THE OHIO STATE UNIVERSITY

PNT in smart cities – are we ready for autonomous driving?

Dorota A. Grejner-Brzezinska
Satellite Positioning and Inertial Navigation (SPIN) Lab

IGNSS 2018, February 5-9, Sydney, Australia

Content

- Smart and connected communities/smart city
- Autonomous driving in a smart city
- Levels of autonomy
- Testing the performance of auton
- Are we there yet?
- Summary and conclusions

Smart city

- Smart Cities are those that have a base level of connectivity and integrated municipal services
- Cities built on *Smart* and *Intelligent* solutions and technology that will lead to the adoption of at least 5 of the 8 following smart parameters
  - smart energy
  - smart building
  - smart mobility
  - smart healthcare
  - smart infrastructure
  - smart technology
  - smart governance and
  - smart education, smart citizen

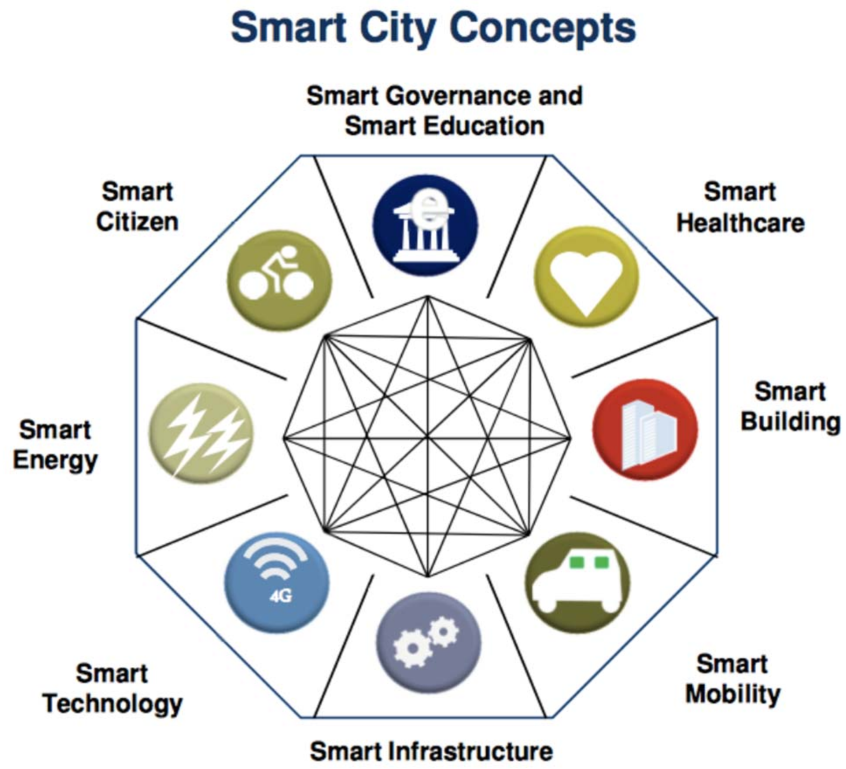
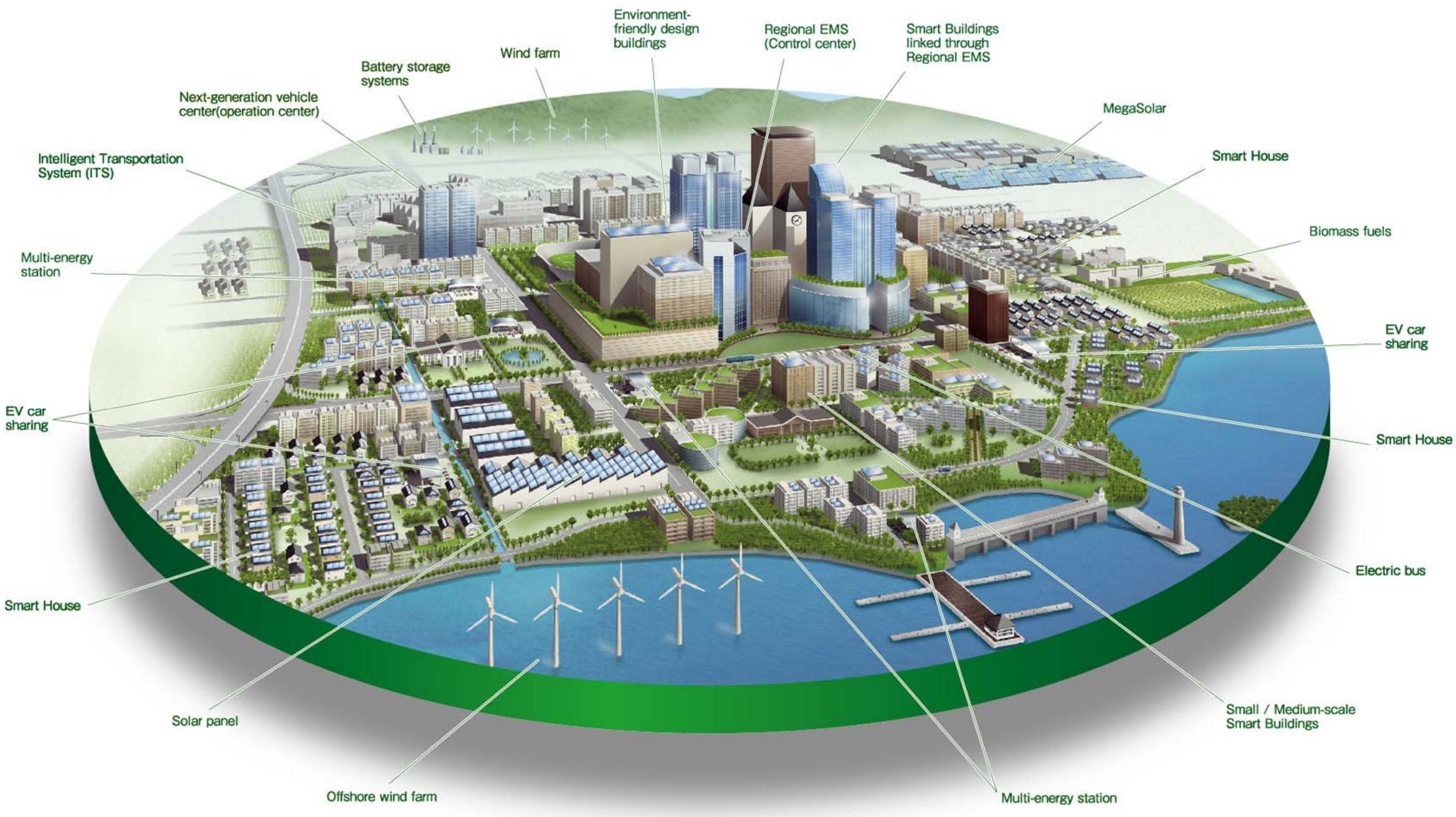


Image source:https://blog.realestate.cornell.edu/2017/03/09/is-digital-the-next-vertical-impact-of-smart-cities-on-real-estate/ Credit: www.frost.com

Smart city



- 26 smart cities are expected by 2025, 50% of which will be in Europe and North America
- At present: smart communities projects in many cities worldwide
- No smart city yet…Amsterdam, Barcelona, NYC, London, Nice, Singapore

Image source:https://blog.realestate.cornell.edu/2017/03/09/is-digital-the-next-vertical-impact-of-smart-cities-on-real-estate/

The Ohio State University

Six trends that will define smart cities in 2018

2017 TRENDS

- Ride-sharing services' growing influence
- Dockless bike-sharing
- Deliberate development
- P3s and municipal collaborations (P3s = public private partnerships)
- Local-level dependence
- Affordable housing plans
- Building smart cities from scratch

2018 TRENDS

- Equitable innovation
- Electric vehicle (EV) infrastructure expansion
- 5G technology
- Cybersecurity
- Blockchain
- Microtransit

https://www.smartcitiesdive.com/news/6-trends-that-will-define-smart-cities-in-2018/513889/

Dockless Lime Bike in San Francisco. Credit: Lime Bike

What is smart mobility?

- Advanced traffic management system (ATMS)
- Parking management
- ITS-enable transportation pricing system
- Connected vehicles/cooperative navigatio
- Autonomous vehicles
- Electric vehicles
- Shared rides
- Integrated multimodal transportation s
- Goals
  - low emissions and low carbon footprint
  - low or no congestion = more efficient a
  - no accidents and fatalities

