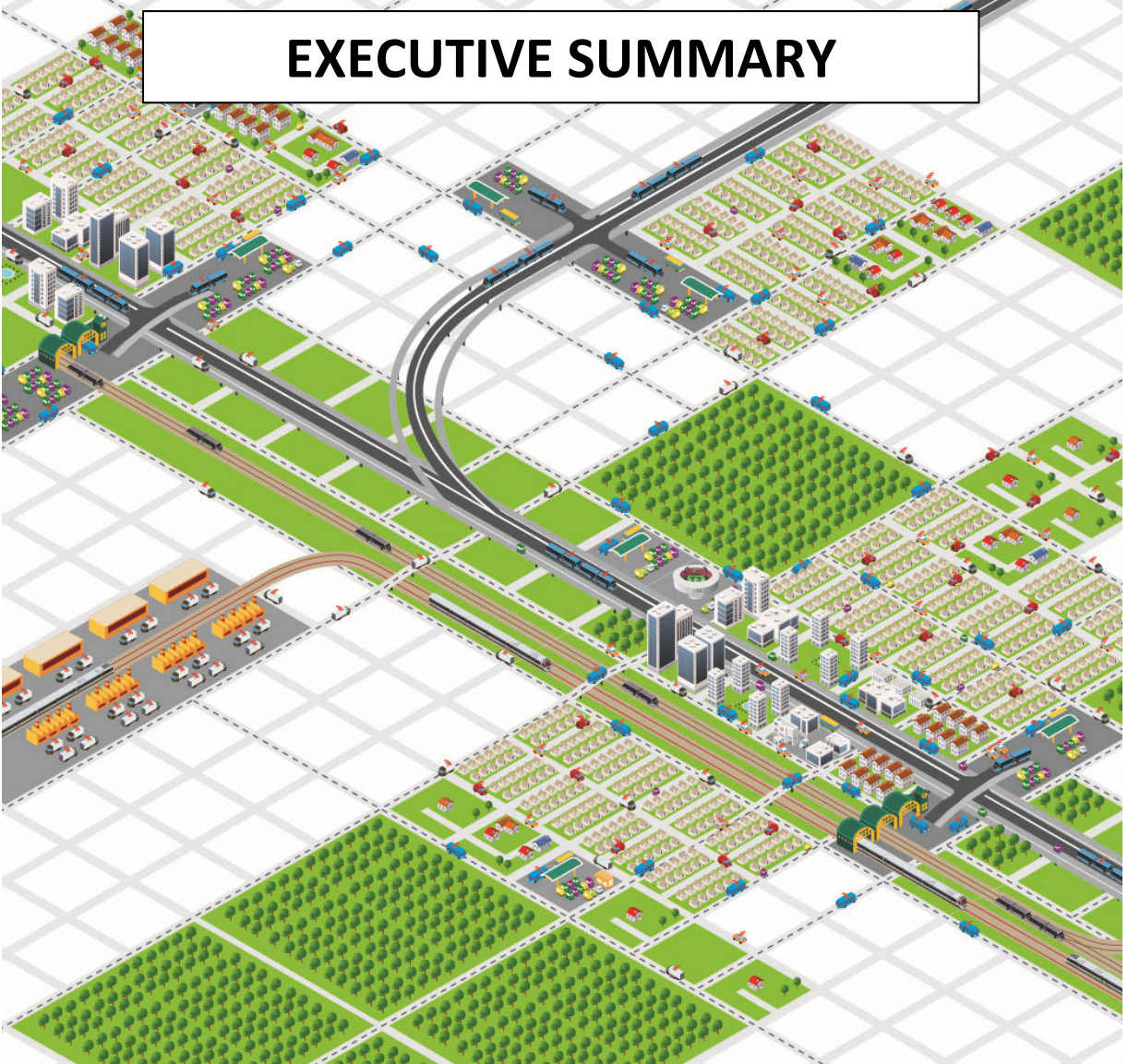


High Capacity Transit for the Houston Region – Creating a Multimodal System Approach for the 21st Century

An Opinion Paper by J. Sam Lott, TSU's Center for Transportation Training and Research, and
Automated Mobility Services, LLC

March 25, 2019

EXECUTIVE SUMMARY



The source of all illustrations is the Houston-Galveston Area Council

The full Opinion Paper, the Executive Summary and the Appendices have been published as separate documents and each is available on request from H-GAC.

Acknowledgements

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Forward

This document has been prepared as an “opinion paper” which is intended to compliment and support H-GAC's Regional Transportation Plan and Houston METRO's continuous planning for public transportation for the Houston Region. However, these opinions as presented herein are neither endorsed nor recommended by any specific entity, and in particular they are not endorsed or recommended by the H-GAC High Capacity Transit Task Force.

It should also be noted that information in this document is not necessarily referencing the very latest studies on any given topic. However, past reports which are referenced are documents I am familiar with, having led or participated in most of the studies that are identified. The points of emphasis herein are believed to not be contradictory to subsequent studies by others with respect to my broad concepts and ideas about high capacity transit for Houston.

I believe that a “crisis is coming” if we fail to comprehend the impacts of traffic congestion in the coming decades. This crisis can be managed if we do not neglect the opportunities to capture the moment when strategic decisions made now will allow us to progressively build the transit system Houston will need in the future.

J. Sam Lott, P.E.
March 25, 2019

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Executive Summary

ES.1 Introduction – A Transportation Crisis is Coming

Houston will soon be the third largest metropolitan area in the United States, passing Chicago in the next few decades. With the prestige of this ranking comes the type of problems that the largest cities in the world must address, particularly in the provision of suitable transportation modes and travel options. And as a precursor to creating new transportation systems, the largest cities of the world must execute creative policy and planning with a long term view to stay ahead of the crushing burden of roadway congestion.

This Opinion Paper was prepared during the period of time that the H-GAC High Capacity Transit Task Force has been assessing the potential ways in which high capacity transit systems and infrastructure could be incorporated into Houston's long range transportation plan. However, the paper presents only the author's opinions on what is the most sustainable approach that we can take to meet the challenges that are facing us as our region doubles in size between now and 2050. The concepts and opinions expressed herein do not represent the work of the Task Force or its recommendations.

To state the problem in simple terms, the Houston-Galveston Region is facing massive roadway congestion on a scale that we have not experienced before. Our congestion problems will soon rival those of Los Angeles and New York, and we are falling behind even auto-centric Los Angeles in preparing for alternative travel modes to the automobile. To remain "sustainable" in our intra-regional travel mobility, multiple new options for travel modes must be created which are convenient and accessible for use when traveling within the region. We must begin to create an integrated multimodal transportation system built around a framework of **High Capacity Transit (HCT)** – a challenging endeavor that will take 30 years to implement.

