What the Future Holds for Automated Roadway Vehicles –

Evaluating Mobility Benefits, Infrastructure Gaps and Transit Applications

J. Sam Lott, P.E.

Automated Mobility Services, LLC

Also Affiliated with
TSU's Center for Transportation Training and Research

Presentation Lecture to H-GAC Lunch and Learn
January 22, 2018

Revised Jan. 29, 2018 for Release with Audio Track

For More Information

- Questions or Comments for H-GAC
  - PublicComments@h-gac.com

J. Sam Lott, P.E.

- Automated Mobility Services, LLC
  - Jsamlott.amsllc@gmail.com
  - Mobile: 713-927-3048
- TSU Center for Transportation Training and Research
  - Jsam.lott@tsu.edu
  - Office: 713-313-1959

J. Sam Lott, P.E. – Resume in Automation Field

- 35 Year Career with Kimley-Horn and Assoc.
- Internationally recognized expert in fully automated transit systems
  - Founding member of ASCE Automated People Mover System Standard
  - U.S. Rep resentative to IEC working group developing IEC 62267 Railway Applications – Automated Urban Guided Transport (AUGT) Safety Requirements
- Affiliated with TSU's Center for Transportation Training and Research
- Automated Mobility Services LLC formed in October 2017

AMS

J. Sam Lott, P.E. – Resume in Automation Field

Experience in Automated Transportation Systems

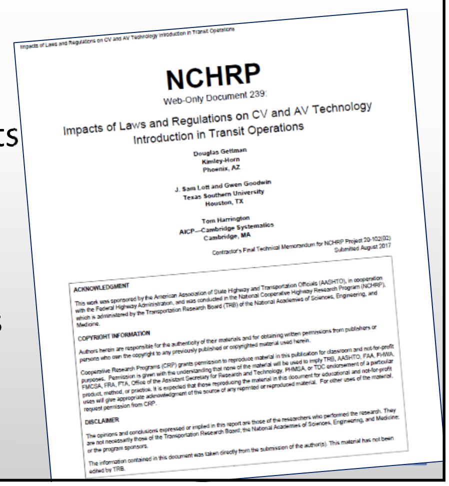
- Project Engineer/Manager on Multiple Automated Transit System Projects
  - Installation/Deployment: Atlanta Airport, Jacksonville Downtown ASE, Miami DPM, London Docklands Light Railway
  - Planning/Engineering: Newark Airport, Miami Intermodal Center, Los Angeles Airport, Hong Kong Airport, Detroit Airport Midfield Terminal, Orlando Airport
  - Conceptual System Analysis: BART Alameda Island, Las Colinas Urban Center, Cal State Univ. – Fresno, Anaheim, Texas Medical Center, Houston IAH Airport, Barcelona, Seattle Airport

AMS

J. Sam Lott – Principal Investigator for TSU Studying AV Transit Implications in 2016/17

NCHRP 20-102(02) – Impacts of Laws, Regulations and Policies on Automation Technology for Transit

- Task 1 AV/CV Transit Technology Baseline
- Task 2 Transit Operator Issues and Impacts
  - Safety Management Methodologies
  - Workforce Deployment
  - Operating Agency Policy
- Task 3 Government Regulations and Laws
  - Conclusions on Regulatory Impacts
- Task 4 Next Steps – A Timeline and Roadmap of Activities



Main Presentation Content

Time	Slide #	Topic
5:15	8	Introduction
11:10	18	Overview of Automated/Connected Roadway Vehicles
24:25	36	Development Timelines for AV Technology
38:07	56	Urban District AV Benefits & Operational Issues
53:23	70	Infrastructure Challenges with AV Technology
59:28	81	Houston's Univ. District AV Transit Circulator System
1:03:11	87	Conclusions

7

Automation of Roadway Vehicles is the Only Topic Addressed in This Presentation

My Opinion on the automation of other modes is currently:

- Automated Trains on Fixed Guideway
  - 50 years of development and application has occurred world-wide
  - Operating environment and safety challenges are well understood
  - LRT Application in mixed traffic operations viable in the near/medium term
- Automated Boats/Ships
  - Simplest operating environment and easiest safety challenges
  - Application in mixed traffic operations viable in the near/medium term
- Automated Aircraft/VTOL Vehicles
  - Most complex operating environment and greatest safety challenges
  - Military applications are earliest and most advanced

8

Introduction

AV Technology Future Must be Addressed within the Context of Houston's Future Growth

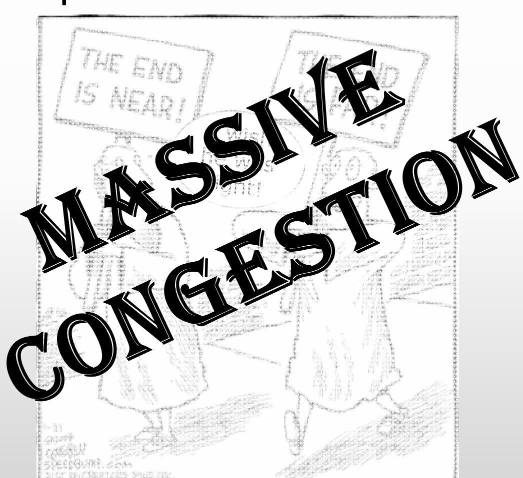
Introduction 9

So What is Houston's Impending Transportation Crisis?

What will be the operating environment in Houston for future AV technology application?

Introduction 10

So What is Houston's Impending Transportation Crisis?



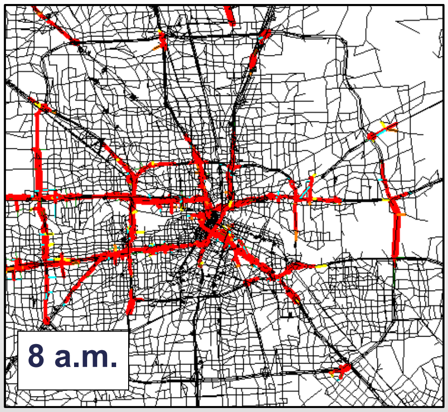
What will be the operating environment in Houston for future AV technology application?

