Safe Operations at Roadway Junctions: Intelligent Roadway Infrastructure as Functional Interlocking

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Organization of Presentation

- What We Have Learned From Automated-Vehicle (AV) Research
- What We Know About the Complexity of Multimodal Operations in Urban Settings
- Concept of Safety-Affirmative Signaling
- Conclusions

Published Papers Contributing to the Basis of This Presentation Content

- Safe Operations at Roadway Junctions – Design Principles from Automated Guideway Transit
  - Coauthors: J. Sam Lott; Stanley E. Young, Ph.D.; Lei Zhu, Ph.D.
  - Proceedings of the SAE/AUVSI 2021 Business of Automated Mobility Forum, June 2021
  - NREL expanded version of conference presentation:
    https://www.youtube.com/watch?v=6zFDBfbRWHo
- A Safety and Management Framework to Enable Automated Mobility Districts in Urban Areas
  - Coauthors: J. Sam Lott; Stanley E. Young, Ph.D.
  - Proceedings of the ASCE 2021 Intl. Conference on Transportation and Development, June 2021
  - NREL expanded version of conference presentation:
    https://www.youtube.com/watch?v=jbH02L_bpXI
- The Automated Mobility District Implementation Catalog: Insights from Ten Early-Stage Deployments
  - Coauthors: Stanley E. Young, Ph.D.; J. Sam Lott
  - Published June 2020, Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-76551. https://www.nrel.gov/docs/fy20osti/76551.pdf
- Concept of Operations of Next-Generation Traffic Control Utilizing Infrastructure-Based Cooperative Perception
  - Coauthors: Stanley Young; Eric Bensen, Lei Zhu, Chris Day, J. Sam Lott, Rimple Sandu, Charles Tripp, Peter Graf
  - Published 2022, ACSE ICTD Conf. Preprint: https://www.nrel.gov/docs/fy22osti/81978.pdf

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What We Have Learned From AV Research

Houston METRO Texas Southern University Shuttle 2019

How Far Have We Come Over the Last 5–10 Years?

- Numerous Demonstration Pilots – Most with 15–20 mph max speed
  - Low-Speed Shuttles
  - Purpose-Built Vehicle Designs
  - Conversions of Conventional Vehicles
  - Buses and Paratransit Vehicles
- Managed Fleet Operations – Norm for deployment sites
- On-Demand Service Operation – Dedicated station stops and pickup locations for passenger boarding/alighting
- Experimentation and R&D – Many sensor stacks, software algorithms, localization methodologies, and AI perception packages

"AV for public mobility is emerging from the 'trough of disillusionment'"

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Where Do We Stand at This Point in AV Technology Development?

- Operational Design Domains (ODDs) – Constrained and focused on certain climates and less complex roadway traffic conditions.

"Geo-Net" Approach

- Delivery of L-4 Operations – The goal of broad deployments with large fleets has been pushed back in time.
- Defense Mechanisms (against complexity):
  - Restricted to a Geo-Net.
  - Operation of AVs at lower speeds, even in mixed traffic conditions.
  - Only a single AV technology for operations in a given district.
  - Retention of safety attendants to assist through the "tough spots."

These point to the need for a more sophisticated approach in complex operating environments to provide safe and efficient AV public mobility.

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What We Know About the Complexity of Multimodal Operations in Urban Settings