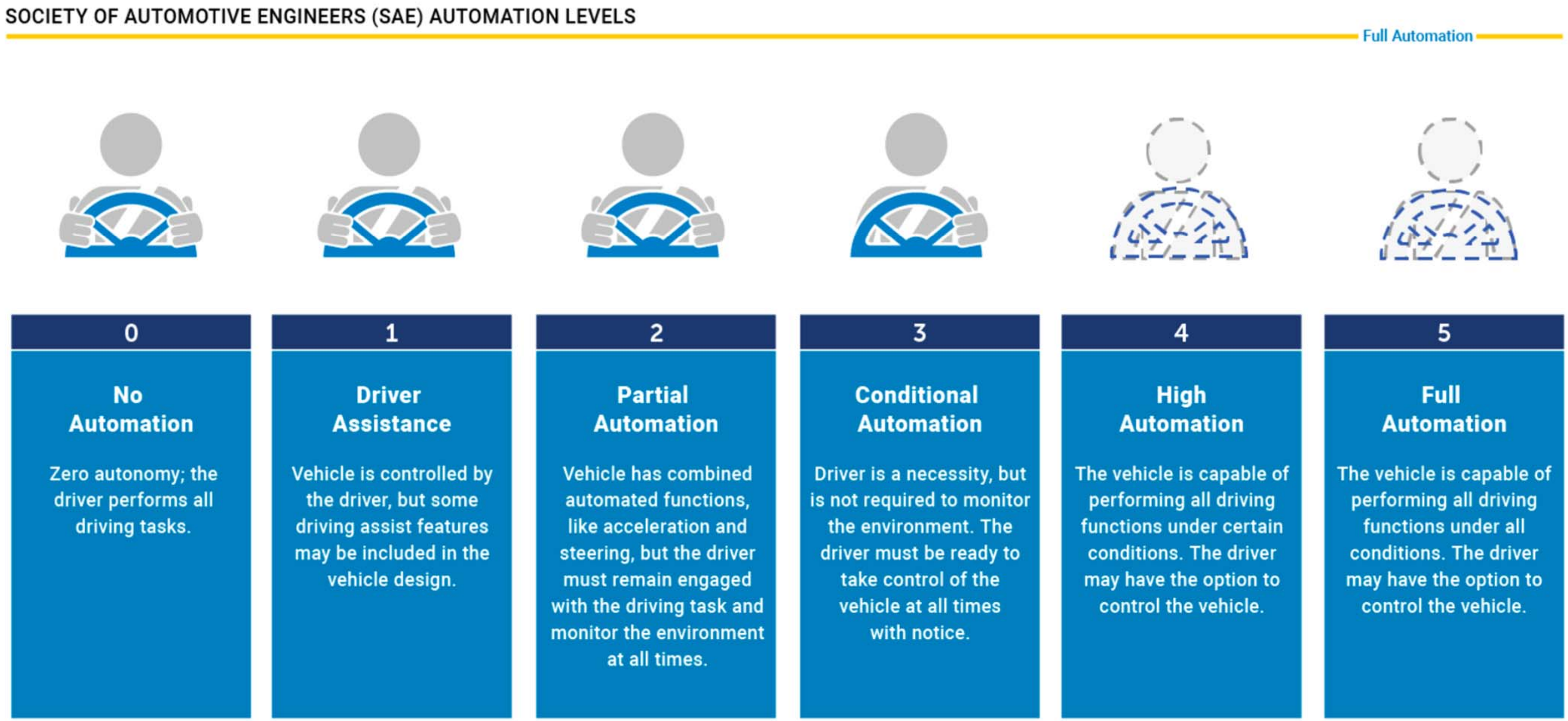
Self-driving cars: motivation

- According to the Global Road Crash Data, traffic crashes are the major cause of death and injuries worldwide
  - ✓ ~1.3 million fatalities/year, on average 3,2[illegible] fatalities/day
- In the US alone, there are over 37,000 fataliti
  injuries in road crashes each year
  - ✓ of these, 94% are caused by human err
- The cost of traffic crashes is incredibly hig
  - ✓ $518 billion globally and $230.6 billior
  - ✓ Unless action is taken, traffic crashe
    leading cause of death by 2030
- Traffic congestion and parking are incr
- Aging population

THE OHIO STATE UNIVERSITY

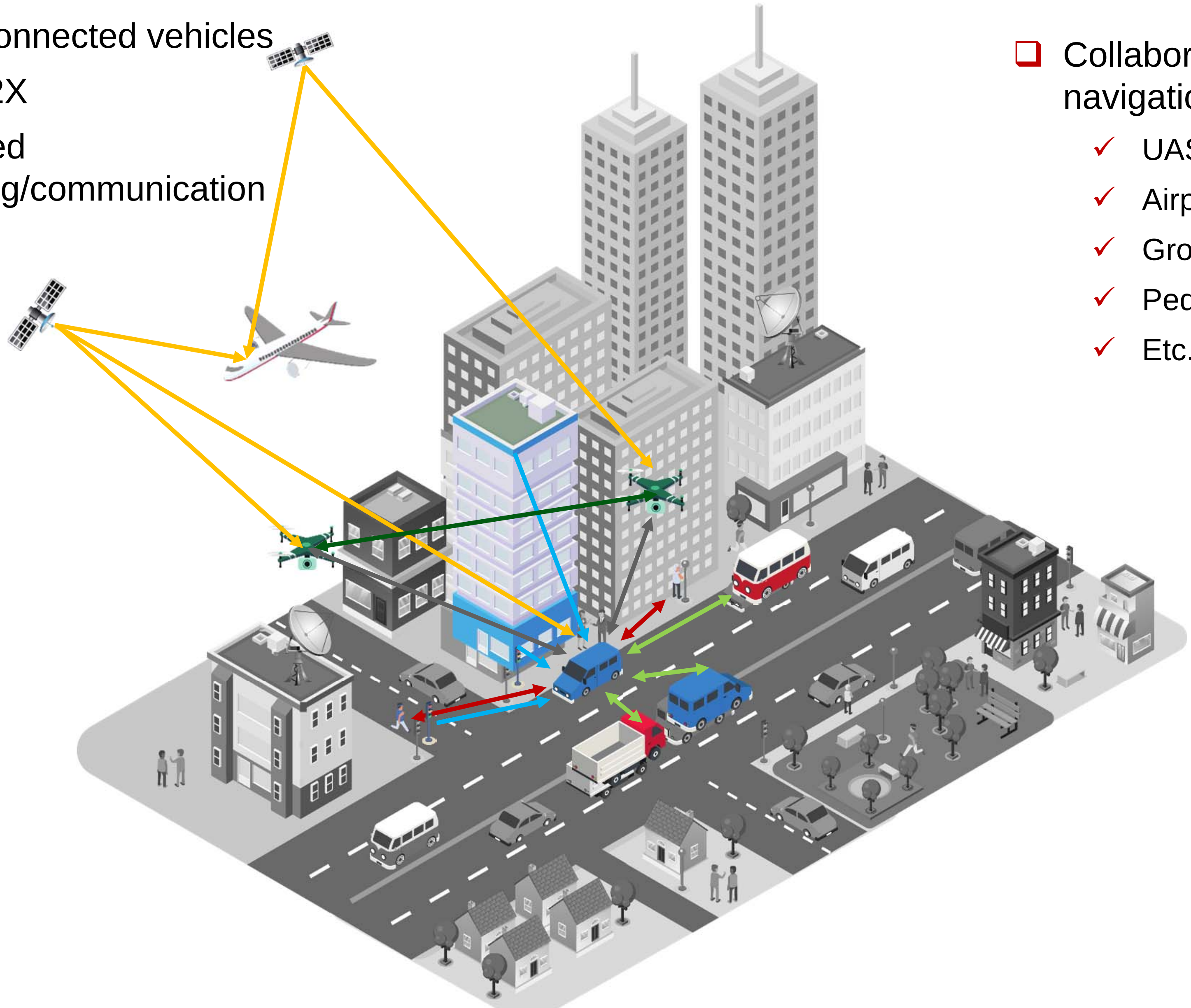
Solution: autonomous driving?

- Driverless technology is rapidly evolving
- High-definition geospatial data + PNT: enablers of high-accuracy localization and better safety
- Crowdsourcing: becoming a dominant data acquisition technology (Big Data, Big Geo Data)
- Communication: crucial aspect!
- Full autonomy… is still a long way



But wait, there is more….

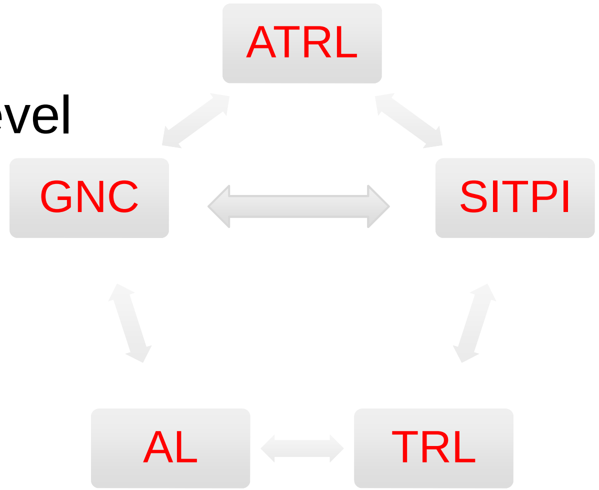
- V2V/connected vehicles
- V2I/V2X
- Layered sensing/communication



- Collaborative navigation
  - ✓ UAS
  - ✓ Airplanes
  - ✓ Ground vehicles
  - ✓ Pedestrians
  - ✓ Etc.

Are we ready for autonomy?

- Autonomy level (AL) ↔ Guidance, Navigation and Control (GNC)
- Technology readiness level (TRL) ↔ System integration, testing, performance evaluation, integrity monitoring (SITPI)
- GNC ↔ SITPI
- ATRL = Autonomy and Technical Readiness Level
- Environmental complexity
- Task complexity
- Ethical, legal and societal implications
- Policy, etc….
- GOAL: implement a safe, efficient and robust system for individual, civil and commercial applications



source: http://www.mdpi.com/2504-446X/1/1/5. Akash Vidyadharan et al., 2017

Are we ready for autonomy?

Level	Autonomy level	Technology readiness level
1	Remote control	Basic principles
2	Automatic motion control	Application formation
3	System fault adaptive	Technology concepts & research
4	GPS assisted navigation	Tech development & proof of concept
5	Path planning & execution	Low fidelity/laboratory component testing
6	Real time path planning	System integration & testing
7	Dynamic mission planning	Prototype demonstration & operation
8	Real time collaborative mission planning	Prototype operation in realistic mission scenario
9	Swarm group decision making	Mission deployment
10	Full autonomous	Fully operational status

source: http://www.mdpi.com/2504-446X/1/1/5. Akash Vidyadharan et al., 2017

Self-driving cars: scoring system

- Since 2015, Navigant has scored the 20-or-so companies working on self-driving technology on 10 different criteria related to strategy, manufacturing, and execution
  - ✓ How good is their technology?
  - ✓ Can they manufacture it at scale?
  - ✓ What's their plan for getting it to the masses?
- After that, Navigant ranks the companies in four categories:
  - ✓ Leaders
  - ✓ Contenders
  - ✓ Challengers, and
  - ✓ Followers


Image Credit: Tesla

Source: https://www.theverge.com/2018/1/16/16893452/detroit-auto-show-2018-google-gm-waymo-ford-tesla

