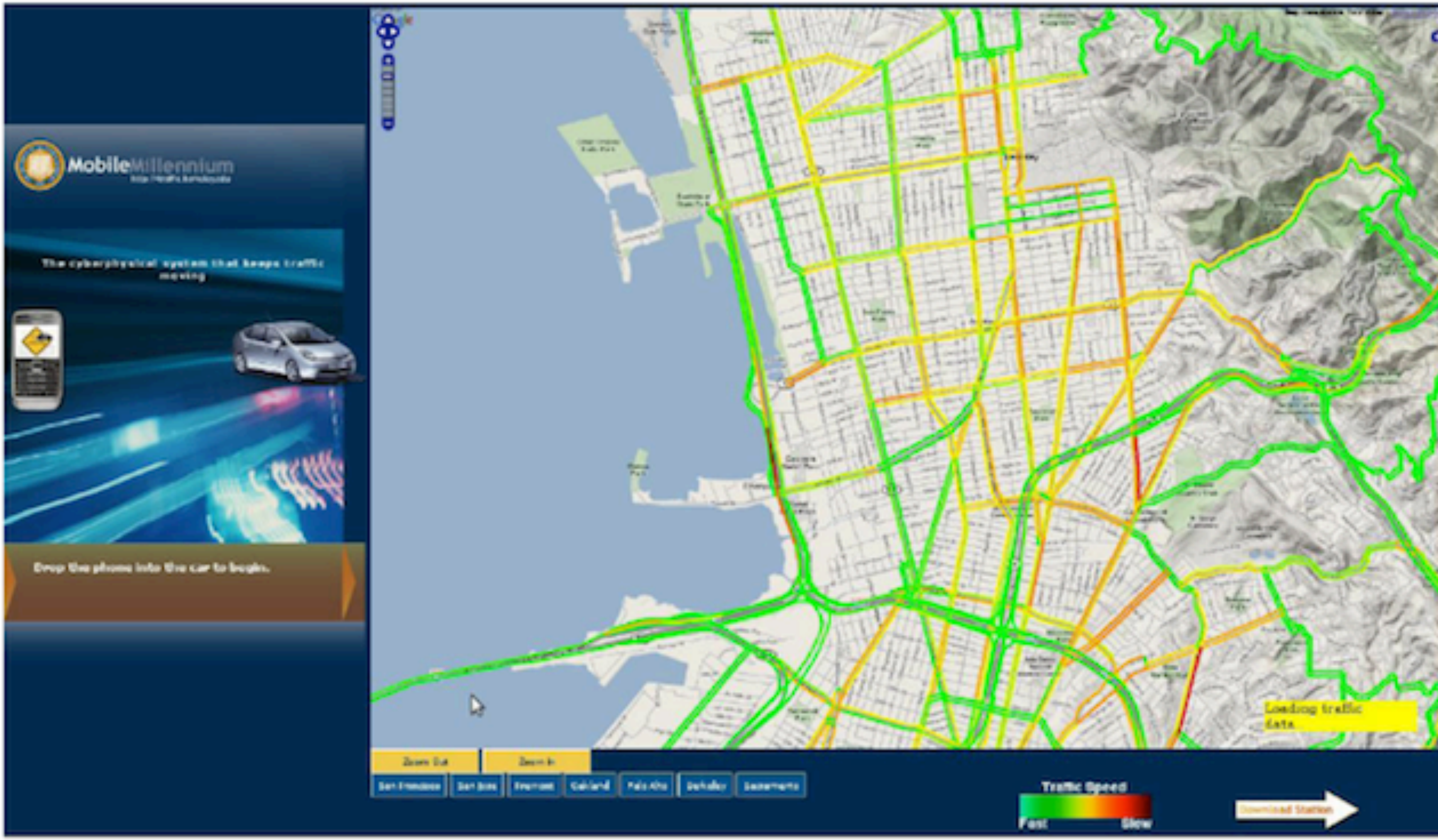
V2V communications require low-latency, high-reliability wireless at high speeds