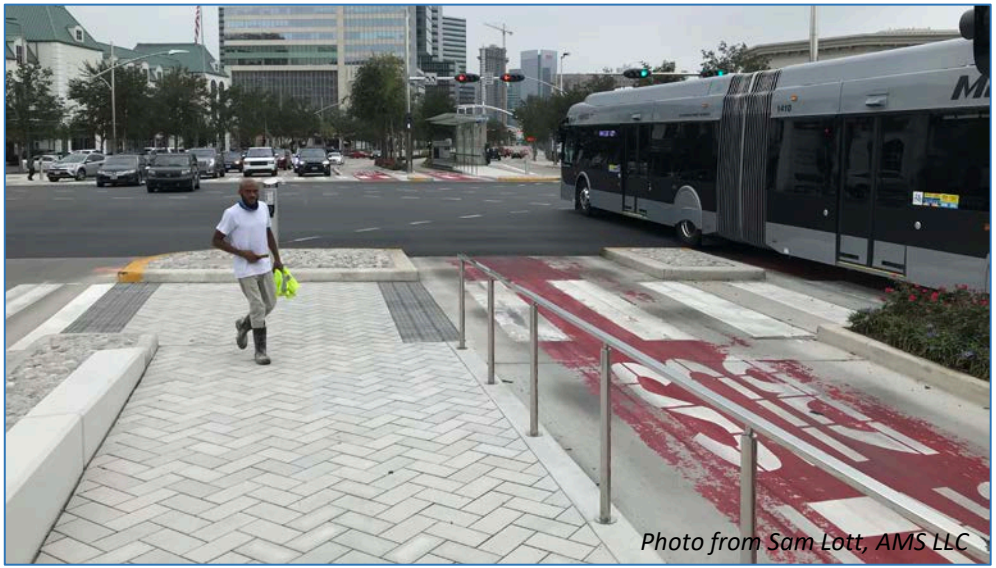

Photo from Sam Lott, AMS LLC

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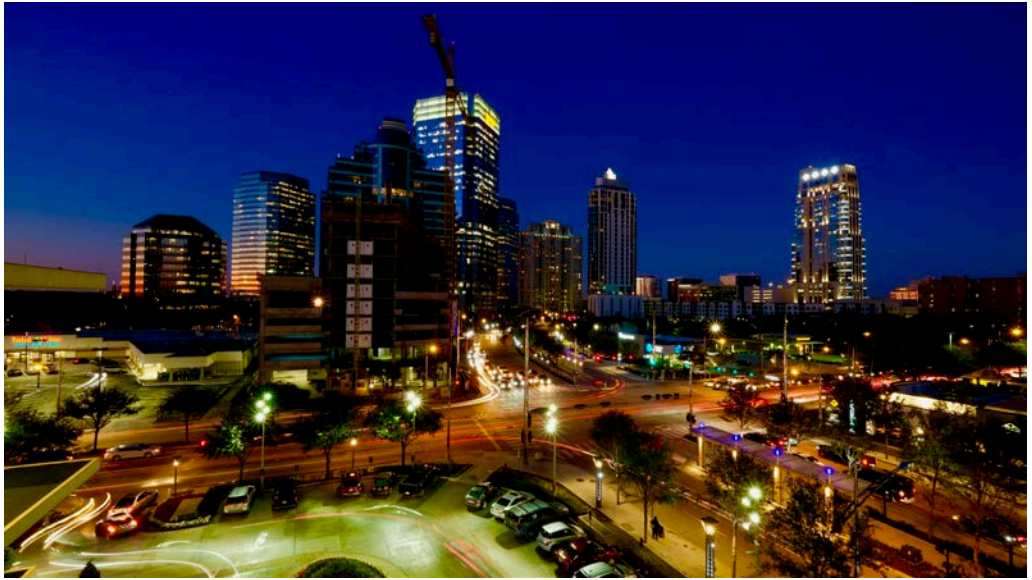
Houston Uptown District Is an Example of Operational Complexity

NREL studies have selected Houston Uptown as an example of the complexity of dense urban environments in which an extensive application of AV technology will occur over the next 5–10 years.