The nature of our impending crisis is that the operating conditions on the region's roadway, freeway and

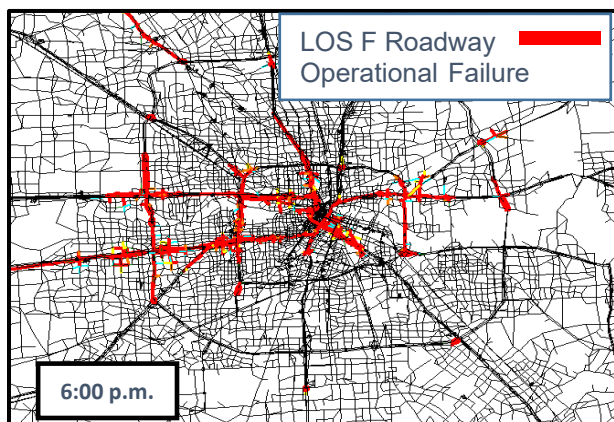


Figure ES-1 Massive Congestion will Characterize Houston's Roadways in the Coming Years

tollway system will soon be at what traffic engineers classify as "level-of-service F" (LOS F). **Figure ES-1** shows the results of an operational analysis of roadway conditions which the author believes are representative of the roadway operating conditions by 2035 and beyond, even with the new roadway capacity now planned or being built, and with advanced automobile technology now in development. These operating conditions fostering massive congestion within the Urban Core will linger throughout the entire day for some portions of the roadway system.

This situation of rapid growth is combined with our inability to build enough roadway capacity to absorb the increasing flood of new vehicles onto our roads, fueling a “transportation crisis” in which we have little time to plan, design and build new infrastructure in advance of the massive congestion. Drawing from the high capacity transit model that Los Angeles has been building for decades, the Houston Region must create a multimodal system that has a combination of commuter rail, regional metro rail, light rail transit (LRT), as well as advanced bus rapid transit (BRT) technologies all operating within an integrated system.

The discussion that follows focuses on the opportunity of leveraging new technology to accelerate the availability of high capacity transit for day-to-day use within the Houston region. The application of new technology in transit service will be essential to help us mitigate the worsening roadway travel conditions, but it will not eliminate the roadway congestion that is driving our coming transportation crisis. Neither will new technology for automobiles eliminate the coming congestion.

In fact, the advent of automated technology for the automobile mode will actually have both positive and negative impacts. The reason for this assertion is that even with higher capacity on our existing roadways, there will also come an escalation in traffic activity when empty autonomous vehicles begin to move through the system.¹ The current development trajectory for automated vehicles adds new fleets of autonomous vehicles moving through the system and ballooning vehicle miles traveled (VMT).

Preparing for the “Storm” – The growth that will double the population of the region, when combined with the future empty autonomous vehicle movements (i.e., vehicles operating without a human onboard), will add major new traffic loads to our roadway system. This eventual reality makes absolutely certain that we will have massive congestion and progressively lower and lower operating speeds along our streets, highways and freeway/tollway system throughout the region – even with the benefits of automation technology. This situation could be compared to a category 5 hurricane bearing down on the city, and there is nothing we can do to avert the storm. What we can do is prepare to live in the midst of the storm.

The answer to our future mobility lies in the Houston region creating alternative ways to move around within the region that are separated from the main lanes of the arterial street, freeway and tollway system. This emphasis on high capacity transit involves creating an integrated, multimodal transportation system that provides access to and mobility within all employment and population centers throughout the region. Ultimately, there must be convenient means to reach all major destinations without the requirement of an automobile to make the trip.

Executive Summary Contents – This Executive Summary makes occasional reference to the full Opinion Paper when significant information has not been addressed in this Executive Summary, and the author believes is important to note it can be found in the full paper. In particular, a set of five appendices are also included in the full paper which document in a more detailed manner the relevant topics drawn from the author’s experience.

¹ The New Automobility: Lyft, Uber and the Future of American Cities,
<http://www.schallerconsult.com/rideservices/automobility.htm>



ES.2 Transit Applications of the New Advanced Vehicle Technologies

The future holds great promise of providing a connected and integrated transit system in which different types of new transit technology are applied to enhance and improve accessibility to a large regional **High Capacity Transit (HCT)** system. The “conventional” transit technologies will certainly still include fixed guideway systems, but with increasing levels of automation. The “advanced” technologies will also include vehicles that today must be driven by humans, but in the future will be steered by artificial intelligence and automation controls which will be referred to in this Opinion Paper as **AV (automated vehicle) Transit**. In any applications of AV Transit technology, what will be different is that each single human – instead of driving one bus – will transition to a role actively engaged in managing the automated system. Each person within the operations staff will be able to manage a number of automated vehicles, allowing a shift towards operating many smaller vehicles. Over the long term, public transit operations will trend toward providing a more customized service for each transit patron – more like “autonomous” taxis. Even “fixed route” bus operations within a corridor will be able to be dynamically adjusted in real-time to better suit transit user trip patterns.

Under the AV Transit technology definition, a range of vehicle sizes – from 4 passenger “pods” to 60 passenger “buses”—will all be operating along a combination of city streets and arterials. But in locations where traffic congestion is a constant problem, these advanced technology vehicles can be operated along dedicated transitways, which may be grade-separated in areas where heavy traffic congestion clogs the city streets. This approach will be comparable to the new Post Oak/Uptown BRT line which will be on an exclusive aerial busway along several miles of the I-H610 West Loop, and then transition down to run along an at-grade transitway when passing through the Uptown District.

For higher speed operations during the early years of deployment, the new **AV Bus** technologies will be operated along dedicated and protected transitways – such as what now exists in the METRO owned and operated HOV lanes running along our major freeway corridors throughout the region.

New Types of Transit Service – One of the most important new types of services that AV Transit will foster is the provision of first-mile/last-mile (FM/LM) connections, by which smaller vehicles may be operated more cost effectively without an operator onboard every vehicle. These smaller and smarter vehicles will be able to offer not only fixed route connections between high demand trip generators, but also the AV Transit vehicles will offer a new type of service customized for each user.

Figure ES-2 shows an example of one of the earliest demonstrations of automated vehicle (AV) Transit technology which is currently operating at low speeds in pilot projects within pedestrian and urban street environments. The discussion that follows describes the early deployments of AV technology possible over the next few years, by which Houston will lead the industry in advanced technology applications.



