Integrating AV Technology with High Capacity Transit –

Creating a Multimodal System Approach for the 21st Century

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Presentation Lecture to H-GAC Lunch and Learn
March 25, 2019

Introduction

Where Have My Ideas Come From?

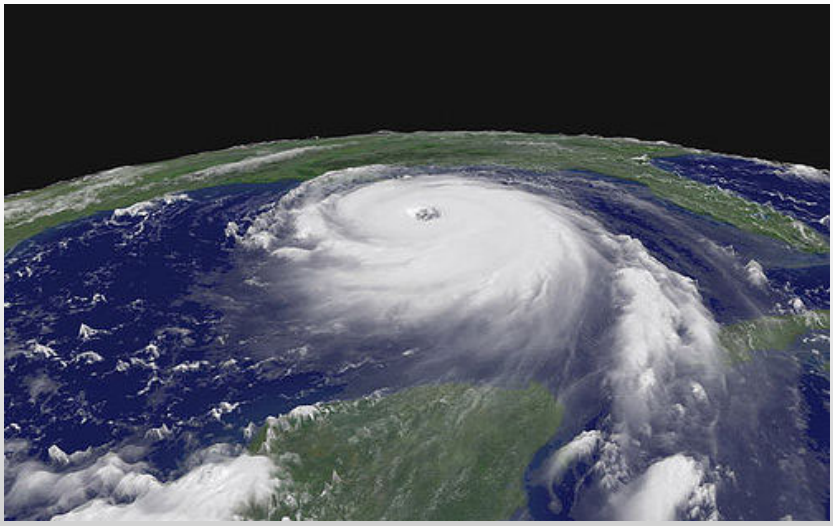
- 40 years of professional work fully automated transit systems field
- 20 years of planning studies and engineering projects for the Houston Region's roadways, railroad and transit systems
- 7 years of presentations on Houston's Impending Transportation Crisis and ways to mitigate its impacts on our lives
- 5 years of study of the new automated roadway vehicle technologies
- 2 years of preparations for the University District AV Transit Circulator System's Phase 1 Deployment

From this experience I will discuss my Twelve Conclusions about how AV technology must be integrated with High Capacity Transit

Introduction

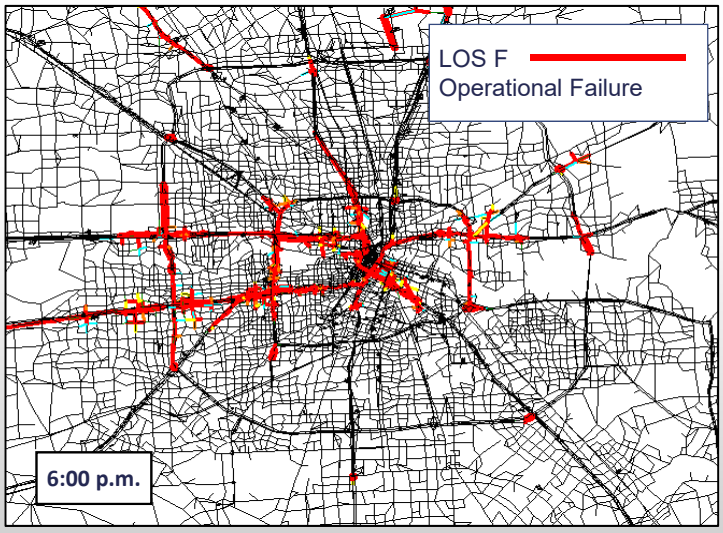
A Storm is Coming

As if a Category 5 Hurricane was bearing down on the city, we are facing a storm of traffic congestion unlike anything we have seen before and there is no way to avert the crisis.



Introduction

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



These results provide operational insight into the regional travel demand models results for 2045 and years beyond. Some portions of our roadway network will have LOS F operating conditions that last all day long.

Introduction

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

TxDOT Study Assumptions Included High Penetration of AV Technology

Freeways and Tollways modeled for 2035 traffic operations with aggressive assumptions of:

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

**** Highest freeway capacity ever recorded of 2,400 pcphpl, measured for human drivers at a free-flow speed of 75 mph in ideal geometric and traffic conditions**

Introduction

H-GAC Brown Bag Series – January 22, 2018
One Year Ago the Topic was:

What the Future Holds for Automated Roadway Vehicles –
Evaluating Mobility Benefits, Infrastructure Gaps and Transit Applications

THIS WAS A GOOD PRIMER ON TECHNICAL ASPECTS OF AV APPLICATIONS

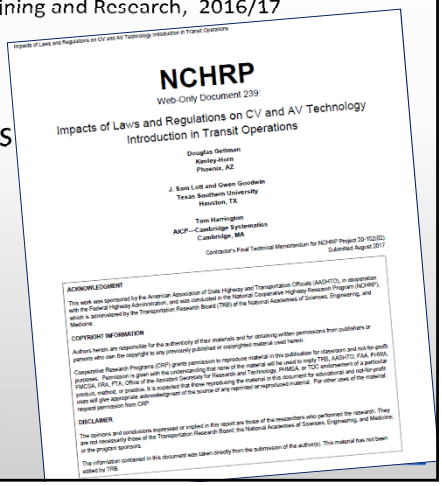
Introduction

2018 Presentation Created from the Findings of:

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

J. Sam Lott – Principal Investigator for TSU Center for Transportation Training and Research, 2016/17

- 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



NCHRP

Web-Only Document 239

Impacts of Laws and Regulations on CV and AV Technology Introduction in Transit Operations

Douglas Gettman
Kimley-Horn
Phoenix, AZ

J. Sam Lott and Gwen Goodwin
Texas Southern University
Houston, TX

Tom Harrington
AICP—Cambridge Systematics
Cambridge, MA

Contractor's Final Technical Memorandum for NCHRP Project 20-102(02)
Submitted August 2017

ACKNOWLEDGMENT

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Introduction

Today's Presentation Builds on the Information Given in the 2018 Presentation

H-GAC Brown Bag Series – January 22, 2018

What the Future Holds for Automated Roadway Vehicles

– Evaluating Mobility Benefits, Infrastructure Gaps and Transit Applications

Audio Track – http://www.h-gac.com/transportation-public-outreach/documents/LOTT-Future_of_AV_in%20Houston-Audio.mp3

Presentation Slides – http://www.h-gac.com/transportation-public-outreach/documents/LOTT-Future_of_AV_in_Houston-PDF-ForAudioTrack.pdf

Introduction

January 22, 2018 Presentation

Definition of Terms

- **AV – Automated Roadway 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**

Introduction

Final Conclusions – January 22, 2018 Presentation

A Comprehensive Multimodal Transportation System will be Required to Meet Houston's Mobility Needs in 2050:

a) **AV Microtransit access to Transit Hubs** in residential "villages" and town centers throughout the region.

b) **Efficient AV Microtransit for first-mile/last-mile** connections to High Capacity Transit in major urban districts.

c) **AV Bus High Capacity Transit** in corridors with concentrated travel demands connecting residential centers with employment centers.

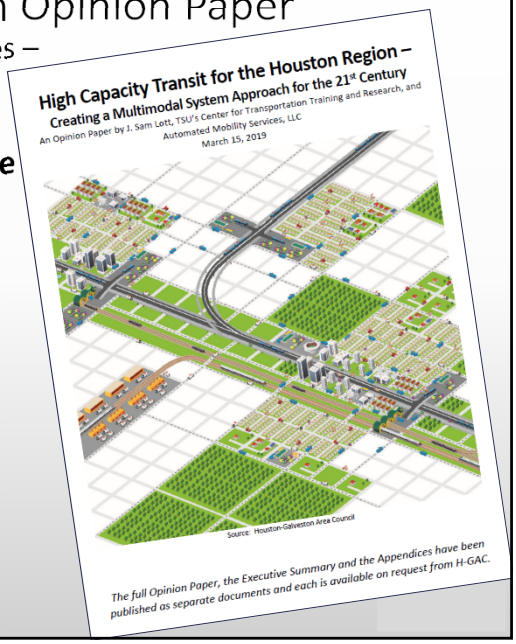
Introduction

This Presentation is Drawn From an Opinion Paper

Download Links Available at H-GAC Brown Bag Series – March 2019 Lecture Webpage

High Capacity Transit for the Houston Region – Creating a Multimodal System Approach for the 21st Century

1. Introduction – A Transportation Crisis is Coming
2. Transit Applications of the New Advanced Vehicle Technologies
3. Mobility Through an Integrated and Connected Multimodal Transit System
4. A Case Study of the Westpark/Richmond Corridor
5. Conclusions on an Integrated Multimodal High Capacity Transit System



Conclusion #2: AV and HCT

Acknowledgements and Disclaimers

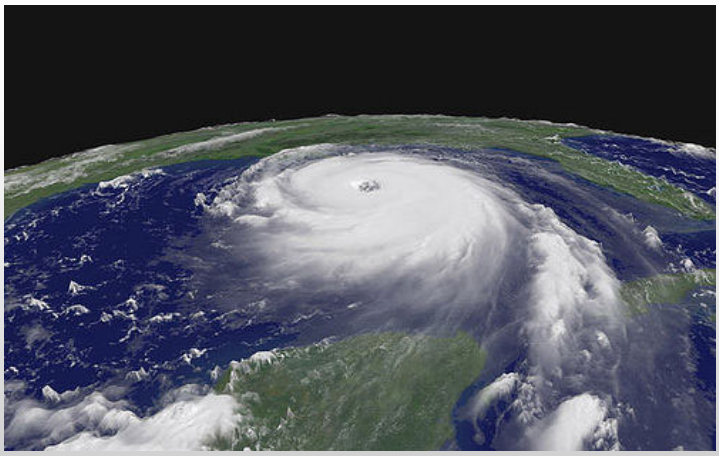
The Opinion Paper and this summary presentation has many of my "old" ideas and proposals, but also many new insights and information that came from the creative environment of new thinking generated by H-GAC staff and the many people who participated in the H-GAC High Capacity Task Force. I greatly appreciate the opportunity to be part of that very important process.