Houston Uptown Management District



- Highly complex traffic and multimodal operations
- District larger than most CBDs in terms of major office, residential, and retail components
- Integral transit with BRT Silver Line within the urban street median

Photo from 2nd edition of the AMD Implementation Catalog, permissions from Houston Uptown District

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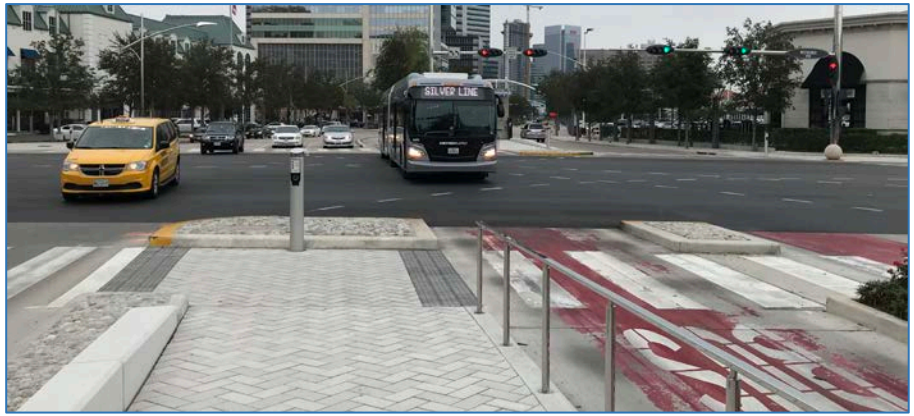

Uptown's Silver Line BRT – Provides first mile/last mile Connections to Houston's Regional Busway System

Integration of transit modes naturally increases pedestrian activity and provides greater opportunity for AV applications

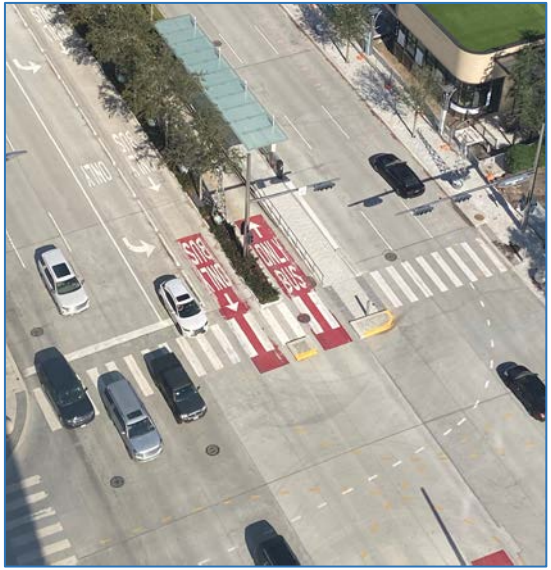

Photo from Sam Lott, AMS LLC

Uptown District Is Bisected by One of the Most Congested Roadway Facilities in the Country – IH-610 West Loop Freeway

Freeway congestion heavily impacts access to the Uptown District, creating an opportunity to provide connections from regional high-capacity transit and fostering the need for effective FM/LM connections in the district.

This traffic congestion spills onto the arterial roadway system, with traffic queues from downstream often backing into upstream intersections, such as this intersection with heavy pedestrian activity.

Photos from Sam Lott, AMS LLC

New Sensing Technology Is Needed for Management of Complex Multimodal Environments Using Intelligent Roadway Infrastructure (IRI)

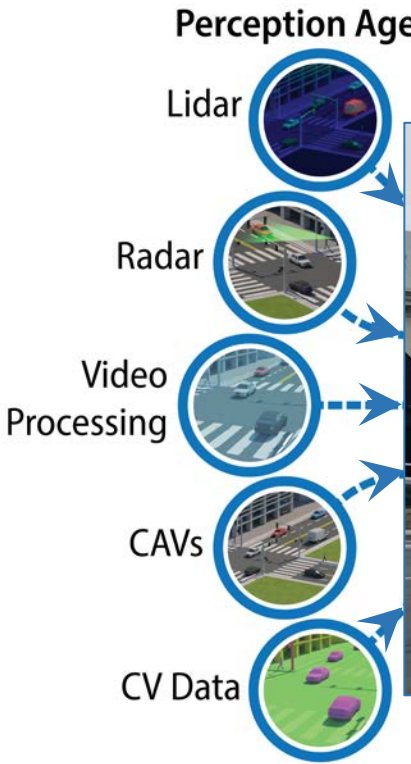

Image by NREL

Houston Uptown District 2021

Photo from Sam Lott, AMS LLC

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Houston Uptown District 2021

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Concept of Safety-Affirmative Signaling

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The Key Question Is This: How Do You Manage Roadway Operational Complexity in a Dense Urban Environment?