Self-driving cars: scoring system

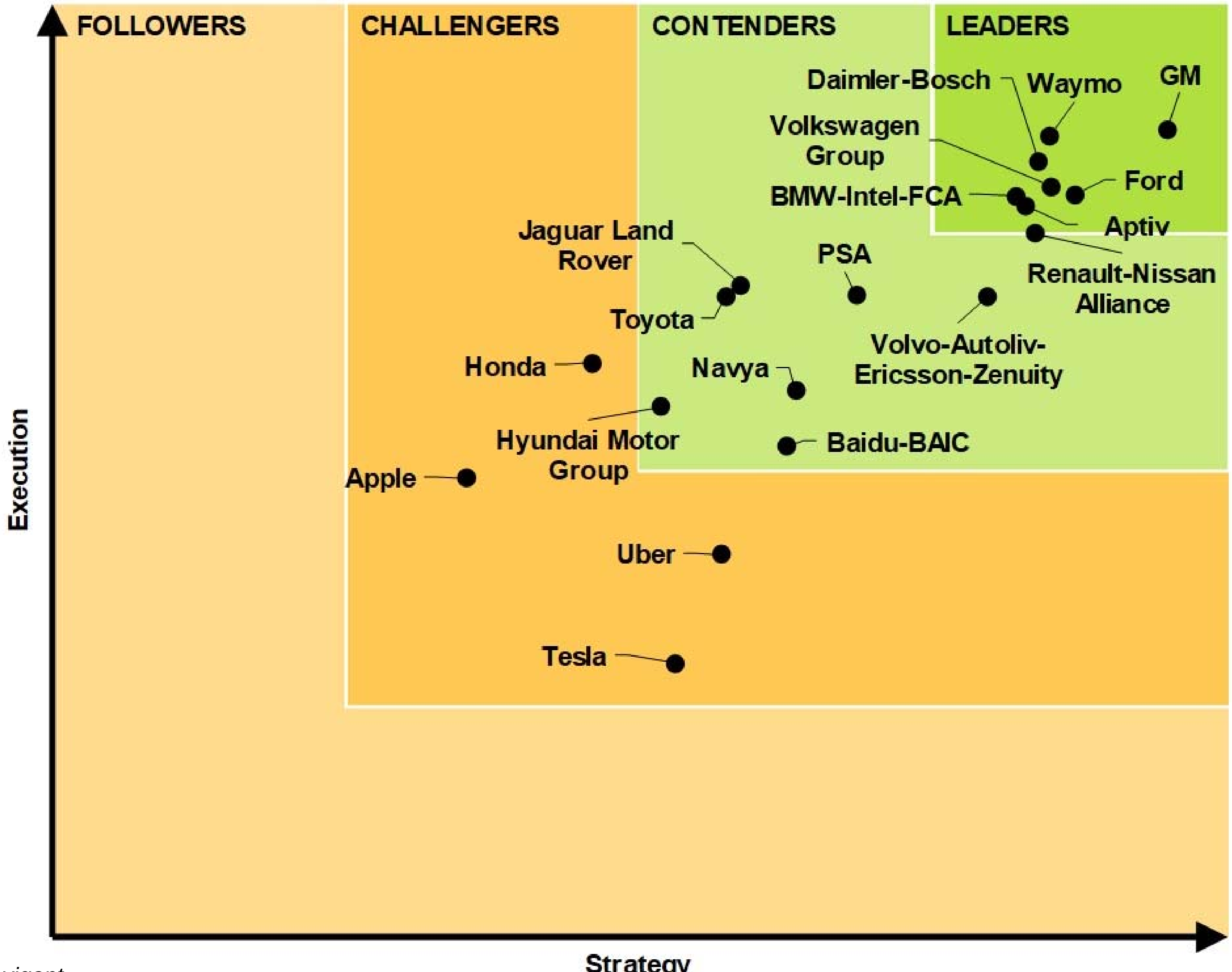


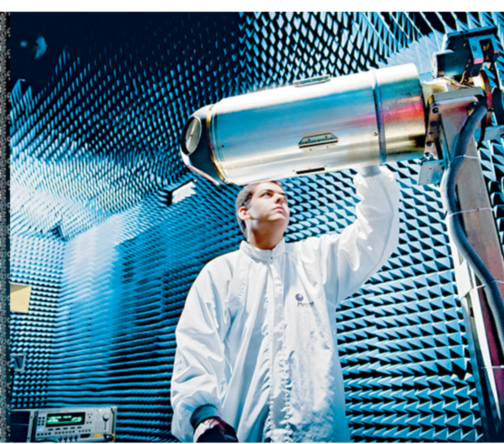
Image: Navigant

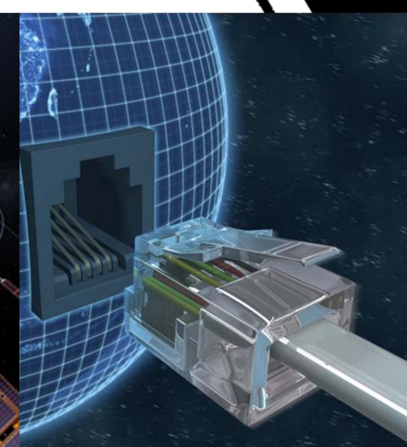
THE OHIO STATE UNIVERSITY

GNSS Market Report | Issue 5, 2017

PNT in smart cities supports many emerging applications

- **GNSS/PNT** has become an essential element of major contemporary technology developments notably including the ***IoT, Big Data, Augmented Reality, Smart Cities and Multimodal Logistics***
- In turn, the advent of ***5G, Automated Driving, Smart Cities and the IoT*** will accelerate further proliferation and dive GNSS-enabled added-value services
  - ✓ Their annual revenues will hit $225 bln in 2025 higher than the expected GNSS device and s ***within, across and beyond conventional G***

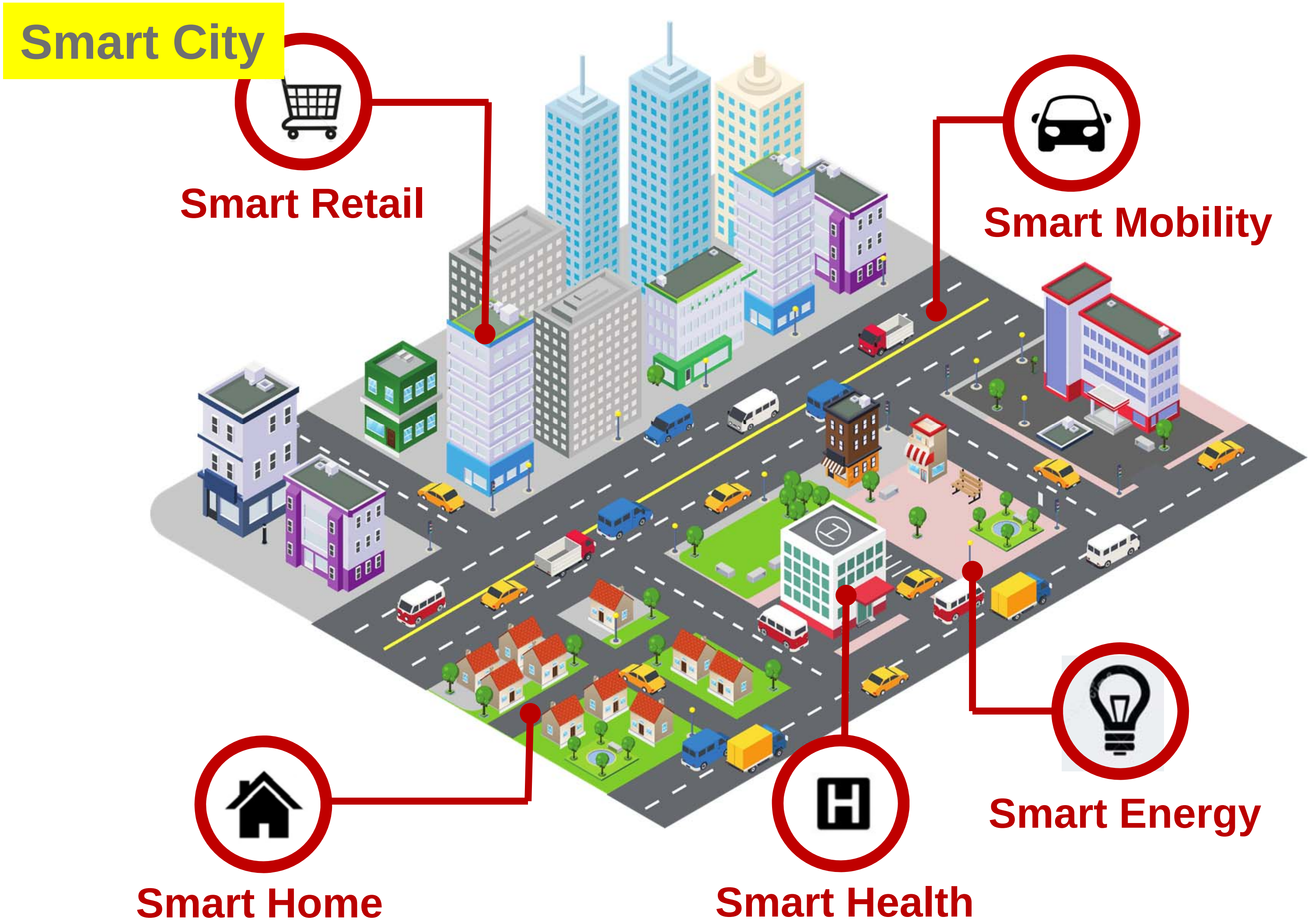




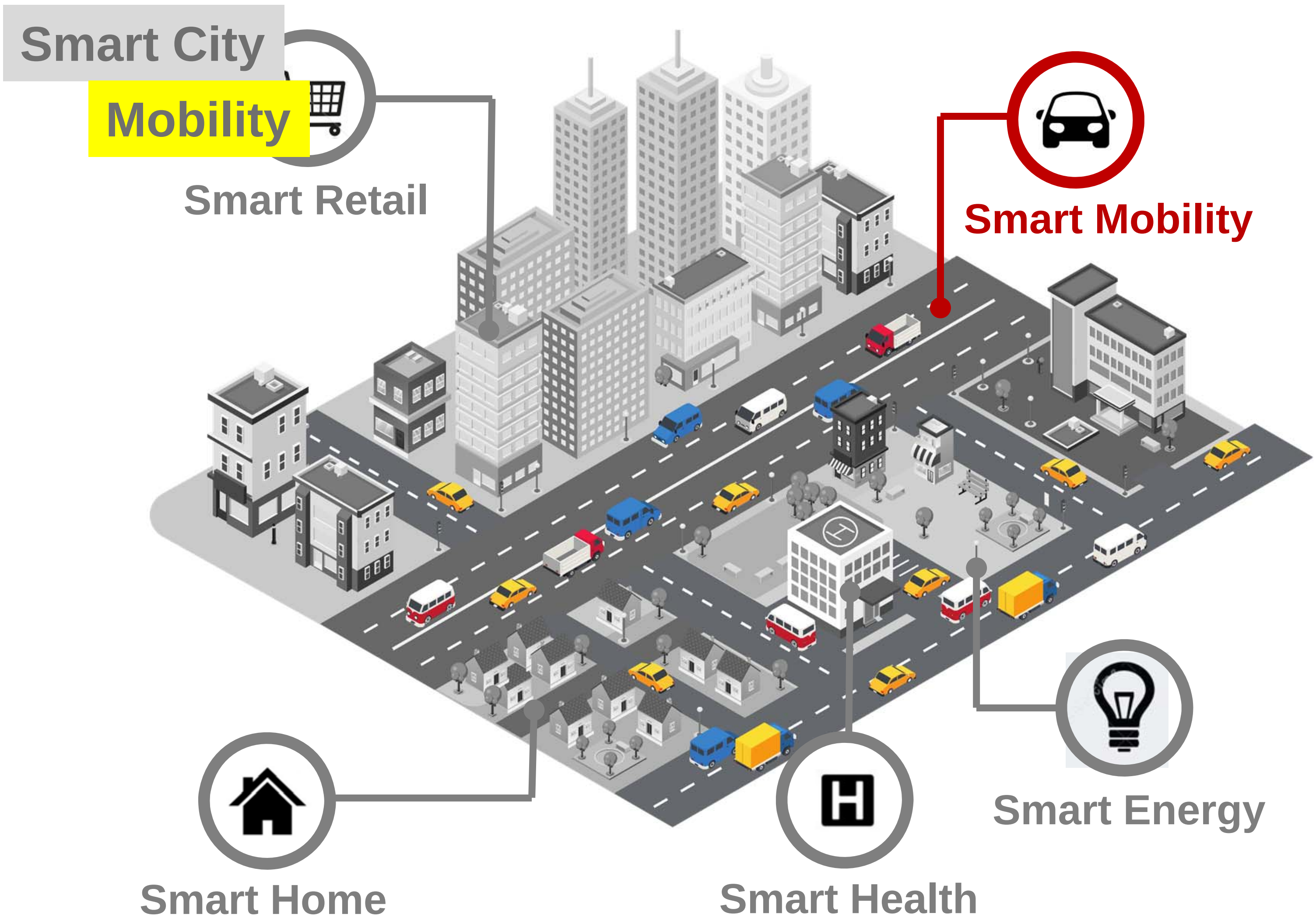
PNT in smart cities supports many emerging applications