Neither this presentation nor the Opinion Paper that is referenced is endorsed by, nor does it necessarily represent the opinions of H-GAC, the HCT Task Force members or the TSU CTTR leadership.

Conclusion #1: A Storm is Coming

Houston must prepare to live in the middle of the storm of traffic congestion by creating a multimodal system approach for the 21st Century –

Beginning today



Conclusion #2: Automated Roadway Vehicle (AV) Technology Must Have Broad Applications with HCT if We are to Mitigate the Mobility Impacts of Congestion

#2: AV Broad Applications

Automated Roadway Vehicle (AV) Technology Will Soon be Ready for Broad Applications with HCT

- AV Microtransit
  - Smaller Vehicles Operating at Slower Speeds of City Streets
  - No Onboard Operators, but with Continuous Oversight by Operations Staff
  - New Operational Paradigm with More Flexible Operating Configurations
- AV Buses
  - Conventional Size Buses Operating at Higher Speeds
  - No Onboard Operators, but with Continuous Oversight by Operations Staff
  - Fixed Route and "Flex-Route" Applications at Moderate Speeds
    - Arterial Streets
    - Dedicated Transitways – Bus Rapid Transit
  - Regional Service on HOV Lane System at High Speeds

#2: AV Broad Applications

Major Factors Affecting the Timeline for AV Technology Deployments

- Almost all ADS developers have deployments as fleet operations
- ADS developers are still deploying at SAE Level 3, even in very controlled environments
- Software development which controls highly complex and safety critical functions will be driven by the 80/20 Rule :

  " 80% of the work is to create the last 20% of system functionality"
- The focus of current R&D is still primarily on the basic ADS capabilities necessary to perform the tactical dynamic driving task (DDT)

Houston AV Timeline

Early Houston AV Services	Example Automated Machine Functions	Transit System Application	Potential Timeline for Early Houston-Deployment
Urban Center AV Circulator First-Mile/Last-and Mile Services	Automated driving, path determination and station berthing without an operator (driver or attendant) onboard at any time	Automated Transit Route or Demand-Responsive Dispatch; Empty Vehicle Repositioning/ Storage	Speeds Under 25mph - ~~2018-2020~~ 2020-2025 Speeds Up to 40 mph – ~~2020-2025~~ 2025-2030
HOV Lane and Transit Center High Capacity Transit System	Automated driving from origin to destination, path determination and station berthing without a operator	Special Environment: Automated HOV with operator boarding at HOV transit centers	Speeds Up to 60 mph – 2025-2030
Dedicated BRT Lane System Operating in City Street	Automated driving, path determination and station berthing without a driver onboard at any time from origin to destination	Special Environment: BRT in exclusive transitways with controlled street & pedway crossings	Speeds Under 25mph - 2020-2025 Speeds Up to 60 mph – 2025-2035

#2: AV Broad Applications

Example Applications of AV Transit Technologies

A small sample of dozens more currently active sites

Location	AV Technology	Application
Arlington	Easy Mile/Drive AI	Entertainment District
Las Vegas	NAVYA	Innovation District
Columbus	May Mobility	Downtown Tourist District
Rotterdam	2getthere	Rivium Business District
Houston	Easy Mile	University District

Currently all U.S. deployments require a “waiver” from NHTSA before passenger service operations can begin

#2: AV Broad Applications

AV Technology is Advancing Across Many Fronts

Source: techcrunch.com
https://techcrunch.com/2018/07/30/drive-ai-self-driving-service-texas/

Drive AI

EasyMile

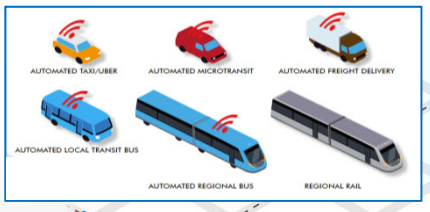
Source: http://www.easymile.com/

May Mobility

Source: https://techcrunch.com/2018/06/13/self-driving-shuttle-startup-may-mobility-partners-with-auto-supplier-magna/

#2: AV Broad Applications

AV Microtransit Circulation and FM/LM Systems Deployed In Town Centers



HCT Corridor Connecting with Remote Suburban Town Centers

HCT Regional AV Bus/BRT on Protected HOV Lanes

On-Demand AV Microtransit and AV Taxi/Uber

Transit Hub in Town Center

AV Local Bus on Fixed/Flex-Route Along Arterial Streets

HCT Corridor Connecting With Major Employment Districts in the Urban Core

#2: AV Broad Applications

AV Microtransit Circulation Systems will Comprise a Range of Vehicle Sizes

Small 4 Passenger Microtransit Vehicles – Seated Passengers Only

Aurrigo

Source: **Aurrigo,** div. of RDM Group https://aurrigo.com/

2getthere

Source: **2getthere** www.2getthere.eu

#2: AV Broad Applications

AV Microtransit Circulation Systems will Comprise a Range of Vehicle Sizes

Medium 10 Passenger Microtransit Vehicles – Seated & Standing Passengers

NAVYA – Arma

Source: Navya https://navya.tech/en/

Local Motors – Ollie

Source: **Local Motors (Olli)** https://localmotors.com/

#2: AV Broad Applications

AV Microtransit Circulation Systems will Comprise a Range of Vehicle Sizes

Large 20 Passenger Microtransit Vehicles – Seated & Standing Passengers

2getthere/Oceaneering Intl.

Source: 2getthere www.2getthere.eu

Source: 2getthere www.2getthere.eu

#2: AV Broad Applications

AV Bus Technology will also provide a Range of Vehicle Sizes

Full Size 30-50 Passenger AV Buses – Seated & Standing Passengers

Daimler/Mercedes – Future Bus

Source: Daimler
https://www.daimler.com/innovation/autonomous-driving/future-bus.html

Local Motors – Ollie

Source: Volvo Group
https://www.volvogroup.com/en-en/news/2019/mar/autonomous-electric-bus.html

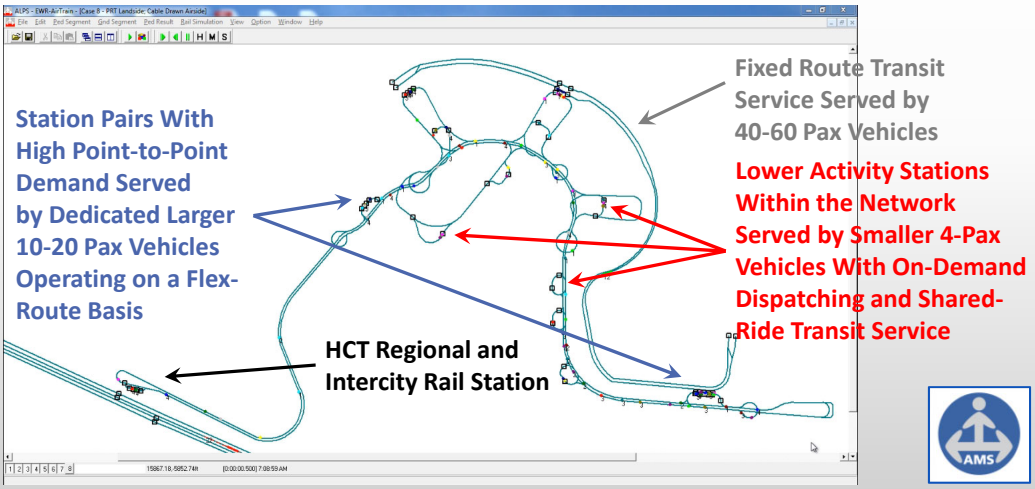
#3: A New Transit Paradigm

Flexibility of AV Operations with Automated Dispatching in Real Time Can Adjust to the Fluctuations in Ridership Patterns