CCC
Computing Community Consortium
Catalyst

RESEARCH CHALLENGE – V2I INTEROPERABILITY

CCC
Computing Community Consortium
Catalyst

3. CITY-SCALE DATA



Mobile Millenium, ITS, UC Berkeley

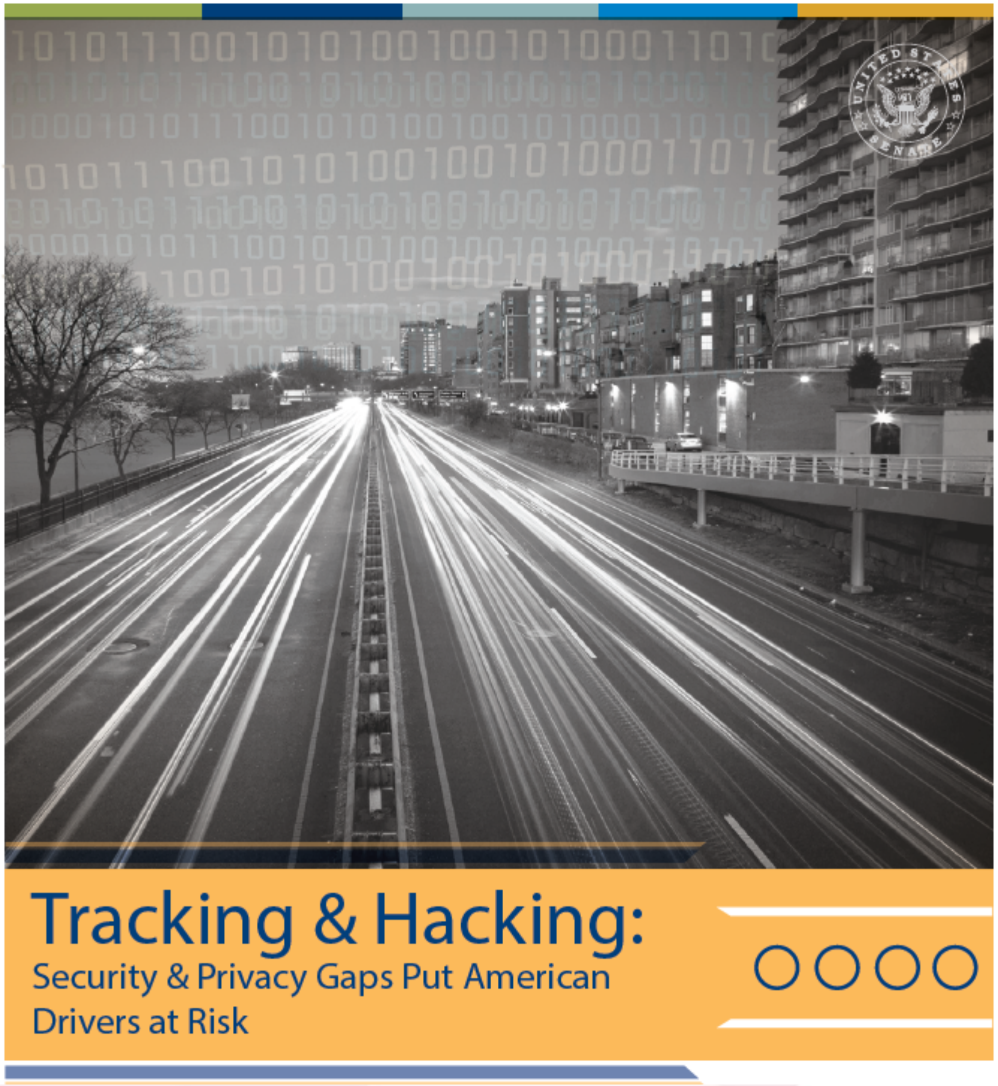
CCC
Computing Community Consortium
Catalyst