- Aside from providing navigation solution to self-driving cars, GNSS/PNT offers numerous opportunities to:
  - **plan** new infrastructure and improve the existing one based on measuring traffic flows – e.g. longitudinal tr data informing future infrastructure investment d
  - **decrease** CO_2 emissions coming from the vehicles – e.g. smart bus stops and effici lights
  - **ensure** safety based on citizens' report e.g. combining citizens' emergency rep
  - **improve** infrastructure monitoring, op intervals and reduce the costs for upk on the use of bridges and sensor-pr elements.

Geospatial technology/PNT and autonomy

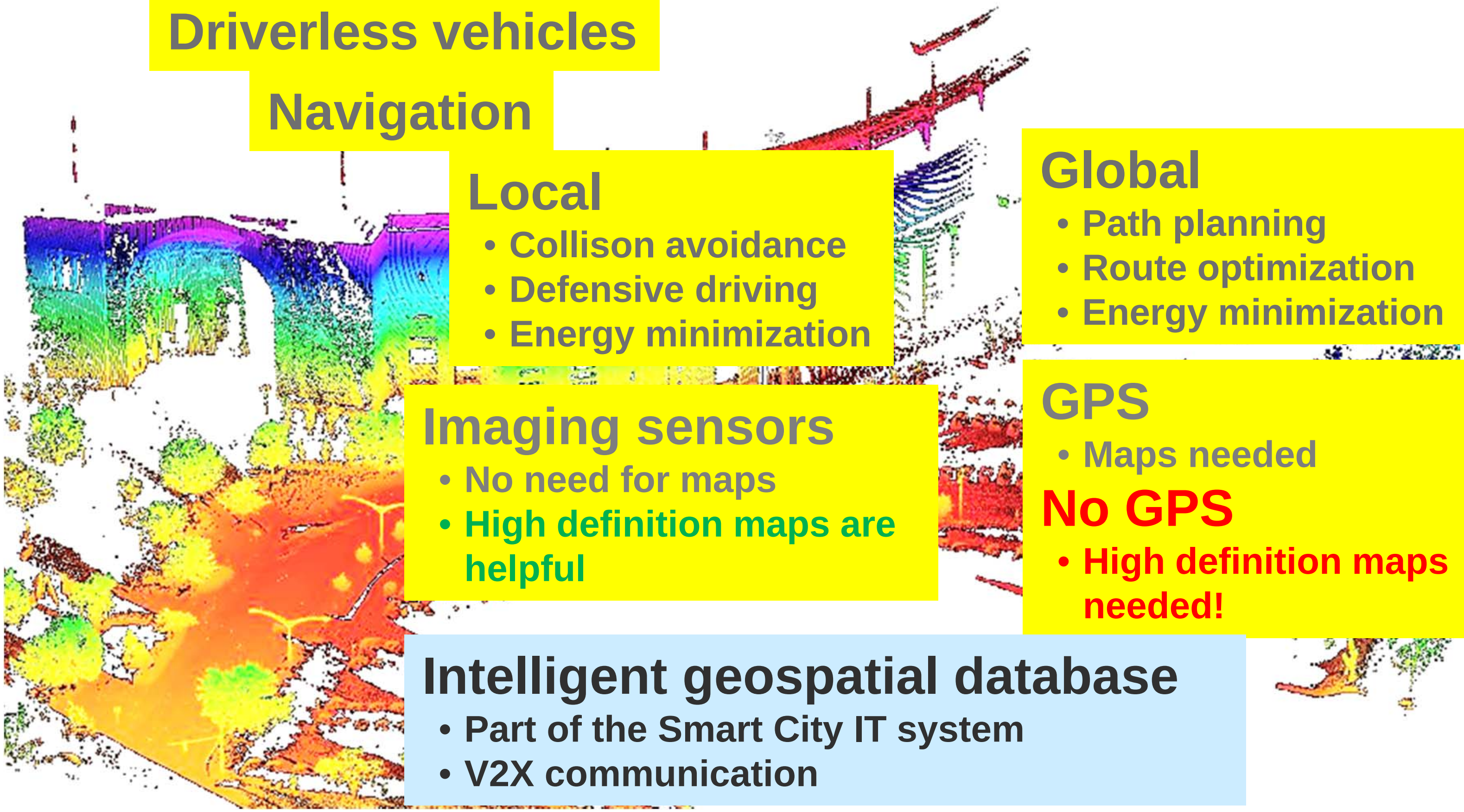


Geospatial technology/PNT and autonomy



THE OHIO STATE UNIVERSITY

Geospatial technology/PNT and autonomy



Smart City

Mobility

Driverless vehicles

Navigation

Local
- Collison avoidance
- Defensive driving
- Energy minimization

Global
- Path planning
- Route optimization
- Energy minimization

Imaging sensors
- No need for maps
- High definition maps are helpful

GPS
- Maps needed

No GPS
- High definition maps needed!

Intelligent geospatial database
- Part of the Smart City IT system
- V2X communication

Vehicle localization

Localization accuracy required by autonomous driving:

- High accuracy: 3-10 cm
- Single frequency GPS is not enough (2-5 m)
- More complex GPS/GNSS processing requ
special infrastructure (RTK, PPP)
- “Urban canyon effect” still a problem
- Commercial grade IMUs suffer from larg
grade IMUs are still expensive

Solution:

- Map matching algorithms: reliable an
- Map matching requires precise *a pri*

Testing autonomous vehicles’ performance

- ✓ Growing developments in autonomous vehicle technology call for accurate, reliable and robust ground reference
- ✓ Post-processed GNSS/IMU data are generally used to generate reference 6DOF trajectory
  - Assessment of localization and mapping results
- ✓ 3D object detection and tracking, as well as semantic segmentation of the driving environment must also be tested
  - ✓ Fully georeferenced omnidirectional vision and LiDAR, Radar etc. data are used to generate reference benchmark environment

Image, NovAtel Apollo: http://gpsworld.com/sponsoredcontent/accurate-ground-truth-for-autonomous-vehicles/

Autonomous driving: requirements

- ✓ Full situational awareness of the vehicles in the system: sensing, navigation, communication (V2V, V2I/V2X)
  - Requires added infrastructure, however, the a ...omous system must still be able to function correctly when r... available
  - High cost
- ✓ Reliability, accuracy, coverage and se... navigation systems
  - Standards and performance requiremen... hardware, and differential services mus... autonomous vehicle
  - Increase accuracy of lower cost platfo... frequency, multi-constellation sensor... positioning

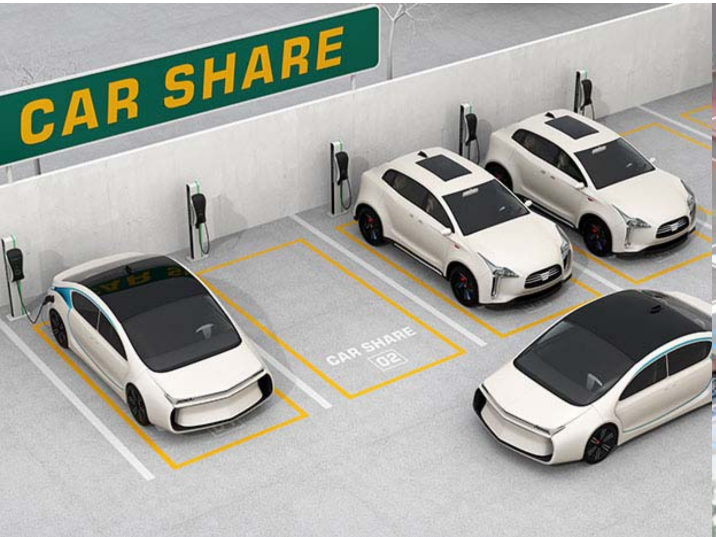
THE OHIO STATE UNIVERSITY

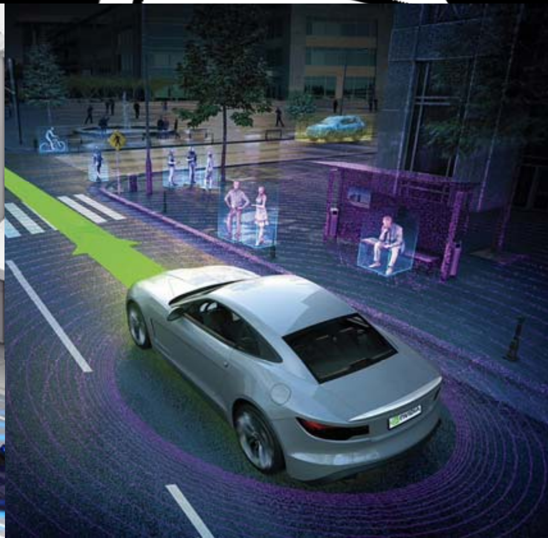
Autonomous driving: requirements

- ✓ Reliability, accuracy, coverage and security of the navigation systems (cont.)
  - Ability to rely on GNSS in auto-guidance applications requires incorporation of integrity functic … GNSS products
  - GNSS alone will not meet all of these s… due to signal attenuation, interference…
  - IMUs, LiDARs, Radars, cameras, acc… ambient signals of opportunity, such… digital TV must augment GNSS
    - Cost? Complexity? Reliability?
  - Collaborative real-time tracking me… assure reliable navigation when a… *driving network* malfunctions