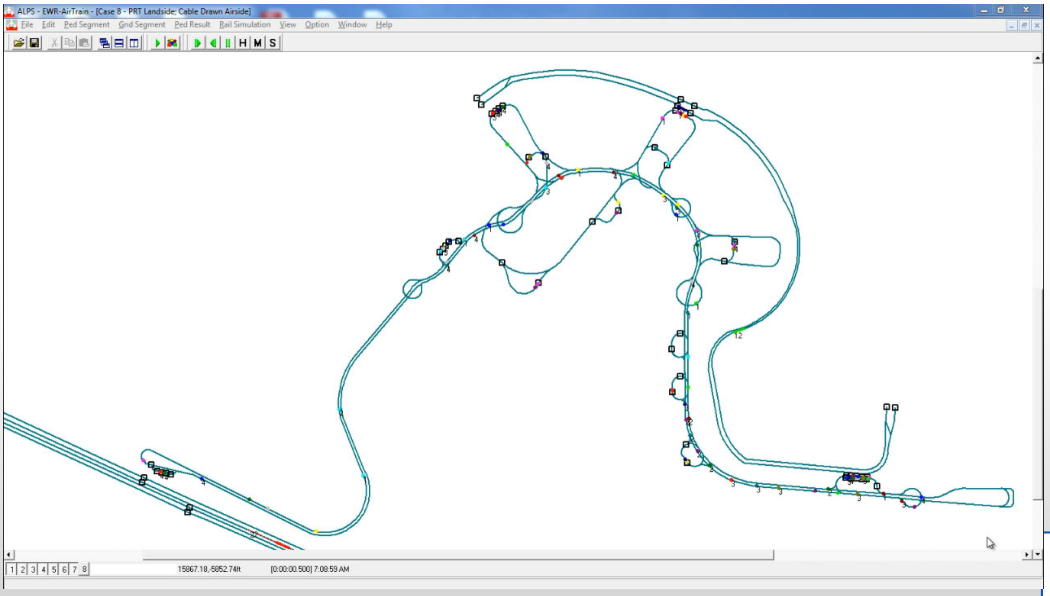
- Optimization of Operating Fleet Size
  - During periods of low ridership demand, many vehicles are dormant
- Mix of Vehicle Sizes
  - All vehicle sizes operating under Operations Supervisory Control System
- Dynamic Route Reconfigurations
  - Fixed route and flex route operations of Large Size Vehicles
  - Automated Transit Network (ATN) operations of Small and Medium Sized Vehicles
- Dynamic Dispatching for Ridership Demand Response
  - Network operations dispatched in real time responding to passenger "calls"

A totally automated transit system will include all this flexibility within and Integrated transit system for town centers, districts and corridors

Conclusion #3 –A New Transit Paradigm is Coming From the Flexibility of AV Operations



#3: A New Transit Paradigm



#3: A New Transit Paradigm

AV Microtransit – Strategically Important Within Urban Districts and Major Activity Centers

- Internal Circulation to the Town Center, Urban District or Major Activity Center, as well as first-mile/last-mile (FM/LM) connections to HCT
- Demand-response dispatching in real time as ridership "demand" requests are made on mobile devices and at kiosks on station platforms
- Vehicle fleet activity optimized when ridership drops with dormant vehicles held in locations where battery charging can occur
- Prior studies have analyzed this type of operational complexity:
  - Automatic Transit Network (ATN) using AV Microtransit vehicles
  - Similar in operational concept to Transportation Network Companies (TNCs) such as Uber/Lyft or taxi companies but with AV unmanned vehicles

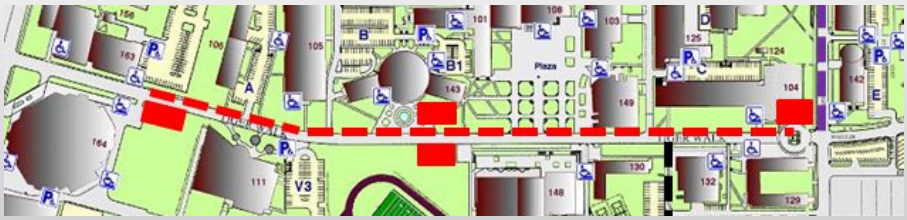
Conclusion #4: Houston's Best First Step in AV Microtransit Deployment Is Being Taken in a Semi-Protected Campus/District Environment, with Phased Expansion to More Complicated Operating Environments and Ultimate Connections to HCT.

#4: AV Microtransit in Districts

University District AV Transit Circulator Phase 1 – TSU Shuttle Demonstration Pilot Project Team

- Houston METRO
- Texas Southern University
- University of Houston
- Houston Galveston Area Council

Phase 1 Demonstration Pilot will operate a single Easy Mile vehicle along ½ mile length of Tiger Walk pedestrian path (former Wheeler Av. Alignment)



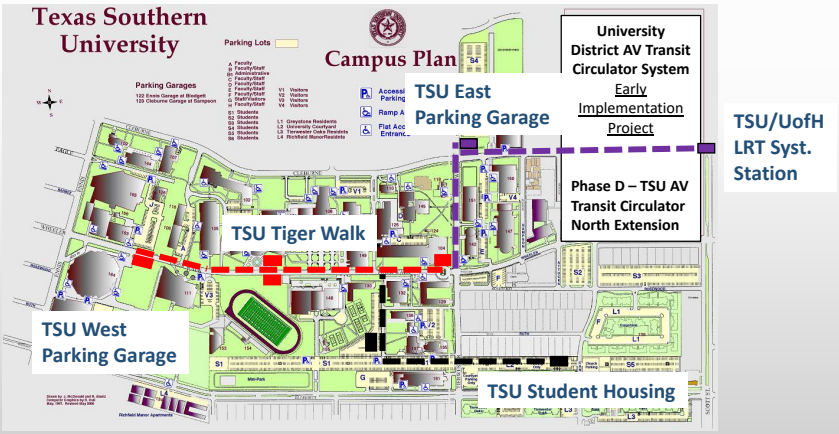
#4: AV Microtransit in Districts

University District AV Transit Early Deployment Phases:

1 - TSU Shuttle on Tiger Walk

2 - North Extension to U of H and METRO LRT

2A - South Extension to Student Housing

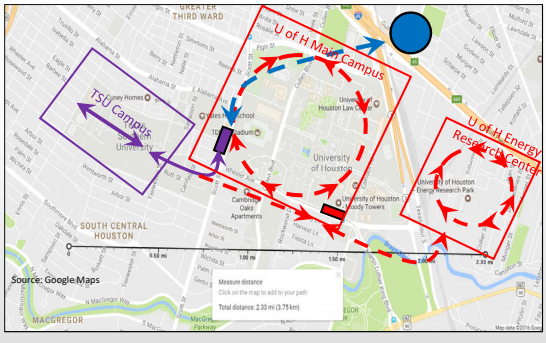


#4: AV Microtransit in Districts

Univ. District AV Transit Circulator – Houston's First AV Deployment

Phased Long Term Implementation Being Evaluated Under a Continuing Work Program by Houston METRO With H-GAC/TSU

- Early Deployment Phases configured as a corridor shuttle system
- Medium Term Deployment Phase create FM/LM connections to transit center serving High Capacity Transit
- Long Term Expansion throughout Univ. of Houston Campus creates an extensive network for Demand-Response dispatch operations

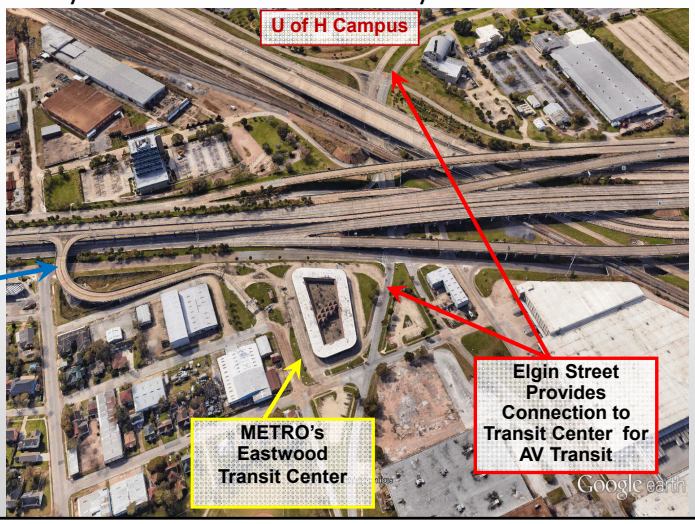


TSU Early Deployment Ph. 1 and 2 ⟷	Early Depl. Ph. 2 LRT Station – Southeast LRT Connection
Medium Term Depl. Eastwood Transit Center ← – →	Medium Term METRO Eastwood Transit Cntr Connection
Long Term Depl. U of H Main Campus and ERC ← – →	Long Term Depl. LRT Station – Southeast LRT Connection

#4: AV Microtransit in Districts

University District AV Transit Circulator System

Medium Term Deployment Provides FM/LM Connections to High Capacity Transit HOV Lane System Within I-45 Corridor