Navya Vehicle Operating in Las Vegas, NV – March 2018

**Figure ES-2 Example of a AV Medium Size Vehicle
Technology Operating in a Demonstration Project**

It is important to provide an integrated multimodal transportation system with AV Transit services operating at the local town-center or urban district level to provide access to HCT Subregional Corridor and Regional Express transit services (such as AV Buses operating in HOV lanes). The key development that new advanced vehicle technology will bring is trip connectivity at both ends of the trip using the small automated vehicles in first-mile/last-mile service to circulate within the destination district or town center.

Applications of AV Transit technology to local district and town-center circulation, combined with first-mile/last-mile service will be generally referenced as **AV Microtransit**, meaning public transit vehicles that are minibus size (e.g., 10-20 passenger vehicles) and even smaller. Ultimately, these AV Transit operations will apply full automation for both driverless operation and individual vehicle dispatching.

AV Bus Rapid Transit Lines – Houston has a transit asset that is unique among the major U.S. metropolitan regions. We have been investing in barrier protected high-occupancy vehicle (HOV) lanes for over 20 years, with about 100 miles of HOV lanes currently operating. Although some cities also have a few corridors with similar transitway configurations, the truly unique configuration features of the Houston METRO busway system are the elevated “direct connector” lanes passing above the freeway main lanes. These bridges connect HOV lanes in the center of the freeways with bus transit centers, as shown in **Figure ES-3**. The HOV connected transit centers and their associated park-and-ride lots are typically spaced along the corridor length about 5-10 miles apart.

The configuration of operational routes and protected transitways is a form of Bus Rapid Transit, and it provides an excellent early deployment opportunity for AV Bus operations. In fact, AV Bus operations without a human operator (SAE Level 4 Automated Driving) will be possible in Houston’s unique protected HOV lanes within the next five years. The findings of the TRB study for AV technology readiness² for transit operations stated that protected operating environments such as HOV lanes will have early deployments of AV bus technology. This timeline can be accomplished in Houston at the earliest possible date using the Houston METRO HOV lane system.



Source: Google Earth



Source: Houston METRO

Figure ES-3 HOV Lane Direct Connector Lanes to Transit Center Bus Only Facilities

² Functionality of Level 4 transit operations, AV technology readiness and the probable timeline for early deployment are discussed on pp. 18-22 in the research report titled “Impacts of Laws and Regulations on CV and AV Technology Introduction I Transit Operations”; TSU’s CTTR served as the Principal Investigator for this study.

AV Bus High Capacity HOV Lane System – With the dedication of the HOV system to automated buses will also come the capability to operate buses in platoons, in which the automation controls allow vehicles to “virtually couple” to move through the HOV/BRT system as if the platoon was a train. Vehicle platooning technology has been tested in various forms for over twenty years. Houston METRO actually participated in proof-of-concept vehicle platooning tests 20 years ago on our system of HOV lanes.

Eventually, the capability of AV buses platooning through the HOV lane system will allow this key asset to be leveraged for an early Level 4 automation technology deployment in Houston. Through automation technology, the current HOV and “park and ride” bus operations will gradually increase its throughput capacity of passengers to a level needed for the ultimate high capacity transit system objectives. What is now mostly a commuter-based park and ride service could be transformed into a bi-directional BRT corridor service with direct connections to “off-line stations” in the form of transit centers along the freeway corridors where HOV lanes have been built.

For this AV Bus system to reach the full capabilities and capacities that will be needed, we must continue creating barrier protected, dual-lane HOV configurations which will allow continuous, bi-directional service all day long. This concept of AV Buses operating in the HOV lane system to connect with local AV Transit circulation systems operating within the local districts and town-centers is strategically important.

AV Microtransit Circulation Systems and FM/LM Connectivity – Houston will soon become one of the early demonstration sites in the United States for a type of AV Microtransit technology which is being generically called in the industry an “AV Shuttle” application. Beginning in the Spring of 2019, a demonstration pilot project will begin passenger service under the auspices of Houston METRO, the City of Houston and TSU University. The use of the vehicles will be under test and evaluation, initially operating as an on-campus circulator and in a second phase as a first-mile/last-mile connector between the TSU and U of H campuses to reach the METRO LRT system along Scott Street.

The advancement of the early demonstration phase and the Phase 2 connection to METRO’s LRT system will progress as soon as possible into an extension to reach Eastwood Transit Center, with an aerial photo showing its proximity to the north edge of the University of Houston campus in **Figure ES-4**.

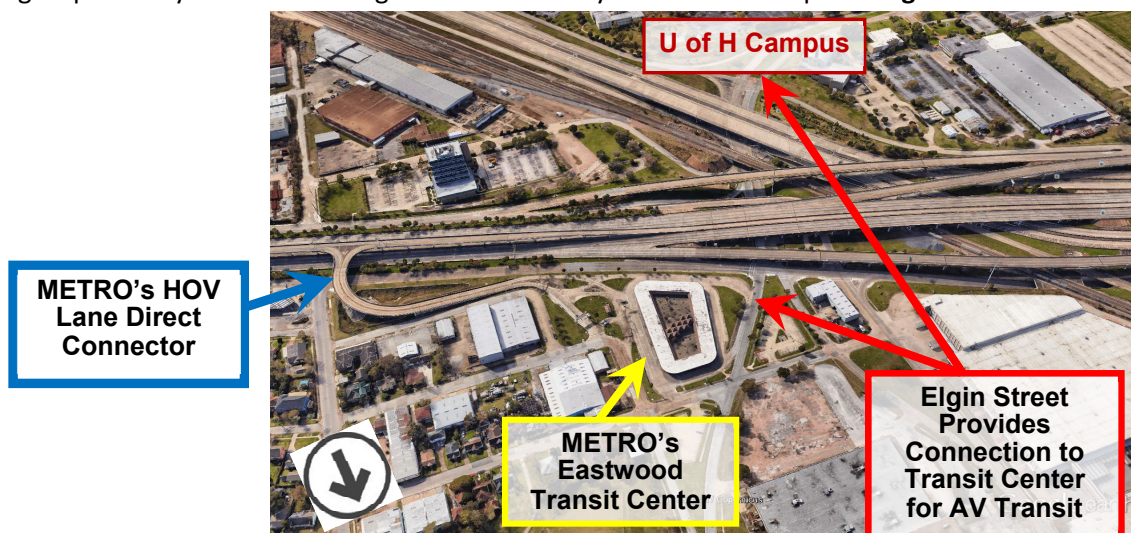


Figure ES-4 Transit Patrons on HCT Automated Buses Within the IH-45 HOV System Will Transfer at Eastwood Transit Center to the University District AV Circulator Serving Both TSU and UofH Campuses

The range of vehicle sizes that are being offered by AV Microtransit technology developers will be generally referred to in this Opinion Paper as small (4 passenger), medium (10 passenger) and large (20 passenger) AV Microtransit vehicles – all of which will ultimately be capable of operating as an on-demand service in what is now being called an automated transit network (ATN) service mode. In practical applications, however, small AV Microtransit vehicles are designed mostly for transit network operations and large AV Microtransit vehicles are designed primarily for fixed route service – but with real time, dynamic reconfiguration of route assignments for each bus as ridership patterns change.