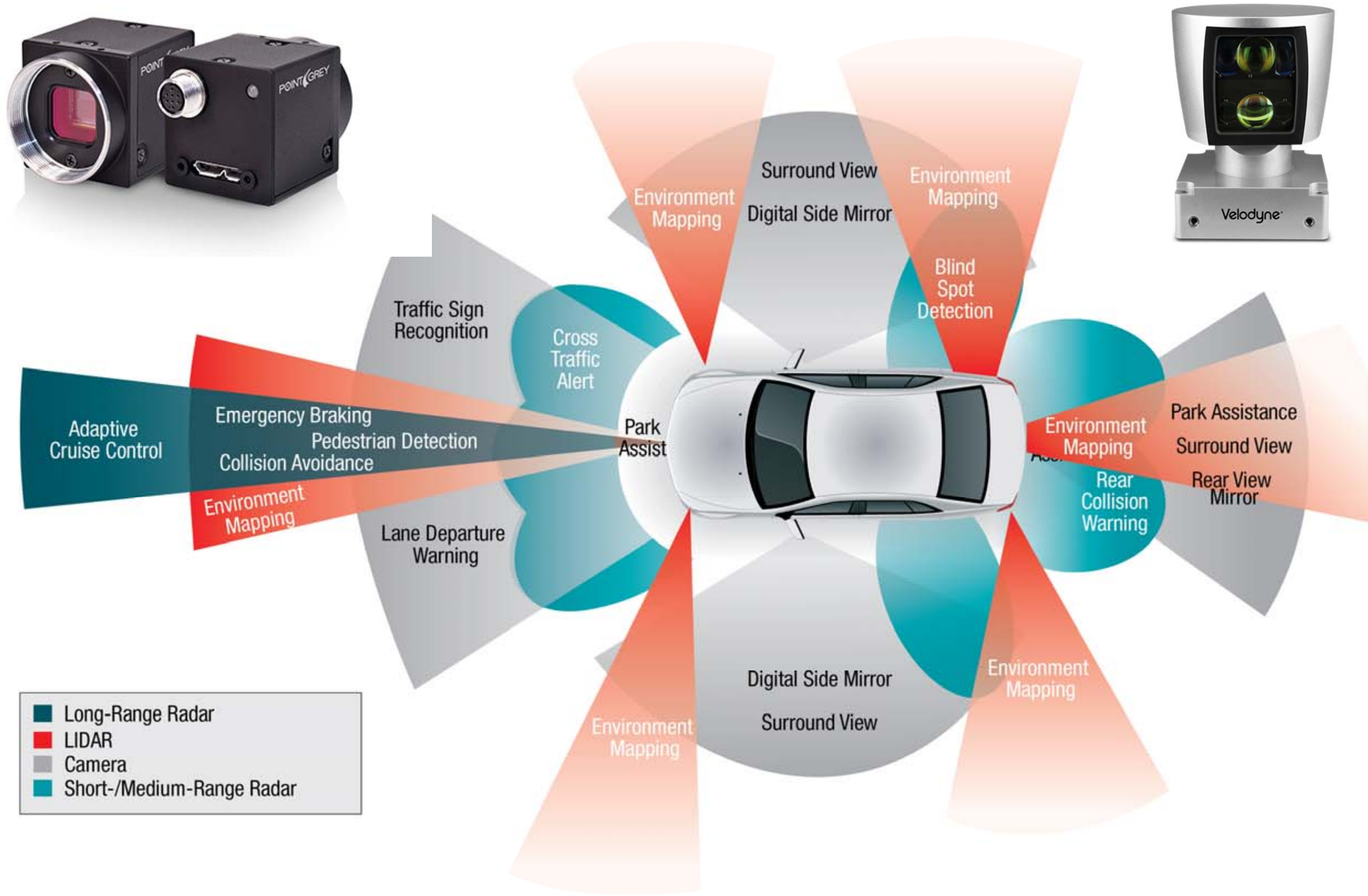
Autonomous driving: requirements

- ✓ Equally crucial is the requirement to develop new safety standards for new motor vehicles and motor vehicle equipment, and
- ✓ To modify existing standards as necessary changing circumstances such as the intro technologies and modes of mobility

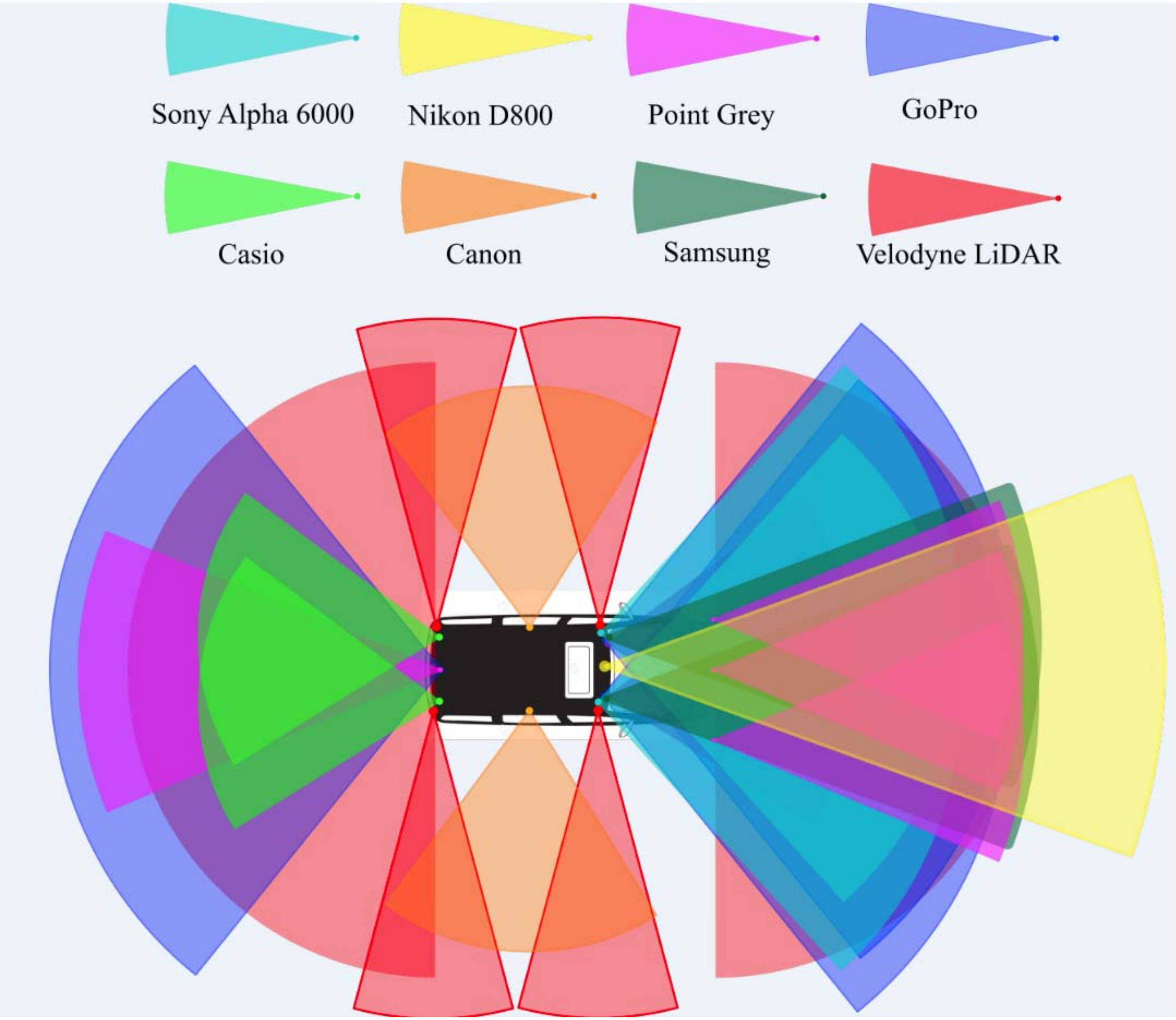




Sensors


POINT GREY
POINT GREY
Velodyne
Surround View
Digital Side Mirror
Environment Mapping
Environment Mapping
Blind Spot Detection
Traffic Sign Recognition
Cross Traffic Alert
Adaptive Cruise Control
Emergency Braking
Pedestrian Detection
Collision Avoidance
Environment Mapping
Park Assist
Lane Departure Warning
Environment Mapping
Rear Collision Warning
Park Assistance
Surround View
Rear View Mirror
Digital Side Mirror
Surround View
Environment Mapping
Environment Mapping
Long-Range Radar
LIDAR
Camera
Short-/Medium-Range Radar