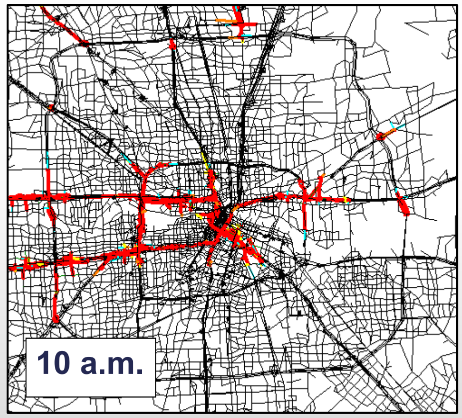
WE WILL DOUBLE IN POPULATION BEFORE 2050 – <u>WE WILL FACE MASSIVE CONGESTION</u>

Introduction

Houston 2035 Regional Operational Analysis

Urban Core Freeway Traffic Congestion Will Last All Day Long in 2035-2040





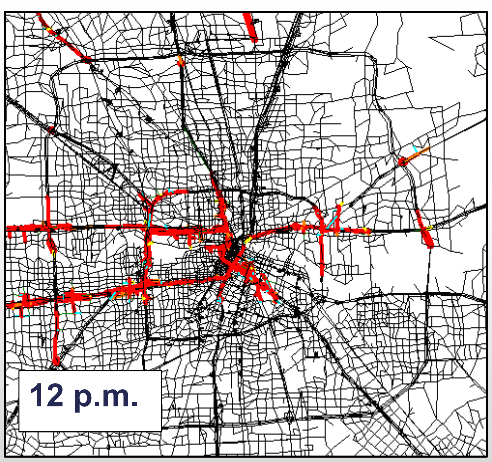
Source:
2012 TxDOT
HSR Ridership
Study

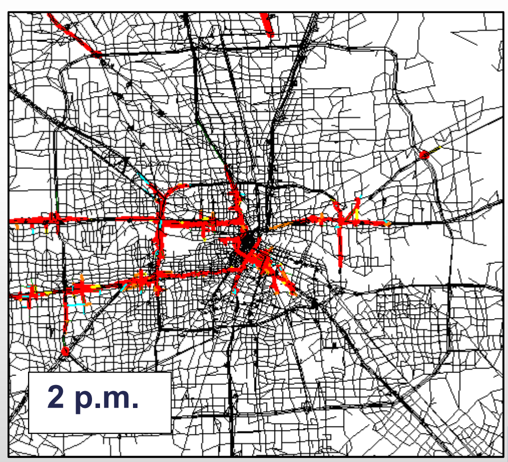
Red Segments Designate Level-of-Service (LOS) F Operating Conditions with Cascading LOS F Congestion Queues

Introduction

Analysis Performed for 2012 TxDOT HSR Study

Urban Core Traffic Congestion Will Last All Day Long in 2035-2040



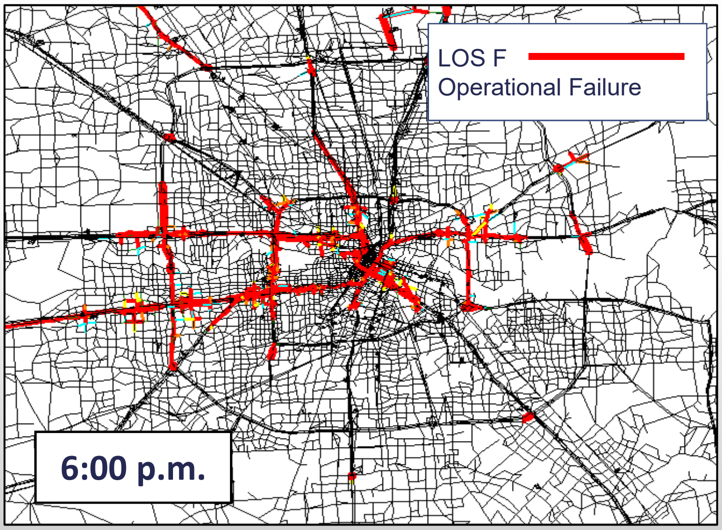


Source: 2012 TxDOT HSR Ridership study

Introduction

13

Latest H-GAC Operational Studies of 2040 Show Overall Roadway Congestion Will Be Much Worse than Today's Operating Conditions



There results provide operational insight into the regional travel demand models results for 2045 and years beyond.

Introduction

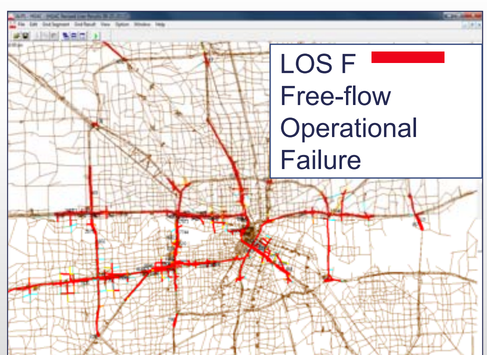
14

2035 Congestion Will Be Much Worse –
Even With Automated/Autonomous Roadway Vehicles

TxDOT Study Assumptions Included High Penetration of AV Technology

Freeways and Tollways modeled with agressive assumptions of:

- 2400 pcph per lane avg. capacity across all lanes – Including weaving areas
- 25' vehicle spacing in LOS F congestion queues (<10' gap)



Manually operated vehicle freeway capacity of 2,400 pcphpl applies when the free-flow speed is 75 mph in ideal geometric and traffic conditions

Introduction 15

Planning for Future Scenarios Must Address Key Variables that Change Congestion Impacts

- **Vehicle Sharing and Ride Sharing** – Fleet Operations are very different from today's norm for vehicle movement
- **Roadway Throughput Capacity** – We will see higher capacity roadway throughput and slower average travel speeds
- **Empty Vehicle Movements** – Fleet operations often double vehicle-mile accumulations relative to "revenue service" vehicle miles

AMS

Introduction 16

How Will New AV Technology Change Traffic Congestion and Mode Choice?

Scenario A: Utopian View –

- Steadily decreasing number of cars and vehicle trips
- Roadway capacity dramatically increasing
- AVs traveling home after dropping us off at work
- We can turn most parking lots into public parks

AMS

How Will New AV Technology Change Traffic Congestion and Mode Choice?

Scenario B: Dystopian View –

- Connected roadways move AV vehicles much more efficiently and capacities will increase
- Everyone will enjoy a private ride to work in their own personal AV and then send it home to park in driveway
- Empty vehicle movements will dramatically increase the number of vehicle-trips
- Resulting traffic congestion will continue to increase to record levels

AMS

Overview of Automated/Connected Roadway Vehicle Technology

AMS

AV/CV Technology Overview

19

Definition of Terms

- **AV – Automated Vehicle**
- NHTSA – National Highway Traffic Safety Council
- CV – Connected Vehicle
- DSRC – Digital Short-Range Radio Communications
- ADS – Automated Driving Systems
- SAE – Society of Automotive Engineers
- V2V – Vehicle-to-Vehicle Communications
- V2I – Vehicle-to-Infrastructure
- **Autonomous – Depends on who you ask**

AV/CV Technology Overview

20

AV Technology will transform the transportation world over the next 30 years

AV Automobiles are being designed by every OEM car manufacturers and many "Silicon Valley" technology companies.

Source: Mercedes

Source: Audi

Source: Nissan

AV/CV Technology Overview

21

Truck Platooning is Under Active R&D by a Number of Companies and Research Universities

<u>Peleton Truck Automation and Platooning Website:</u>

"Platooning only occurs when it's safe, where it's safe, and how it's safe. Peloton's cloud-based Network Operations Center approves each platoon. It adjusts platooning parameters to be safe for conditions. Each driver is empowered with over-the-horizon alerts at all times."