RESERCH CHALLENGE : DATA ANALYTICS

Fast machine learning with real-time, streaming physical data
Privacy-aware algorithms and computation over user/car data
Access and sharing of SmartCity and transportation data
Data ownership models (economy?) for transportation data

SmartBay Project, ITS, UC Berkeley

RESERCH CHALLENGE : DATA PRIVACY

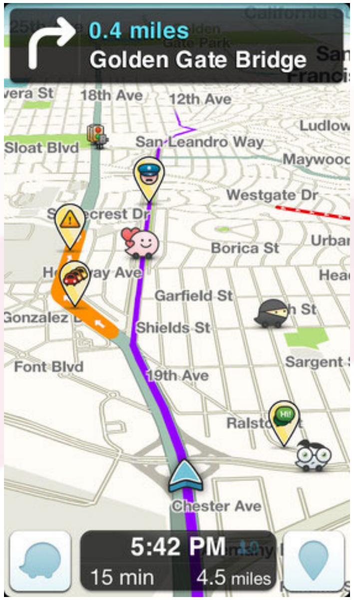


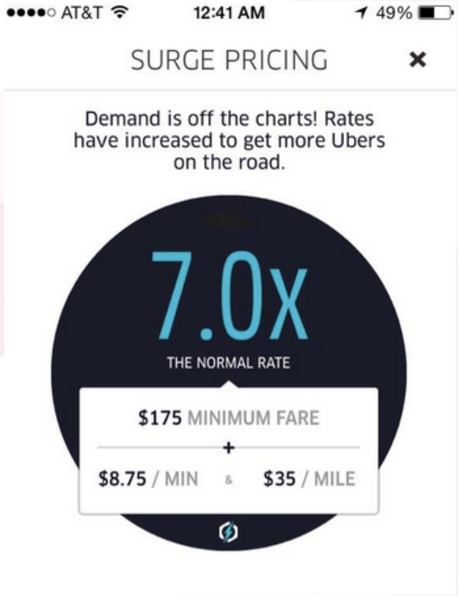
April 2015 Report by

Sen. Deb Fischer (Nebraska)
Sen. Cory Booker (New Jersey)
Sen. Kelly Ayotte (New Hamphsire)
Sen. Brian Schatz (Hawaii)