Sensors: OSU vehicle

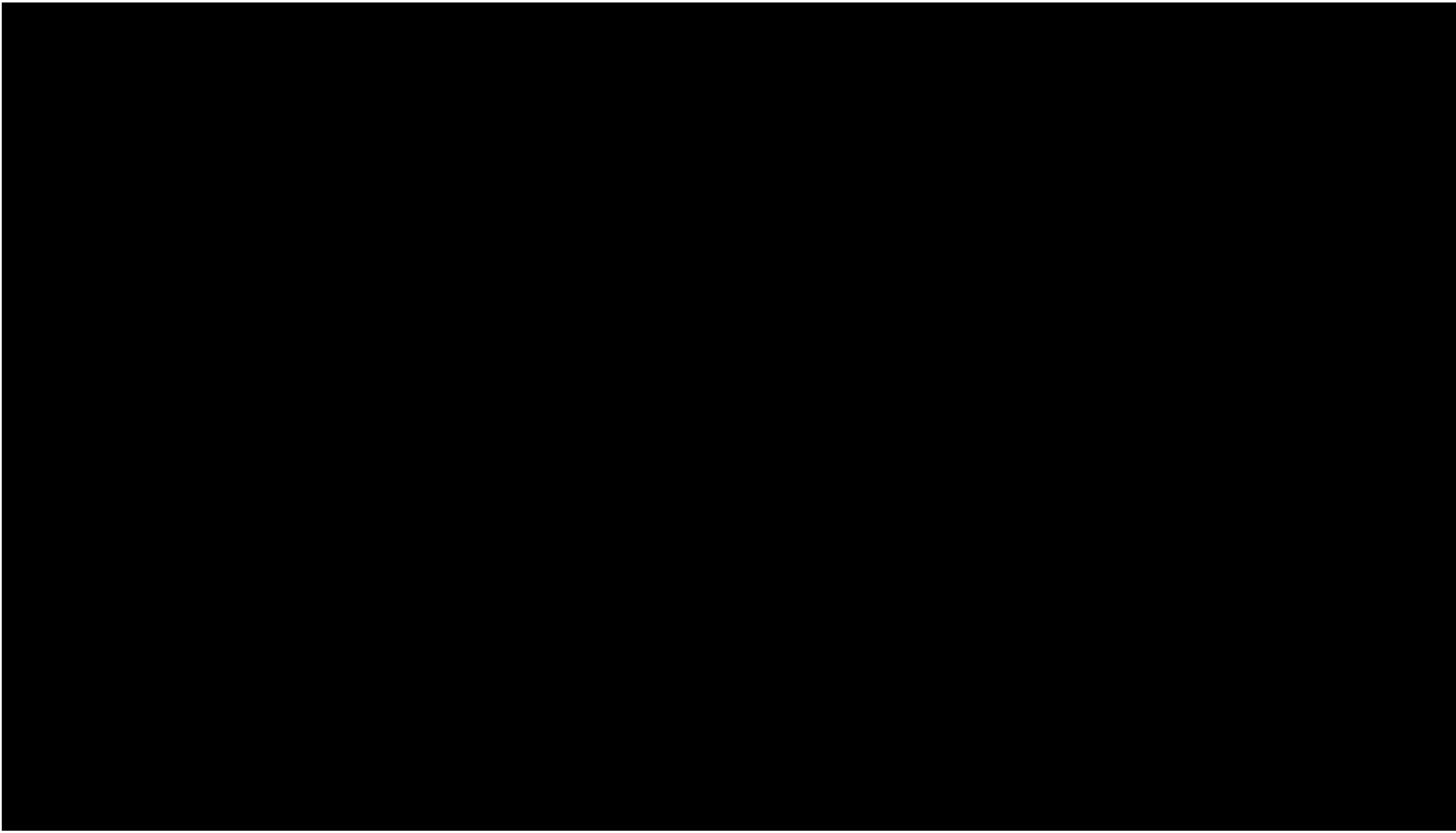


GPSVan is a general sensor platform with highly accurate georeferencing system
Data acquisition capabilities to support

- Creating accurate high-definition maps
- Providing sensor data streams to support driverless vehicle technology research

Sensors: various data streams

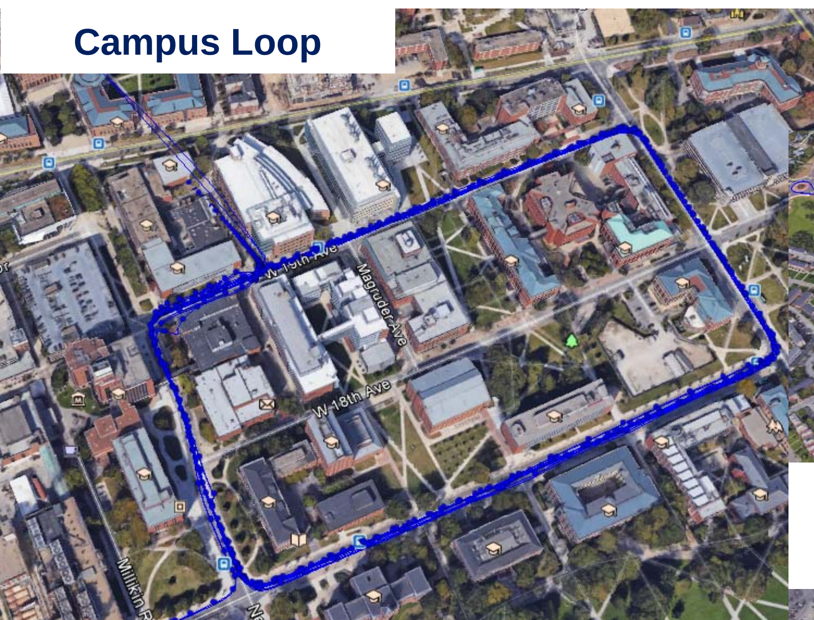
Collaborative navigation without maps



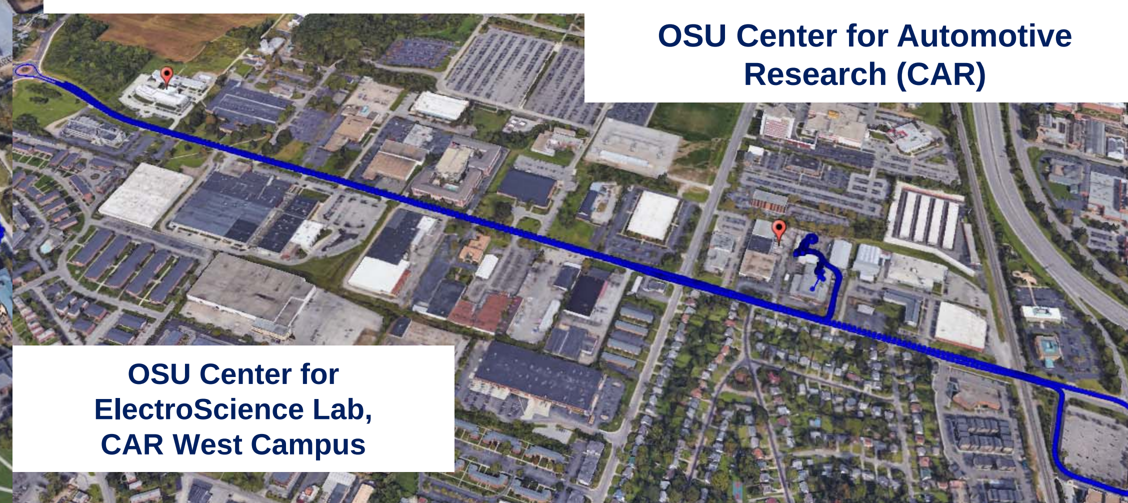
KITTI data, widely used benchmark, SPIN Lab CDD/IMU/SLAM solution

Test data for autonomous mobility

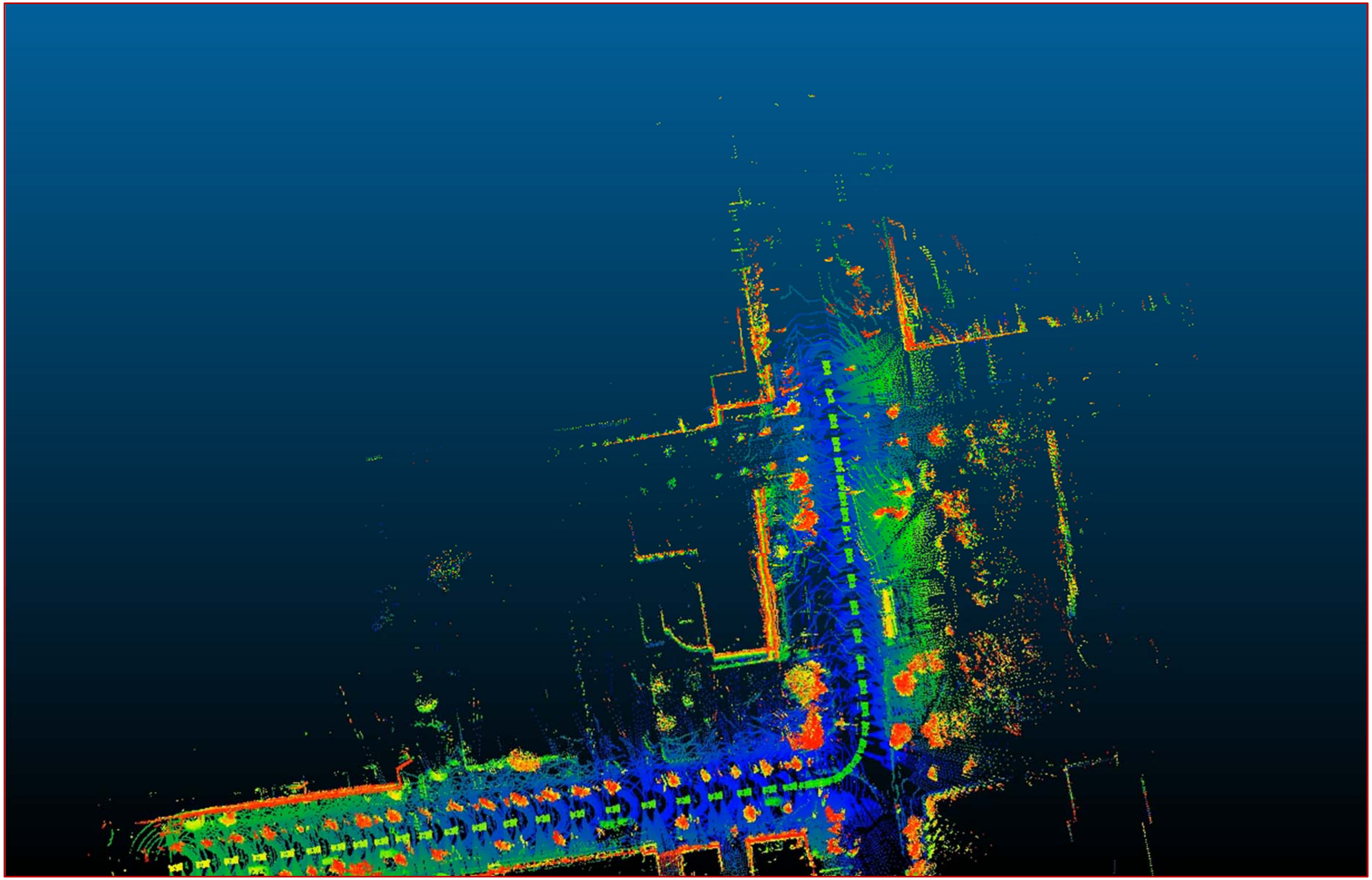
- OSU Campus benchmark dataset for autonomous vehicle testing
  - Acquire data streams from mobile platforms, including vehicles, bicycles, pedestrians, etc.
    - ✓ Essential to testing vehicle sensing and maneuvering capabilities
  - Create a high-definition map of the test area using mobile data collection and additional surveying of the area for benchmarking
  - Test the potential of Big Data/Data Analytics technology for map production based on highly redundant multi-sensor data, including crowdsourcing.