Figure ES-5 shows a small AV Microtransit vehicle operating over a congested roadway on an aerial transitway. This shows the benefits of grade separation over the arterial street system in dense urban districts where traffic congestion is critically detrimental to transit operations. This specific small vehicle technology has been in service at London’s Heathrow International Airport for over 7 years.



Figure ES-5 Example of AV Transitway Passing Over Congested Roadways

Source: ULTra Global PRT

Flexibility of Operations: A New Paradigm – Advancements in AV technology are beginning to change our understanding of how transit services and fleet operations will occur 25 to 30 years from now. Although the transit industry is only at the very beginning of the changes that are coming, there is an understanding being gained of the new operating paradigm through initial demonstration pilots and through simulation-based analytical modeling studies.

Currently transit services are almost totally characterized by fixed route services with each vehicle operated by an on-board human driver according to a fixed schedule. Although fixed route services will continue to operate in the future, they will be gradually converted to operations applying AV Transit automation across the entire transit system. This transformation will allow fixed route service to also evolve in ways that can provide more frequent service with diversity of routes, thereby providing to each transit user a greater selection of possible destinations and more customized service for their specific travel path.

Ultimately automation will allow the role of operations employees to transition from the current requirement of one employee driving one large bus along a fixed route into a future role of one operations employee overseeing the operations of many smaller AV Microtransit automated vehicles. Based in local operations centers spread throughout the region, personnel will also be moving through the system to provide rapid response to customer needs, to address equipment performance issues, and to manage station operations when required. In essence, the existing level of staffing should be able to provide much higher transit system capacity and much better service, resulting in increasing transit ridership without requiring a larger operations staff.

In the field of automated guideway transit, this mode of operations has been called **Automated Transit Network (ATN)** service. For purposes of this Opinion Paper, this term ATN will also be applied to AV Microtransit vehicles operating along at-grade roadways and on dedicated transitways when they are continually dispatched in real-time by a supervisory system acting in response to specific transit user demand-calls for service.

In ATN operations, the system's automated dispatching typically occurs in real-time, and provides the utility of a passenger boarding a vehicle at any station, designating their desired destination station and then having the vehicle take them directly to their destination with no stops (or minimal stops) along the way. This highly customized routing, to serve transit passengers with a very high level of convenience and rapid travel times, is the highest level of service that an **AV Microtransit Circulator and First-Mile/Last-Mile (FM/LM)** service can provide at each end of a transit user's high capacity transit trip.

AV Microtransit Implications for HCT Ridership – In the discussion of high capacity transit service concepts that has occurred within the region over the past few years, the automation of large buses has been recognized as a technology application well suited for METRO's system of HOV Lanes and Transit Centers. However, the new types of AV Microtransit technology with smaller vehicles providing first-mile/last-mile services will be equally important as they make high capacity transit lines work much more effectively. This new level of convenience and utility will attract a greater percentage of travelers to the public transit mode.

Infrastructure and Facility Requirements – Transit operations have always utilized dedicated communications systems for bus and train operations, and this type of transit infrastructure is expected to continue in use. However, the communications systems connecting each vehicle with an operations center, as well as the communications infrastructure needed to communicate with passengers and ensure their safety at station stops served by AV buses and microtransit vehicles, will increase in complexity. The complexity of operations within intermodal facilities, and the configuration of the station "platforms" where passengers board and alight the transit vehicles, must evolve along with the AV technology.

But most important among all infrastructure and facility requirements is the continued expansion and improvements to our **barrier-protected system of HOV Lanes**. The existing system still has many critically important locations where the bus must pass out of the protected operating environment to enter the main lanes of the freeway, and these gaps need to be filled with suitably protected HOV lanes. Furthermore, existing single-sections currently operating as unidirectional reversible lanes need to be expanded to dual bidirectional lanes in order to allow continuous, all-day AV Bus service.



ES.3 Mobility Through an Integrated and Connected Multimodal Transit System

“Mobility” is difficult to quantify as a performance metric, but it is a useful concept when it is viewed as measuring transportation system accessibility and utility. In general, measurements of mobility that go beyond simple travel time can be understood as attributes of a modal option by which a person can easily travel during normal waking times of the day – both within the region overall and within the core of the city in particular. Some attributes of a transportation system that help define “mobility” are the user’s convenience, comfort, safety and affordability of travel between their principle trip origin and principle destination. To accomplish “mobility” in the decades to come on a comparable level to what we enjoy with our private automobiles will require that a high capacity transit system be carefully designed at all levels across the multimodal spectrum.

Fundamental to achieving mobility is the fact that for the transportation system to be effective and useful to all Houstonians, it must also be accessible to everyone. Therefore, discussion below addresses how all the public transit modes can be interconnected to provide accessibility and mobility, with a particular focus on the center of the urban core where all of the modes come together in a concentration much denser than other parts of the region. This is not in any way indicating that multimodal transit systems with good connectivity are not also important at many other places in the region; however, this Opinion Paper is written with a particular focus on the urban core. The center of the region is the most critically important and most complicated subregional area. Here, more than anywhere else, the time to plan, design, finance and build the necessary infrastructure will take a focused effort over the next 20 to 30 years. Extensions of the principles herein can also be applied to many other large and small urban districts, major activity centers and town centers around the region.

H-GAC has been investigating the “Service Concepts” that should be considered as part of our multimodal transportation system. These Service Concepts are summarized in the following list. It should be noted that all are defined as providing bi-directional transit services all day long, except for Regional Commuter/Express Service which operates during the morning and evening commute periods.

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

The demand patterns forecast through H-GAC’s recent 2045 modeling exercises, which have been performed to assess a high-transit deployment scenario, reflect how growth of employment concentrations is anticipated to increase significantly around the edges of the region, although the highest concentration of jobs will remain within the urban core. This reality is what drives the need to provide increasing transit services and dramatically more transit capacity in order to carry the majority of workers during the morning commute period from the edge of the region where they live into the urban core where they work, and then back out to the regional edges in the afternoon commute period.

The latest results in H-GAC’s modeling of ridership forecast for this conceptual high-transit deployment scenario are shown in **Figure ES-6**, and have been referred to as the H-GAC 2045 HCT Vision Plan. This theoretical transit ridership pattern provides an important definition of the relative transit use (or at least

relative transit demand) that could be expected in each of the major corridors when very high transit system capacity and connectivity are provided. It should be noted that a more detailed analysis of each corridor will be required through subsequent corridor studies in order to provide the final determination of an actual transit ridership forecast appropriate for use in the official Regional Transportation Plan.