AV/CV Technology Overview

22

AV Transit Vehicle Development is Happening Now

Source: 2getthere

Source: Mercedes

Source: Easy Mile

AV/CV Technology Overview

It is Important to Understand the Parallel Path of Automated and Connected Technology Development

CURRENT

AUTOMOTIVE AND TRANSIT VEHICLE TECHNOLOGIES
R&D Activities focused on Vehicles

Automated Vehicle (AV)
Development By Private Sector/Auto Manufacturers

Connected Vehicle (CV)
Development By USDOT and State DOTs with Detroit OEM participation

NEAR/MEDIUM TERM

TRANSIT/FLEET OPERATORS
Vehicles, System Equipment and Facilities

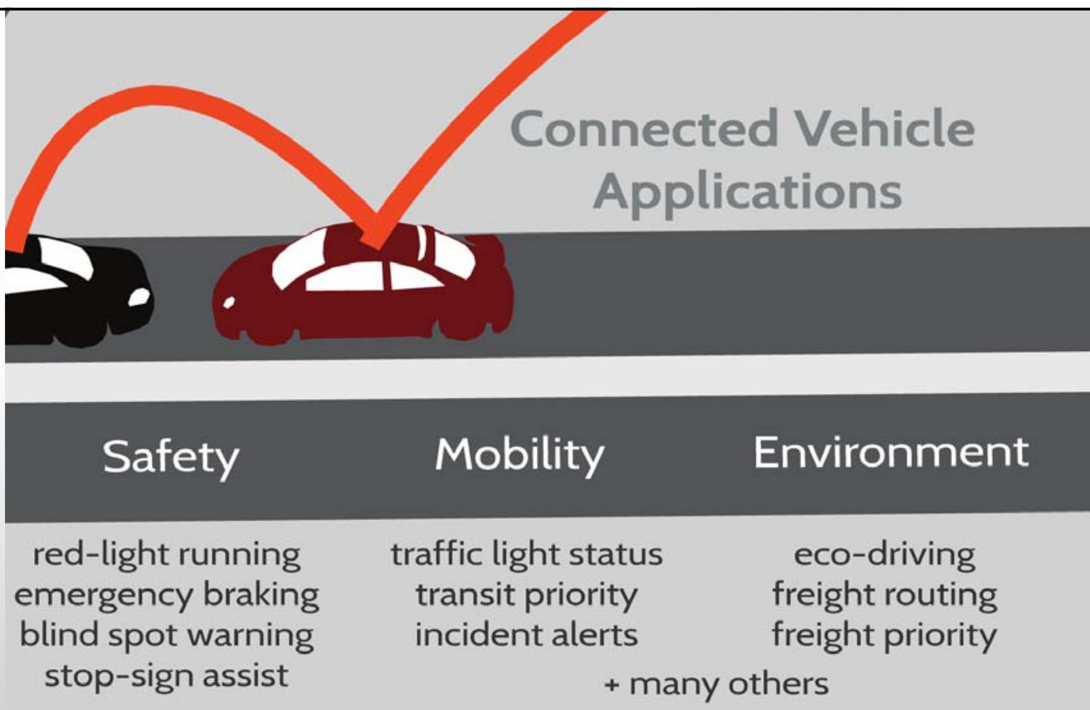
LONG TERM

TRANSIT/FLEET OPERATORS
Complex Dynamic Operations

Universal Fully-Automated Transit Applications

Automated Supervisory Control System

- Dynamically Change Operating Modes of the System
- Dispatch Each Transit Vehicle
- Respond to Passenger Trip Requests
- Take Vehicles In and Out of Service
- Optimize all Performance Metrics



State of the industry

Applications for V2V are ahead of V2I

5.9Ghz DSRC for V2V

Low-latency, safety-critical

Basic Safety Message ("BSM")

DSRC needs line-of-sight

Signal Phase and Timing "SPaT"

Early V2I
Deployment
in Development

What is the difference

27

Connected

Warnings to driver

Near term
DOT impacts - V2I apps

Automated

Sense surrounding and take action

Short term!
~~Long term~~
Changes to Society

Much more powerful together

AV/CV Technology Overview

28

Active Discussion of the Role of 5G Combined with DSRC Communications Technologies

<u>5G Wireless Mobile Communications</u>

- 5G mobile – new LTE (long term evolution) communications level
- Access to the cloud & "Internet of Things"
- Capabilities like "Wi-Fi" on a regional scale
- Inherent cyber-security weaknesses as other internet technologies

<u>DSRC – Digital Short-Range Radio</u>

- USDOT/Detroit OEMs conducting R&D for 20 years
- Robust and secure Signals
- OEMs are adding to new models
- New equipment integrated into ITS infrastructure

AV/CV Technology Overview

29

NHTSA is Beginning to Define the USDOT Position on Automated Driving Systems (ADS)

Released the latest Guidance Document on September 12, 2017

Source of the following summary – SAE Oct. 2017 Update Newsletter

Automated Driving Systems 2.0 – A Vision for Safety addresses:

- Focuses on SAE International Levels of Automation 3-5 Automated Driving Systems – Called Conditional, High and Full Automation
- Clarifies the guidance process to advise that entities developing ADS technology do not need to wait to test or deploy their systems
- Revises unnecessary design elements from the safety self-assessment
- Aligns Federal guidance with the latest development and industry terminology
- Clarifies Federal and State roles in governmental oversight

AV/CV Technology Overview

30

AV Technology Baseline for ADS Now Set by SAE J3016 Taxonomy and Definitions*

Automated Driving System (ADS) refers to L3 to L5

Driving automation system (non-capitalized) refers to functional capabilities for L1-L5 levels of automation

Roles and Responsibilities of Primary Driving Actors:

- Human driver/operator
- Driving automation system
- Other vehicle systems and components

* Sept. 30, 2016 Recommended Practice Update

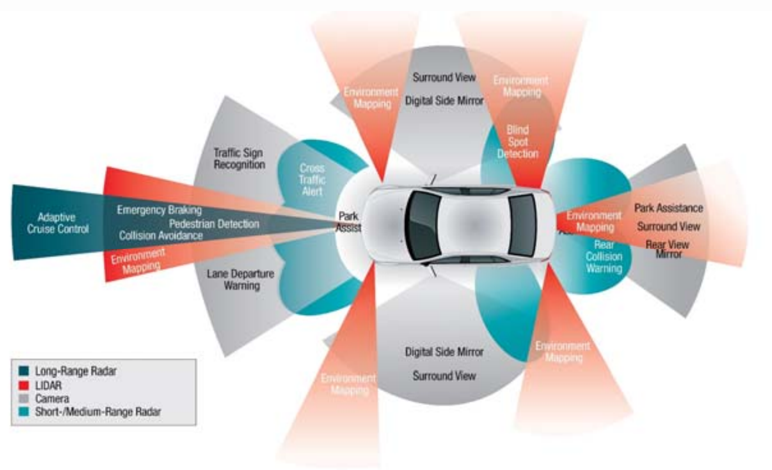
AV Technology Baseline for ADS Now Set by SAE J3016 Taxonomy and Definitions

Dynamic Driving Task (DDT) – Real-time functions that are operational and tactical and necessary for driving, but not strategic decisions (trip planning/scheduling)

Operating Design Domain (ODD) – Specific boundary conditions within which ADS is designed to function – geographic, roadway, environmental, traffic

Automated Driving Systems Involve Incredibly Complex Integration of Sensor Information

Separate and apart from the AI necessary to automatically steer a vehicle is the necessary fusion of many different signals and sensor information