One hundred years ago, we learned the benefit of having an authority in charge of roadway intersections to ensure safe passage of multiple modes and vehicle types.

Photo from Adobe

Automated Mobility District (AMD) Has Multiple AV Fleets Operating Within the District

AMDs in urban districts and major activity centers with AV circulation and first-mile/last-mile connections to high-capacity transit

- Automated BRT and local bus lines
- Automated AV fixed-route transit and on-demand service transit modes
- AV on-demand car services and AV taxi fleets.

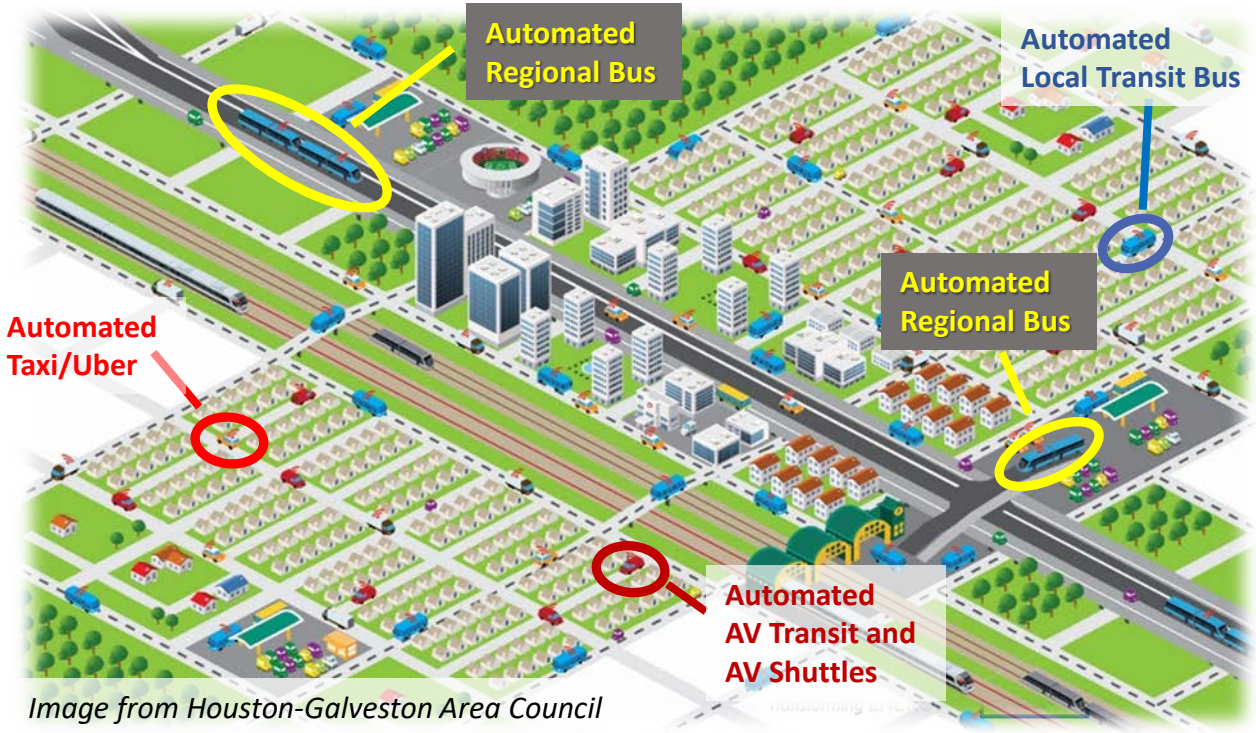
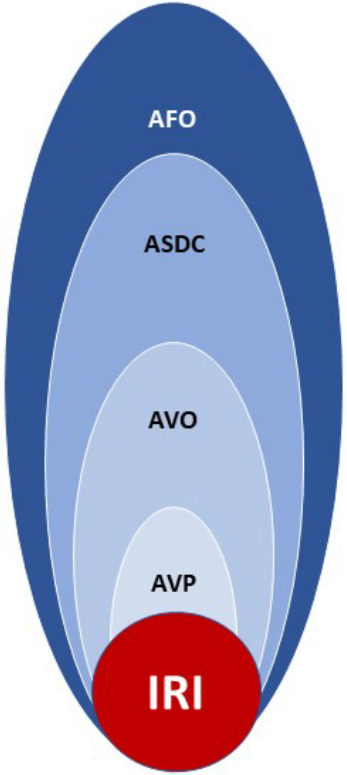