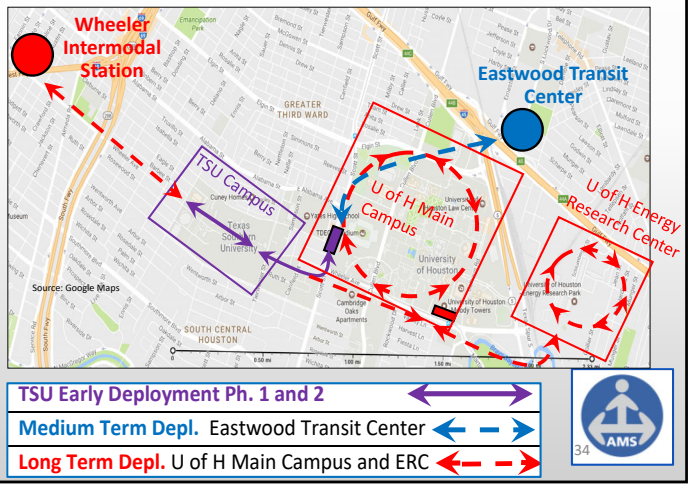


#4: AV Microtransit in Districts

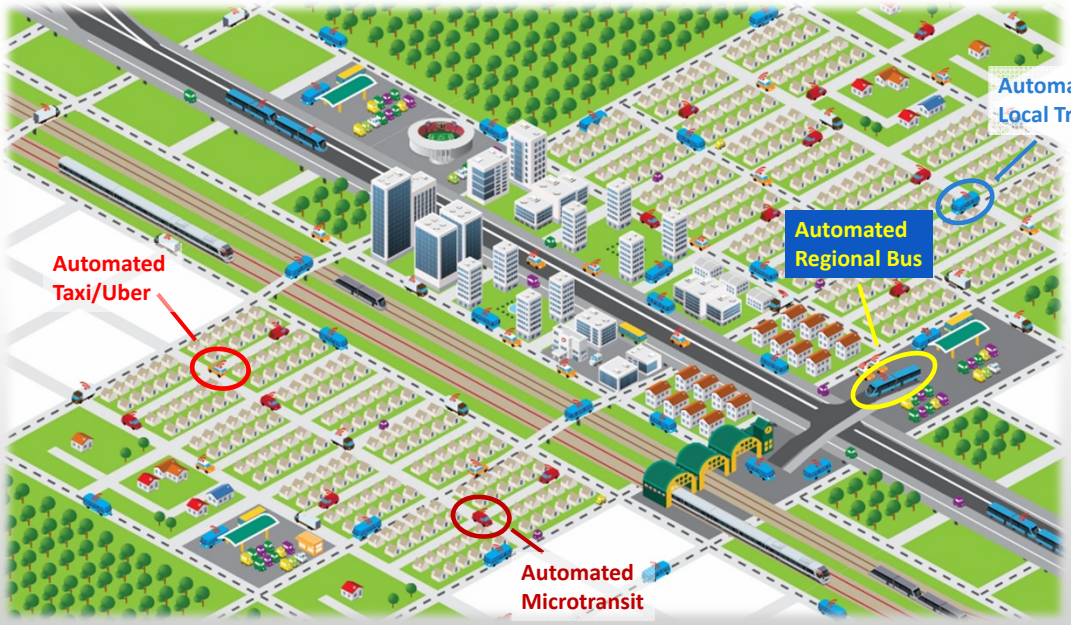
Houston's University District AV Transit System Will Become a Early Model of District Circulation and FM/LM Connectivity to HCT Services

As currently envisioned, the Univ. District AV Microtransit system will progressively be deployed with first-mile/last-mile connections to:

- Scott Street @ U of H Campus – Purple Line LRT
- Eastwood Transit Center – AV Buses on HOV system
- Wheeler Intermodal Station – Red Line LRT and Potentially AV Buses on HOV System



#4: AV Microtransit in Districts



Conclusion #5:
Second Step of AV Buses in Protected HOV System Gives Houston a Unique Opportunity in the World of Transit

#5: AV Buses in HOV Lane System

AV Buses – The Backbone of Houston's High Capacity Transit System Will be Full Size AV Buses on Transitways

- Travel in Corridors connecting the region's largest Town Centers, Urban Districts and MACs cost effectively accomplished using AV Buses
- Bus Rapid Transit features with protected transitways and dedicated stations are natural transit facilities to deploy AV Buses
- Houston's extensive HOV lane system and corridor transit centers will allow early deployment of regional AV Buses

Mercedes-Benz Future Bus operating with SAE L-3 automation during a 2016-17 pilot on the 20km transitway to Amsterdam Schiphol Airport.

Souce: https://www.daimler.com/innovation/autonomous-driving/future-bus.html

#5: AV Buses in HOV Lane System

Barrier Protected HOV Lanes are Excellent Transit Facilities to Deploy Bus Platooning

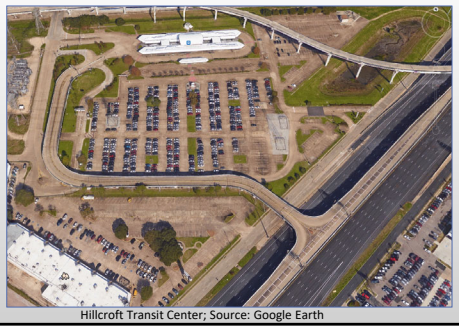
Houston's HOV lane system used in the 1997 pilot of USDOT's Automated Highway System

Source: Caltrans/PATH

#5: AV Buses in HOV Lane System

HOV Direct Connector Lanes to Transit Centers are Natural Transit Infrastructure for AV Bus Operations

Source: Houston METRO



Hillcroft Transit Center; Source: Google Earth

Metro Kuykendahl Park & Ride
Source: Google Maps

#5: AV Buses in HOV Lane System

Barrier-Protected HOV Lanes Must be Preserved and Enhanced as Freeway Expansion Occurs

- METRO's HOV lane system originally funded by FTA provides a 100 mile corridor transit system with "off-line" stations
- Excellent environment for early deployment of L-4 AV Bus technology will form the backbone of the region's HCT system
- Recent freeway construction has reduced or eliminated key HOV lane segments – this must be reevaluated going forward
- Extensive L-4 operations may require that all vehicles in HOV lanes to pass strict L-4 safety certification inspections

Conclusion #6:
Ridership Levels Forecasted From the H-GAC 2045 HCT Vision Plan Indicate Transit Use Would Occur on a Level Equal to That of Other Major Cities of the World

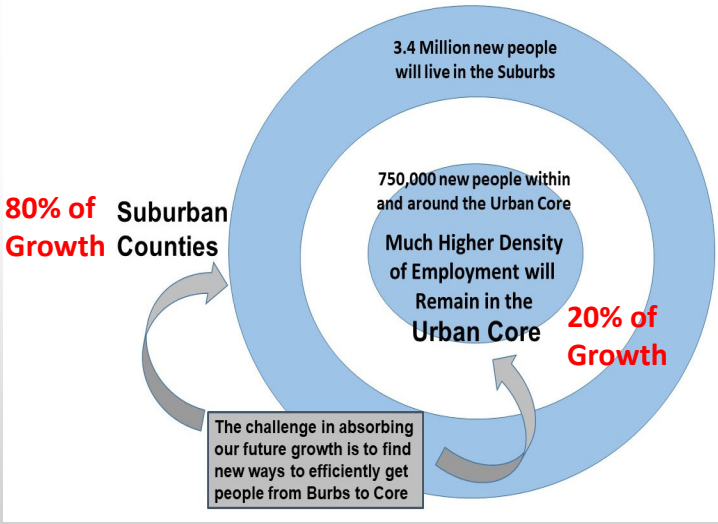
#6: H-GAC 2045 Vision Plan

H-GAC's HCT 2045 Vision Plan Utilized a Region-Wide Conceptual HCT System to Analyze Transit Ridership Potential Assuming Sufficient Capacity was Created

- Transit ridership forecasts showing transit use would grow by a factor of 10 times over the next 25 years if transit capacity was provided.
- The roadway system assumed for the analysis was the complete buildout of planned roadway projects by the year 2045.
- Aggressive assumptions of unconstrained financial limits to new transit deployments and extensive bi-directional services operating all day.
- Transit ridership forecasts are Indicative of massive traffic congestion that will occur by 2045.

#6: H-GAC 2045 Vision Plan

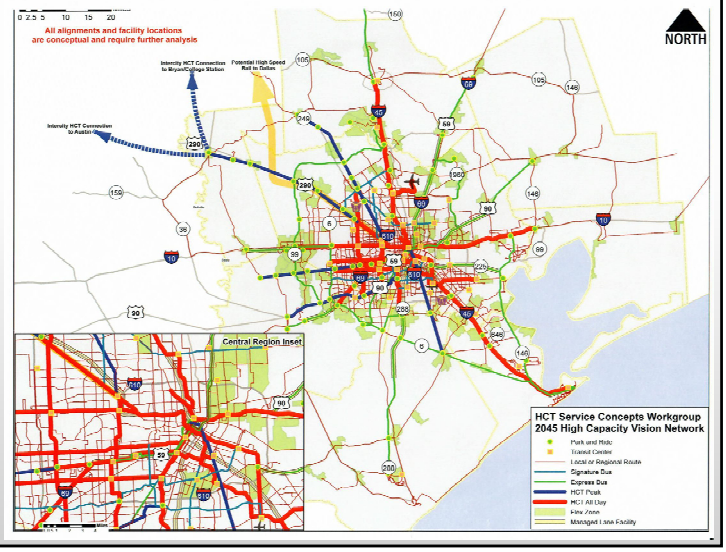
Distribution of Houston's Growth Between 2018 and 2045 Will Drive HCT Necessity



#6: H-GAC 2045 Vision Plan

H-GAC has Evaluated Ridership Potential for a HCT Prototype System Under Various 2045 Scenarios

Working with the HCT Task Force as a "think tank" in support of the 2045 RTP process, H-GAC has developed several scenarios of HCT service that span the entire 8 County region.

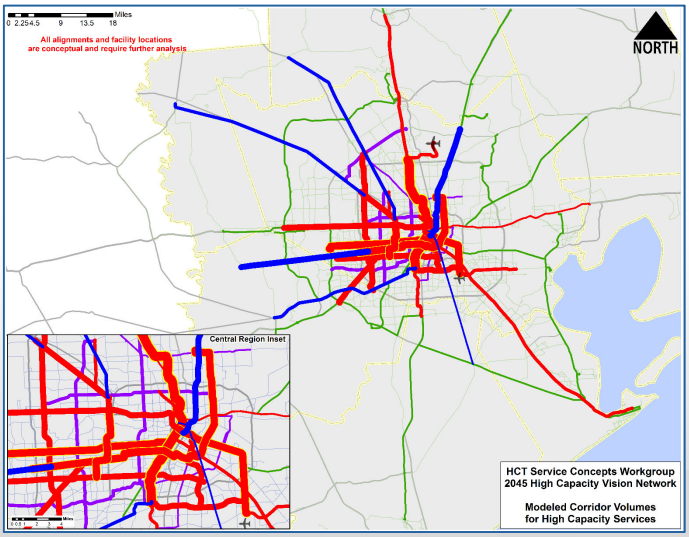


#6: H-GAC 2045 Vision Plan

H-GAC's Analyses of Financially Unconstrained Transit Development Scenarios Produced Forecasts of Transit Ridership Demands

Thickness of segments indicates relative demand in terms of passenger trips and boarding activity.