Technology R&D Challenges

- Synthesizing sensor signals and processing many different sensor data streams to properly interpret 360 degree operating conditions
- Staying within the Operational Design Domain parameters
- Artificial Intelligence (AI) making Tactical driving decisions (next 10 seconds) equal to that of a mature human driver
- Machine-intelligence making Strategic trip decisions necessary for a vehicle to find their way to a specific destination and appropriate stopping location

AV Technology Baseline for ADS Now Set by SAE J3016 Taxonomy and Definitions

Dynamic Driving Task Fallback – Reverting to a condition of "minimum risk" when DDT performance-related failure or vehicle exiting ODD geospatial or ODD operating conditions

Minimal Risk Condition – Condition where an ADS may:

- Stop vehicle in current travel path
- Maneuver vehicle from active lane and then stop
- Return the vehicle to its dispatching facility

AV/CV Technology Overview

AV Technology Baseline for ADS Now Set by SAE J3016 Taxonomy and Definitions

DDT Fallback Ready User – Person who is alert, monitoring operations and "receptive" to intervene and take control

Remote Driver – Human Driver/Operator who is not in a position to manually operate steering/propulsion input devices inside the vehicle, or one who is remote from the vehicle and who takes control of the DDT

Dispatcher – Person who is monitoring the vehicle's operational readiness and engaging/disengaging the ADS

Development Timelines for Automated Vehicle (AV) Technology

General Automotive, Transit and Freight-Haul Applications

AV Technology Applications in the Automotive Marketplace Require Agreements Between NHTSA/USDOT and SAE/Vehicle Manufacturers

Announcements and Updates to Key AV Technology Policy and Standards Documents

- Sept. 16, 2016 Federal Automated Vehicles Policy – USDOT/NHTSA Policy Guidance document released
- Sept. 30, 2016 Update to SAE J3016 – Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles
- September 12, 2017 Automated Driving Sytsems 2.0 – A Vision for Safety – Updated USDOT/NHTSA Guidelines

AV Technology Agreement for Automated Driving Systems Between NHTSA and SAE

Driving Automation Levels in accord with SAE J3016

- **L0** – Human Driver
- **L1** – Automated System can assist Human Driver with some of the driving task
- **L2** – Automated System can conduct some parts of the driving task while Human Driver monitors and performs the remainder of the driving tasks

General Automotive Applications

39

AV Technology Agreement for Automated Driving Systems Between NHTSA and SAE

NHTSA has now adopted terminology from SAE J3016 refering to higher levels of automation as Automated Driving Systems (ADS)

General Automotive Applications

40

AV Technology Agreement for Automated Driving Systems Between NHTSA and SAE

NHTSA has now adopted terminology from SAE J3016 refering to higher levels of automation as Automated Driving Systems (ADS)

L3– *(Conditional Automation*)* Automated System conducts some parts of driving task and monitors driving environment in some instances, but Human Driver must be ready to take control

** New NHTSA Designation*

General Automotive Applications

41

AV Technology Agreement for Automated Driving Systems Between NHTSA and SAE

NHTSA has now adopted terminology from SAE J3016 refering to higher levels of automation as Automated Driving Systems (ADS)

L3– *(Conditional Automation*)* Automated System conducts some parts of driving task and monitors driving environment in some instances, but Human Driver must be ready to take control

L4 – *(High Automation*)* Automated System conducts driving tasks and monitors driving environment, but only in certain environments and under certain conditions

** New NHTSA Designation*

General Automotive Applications

42

AV Technology Agreement for Automated Driving Systems Between NHTSA and SAE

NHTSA has now adopted terminology from SAE J3016 refering to higher levels of automation as Automated Driving Systems (ADS)

L3– *(Conditional Automation*)* Automated System conducts some parts of driving task and monitors driving environment in some instances, but Human Driver must be ready to take control

L4 – *(High Automation*)* Automated System conducts driving tasks and monitors driving environment, but only in certain environments and under certain conditions

L5 – *(Full Automation*)* Automated System conducts all driving tasks and monitors all driving environments

** New NHTSA Designation*

General Automotive Applications

Expected Readiness Timeline for AV Automobiles We Will Purchase or Hire for Car Services

- Today – **L3** operations on Freeways/Highways
- Near-Term (5 -10 Years) – **L3** operations on major arterials and selected city streets within Urban Centers, **L4** operations on Freeways and Managed/HOV lanes
- Medium-Term (10 -15 Years) – **L4** operations in low speed in mixed traffic along most city streets and in selected neighborhoods/districts
- Long-Term (15 - 30 Years) – **L4** and **L5** operations in all environments, and with fully automated driving systems

Development Timelines for Automated Vehicle (AV) Technology

Transit Applications

Source: 2getthere
https://www.2getthere.eu

Transit Applications

45

Over Last 20 Years Roadway Transit Began to Enter R&D Phase for the New Paradigm of AV Transit

United States R&D

2009 Source: Caltrans PATH

2003 Source: Caltrans

Transit Applications

46

International R&D has been Accelerating AV Transit Technology Forward over Past 15 years

Japanese R&D

2005 Aichi Japan
Source: Wikimedia

Toyota ITMS Automated Buses Following Magnetic Markers in Roadway at 2005 Aichi Expo

Transit Applications

47

Over Last 5 Years AV Transit has Begun to Enter Preparations for Fully Automated Passenger Service

Source: Navya

US & European Union R&D

Source: 2getthere
https://www.2getthere.eu

Transit Applications

48

AV Transit Implications for Planning, Operations, Policy and Regulations Now Being Defined

NCHRP 20-102(02) – TSU's J. Sam Lott, P.E. – Principal Investigator

Working Papers and Reports now published and available for download

- Safety Assurance process more complicated than rail systems
- AV Transit vehicle functional operations more complicated than just Automated Driving Systems
- 30 new research projects now defined

Transit Applications

49

AV Transit Technology is More Complicated than Just L4 Automated Driving Systems

Definition of Automated Vehicle (AV) Transit

- Automated Driving Systems(ADS) per SAE J3016
- Other vehicle systems, facilities and components:
  - ***Operational Safety Systems*** – e.g., Automated Emergency Braking
  - ***Vehicle location and path guidance systems***
  - ***Vehicle/station berth interfaces***, safety protection systems, and precision docking systems
  - ***Other monitoring, supervisory control and passenger safety systems*** and facilities appropriate for public transit

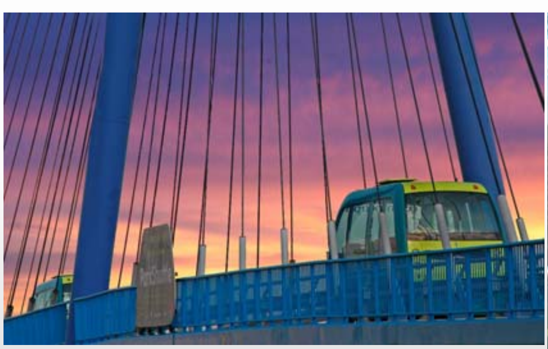
Source: 2GetThere

☆

Transit Applications

50

AV Transit Technology is More Complicated than Just L4 Automated Driving Systems



Source:
2getthere
https://www.
2getthere.eu/

This fully automated shuttle system has been operating since 1999 from the metro rail station, across a single-lane bridge spanning an expressway to connect with the Rivium office park in Capelle aan den Ijssel, Netherlands near Rotterdam

Transit Applications 51

Benefits and Other Requirements for AV Transit Technology to be Deployed with Full Automation

- Operational Design Domain (ODD) for transit must be precisely defined
- Driverless vehicles with unmanned operations are essential if significant improvement of transit operating costs and ridership are to be realized
- AV bus transit operating agencies required to have an advanced Safety Assurance program equal to that of present day rail system operators
- Smaller vehicles and more complex operations will be possible to provide customized and highly optimized services for each patron.