Image from Houston-Galveston Area Council

Parallels With Automated Train Control

AV Automatic Fleet Operations Control System



AFO – Automatic Fleet Operations
System controls vehicle performance, enforces AV safety, directs fleet operations.

ASDC – Supervisory and Dispatch Control
Monitors fleet, adjusts vehicle performance, dispatches on-demand or per schedule, and sends vehicles to storage/charging locations.

AVO – Automatic Vehicle Operations
Performs ADS functions, regulates speed and stopping location, monitors passenger entry points for door control and threshold.

AVP – Automatic Vehicle Protection
ADS Functional protection against collision, excessive speed and other DDT hazards.

Intelligent Roadway Infrastructure is Analogous to a Junction Interlocking

CBTC Automatic Train Control System

IEEE 1474 Communications Based Train Control (CBTC)

ATC – Automatic Train Control
System controls train movement, enforces train safety and directs train operation.

ATS – Automatic Train Supervision
Monitors train, adjusts performance of individual trains to maintain schedule.

ATO – Automatic Train Operation
Regulates speed, programmed stopping, door control, performance level regulation.

ATP – Automatic Train Protection
Maintain fail-safe protection against collision, excessive speed and other hazardous conditions (train detection, train separation and

Junction Switch-Interlocking)

Management of Multiple Fleets With Diverse AV Technologies Will Require a 21st Century Authority Having Jurisdiction Over Roadways

1910

1970

An AMD management authority will need to deploy a next-generation traffic control and signaling system to protect roadway intersections.

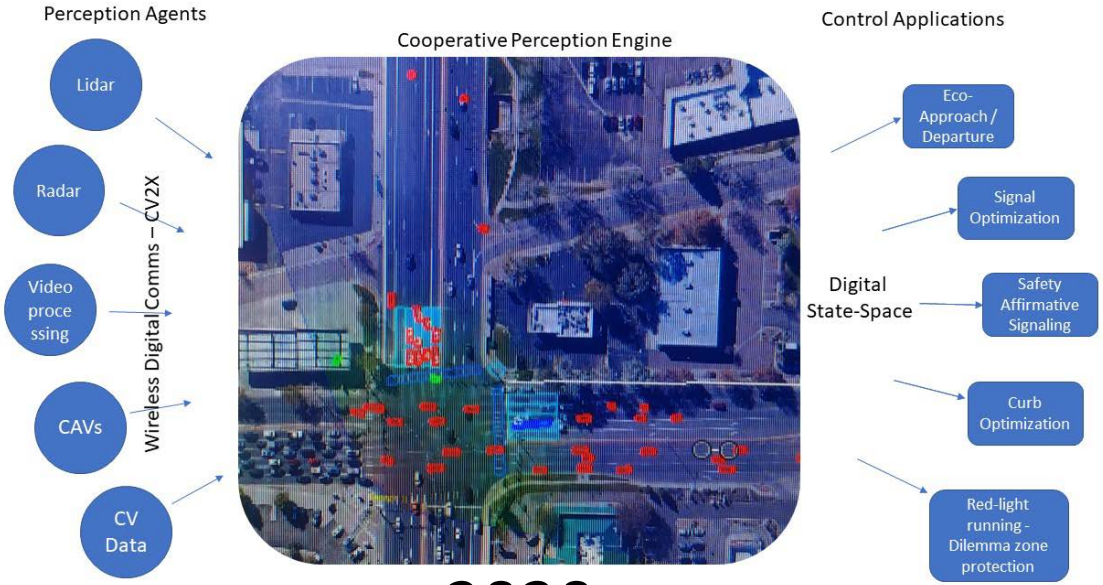


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Photo by Stan Young, NREL

NREL's Research on Next-Generation Traffic Control Technology Focuses on Control Applications for Connected/Automated Vehicles