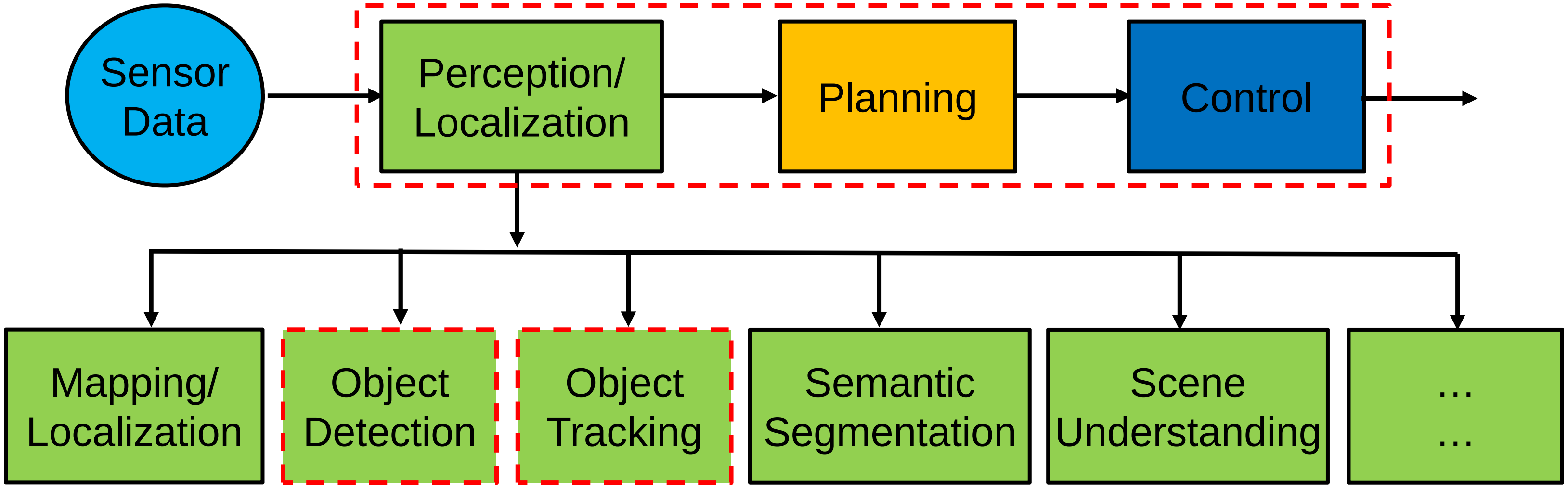
Total Data Acquired	**6 hr (5 TB)**



Object space reconstruction: all LiDAR data



OSU's autonomous navigation system architecture

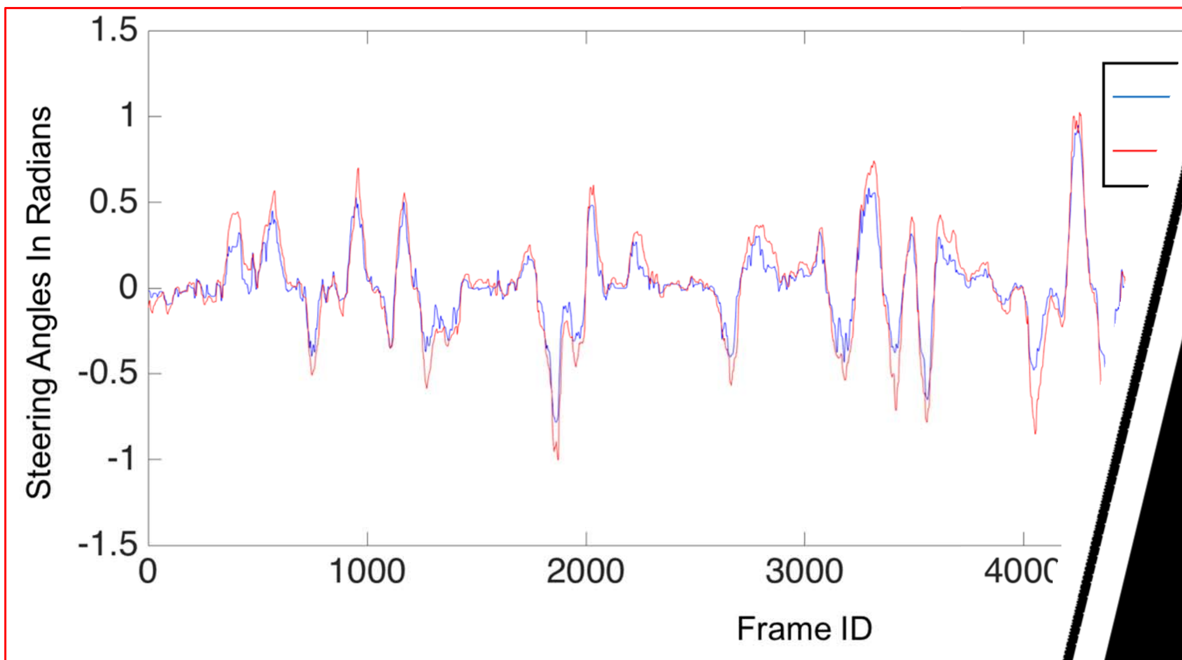


- Dynamic object detection on the road
- Video object detection for multiple object tracking
- End to end learning for vehicle control
- ***Deep learning***: machine learning approach that allows the computer to learn multiple levels of representation and abstraction from the data such as image, sound, and text
- Artificial Neural Network is at the core of deep learning

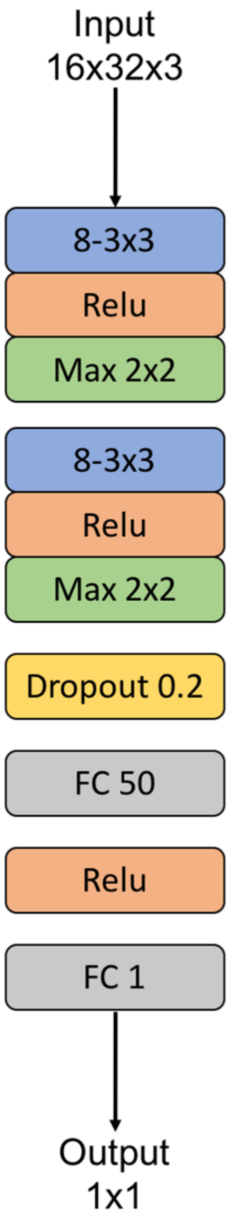
Example: steering angle fit to ground truth

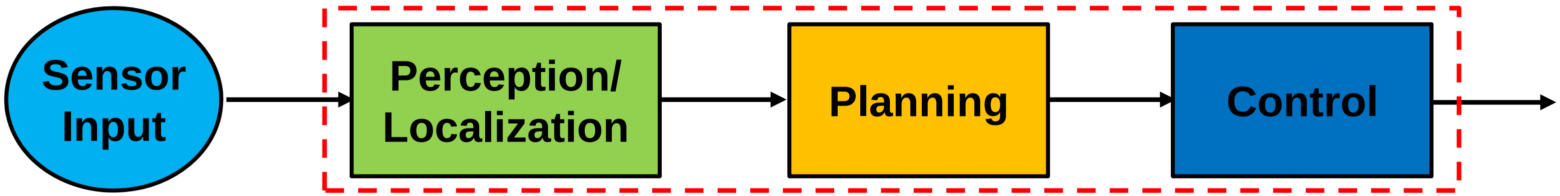
- Vehicle steering angle fit to ground truth (radian):

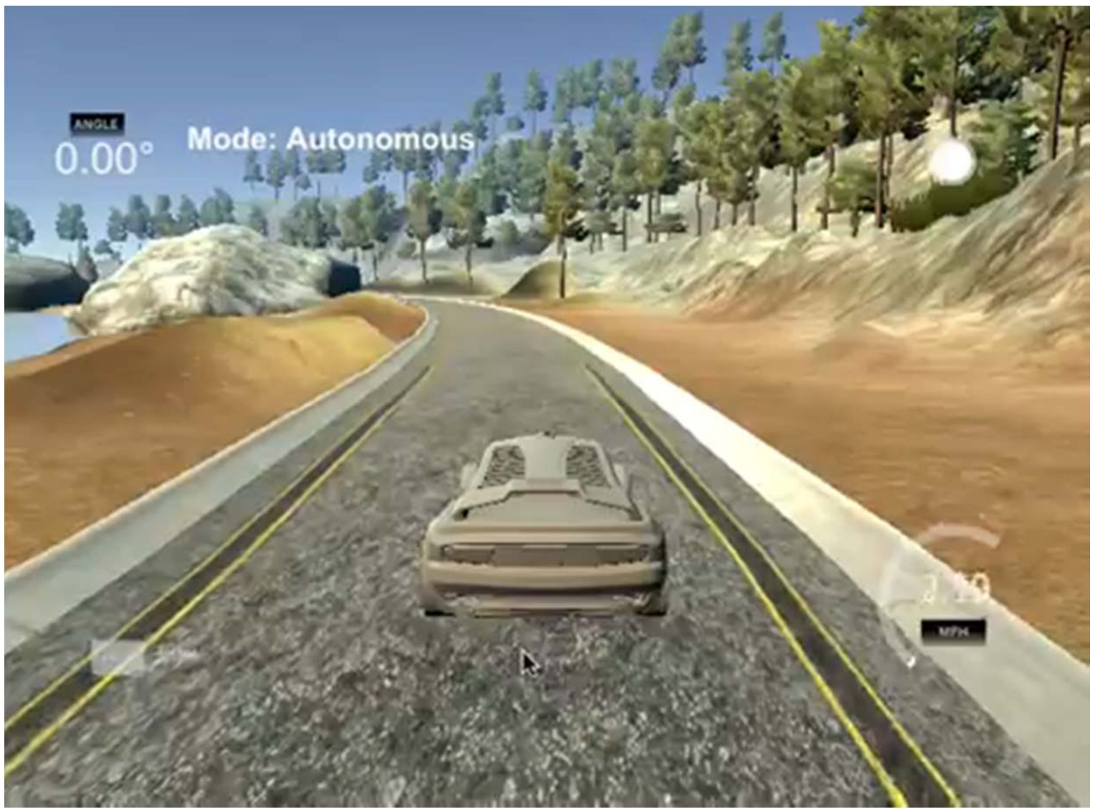
Architecture	Base CNNs	L1	L2	L2 Fb (GT)	L2 Fb (PRE)	L2 Fb Skip (	L2 Fb Skip (PRE)
Abs Mean	0.140	0.085	0.081	0.069	0.073	[illegible]	[illegible]
Std	0.193	0.121	0.113	0.097	0.102	[illegible]	[illegible]



Example demo







THE OHIO STATE UNIVERSITY

Five eras of safety: are we there yet?