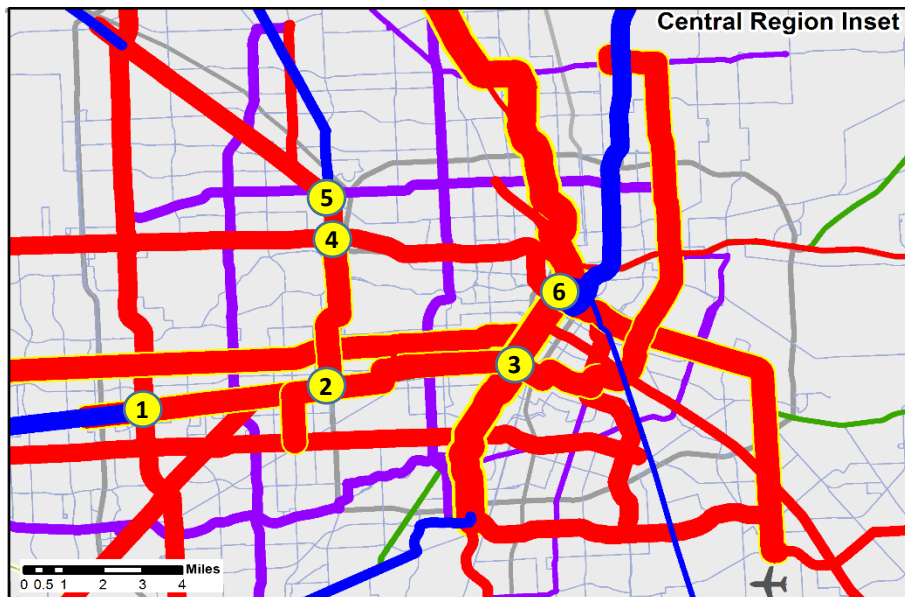


Figure ES-6 H-GAC 2045 HCT Vision Plan's Transit Ridership Preliminary Forecast of Link Demands

Thickness of segments indicates relative demand in terms of transit passenger ridership volumes. All alignments and station locations are conceptual in nature and require further analyses

Connected Corridors, Districts and Town Living Centers – Regional and Subregional Corridor HCT systems should be created to carry passengers from town-centers and suburban districts located around the perimeter of the region and into the urban districts located within the Urban Core. In each district, connections to the AV Microtransit circulation systems should be convenient and accessible. This integrated and connected transit system will be able to provide legitimate options to traveling by automobile for long distance and moderate distance trips across the region.

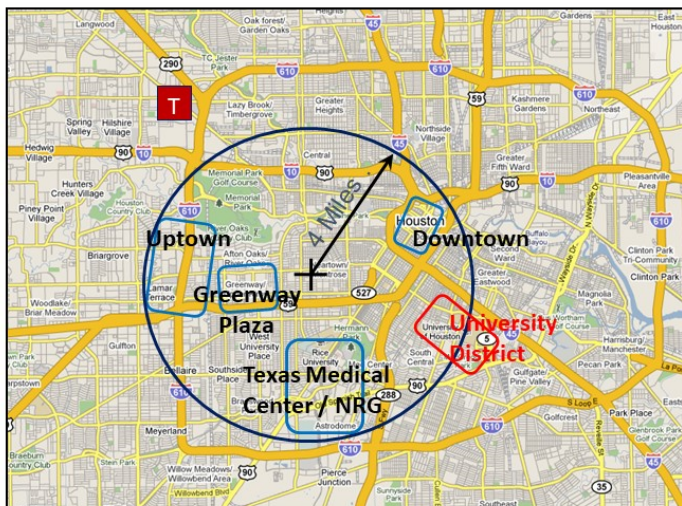
Implementing this multimodal transit system plan for Houston will be challenging in light of our suburban/urban development patterns over the last 50 years. The proliferation of master planned communities around the exurban edges of Houston – which then evolve into the new ring of suburban small towns and “town centers” – has shown that residential development truly has reshaped the landscape from the more historic growth patterns that progressively grow out from the urban core. The excellent system of radial freeways and tollways have made the combination of cheap land and master planned communities into a wonderful lifestyle scenario which combines small town living far from the urban core with big city jobs in the center of the region.

This development pattern has resulted in major travel corridors connecting between remote suburban towns and living centers, and central city major activity centers and urban employment districts. As a result, the long distance trips generated during the most congested commuter travel periods of the day are funneled primarily through a few roadway travel corridors. What will compound this challenging development pattern is the sheer quantity of new Houstonians that are forecasted to live in this remote suburban/exurban ring.

Work related trips moving through our system of “hub and spoke” travel corridors that connect town centers with employment districts will remain the most challenging trips to serve, even as AV technology transforms both our personal vehicles, the new ride-hailing car services, as well as the public transit vehicles and systems. Studies continue to indicate that traffic congestion in general will be increasing rapidly due to our massive growth.

As a result of Houston’s growth patterns, newly developing urban districts and major activity centers are beginning to thrive around the Beltway and beyond. However, the fact remains that the largest concentration of employment centers that must be served through HCT systems and infrastructure will continue to exist within the area encircled by IH-610.

Figure ES-7 shows an area which is defined as the “Urban Core” for purposes of this Opinion Paper. This Urban Core is formed by an area with a 4-mile radius around and within IH-610 Loop to the south and west of Downtown. An approximation of person-trips into the Urban Core area totals in the order of 500,000 daily commute trips, a majority of which are traveling from the edge of the region into this dense concentration of districts and major activity centers within the Urban Core.



Source: Google Earth

Houston's Urban Core
Within Loop I-610
contains the University
District Plus Four Urban
Districts Which are
Major Employment
Centers*

* Each Urban District (if it
were classified as a CBD)
would be large enough to be
on the list of the 15 largest
CBDs in the U.S.

**Figure ES-7 Concentration of
Major Urban Districts Within
the Urban Core**

When new high capacity transit services are applied with a scale suitable to address this increasingly larger number of people traveling between the suburbs and the Urban Core each day, there will also need to be new means to provide for circulation within the Urban Core. This new means for access into each of the major employment districts requires “last-mile” connections from the closest HCT intermodal station located in proximity to the district. Similarly, mobility within each employment district will require a means of circulation within the district.