Source: 2getthere
https://www.2getthere.eu

Transit Applications 52

AV Transit Technology Baseline – NCHRP 20-102(02) Project Findings

Timelines Expected for AV Technology indicate ***readiness by multiple technology suppliers for general transit applications***

- Near-Term (5 -10 Years) – **L3** BRT Transitways and HOV lanes, **L4** operations in campus environments
- Medium-Term (10 -15 Years) – **L4** operations in BRT/HOV and low speed in mixed traffic on city streets
- Long-Term (15 -30 Years) – **L4** and **L5** operations in all environments, and with fully automated transit systems

NOTE: Universal Deployment across all Transit Operator/Systems will follow after these Readiness Milestones – i.e., by 2050

53

Development Timelines for Automated Vehicle (AV) Technology

Freight-Haul Applications

Source: Uber Otto

Freight-Haul Applications

54

AV Freight Haul Truck Operations May be as Complex as AV Transit Systems due to Vehicle Weight and Size

NHTSA/USDOT's September 2017 release of *Automated Driving Systems 2.0 – A Vision for Safety* – a voluntary guidance document for all AV developers – states that currently the Federal Motor Carrier Safety Regs requires "a trained commercial driver must be behind the wheel at all times, regardless of any automated driving technologies available on the commercial motor vehicle" …

Freight-Haul Applications

55

AV Freight Haul Truck Operations May be as Complex as AV Transit Systems due to Vehicle Weight and Size

Source: Uber Otto

- Near Term (5 -10 Years) – **L3** on Highways and Managed Lanes (with platooning), **L4** operations in Controlled Environments (e.g., ports)
- Medium Term (10 -15 Years) – **L4** operations on Highways and Managed Lanes and low speed in mixed traffic on city streets
- Long Term (15 -30 Years) – **L4** and **L5** operations in all environments

AMS

56

Urban District AV Benefits & Operational Issues

AMS

Urban Districts

57

Benefits of AV Technology Applications

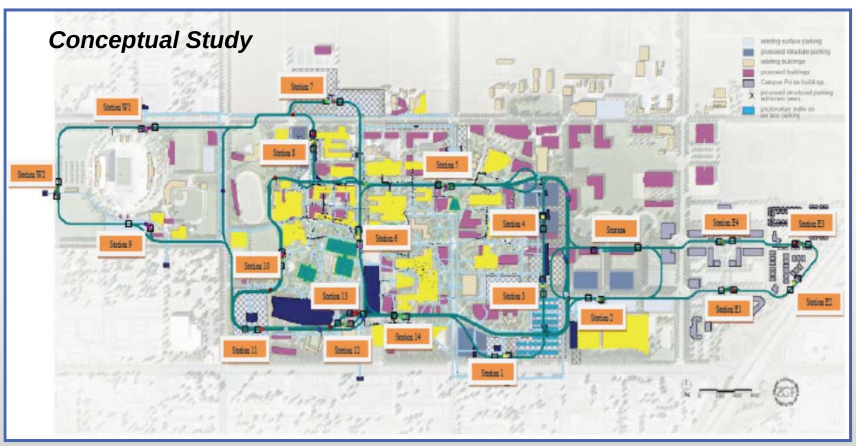
- Personal Convenience and Customized Service
- Mobility on Demand
- Environmental and Energy Sustainability
- More Efficient Access to High Capacity Transit

AMS

Urban Districts

58

District Area Circulation Systems with On-Demand Network Operations Will Become Common for Automated Buses in the Long Term



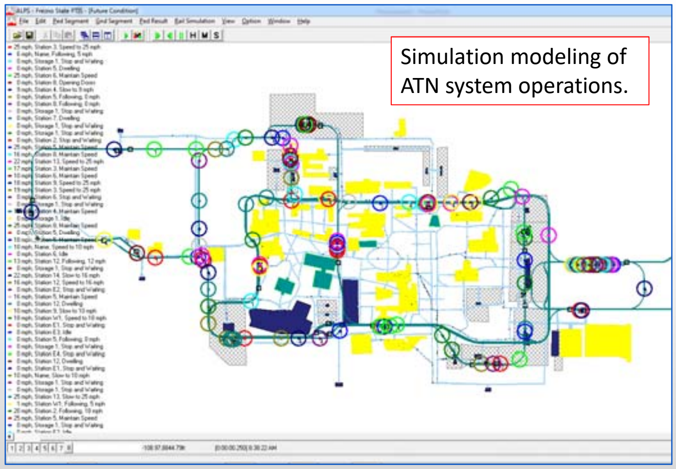
AMS

Urban Districts

59

Automated Transit Network (ATN) Operations Will be Possible with Automated Bus AV Technologies

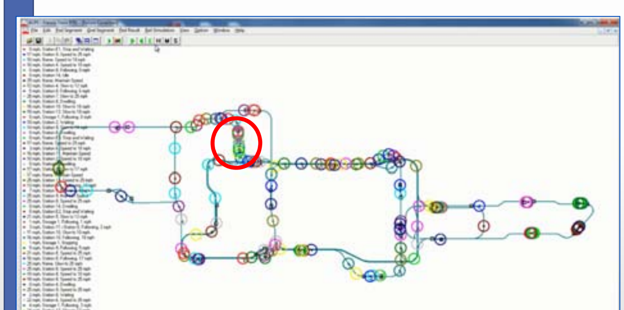
- CSU-Fresno conceptual campus circulation system
- On-Demand Dispatch
- Direct O/D Service
- Shared Rides with Small 4-Passenger Vehicles ***– JUST LIKE AUTOMATED TAXIS AND CAR SERVICES***

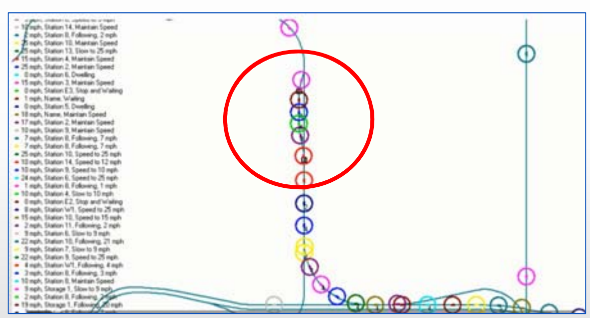


Urban Districts

60

Example of Demand-Response Curbfront Operation with Swarming of AV Demand-Response Vehicles