1950 – 2000
Safety/Convenience Features
- ✓ Cruise Control
- ✓ Seat Belts
- ✓ Antilock Brakes

2000 – 2010
Advanced Safety Features
- ✓ Electronic Stability Control
- ✓ Blind Spot Detection
- ✓ Forward Collision Warning
- ✓ Lane Departure Warning

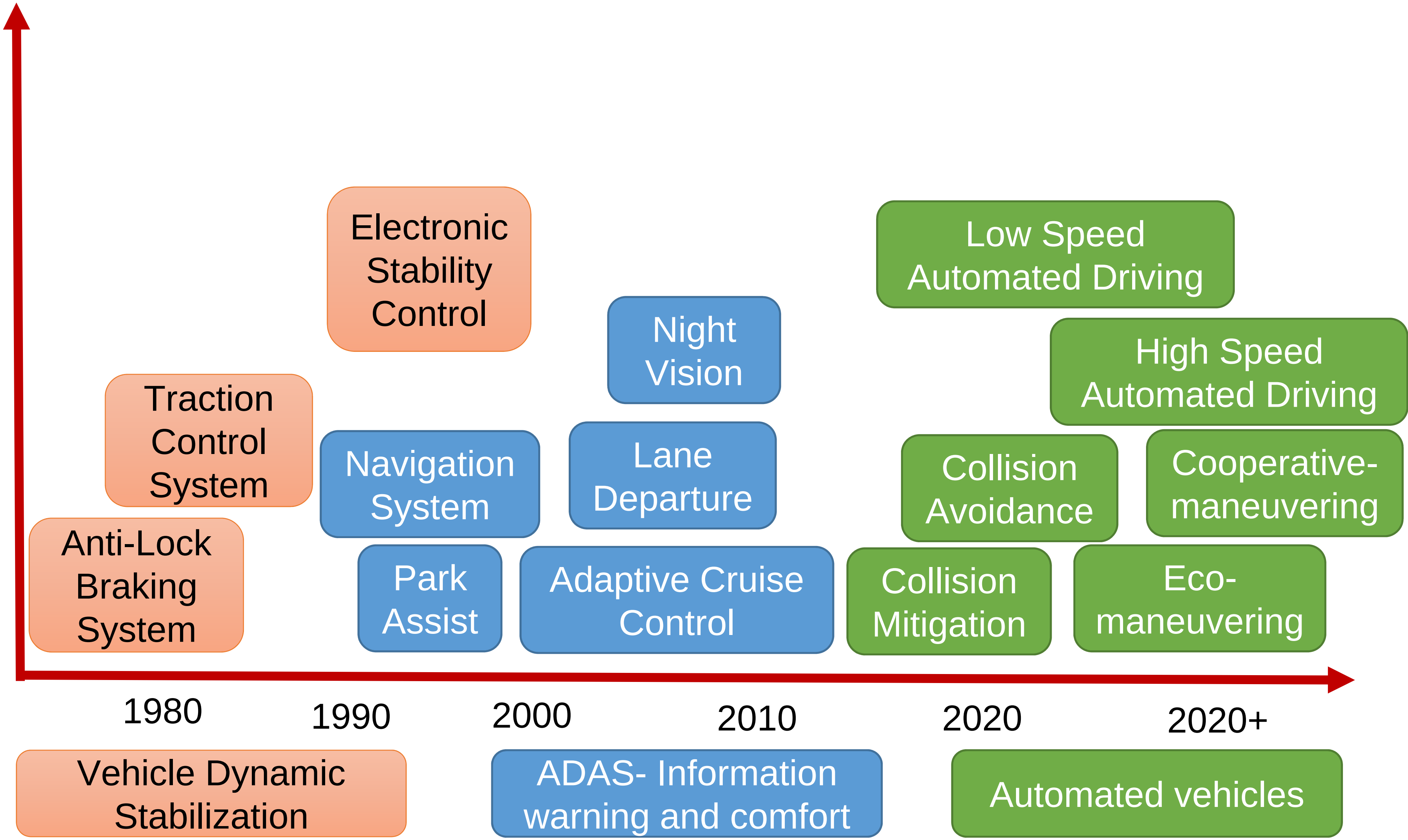
https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety#issue-road-self-driving

2010 – 2016
Advanced Driver Assistance Features
- ✓ Rearview Video Systems
- ✓ Automatic Emergency Braking
- ✓ Pedestrian Automatic Emergency Braking
- ✓ Rear Automatic Emergency Braking
- ✓ Rear Cross Traffic Alert
- ✓ Lane Centering Assist

2016 - 2025
Partially Automated Safety Features
- ✓ Lane keeping assist
- ✓ Adaptive cruise control
- ✓ Traffic jam assist
- ✓ Self-park

2025+
Fully Automated Safety Features
- ✓ Highway autopilot

Automation in vehicles



Courtesy: Prof. Giorgio Rizzoni, OSU

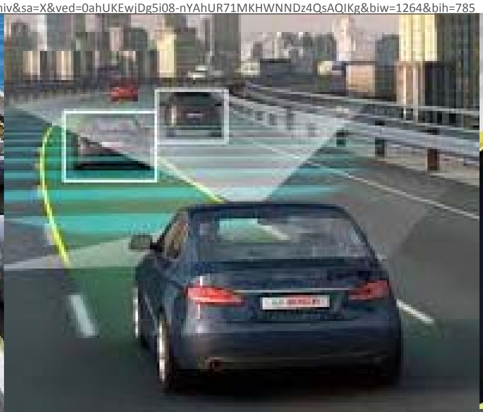
Summary and conclusions

- We may not be there yet, but…we are making progress: self-driving cars…according to NTSHA:
  - ✓ Self-driving vehicles ultimately will integrate onto U.S. roadways in the coming years, as a result of technological advances and accompanying guidelines and best practices for policymakers
  - ✓ In Sept. 2017, NHTSA released new federal guidance for *Automated Driving Systems (ADS): A Vision for Safety 2.0*.
  - ✓ Supports further development of this important new technology
  - ✓ Calls for industry, state and local governments, safety and mobility advocates and the public to lay the path for the deployment of automated vehicles and technologies

Summary and conclusions

- We may not be there yet, but…we are making progress: self-driving cars…according to NTSHA:
- DOT and NHTSA are already planning for 3.0.
  - ✓ *A Vision for Safety* is the newest version replacing previous guidance and offers a more flexible approach to advancing the innovation of automated vehicle safety technologies
  - ✓ NHTSA wants to avoid impeding progress with unnecessary or unintended regulatory barriers to motor vehicles that have Automated Driving Systems (ADS) and unconventional designs, especially those with unconventional interior designs

https://www.google.com/search?q=images+of+self+driving+cars&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjDg5i08-nYAhUR71MKHWNNDz4QsAQIKg&biw=1264&bih=785

THE OHIO STATE UNIVERSITY

What's buzzing?

- **Renault, Nissan Motor**, and **Mitsubishi Motors** announced up to $1 billion investment over five years in startups working on electric and self-driving cars, connectivity and artificial intelligence
- **Toyota** plans to embed **Amazon's Alexa** v digital assistant in some of its Toyota and l year
  - Alexa of the feature will have the capabili read news, or even control Internet-conr
- According to **Ford**, future relies not so r *transportation systems*
  - Systems-based approach, based on I operating system for transportation
  - Plans to start testing self-driving net

Source: http://fortune.com/2018/01/10/data-sheet-ford-ceo-jim-hackett-ces-2018/

THE OHIO STATE UNIVERSITY

What's buzzing?

- Transportation modes in cities include
  - Personal vehicles
  - Ride-share services
  - Bike-sharing networks
  - Delivery services, buses and trains
- According to Ford, all components o
information and streamline services
  - Key to this information sharing will be
everything (C-V2X) technology, which
stoplights, signs, cyclists and pedest
quickly and securely

Source: http://fortune.com/2018/01/10/data-sheet-ford-ceo-jim-hackett-ces-2018/
https://www.smartcitiesdive.com/news/ford-mobility-cloud-service-platform-automatic-CES/514432/

What's buzzing?

- At CES 2018, **Honda** came out with a new generation of robotic-related things - 3E Robotics Concept - both for transportation and human companionship
  - With the Asimo robot and the Uni-Cub unicycle, Honda demonstrated it thinks beyond the humble automobile
- And, in customary Japanese fashion, Honda makes a big effort to humanize these robotic devices, most notably with the 3E-A18 robot, designed to show "compassion to humans with a variety of facial expressions"

Source: https://www.cnet.com/roadshow/news/honda-welcomes-our-warm-and-fuzzy-robot-overlords-to-ces-2018/

What's buzzing?

- **Waymo,** a self-driving technology company that originates (2009) of **Google** parent Alphabet, performed world's first fully self-driving ride on public roads in Austin, TX, in 2015
- In 2016 company became Waymo and introduced fully self-driving Chrysler Pacifica Hybrid minivans
  - First vehicle built on a mass-production platform with a fully-integrated hardware suite
  - In 2017 Waymo invited residents in Phoenix, AZ to join a public trial of its self-driving vehicles
- Waymo has surged passed legacy car companies like Ford, Daimler, and Renault Nissan to grab No. 2 spot in *Navigant Research* annual autonomous driving scorecard
  - General Motors is still in the lead, but Waymo is close second, despite its complete inability to manufacture a car at scale

Source: https://www.theverge.com/2018/1/16/16893452/detroit-auto-show-2018-google-gm-waymo-ford-tesla

https://www.google.com/search?biw=1264&bih=785&tbm=isch&sa=1&ei=WwZlWpWMNeKHggetnYqQBg&q=car+of+the+future&oq=car+of+the+future&gs_l=psy-ab.3..0l4j0i30k1l3j0i5i30k1l3.14520.17504.0.17697.17.16.0.1.1.0.196.1686.11j5.16.0....0...1c.1.64.psy-ab..1.16.1582...0i67k1j0i24k1.0.VWzJnEUix6Q#imgdii=JE5SeVw8qY2ChM:&imgrc=qb9KmbO0bJM9AM:

Thank you!