All of these factors add urgency to the consideration of how to tie together all existing and future HCT services carrying passengers into and out of the very large urban districts and major activity centers within the Urban Core. It is clear that a suitable circulation and distribution system is needed which will provide a first-mile/last-mile connectivity essential for HCT to succeed to the level needed. Furthermore, when transit mode travel demands reach the levels forecasted (ref. **Figure ES-6** above), meeting the objective of providing efficient mobility with high capacity transit will require new, grade-separated transit infrastructure to be created. This new infrastructure will facilitate circulator systems with FM/LM functions becoming a critically important part of the region’s overall transportation plan.

Circulation and Connectivity in Houston’s Urban Core – The Houston Region has an unusually dense concentration of major urban districts in close proximity to each other within the Urban Core. **Figure ES-7** above depicted the four very large and closely-spaced employment and activity centers which have a rapidly growing residential population within the surrounding Urban Core, as well as a fifth major activity center formed by the cluster of U of H and TSU university campuses – the University District.

Figure ES-8 shows a concept for Urban Core circulation within the identified large districts, with FM/LM connectivity to HCT using a wholly new, advanced technology AV Transit system network. This new AV Transit network will serve circulation trips primarily within each of the major districts. Then with the addition of interconnecting transitway linkages, express service between the major districts can be provided. The current systems of at-grade local bus transit and LRT services will complement this new system by moving the majority of residents who live within the urban core to/from destinations in and around the major districts where access to the new grade-separated systems would be possible.

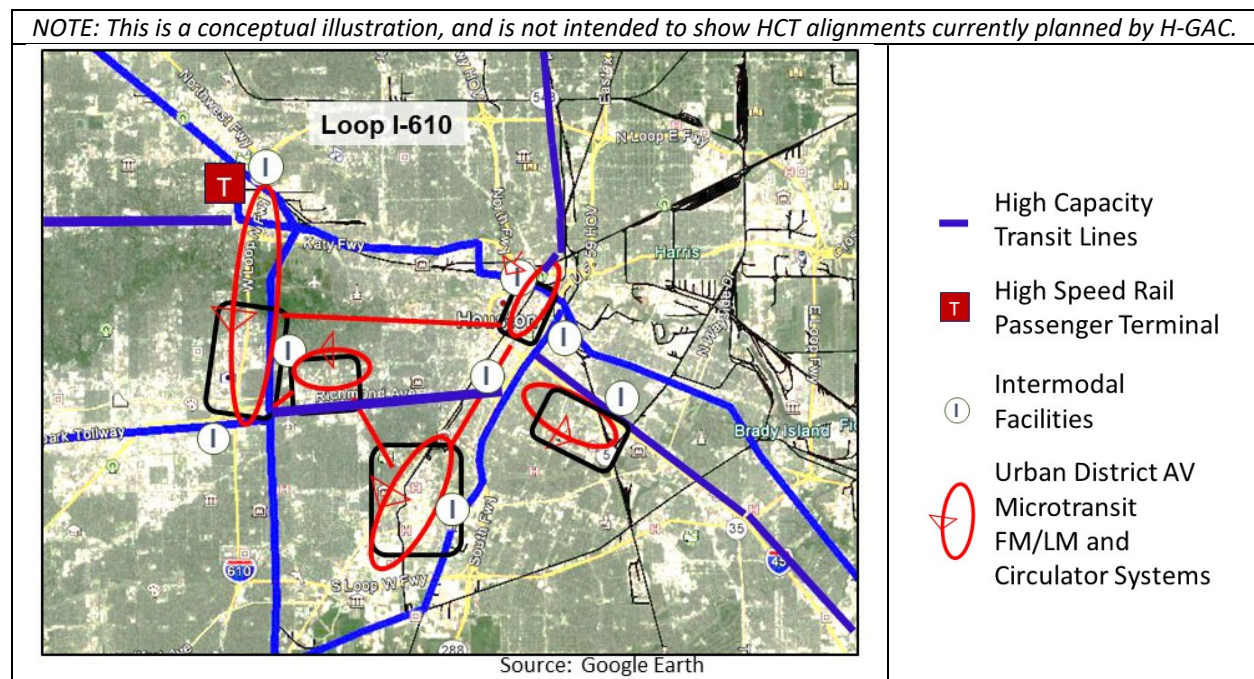


Figure ES-8 Linking of Urban District Circulator Systems with Express Service Between Districts Would Create a Unified “CBD” Through the Interconnection of All Districts Within the Urban Core

Urban Core Transitway System – The creation of a connected and integrated multimodal system is absolutely essential to a future which includes HCT access and overall mobility. To accomplish this future objective, the concept of creating a grade-separated transitway system for AV Microtransit and AV Bus circulation within the Urban Core is proposed in this Opinion Paper as a key element of this HCT future. Although the new AV Microtransit and full size AV Buses are still in prototype form, it is not difficult to understand how this technology can be operated in a fully automated operation to carry transit passengers to and from HCT Intermodal stations and circulating within major urban districts.

This conceptual transitway that is proposed as a grade-separated system with an aerial alignment will be referred to as the Urban Core Transitway System. **Figure ES-9** shows the author’s photographs of a similar transit circulator and FM/LM system operating in several major districts of Singapore.

There is another relevant example of this concept of an aerial transitway configuration that is being designed for AV Microtransit technology, which will include operations along both at-grade roadways and on elevated transitways. This example of transit infrastructure directly comparable to the proposed Urban Core Transitway System for Houston is being developed by Jacksonville Transportation Authority (JTA) in their plans to create the Ultimate Urban Circulator (U²C) system. **Figure ES-10** has a rendering prepared by JTA which illustrates the concept for the transition of an aerial transitway to an at-grade transitway.



Figure ES-9 Automated Transit Circulator System Providing FM/LM Service Along an Aerial Transitway In the Sengkang and the Punggol Districts of Singapore