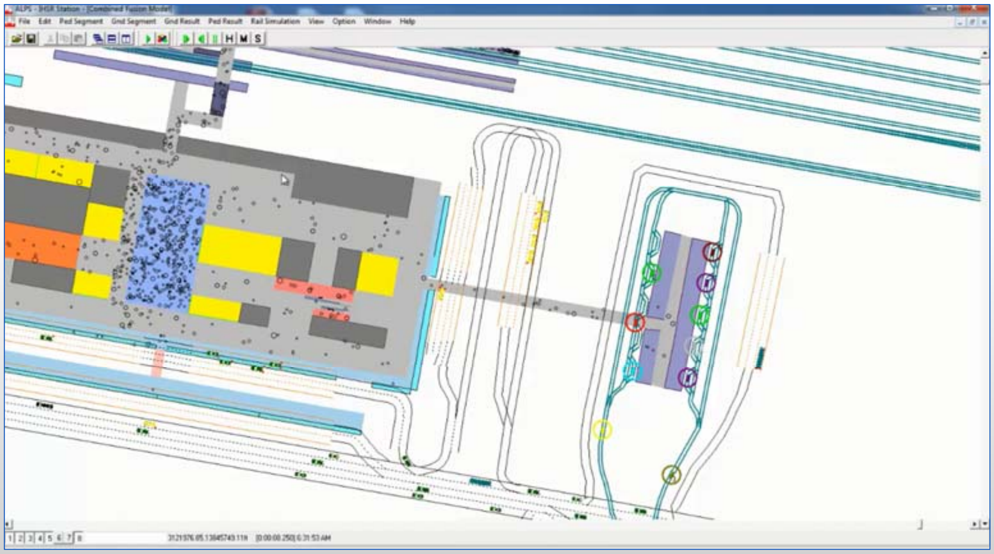




Demand Overloads at a capacity-constrained station Impact the mainline operation of the entire system.

Urban Districts

Comparison of Dedicated Demand-Response AV Transit Station with Curbfront Operation and Swarming of AV Automobiles

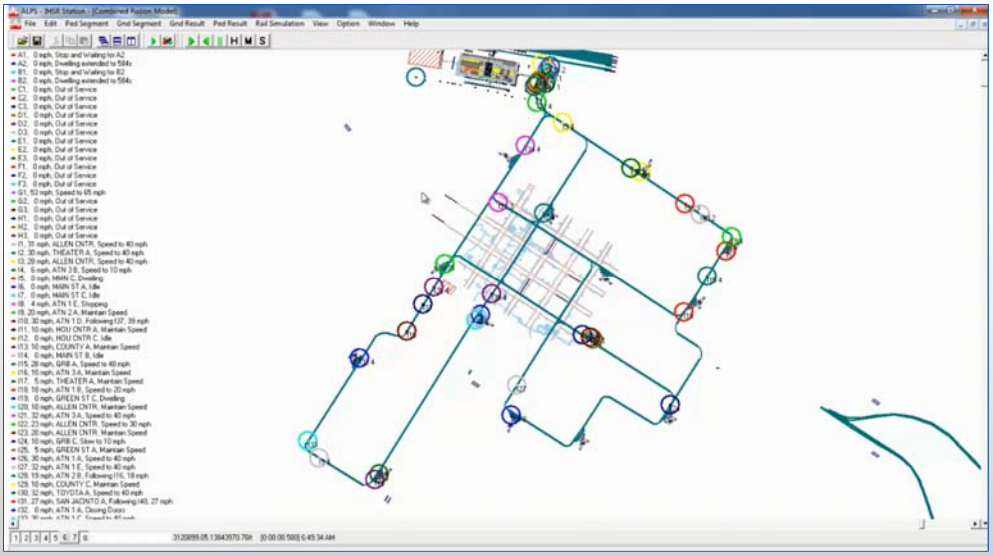


Urban Districts

Comparison of Dedicated Demand-Response AV Transit Station with Curbfront Operation and Swarming of AV Automobiles

Urban Districts

Comparison of Dedicated Demand-Response AV Transit Station with Curbfront Operation and Swarming of AV Automobiles



Urban Districts

Simulation Studies Have Demonstrated that AV Technology Applications are Effective

- Drop-off/pick-up in proximity to destinations
- Smaller transit vehicles operating on closer headways
- Demand-responsive dispatching in real time
- Optimization of travel times
- Sustainable optimization of environment/energy impacts
- Efficient first-mile/last-mile connections to high capacity regional transit systems

Urban Districts

65

Future Urban District Operational Issues

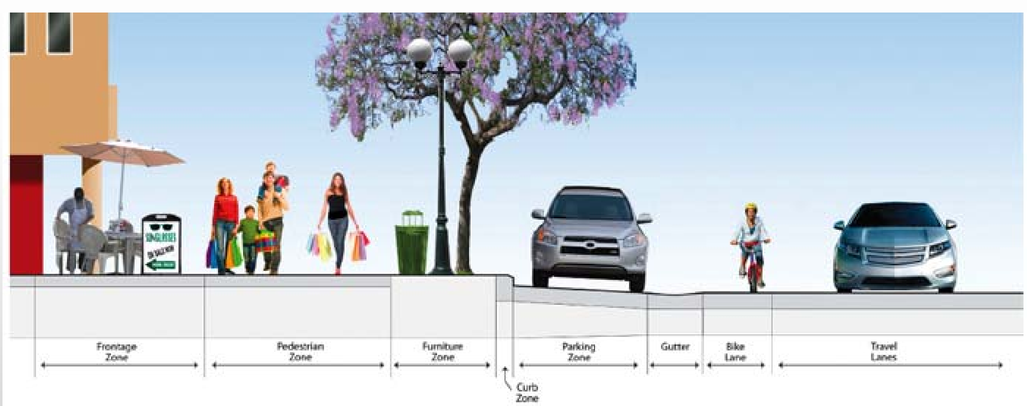
Major operational issues in Urban Districts and Major Activity Centers could result without design for the following factors

- Curbfront Provisions
- Empty Vehicle Accommodations
- Failed Vehicle Impacts

Urban Districts

66

AV Accommodations Bring More Questions Than Answers to Complete Street Concepts



Curbfront Provisions – Strategic Planning and Design for AVs is Essential

- AV Private Vehicles -- How will we provide dedicated drop-off/pick-up facilities within the development design?
- AV Transit Network Companies – Where will Uber/Lyft and AV Taxis be accommodated on the public streets?
- Public AV Transit Vehicles – Will Urban District street design integrate dedicated street curbfronts, off-street curbfronts, or in some locations off-street transit stations?

AMS

Empty Vehicle Accommodations – Strategic Planning and Design for AVs is Essential

When Private AVs or ATN Fleet Operations AVs are empty, there could be major planning issues assessing where they will they go until dispatched to pick up a passenger.

- Will automated parking facilities be built in proximity to the passenger's trip destination?
- Will empty AVs circulate continuously until dispatched into service?
- Will empty AVs be programmed to find "free parking" somewhere nearby (e.g., AV vagrancy)?
- Will empty AVs travel to a remote destination, imposing significant no-occupant vehicle (NOV) traffic demands on roadways?