CCC
Computing Community Consortium
Catalyst

4. USER-AUTONOMY INTERACTION

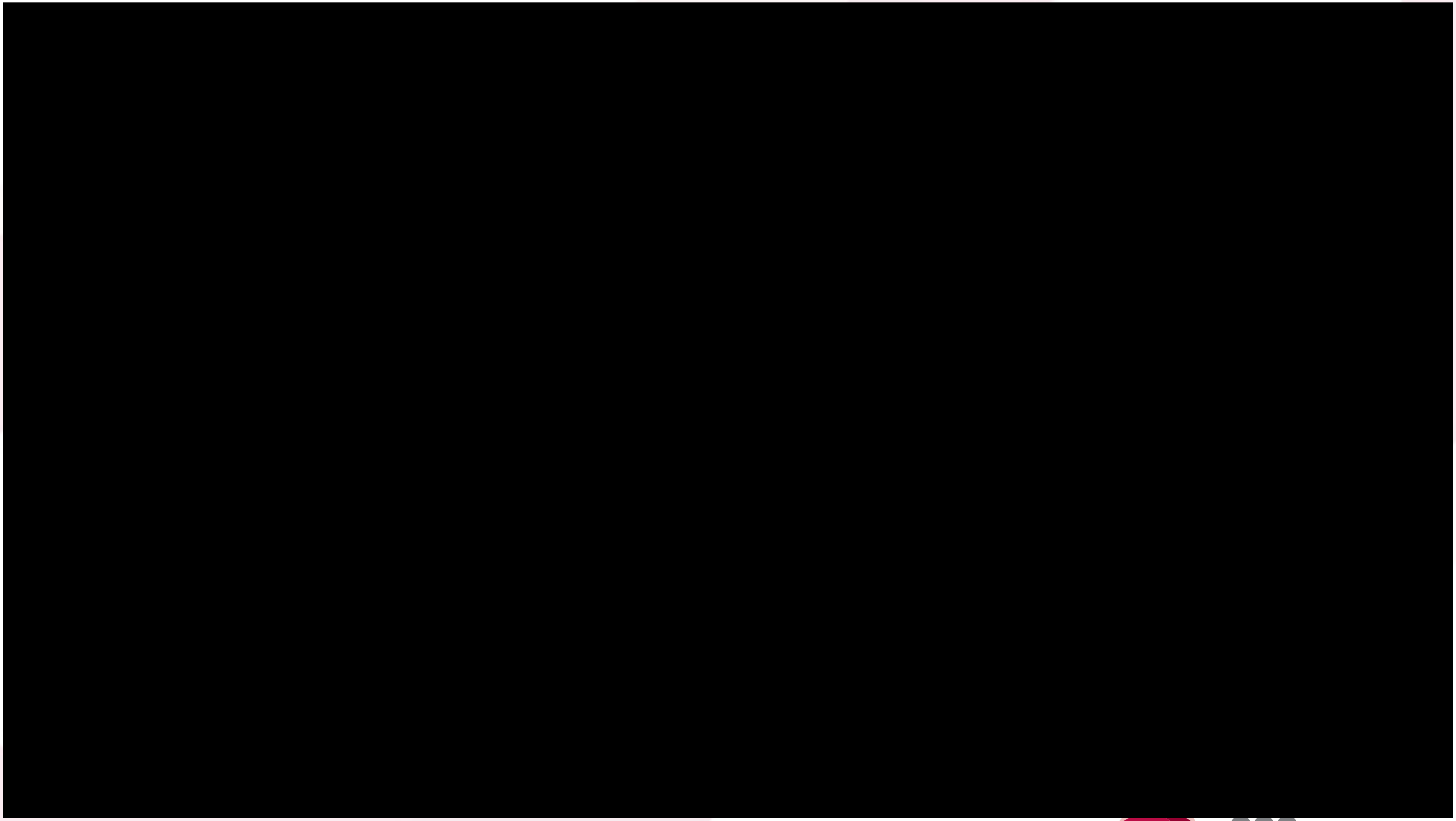




Users exploit richness of real-time data for safe and efficient routing
Mobility-as-a-service provides new ownership models, new incentives, new economics
Variable autonomy levels from human driver to fully autonomous
Distracted driving results in 9 deaths and 1,000 injuries every day in the U.S.