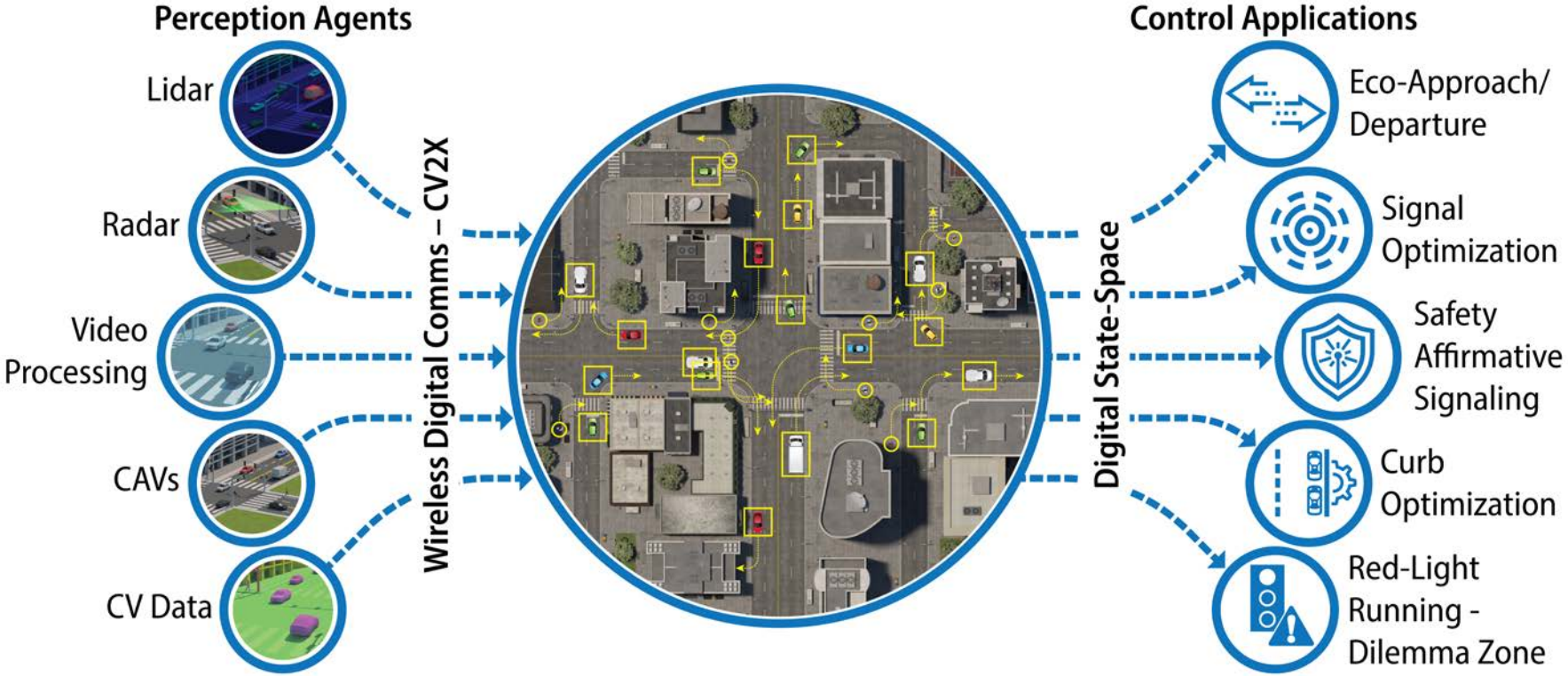

Image from NREL

Infrastructure Perception and Control

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Next Generation of Traffic Control at Roadway Junctions Is the Essential Tool for AMD Management Authority Applications