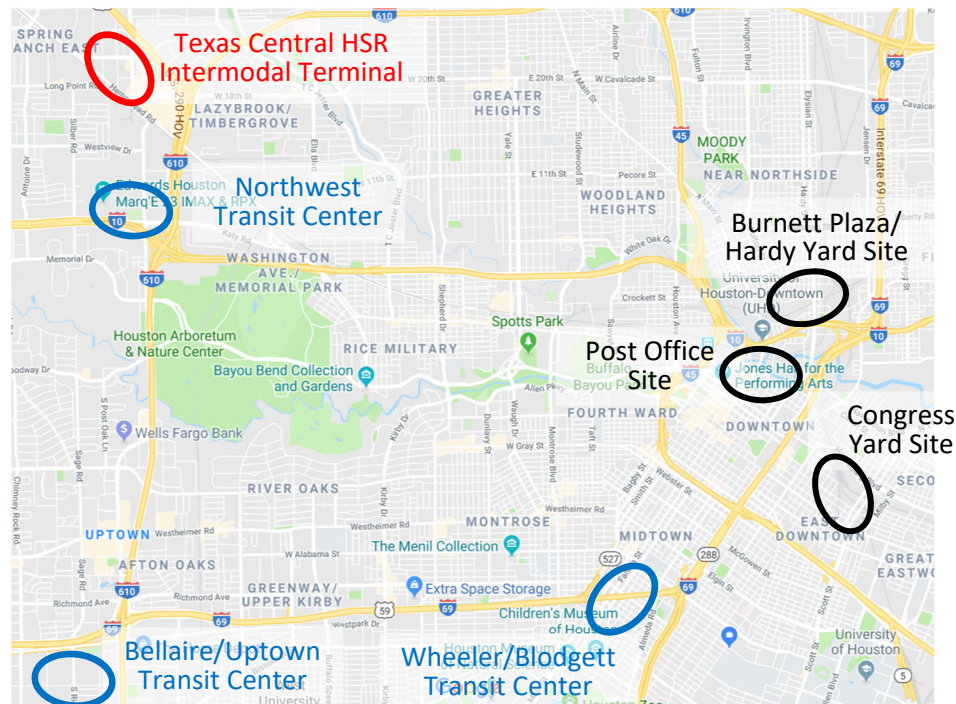
Figure ES-10 Illustration of JTA's U²C Transitway Transitions from Aerial to At-Grade Segments

Illustration used by Permission of: Jax
Transit Innovation Corporation (JTI)



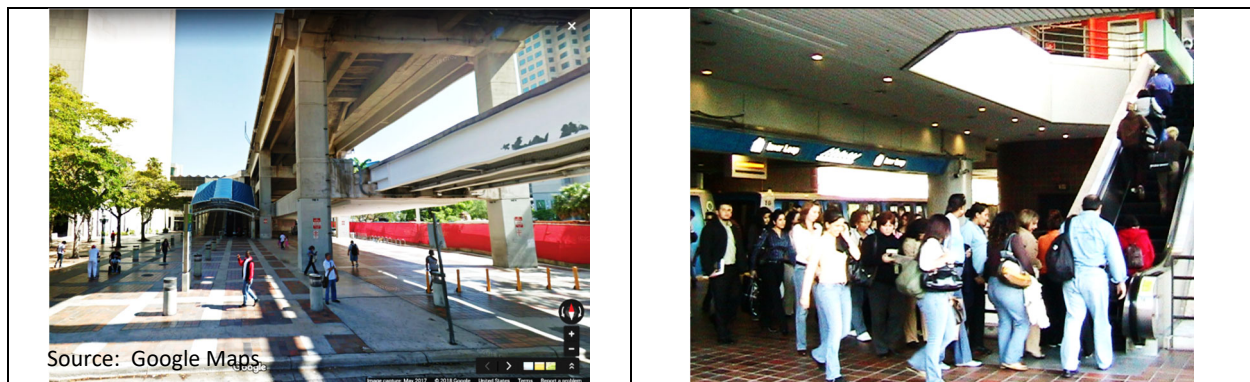
Strategic Locations and Configurations for HCT Intermodal Facilities – For this new transit paradigm to work well, there will need to be stations where many people transition between travel modes at strategic locations in direct proximity to each of the major urban districts and major activity centers. For example, a traveler leaving a district office building would board a district FM/LM circulation system, travel to a nearby intermodal facility to transition to HCT service and continue their travel to the edge of the region along a specific travel corridor. Similarly, a person traveling to the urban district from another smaller district along the corridor would alight the HCT mode and then board the FM/LM system at the Intermodal Station to reach their residential tower nearby. Or they could exit the Intermodal Station facility to continue to an adjacent transit oriented development (TOD) development as a pedestrian.

All of the intermodal facilities considered here are of potential strategic importance for serving an integrated and connected multimodal HCT system. **Figure ES-11** shows the HCT intermodal station sites that have been studied in the past or are currently in development within the Urban Core. Each of these should be considered for further development as a part of a concept for HCT connectivity.



**Figure ES-11 Strategic Locations to be Considered for
Transit Intermodal Station Placement Within the Urban Core**

Intermodal Station Configuration – The configuration of complex intermodal stations typically requires some separation of modes between different levels of the facility – especially when fixed guideway rail systems are being interconnected with roadway vehicles. **Figure ES-12** shows a multi-level intermodal station at Downtown Miami’s Government Center Station. This station serves the Subregional Corridor Metrorail system on the third level, the Downtown District Metromover grade-separated transit circulator system on the second level, and local service buses and pedestrian access at ground level.



**Figure ES-12 Government Center Station is a Major Intermodal Facility Providing FM/LM Connectivity
Between Miami Metrorail Regional System and the Downtown Metromover Circulation System**

In the future, the importance of AV Transit technologies will reshape how HCT intermodal stations operate and how they are configured, especially with design configurations that must accommodate both large AV Buses and AV Microtransit vehicles. This reconfiguration should begin to be included in Houston’s planning studies of intermodal facility ROW, access roadways, and passenger boarding platforms.

Rail Systems in Strategic Corridors for Sustainability, Resiliency and Reliability – Houston must begin to think of its overall transportation system in terms of both the sustainability of operations as massive growth occurs, as well as reliability and resiliency during times of extreme weather events or other catastrophic events that may require an evacuation of portions of the region. As discussed throughout this Opinion Paper, building in high capacity transit elements that will support long term, sustainable growth will be critically important as our roadway systems become heavily congested. AV Roadway Vehicle transit operations will also be susceptible to the impacts of roadway operational failure in locations where transitway lanes connect to the regional roadway system. Transportation planning must also be undertaken to provide other high capacity modes which are separate from the roadway system.

Further, we know that our freeway/highway system has shown during past hurricane evacuation events that it cannot adequately accommodate the massive traffic flows. Equally concerning is the current survey data beginning to indicate that future societal trends will result in many urban residents not even owning an automobile. These urban residents will primarily rely on the public transit system and ride-hailing car services (now being called transportation network companies – TNCs) and will therefore need some means of evacuating the region when such orders are given. In those situations some type of very high capacity transportation system that is separate from the roadway system will be needed to safely evacuate these most vulnerable portions of the population, with an elevated system being most reliable.

Passenger Rail Systems placed in a few strategic corridors would, for the reasons stated above, provide the region a way to achieve a level of transportation system reliability and resiliency when faced with even the most extreme conditions of regional evacuations.