CCC
Computing Community Consortium
Catalyst

RESEARCH CHALLENGE – IMPACT OF USERS HAVING ACCESS TO NEW DATA SOURCES



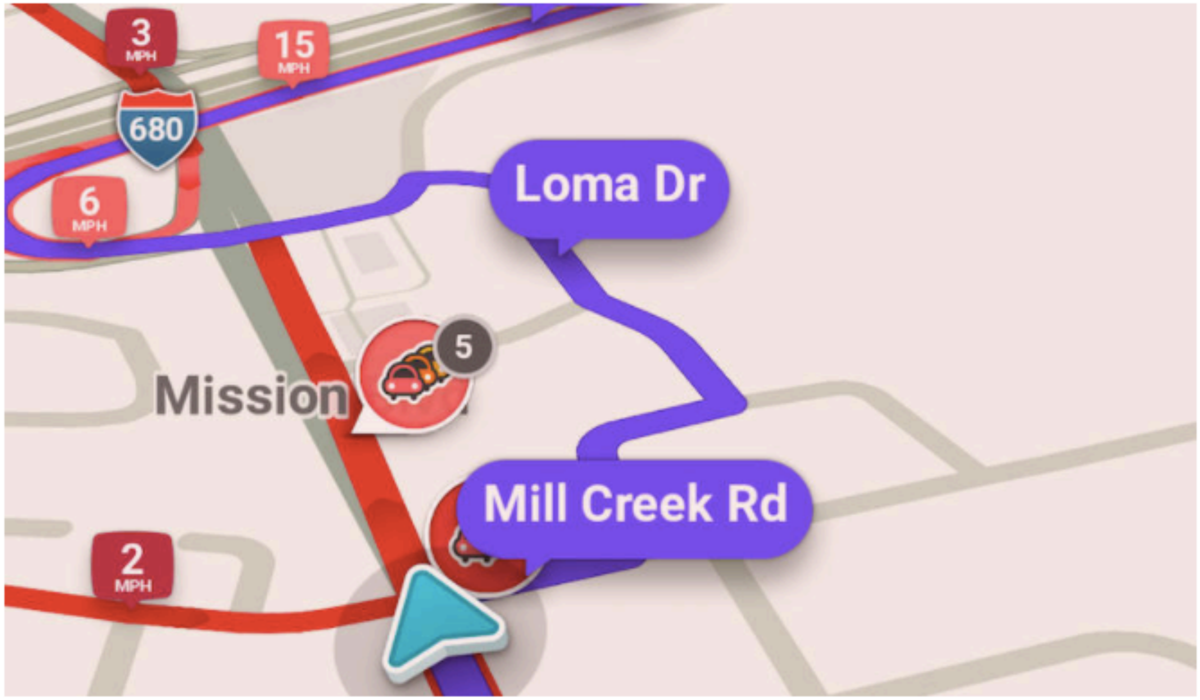
RESEARCH CHALLENGE – IMPACT OF USERS HAVING ACCESS TO NEW DATA SOURCES

Driving apps like Waze are creating new traffic problems

By ELI WIRTSCHAFTER • MAR 23, 2017

PROGRAM
Crosscurrents

Tweet
Share
Google+
Email



The app Waze suggests a circuitous route around traffic in Fremont. (Screenshot)