All alignments and station locations are conceptual in nature and require further analyses. These forecasted numbers are based on highly aggressive and hypothetical parameters such as unconstrained capacity.



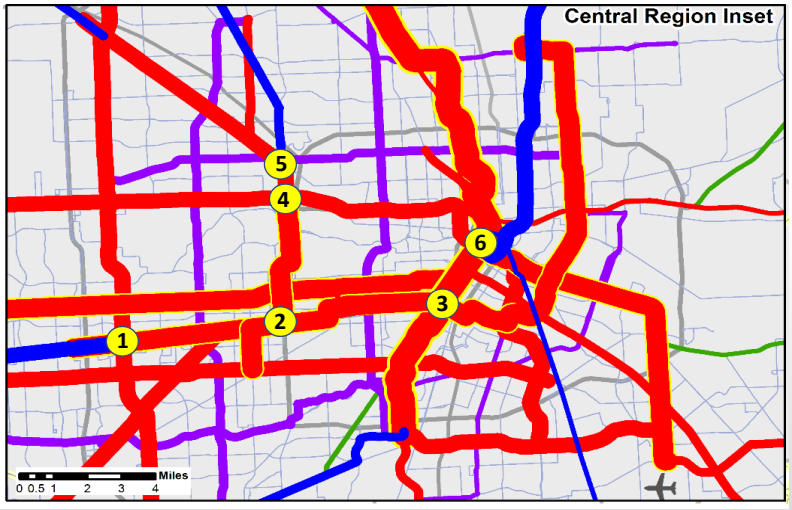
#6: H-GAC 2045 Vision Plan

Highest Demand Corridors from 2045 HCT Vision Plan Scenario

Corridor	Total Daily Boardings	Length (Miles)	Daily Boardings/Mi.
Westpark/Richmond/Lockwood – Westchase to Tidwell Transit Center	282,385	26.4	10,680
Main Street/North Red Line LRT – Greenspoint District to Fannin South P&R	259,821	21.6	12,018
Westheimer – West Oaks to Downtown	171,170	18.6	9,227
East End/Green Line LRT – Downtown to Hobby Airport	119,384	10.9	10,983
Gessner/West Belt – Willowbrook Mall to Missouri City	89,970	25.0	3,593
Inner Katy – Northwest Transit Center to Downtown	87,222	6.5	9,201
Bellaire – Mission Bend P&R to Palm Center Transit Center	83,056	19.8	4,186
Post Oak – Northwest Transit Center to Gulfton Transit Center	68,236	7.0	9,776
Hempstead Highway – West Little York P&R to Northwest Transit Center	51,284	6.3	8,140
East Bellfort – Fannin South P&R to Hobby Airport	30,229	8.9	3,397

All Corridors were assumed to have bi-directional Subregional Corridor service operating all-day.
These forecasted numbers are based on highly aggressive and hypothetical parameters such as unconstrained capacity.

#6: H-GAC 2045 Vision Plan



Boarding Activity Forecasted for the H-GAC 2045 HCT Vision Plan Loads Strategically Located Intermodal Facilities at Levels Comparable to the Largest Transit Facilities in the Country

#6: H-GAC 2045 Vision Plan

Intermodal Station Daily Boardings From H-GAC 2045 Vision Plan Forecast

Westpark/Richmond HCT Line

1. Westchase District Intermodal Station – 199,900 Boardings
   - Includes transferring passengers from Westpark/Richmond, Gessner/West Tollway, and Outer Westpark commuter lines
2. Bellaire/Uptown Transit Center – 70,100 Boardings
   - Includes transferring passengers from Westpark/Richmond and Uptown/Post Oak Lines
3. Wheeler/Blodgett Transit Center – 43,400 Boardings
   - Includes transferring passengers from Westpark/Richmond and Red Line LRT

Uptown/Post Oak HCT Line

4. NW Transit Center – 30,700 Boardings
   - Includes transferring passengers from Inner Katy and Outer Katy Line
5. HSR Terminal – 26,300 Boardings
   - Includes transferring passengers from Hempstead HCT line, but not Texas Central HSR Line (no data available)

HCT Red Line

6. Downtown Central Station – 86,600
   - Includes transferring passengers from HCT Green Line and HCT Purple Line

Conclusion #7

Forecasted Ridership Levels Will Require Major New HCT Systems and Large Intermodal Stations by Mid- 21st Century

#7: Major New Systems/Facilities

HCT is Defined by Many Different Transit Operating "Modes" and Vehicle Technology Applications

HCT Service Concepts:

- Local
  - First-Mile/Last-Mile Service
  - District Circulator Service
  - Local Circulation and Connectivity
- Subregional
  - Subregional Corridor and Inter-Nodal Service
- Regional
  - Mega-Region Service
  - Regional Commuter/Express Service

NOTE: Source for these terms is the H-GAC High Capacity Task Force

#7: Major New Systems/Facilities

Local Service Concept

Example Vehicle Technologies in District Applications

Cleveland Healthline BRT
Source: Wikipedia https://en.wikipedia.org/wiki/HealthLine

Miami Metromover
Source: J. Sam Lott

Local Circulation and FM/LM Service in Urban Districts, Town Centers and Major Activity Centers

Dubai Bluewaters District APM Connector
Source: 2getthere website
https://www.2getthere.eu/

#7: Major New Systems/Facilities

Houston's Oceaneering Intl. is Offering Driverless AV Transit for Certain Operating Environments

Oceaneering's trackless vehicles become self-driving as well

Inpark Magazine, December 14, 2018

Source: http://www.inparkmagazine.com/oceaneerings-trackless-vehicles-become-self-driving-as-well/

"Specializing in vehicles for visitor attractions, Oceaneering Entertainment is part of Oceaneering, a global provider of engineered services and products with markets in offshore, energy, defense and aerospace."

… "Oceaneering describes the REVO-GT™ as an "automatic guided vehicle for transit applications." The first vehicles are scheduled to start shipping in 2019."

#7: Major New Systems/Facilities

Subregional Service Concept

Example Vehicle Technologies in Corridor Applications

Dubai Al Sufouh 2 Line
Source: Dubai Roadway and Transport Authority website

Los Angeles Orange Line BRT
Source: J. Sam Lott

Subregional Corridor Service Connecting Districts and Town/Activity Centers

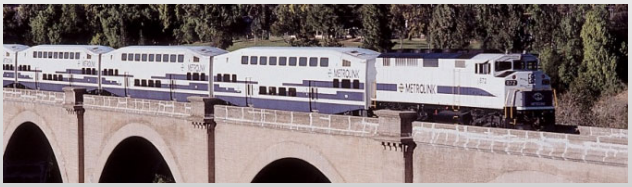
Dallas LRT System
Source: DART

#7: Major New Systems/Facilities

Regional Service Concept

Example Vehicle Technologies in Regional Applications

Austin Metrorail Red Line
Source: Capital Metro



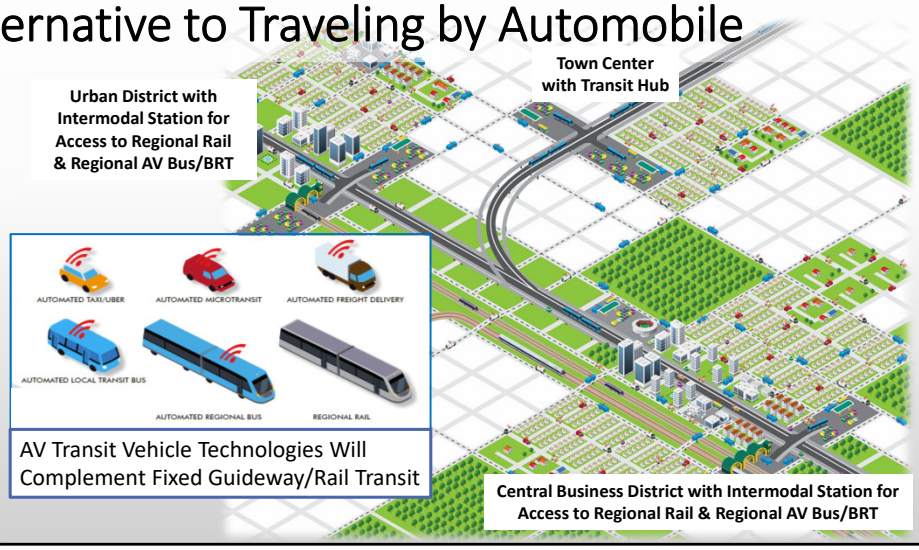
Los Angeles Metrolink Commuter Rail
Source: Los Angeles Metrolink

Long Distance Express Service Spanning Across the Entire Region

Woodlands Express
Source: Woodlands Express website
https://www.thewoodlandstownship-tx.gov/994/Park-and-Ride-Service

#7: Major New Systems/Facilities

Mobility Can Only Be Sustained Through an Integrated and Connected Multimodal Transit System as an Alternative to Traveling by Automobile