- ***Safety-affirmative control*** to not only protect AV fleets, but also:
  - Resolve the issue of slow-speed AV approaches to complex intersections.
  - Mitigate the speed volatility of human-operated vehicles maneuvering to pass slow-moving AVs.
  - Ensure AV fleets do not operate at different speeds and different protocols.
- ***Operational traffic management*** in real time to:
  - Augment the capabilities of individual AVs—"see around the corner."
  - **Provide independent verification (redundancy)** for operational control.
  - Guarantee safety for vulnerable movements (left turns) and users.

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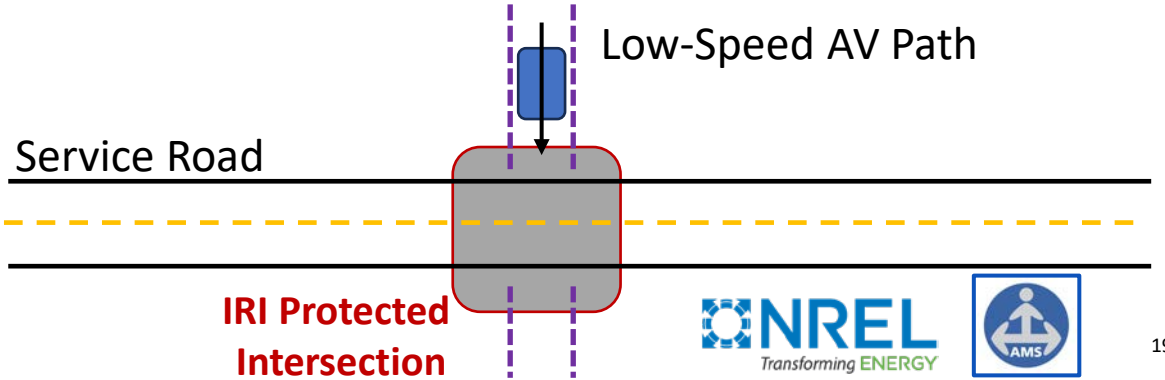
Example of Safety-Affirmative Signaling Application

- Automated parking from terminal to outer lots
- Currently, technology supports low-speed automated operations and parking maneuvers
- Getting from the curb to the parking lot requires crossing a service road



Conclusions

Photo from City of Arlington, Texas

Safe operations of AV transit, AV ride-hail car services, and AV package delivery fleets in dense urban environments will depend on next-generation traffic control policy and technologies.

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The Next 25 Years of AV Technology Advancement

1. Future traffic involving multiple AV fleets will increase complexity of operations particularly in dense urban settings.

2. Principles of cooperative automation are needed for safe operational management, including **active infrastructure elements** at intersections and multimodal junctions.

The Next 25 Years of AV Technology Advancement

3. Next-gen management authorities will share safety and operational responsibilities for roadways in cooperation with vehicles (evolution of traditional traffic management discipline).

4. Development of an open, standards-based next-gen traffic control system will enable multiple fleets of AVs to operate safely within a dense urban district while sustaining efficient traffic operations AND will enhance and protect the operation of non-AVs and vulnerable road users.

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The Next 25 Years of AV Technology Advancement

5. Automated vehicle fleets providing public transit, private ride-hailing, and package delivery services will be required to cooperatively respond to the real-time directives issued at intersection by the AMD's next-gen traffic control system.

Photo from Houston Uptown website

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Thank you!!

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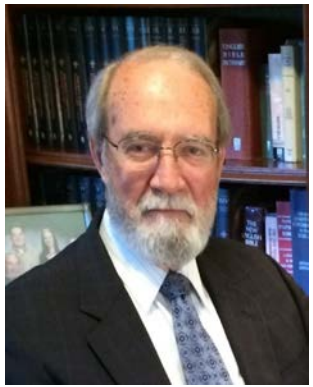

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