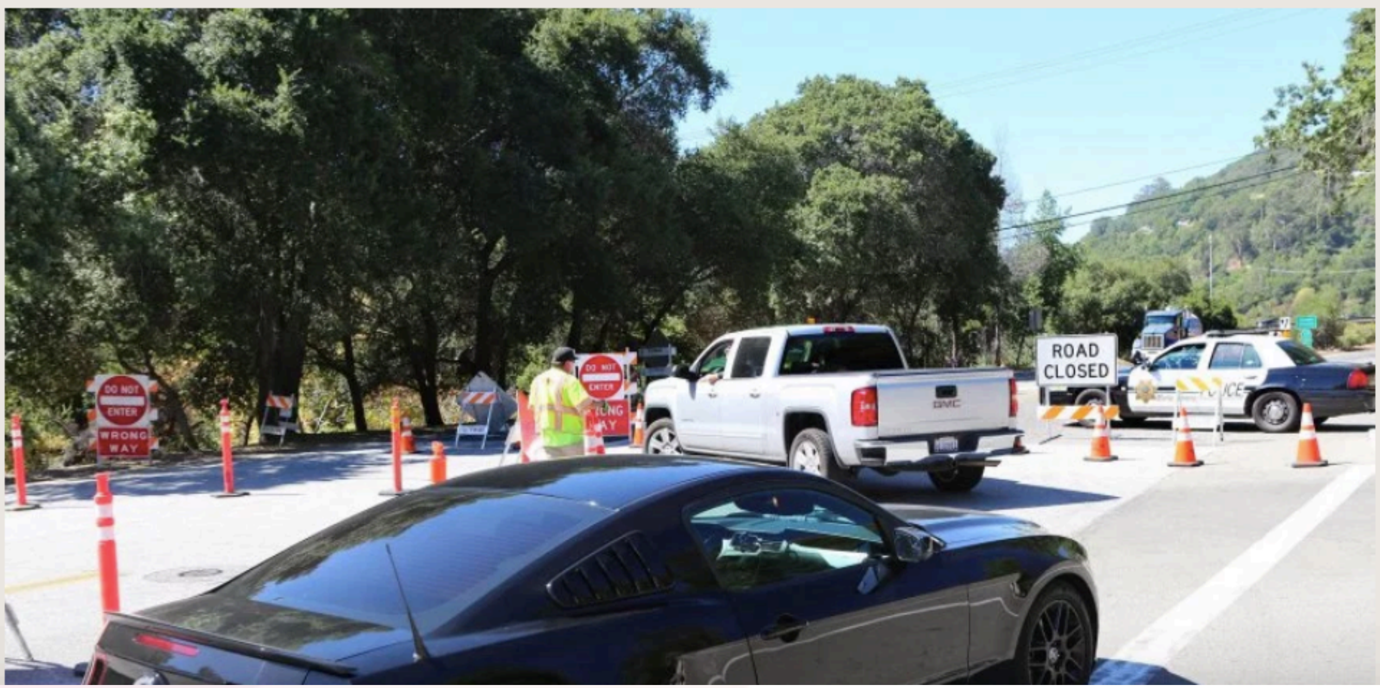
ELI WIRTSCHAFTER

RESEARCH CHALLENGE – IMPACT OF USERS HAVING ACCESS TO NEW DATA SOURCES

Driving apps like Waze are creating new traffic problems

News > Transportation

Roadshow: Stay off my street! Waze woes spreading to more cities



FINAL THOUGHTS

Opportunities across heterogeneous transportation/SmartCity modalities

- Data integration and optimization across biking, cars, subway, energy grid, etc

Research will require collaboration across many disciplines

- Computing, transportation, social scientists, economics, law, etc

Very limited research initiatives that holistically address these challenges

- DoT centers, NSF CPS, NSF S&AS, NSF Smart & Connected Communities

Transportation planning institutions are more reactive than proactive in planning for new technology and regulating/accommodating as necessary.

Partnerships between academic, government, city planners, and industry are critical

- Interoperability, standards, urban data access, data ownership, safety regulation, privacy norms, autonomy liability etc

Analyze skills and education requirements to facilitate new technical jobs for shared, autonomous and data-driven transportation. Rethink education across boundaries to prepare the workforce

CCC
Computing Community Consortium
Catalyst

RESEARCH CHALLENGE – WHO IS RESPONSIBLE FOR SAFETY WHEN TRAFFIC IS MIXED BETWEEN LEVEL 3 & CONVENTIONAL VEHICLES

	Driver:		Vehicle:		Physical Environment		Social Environment	
	Conventional:	Autonomous:	Conventional:	Autonomous:	Conventional:	Autonomous:	Conventional:	Autonomous:
Pre-Event (→ primary prevention)	Driving skill, experience, attention and physical/ mental state	Driver attention and re-engagement	Vehicle design & handling; anti-lock brakes; electronic stability control; vehicle condition	HAV computer and sensor capability; Sensors detecting ODD	Road design; road signs; speed limits; weather conditions	Presence and security of connected vehicle infrastructure	Existence and enforcement of traffic safety laws; traffic flow and congestion.	Market penetration of HAVs
During the event (→ secondary prevention)	Seatbelt use and occupant position	Brace position of driver	Advanced restraint systems; size of vehicle & its crash-worthiness.	Vehicle alert systems; Presence of "minimal risk condition" to reach safety after failure	Presence of trees, guardrails, etc.; Separated traffic	Speed of communications network to transmit messages	n/a	Mix of HAVs and conventional vehicles immediately proximate
Post-event (→ tertiary prevention)								

- **Haddon Matrix is for understanding responsibilities pre, during and post car crash**
- **Penn Researchers envisioned how the Haddon Matrix will have to change with mixed HAV and conventional vehicle traffic**

CCC
Computing Community Consortium
Catalyst

RESEARCH CHALLENGE – USER-ATONOMY INTERACTION

People Want to Interact -- Even with an Autonomous Car

Semcon's smiling car experiment shows pedestrians' fear of self-driving cars

By Kristen Hall-Geisler *September 21, 2016*