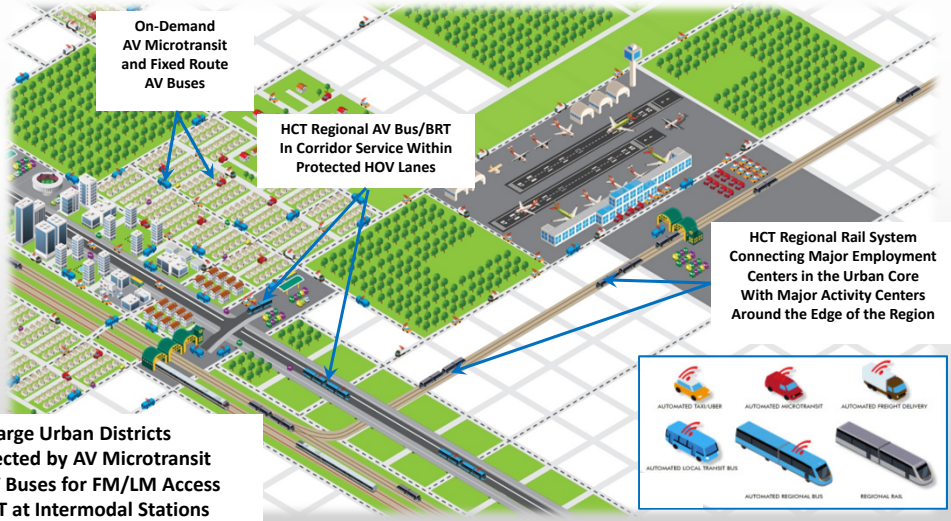


Conclusion #8

AV Microtransit in Districts and AV Buses on a Regional HOV Lane System Will Facilitate the Interconnection of Major Districts Inside the Urban Core

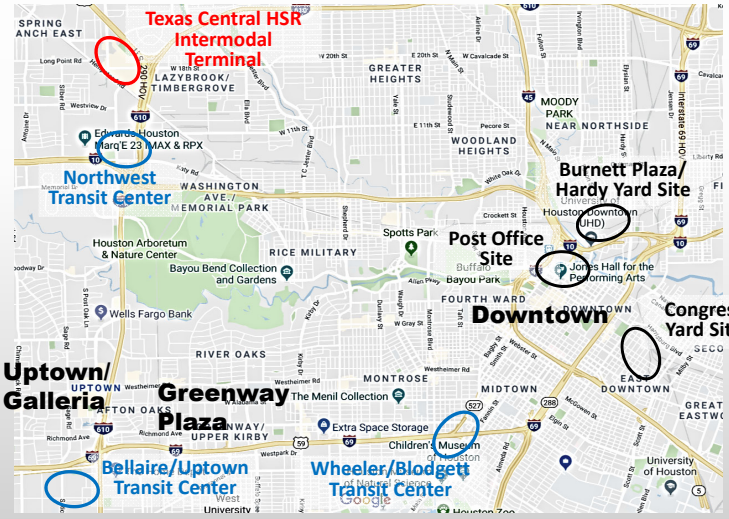
#8: Connections in the Urban Core

Connectivity becomes Critically Important at Strategically Placed Intermodal Stations



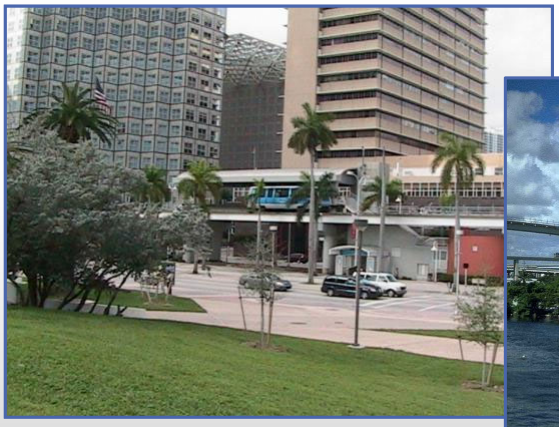
#8: Connections in the Urban Core

Strategic Intermodal Station Locations Houston has Studied in the Past Ten Years



#8: Connections in the Urban Core

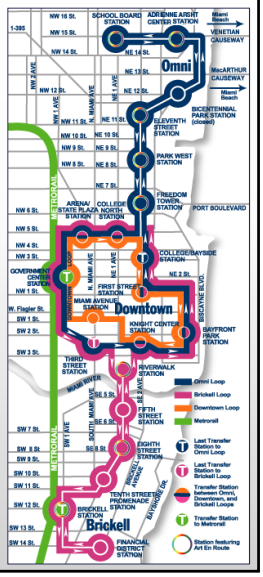
Miami's Downtown Metromover Example of a District Circulator and FM/LM System Connecting to a Major HCT Intermodal Station



Source: Kimley-Horn & Assoc.

Miami Metromover Downtown District Circulator

Source: Kimley-Horn & Assoc.



#8: Connections in the Urban Core

Create Multilevel Intermodal Stations Like Miami's Government Center Station

Source: J. Sam Lott

Source: Google Maps

Source: J. Sam Lott

Level 1 – Ped Access and Local Buses
Level 2 – District Metromover System
Level 3 – Regional Metrorail System

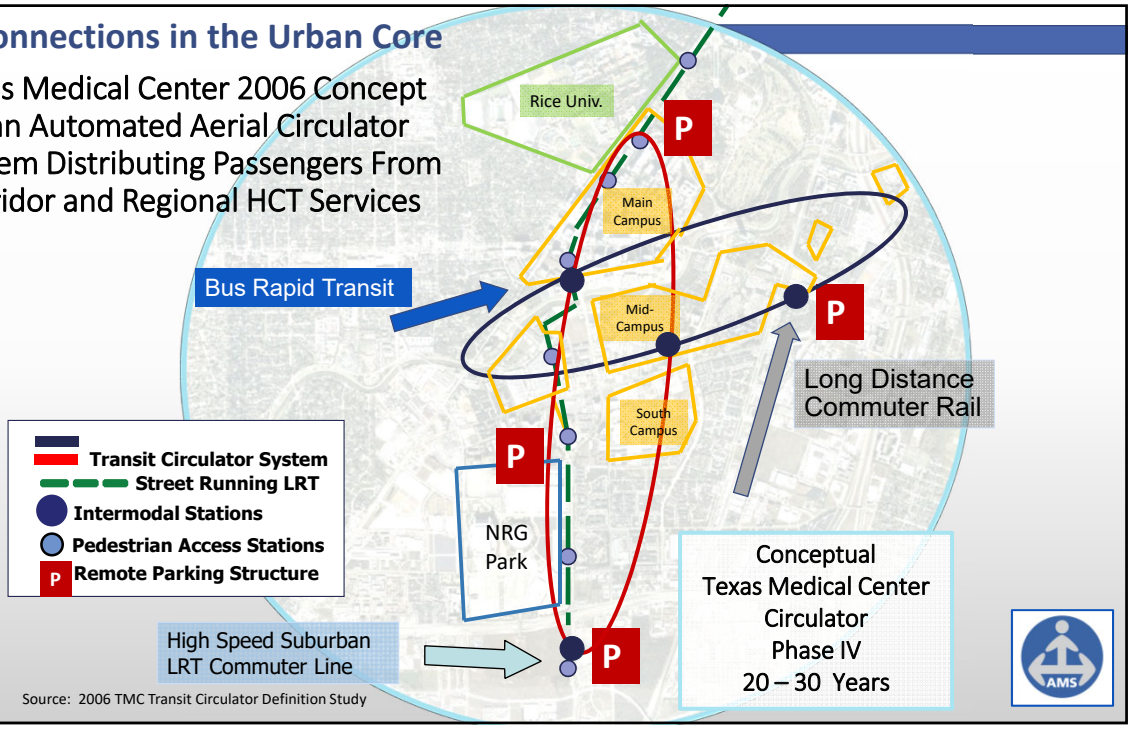
#8: Connections in the Urban Core

Street-Level Transit in Major Urban Districts Will Become Increasingly Constrained by a Congested Roadways

Because of practical constraints of roadways, Texas Medical Center was studied in 2006 to assess the benefits of a conceptual grade-separated transit circulator system

#8: Connections in the Urban Core

Texas Medical Center 2006 Concept for an Automated Aerial Circulator System Distributing Passengers From Corridor and Regional HCT Services

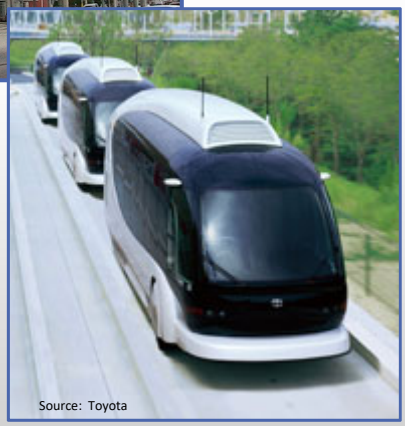


Source: 2006 TMC Transit Circulator Definition Study

#8: Connections in the Urban Core

Source: J Sam Lott

The Conceptual TMC Automated Aerial Circulator Can Best be Implemented Using Platooning "Virtually Coupled " AV Buses