Urban Districts

69

Vehicle Failure Impacts – Strategic Planning and Design for AVs is Essential

- There are very daunting implications when:
  - AV's Automated Driving System (ADS) fails and reverts to a Fallback Condition
  - AV enters operating conditions which are outside its Operational Design Domain (ODD).
- Exiting the ODD may include things as simple as:
  - Entering a driveway not in the vehicles "mapping" system
  - Inclement weather conditions
  - Construction zone "maintenance of traffic" operations.

AMS

70

Infrastructure Challenges with AV Technology

★

AMS

Infrastructure Challenges

71

Infrastructure Challenges

AV Technology Issues – Infrastructure that is required to support the sustainable operation of AV technology

Roadway Right-of-Way – Physical space required to allow AV technology to operate in self-driving modes and to accommodate vehicle failures

EV Technology Provisions – Power supply and charging stations required to sustain a primarily electric vehicle fleet

Infrastructure Challenges

72

Infrastructure Challenges

AV Technology Issues

- AV Machine-Vision System provisions
- Connected Vehicle provisions
- AV "Localization" System provisions

Infrastructure Challenges

73

Infrastructure Requirements to Implement AV

AV Machine-Vision System Provisions:

- Paint will require higher investments in maintainance for lane striping, turning lanes and stop bars.
- Signage must always be clearly visible to the travel lane
- Suitable traffic signals must be clearly distinguishable to the travel lanes
- Temporary lane closures and traffic pattern reconfiguration in construction zones are a major complication for AVs

Infrastructure Challenges

74

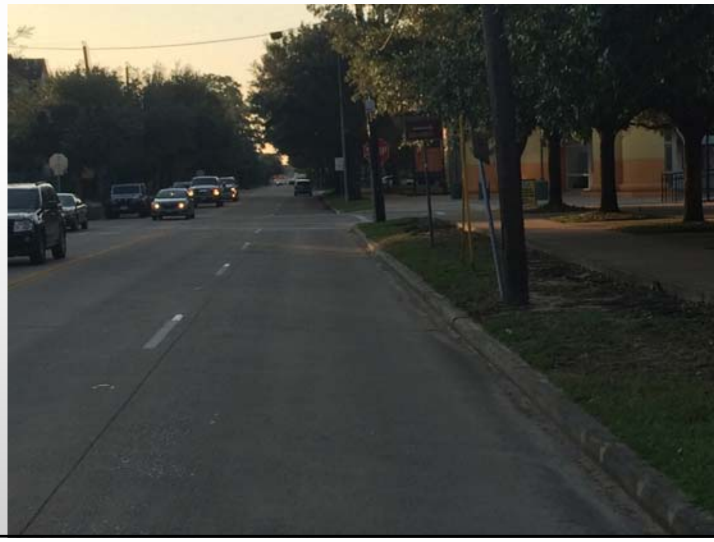
Crisp Paint Striping is Very Important

Weather Conditions Pose Difficult Obstacles for Machine Vision

Infrastructure Challenges

75

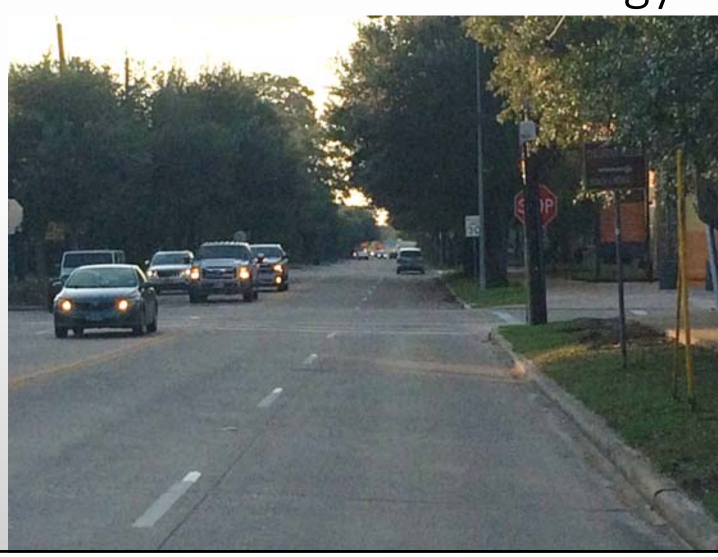
Signage Placement and Maintenance Critical for Machine Vision of AV Technology



Infrastructure Challenges

76

Signage Placement and Maintenance Critical for Machine Vision of AV Technology



Infrastructure Challenges

77

Signage Placement and Maintenance Critical for Machine Vision of AV Technology

Infrastructure Challenges

78

Temporary Lane Closure and Traffic Management in Construction Zones are Confusing to AVs

Infrastructure Challenges

79

Infrastructure Gaps

AV Technology Issues that Identify Infrastructure Gaps

- Connected Vehicle provisions
  - ITS Equipment installations for V2I communications
- AV "localization" system provisions
  - Supplemental equipment installations to compensate for GPS signal weaknesses in urban environments

AMS

Infrastructure Challenges

80

Infrastructure Gaps

Roadway Right-of-Way – The major operational issues in Urban Districts and Major Activity Centers identify important gaps in the infrastructure planning and design – challenges that could be the most difficult to resolve.

- Curbfront Provisions
- Empty Vehicle Accommodations
- Failed Vehicle Impacts

AMS

Houston's University District AV Transit Circulator Project

The University District Partnership:

Texas Southern University

University of Houston

Houston METRO

City of Houston

Houston-Galveston Area Council

University District AV Transit

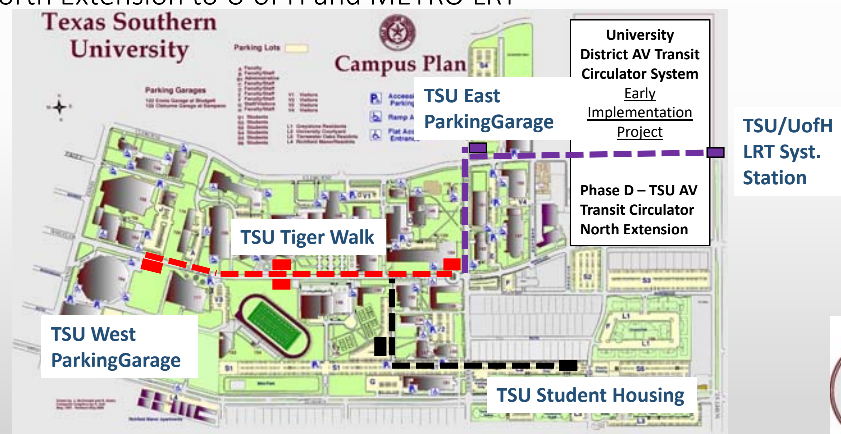
NCHRP 20-102(02) Study Identified Numerous Policy Questions Needing a Test Bed with L4 Operations to Assess Answers

- ***Campus Environments are currently the best test beds*** for automated vehicles deployment operating with L4 automation in Transit Service
- ***Research needs to address key aspects of Safety, Policy and Regulatory*** issues to allow AV Transit to advance beyond campus environments
- ***Practical design and operational issues need suitable "test beds"*** to address system-level operational challenges in the Near Term

University District AV Transit

University District AV Transit Circulator Project
Early Deployment Phases:

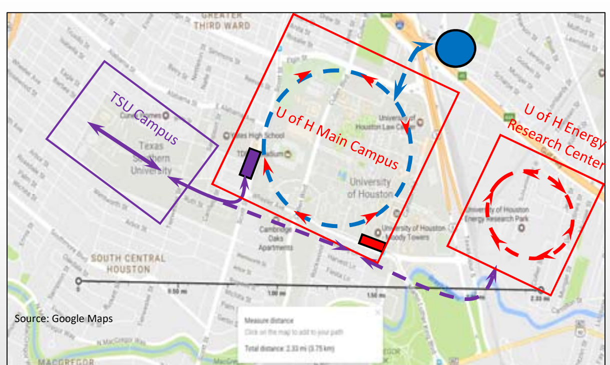
A - Initial TSU Tiger Walk
B - South Extension to Student Housing
D - North Extension to U of H and METRO LRT



University District AV Transit

University District – Phased Long Term Implementation Plan Over Next 10-15 Years

Early Deployment Project (5 years) launches a fully operational transit system, followed by Medium Term to Long Term Implementation Phases



Source: Google Maps

TSU Early Deployment Ph. A-D	⟷	Early Depl. Ph. C LRT Station – Southeast LRT Connection	purple box
U of H ERC Connections Early Depl. Phase E	⟵ – – ⟶	Early Depl. Ph. E LRT Station – Southeast LRT Connection	red box
U of H Main Campus Medium and Long Term	⟵ – – ⟶	Long Term METRO Eastwood Transit Center Connection	blue circle

University District AV Transit 85

PLANNING BASELINE – Proven AV Technology with Houston Roots

2GT has provided multiple GRT operating systems since the 1990's which are now crossing over into the AV Transit field

Oceaneering International is one of the most experienced firms in commercial robotics and has partnered with 2GT to provide the U.S. based manufacturing and operational support of the AV technology.

University District AV Transit 86

University District's Controlled Campus Environment has Low Hanging Fruit for R&D

Provides the ideal conditions to study, improve and develop AV/EV technology to meet Strategic Objectives:

1. ***R&D of electrical supply systems***
2. ***Operational research in fully-automated driverless vehicles***
3. ***Development of advanced operating concepts***
4. ***Research in ADA design and safety analyses***
5. ***Demonstration of First-Mile/Last-Mile Connectivity***

Center For Transportation Training & Research (CTTR)

Conclusions

Conclusions

1. **Coordinated Development of Automated and Connected Vehicle Technology** continues as NHTSA/SAE cooperate
2. **AV Technology Deployment will take decades** due to many technical and policy/regulatory challenges that will have to be met.
3. **Urban Districts will greatly benefit from AV deployment**, but the issues that come the benefits will create daunting challenges the must be addressed now in strategic planning and design activities.

Conclusions

4. **Infrastructure Challenges and Gaps May Impact AV Deployments**
   a) AV machine-vision system requirements for paint striping, signage and traffic signal systems.
   b) Roadway ROW provisions with dedicated lanes allowing curb stops and failed vehicle pull-off.
   c) Connected Vehicle provisions for V2I communications along all types of roadway facilities.
   d) AV "localization" system provisions for GPS signal strength compensation is essential in urban "canyons.

Conclusions

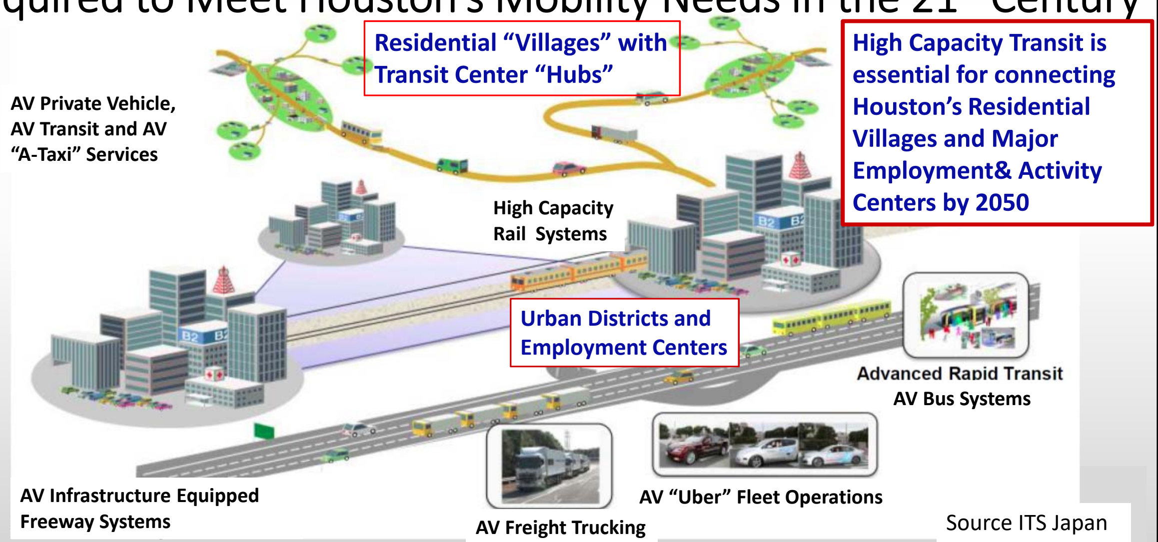
5. **University District AV Transit Circulator System provides proper environment to validate automation technology:**
   a) **A living laboratory** to address key challenges and help accelerate AV and EV technology implementation.
   b) **An excellent environment to demonstrate AV Transit** technology providing cost effective Internal Circulation in urban districts with complex operating environments.
   c) **First-mile/last-mile feeder systems** connecting high-capacity regional and mega-regional transit corridors with nearby urban districts and major-activity-centers.

Conclusions

6. **A Comprehensive Multimodal Transportation System will be Required to Meet Houston's Mobility Needs in 2050:**
   a) **AV access to Transit Hubs** in residential "villages" throughout the region.
   b) **High Capacity Transit** in corridors with concentrated travel demands connecting residential centers with employment centers.
   c) **Efficient AV Transit for first-mile/last-mile** connections to High Capacity Transit in major urban districts.

Conclusions

A Comprehensive Multimodal Transportation System is Still Required to Meet Houston's Mobility Needs in the 21st Century



Japan's 2050 Plan

93

Thank you for your time!

Automated Roadway Vehicle Technology and the Implications for Houston's Future Mobility

J. Sam Lott, P.E.
Automated Mobility Services, LLC

Presentation to the H-GAC Brownbag Lecture Series
January 22, 2018

Automated Mobility Services LLC

94

For More Information

J. Sam Lott, P.E.

- Automated Mobility Services, LLC
  - Jsamlott.amsllc@gmail.com
  - Mobile: 713-927-3048
- TSU Center for Transportation Training and Research
  - Jsam.lott@tsu.edu
  - Office: 713-313-1959

NCHRP 20-102(02) **Impacts of Regulations and Policies on CV and AV Technology Introduction in Transit Operations**

Webinar: http://www.trb.org/Main/Blurbs/176654.aspx

Reports: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3935