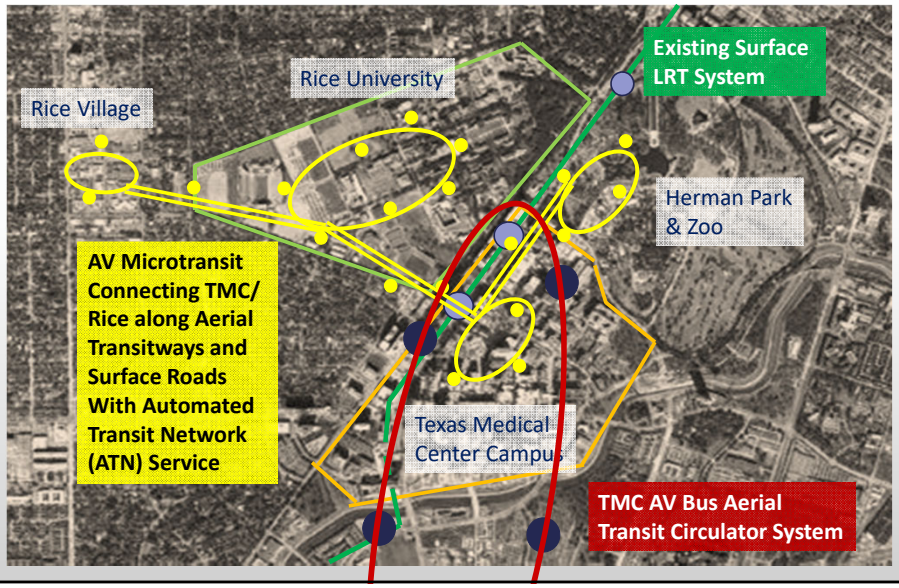


Source: Toyota

Source: J Sam Lott

#8: Connections in the Urban Core

An AV Microtransit System Can Connect with the TMC Aerial Circulator



AV Microtransit System Servicing Rice Univ., Rice Village, Museum District and Herman Park can provide flexible ATN Service along combinations of aerial and at-grade transitways, as well as surface roadways.

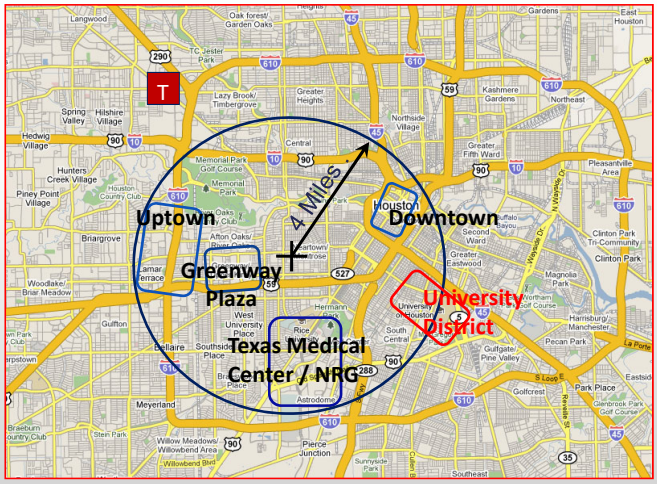
#8: Connections in the Urban Core

AV Microtransit System Can Operate With Small Driverless Vehicles Running on Campus Roadways and Passing Over Heavy Traffic on TMC Streets & Arterials

Source: ULTra PRT

#8: Connections in the Urban Core

Multimodal Connectivity with HCT With AV Microtransit Circulation Systems in All Major Districts Within Urban Core



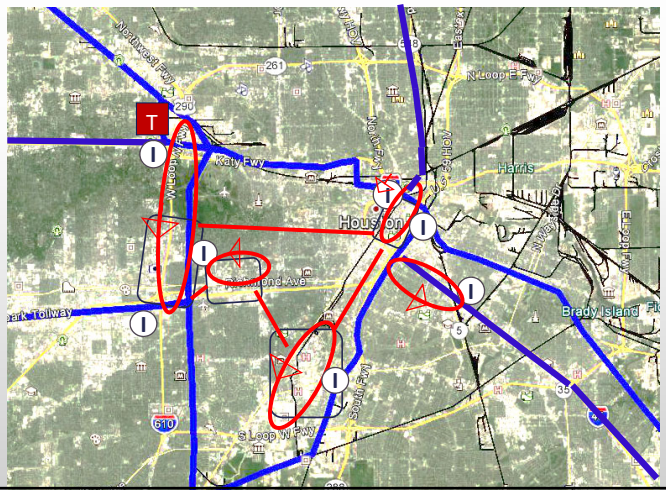
Source: Google Maps

T HSR Passenger Terminal and Intermodal Hub

Four Urban Employment Districts Other than the University District are large enough to be in the list of the top 15 CBDs in the country.

#8: Connections in the Urban Core

Critically Important Regional Access to Urban Core Districts will be provided by Subregional and Regional HCT Services accessible at strategically located Intermodal Stations with connections to AV Microtransit Circulator and FM/LM Systems.



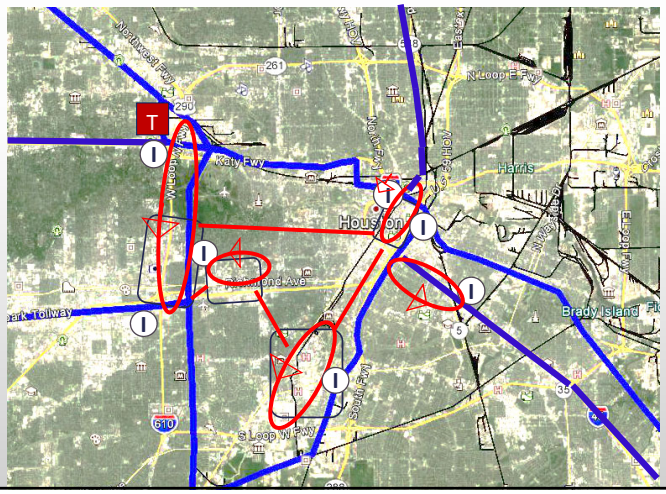
- High Capacity Transit Lines
- T — High Speed Passenger Rail Terminal
- I — Intermodal Facilities
- Urban District AV Transit Circulator Systems

Conclusion #9

Serving the Region With an Integrated Multimodal Transit System Will Require an Aerial Transitway System Inside the Urban Core to Effectively Connect All Major Districts

#9: Urban Core Transitway System

The massive HCT Ridership Demands forecasted by H-GAC's 2045 Vision Plan studies would overwhelm at-grade transit operating capacity when constrained by surface street traffic congestion.



Serving the Region With an Integrated Multimodal Transit System Will Require an Aerial Transitway System Within the Urban Core to Effectively Connect All Major Districts

#9: Urban Core Transitway System

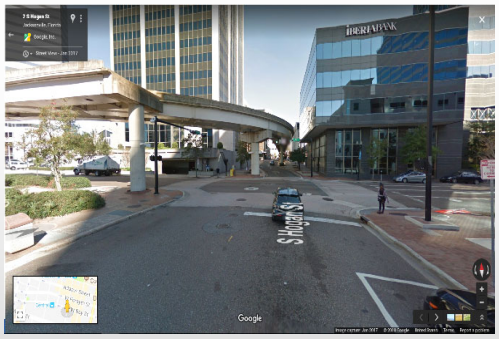
An Aerial Transitway System Connecting Major Districts is Necessary inside the Urban Core

Source: J. Sam Lott

Automated Transit Circulator System Providing FM/LM Service Along an Aerial Transitway In the Sengkang and the Punggol Districts of Singapore

#9: Urban Core Transitway System

An Aerial Transitway System Connecting major Districts is Necessary inside the Urban Core



Source: Google Maps, Street View

Jacksonville ASE transitway structures are being converted from the current fixed guideway system to roadways for AV Microtransit Use

#9: Urban Core Transitway System

An Aerial Transitway System Connecting major Districts is Necessary inside the Urban Core

Illustration of JTA's "Ultimate Urban Circulator" (U^2C) transitway transitions from aerial alignment to at-grade segments shows the flexibility of AV Microtransit vehicle applications.

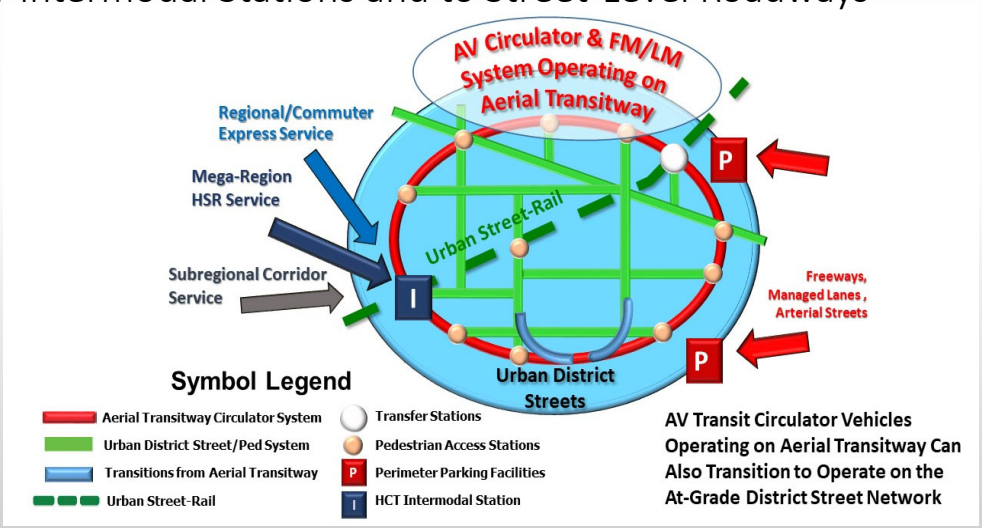
Source: JAX Transit Innovation Corporation (JTI)

Conclusion #10

The combination of the HOV lane system and the Urban Core Transitway System would allow a "one-seat ride" for many transit users traveling to/from the edge of the region

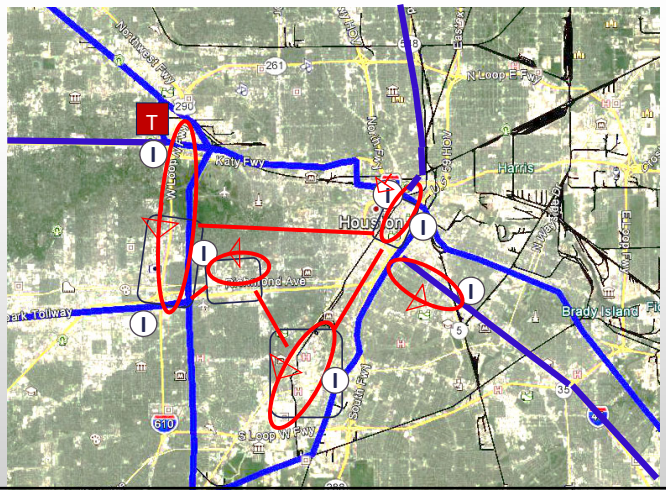
#10: One-Seat Ride for Many

Aerial Circulator Transitway Would Provide Unconstrained Circulation Above Traffic Congestion and FM/LM Connectivity to HCT Intermodal Stations and to Street-Level Roadways



#10: One-Seat Ride for Many

Creating an Aerial Transitway System Within the Urban Core Would Allow Direct Connections to the Radial HOV Lane System



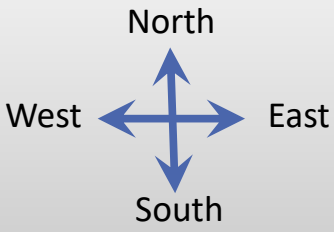
The combination of the HOV lane system and the Urban Core Transitway System would allow a "one-seat ride" for many transit users traveling to/from the edge of the region.

Conclusion # 11
Fixed Guideway/Rail Systems Will Also Need to be Part of the Houston Region's HCT Deployments in Selected Corridors

#11: Rail Systems Also Needed

Strategically Located Passenger Rail Lines Add Sustainability and Resiliency Characteristics to a Multimodal Transit System

- Sustainable operations throughout massive growth in this century (beyond 2050) will require a few transit systems that have the highest possible capacity in selected corridors.
- Redundancy of transit separate from the roadway system is essential to begin to implement for resiliency and reliability purposes
- Hurricane evacuations of the past are indicative of why we also need HCT rail systems in strategic corridors:



#11: Rail Systems Also Needed

Subregional Corridor Service Concept Example of Automated Transit System (ATS) from Dubai UAE

Source: Dubai RTA Metro; http://www.dubaimetro.eu/public-transport/

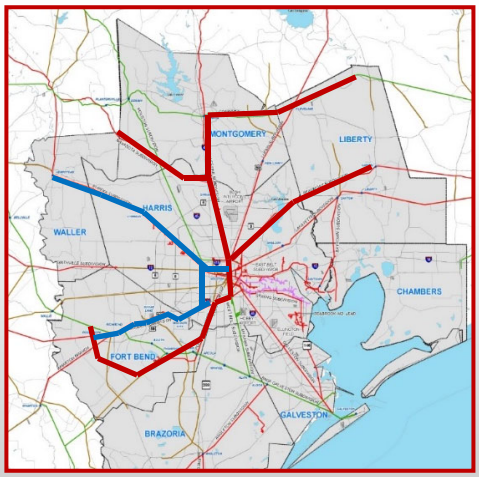
#11: Rail Systems Also Needed

Subregional Corridor Service Concept Example of Automated Transit System (ATS) from RTA Metro and Vancouver Skytrain

Source: Mobile Syrup Online Magazine, https://mobilesyrup.com/2018/05/23/freedom-mobile-customers-wireless-access-skytrain-dunsmuir-tunnel/

#11: Rail Systems Also Needed

Creation of a High Capacity Grade-Separated Freight Corridor System (Red) Would Allow Bi-Directional Passenger Rail Service in Selected Corridors (Blue)

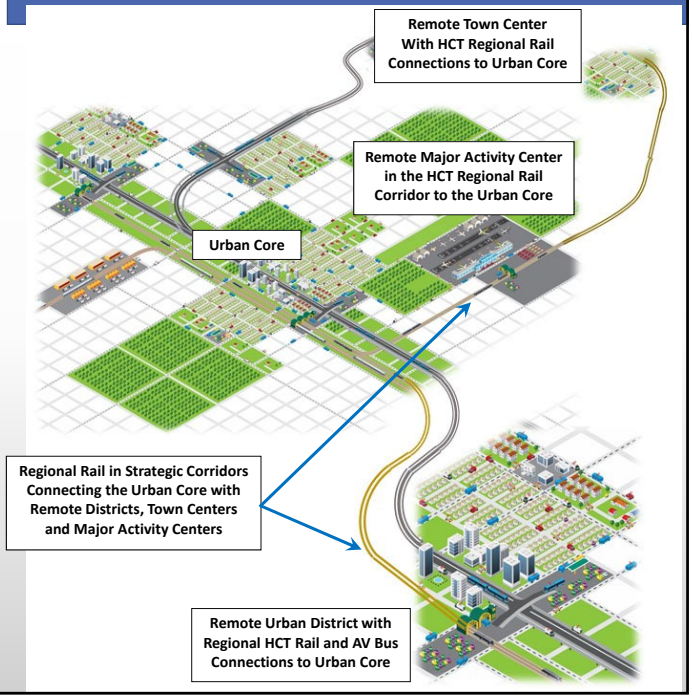


Amtrak provides inter-city service Throughout the Southern California Regions of Los Angeles and San Diego

#11: Rail Systems Also Needed

Very High Capacity Fixed Guideway Systems Enable:

- Sustainable operations throughout this century (beyond 2050).
- Redundancy of transport separate from the roadways for resiliency and reliability purposes.
- Hurricane evacuation of coastal communities and the Urban Core quickly and efficiently.



#11: Rail Systems Also Needed

Elevated Rail Systems Justifiable In Selected Corridors When Grade Separations Required Due to Operational Impacts

Typical Characteristics	Bi-Level Commuter Rail	LRT Configured for Long Distance Travel	AV Buses Operating in Platoons	Automated Metro on Aerial Guideway
Seated Capacity of Vehicles	135	75	50	50
Multi-vehicle Consists	8	4	4	8
Headways (min.) to Meet 6,000 pphpd Benchmark	10 min. at Benchmark	3 min. at Benchmark	2 min. at Benchmark	4 min. at Benchmark
At-Grade Roadway Traffic Impacts	Moderate	High	Very High	None
Max. Throughput Capacity with Standing Pass.*	11,100 pphpd	16,000 pphpd	18,000 pphpd	36,000 pphpd

* Refer to Opinion Paper for details of these comparisons

Conclusions

- #1 A Storm of traffic congestion is coming
- #2 AV must have broad applications with HCT to adequately mitigate the mobility impacts of massive congestion
- #3 New transit paradigm is coming with the flexibility of AV operations
- #4 AV Microtransit deployment Is first step in a semi-protected Campus/District environment, with phased expansion to more complicated operating environments and ultimate connections to HCT
- #5 AV Bus as a second step with deployment in protected HOV system gives Houston a unique opportunity in the world of transit

Conclusions

- #6 Ridership levels forecasted from the H-GAC 2045 Vision Plan indicate transit use would be equal to other major cities of the world
- #7 Forecasted ridership levels will require major new HCT systems and large Intermodal Stations by mid-21st Century
- #8 AV Microtransit in Districts and AV Buses on a regional HOV Lane System will facilitate the interconnection of Districts inside the Urban Core
- #9 Connecting the Houston Region with an Integrated Multimodal Transit System will require an Aerial Transitway System inside the Urban Core
- #10 The combination of the HOV Lane System and the Urban Core Transitway System would allow a "one-seat ride" for many transit users
- # 11 Fixed Guideway/Rail Systems will also need to be part of the Houston Region's HCT deployments in selected corridors

Conclusions

- #12 Beginning the process of Planning, Designing, Funding and Implementing AV transit technologies as an integral part of High Capacity Transit Systems will provide the Multimodal Transit System Houston will need by 2050.

Accomplishing this Goal of an Integrated Multimodal Transit System in Time to Mitigate the Impacts of Congestion in the Year 2050 Requires that the Process Must Begin in NOW and Not Later.

QUESTIONS?

Integrating AV Technology with High Capacity Transit –
The Way to Create a Multimodal System Approach for the 21st Century

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

Presentation to the H-GAC Brownbag
Lecture Series
March 25, 2019

Automated Mobility Services, LLC

For More Information

Access this presentation's live-stream broadcast recording, download the slides, and download the Opinion Paper on High Capacity Transit as follows:

Google:	H-GAC Brown Bag Series
Select :	March 2019
Open:	Internet links to these resources

Questions or Comments for H-GAC

- PublicComments@h-gac.com

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- Mobile: 713-927-3048

Integrating AV Technology with High Capacity Transit –

Creating a Multimodal System Approach for the 21st Century

J. Sam Lott, P.E.

Automated Mobility Services, LLC

Presentation Lecture to H-GAC Lunch and Learn
March 25, 2019