In some corridors where moving very large numbers of people is considered of critical importance, there could be a practical HCT solution of deploying advanced metro-rail technology that is operated with 21st Century capabilities of fully automated controls. These types of automated “heavy rail” or “metro-rail” systems, which were called automated transit systems (ATS) in recent H-GAC studies, are designed to carry the maximum number of people. In fact, fully automated passenger rail systems capable of carrying 30,000 to 40,000 passengers per hour per direction are now in operation all over the world. Over the long term, the Houston Region will need this level of carrying capacity in a few strategic corridors. **Figure ES-13** shows two of the automated metro-rail systems from the cities of Dubai and Vancouver that have been recently studied by H-GAC.

Some types of rail technologies should also be included which can provide high capacity service extending to towns and cities outside the Houston-Galveston metropolitan region. This is relevant to consider as part of this HCT Opinion Paper since these same “Intercity” passenger rail operations can also provide regional/express service during the normal weekday peak periods – a service type that is also commonly called “commuter rail”. For example, this blend of intercity and regional commuter rail services is provided by Amtrak every day within the Northeast Corridor, especially into and out of New York City.

Similarly, Amtrak provides this same type of service along the West Coast. **Figure ES-14** shows a graphic taken from the Amtrak website with the red lines indicating the train travel routes on which Amtrak trains operate every day in Southern California serving the stations shown in blue. Amtrak provides a service very similar to and supplemental to Metrolink – the regional commuter rail service operator. Through these operating routes covering much of the LA region, Amtrak intercity trains also provide Regional Express Services which bring commuters into and out of LA “Union Station” every weekday.



Figure ES-13 Subregional Corridor Service Concept Examples of Automated Transit System (ATS) are taken from Dubai UAE, RTA Metro and Vancouver Skytrain

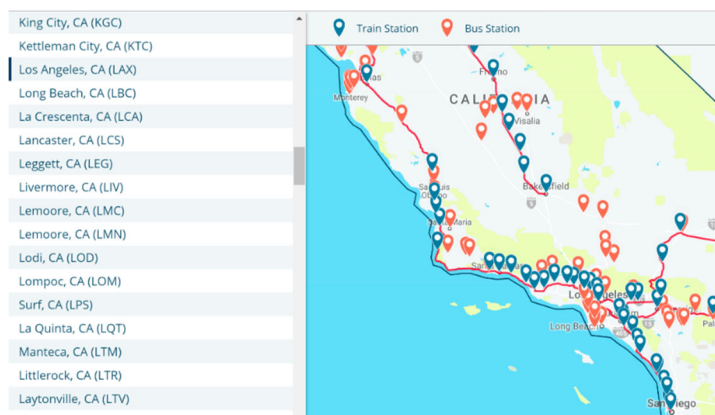


Figure ES-14 Amtrak Intercity and Regional Train Service throughout the Los Angeles Region

Source: Amtrak
<https://www.amtrak.com/california-a-train-routes>

A “system approach” to a regional high capacity, multimodal transit system for Houston should include strategic corridors where very high capacity rail service is provided – similar to the many corridors where Amtrak intercity/regional trains operate in Los Angeles. However in order to operate passenger trains on the railroad network, there will need to be important increases to the freight railroad network capacity, in addition to creating the added safety of an advanced railroad PTC system. The railroad infrastructure in the center of the region where capacity constraints prevent the free-flowing of freight trains must also be improved. Having sufficient capacity for freight rail operations will determine whether in the future there is also capacity to allow passenger trains to operate on selected corridors within the railroad network. And for this to occur, our regional decision makers must first embrace a common set of goals and objectives, and be willing to commit to a public-private partnership with the Class One railroad companies.

Where railroad right-of-way and track infrastructure can accommodate passenger service, there should continue to be an assessment of selected corridors where classical commuter/ inter-city passenger rail services could be deployed. This type of passenger rail operations along a combined freight and passenger rail network can be accomplished safely using modern positive train control (PTC) technology.



ES.4 A Case Study of the Westpark/Richmond Corridor

The planning process by which high capacity transit is evaluated for a given corridor will determine what should be the Service Concept(s) and even the technology(ies) to be deployed. For purposes of this Opinion Paper, one example corridor is discussed with respect to Service Concept(s) and the comparative technology assessment. The corridor chosen for this exercise is the Westpark/Richmond Corridor.

This exercise is not intended to be a recommendation, but rather a way to view the implications of various high capacity technologies that could be deployed in this or any other corridor. The Westpark/Richmond Corridor has a unique status within the region in light of the following points:

1. No current high capacity transit operating within the corridor (other than a parallel segment of IH-69 with an HOV lane).
2. Highest demand corridor in total daily boardings resulting from the H-GAC HCT ridership forecast modeling.
3. Passes in proximity to 6 urban districts and major activity centers (Westchase/Energy Corridor, Uptown, Greenway Plaza, Texas Medical Center, Downtown and the University District).
4. Connections to 3 major Intermodal Stations (Gessner/BW8, Bellaire/Uptown and Wheeler/Blodgett) and 3 additional transit centers.
5. Passes directly adjacent to the Gulfton area which has the highest density of residential population in the region, as well as a large population having a high transit dependency.
6. Parallel to one of the most capacity constrained segments in the roadway system – IH-69 between the Spur 527 connector to Downtown and the 288 interchange.
7. Publically controlled right-of-way (ROW) along the former Bellaire Subdivision railroad line, which has a currently available ROW width of approximately 50' for most of the roughly 22 mile length between Kirby Drive and 99 Grand Parkway, and with a constrained width of 26' continuing west of Grand Parkway.

The Full Opinion Paper compares the deployment pluses and minuses of alternative technologies: commuter rail, light rail, AV Bus/BRT and automated metro-rail (also referred to as an automated transit system technology – ATS). The following is only a brief overview of this case study of the Westpark/Richmond Corridor for purposes of this Executive Summary.

ROW, Infrastructure and Cost – The original 100' ROW was purchased by METRO from SPRR in 1992 between Houston and Fulshear, and about half of the ROW width was sold to the Harris County Toll Road Authority (HCTRA) in order to accommodate the construction of the Westpark Tollway. This reduced the ROW width to a nominal 50' width between IH-610 and SH 99 Grand Parkway. West of Grand Parkway the ROW has been reduced to a 26' width to accommodate the Fort Bend County Tollway Authority's west extension of the Tollway. However, inside Loop 610 the original ROW remains with a width of 100' for a short distance inside Loop 610, then approximately 50' to a point east of Kirby Drive, with high-tension electrical power transmission lines straddling the ROW.

Capacity/Operational Characteristics and Related Impacts on other Modes – Our experience in Houston with the METRO LRT system has revealed that there can be significant detrimental operational impacts on roadway traffic when transit signal priority is given to the transit line – particularly when full signal preemption is allowed. Along the Westpark and the Richmond corridor, there are many north/south high traffic volume roadways crossing the alignment throughout its length. With the characteristic placement

at-grade, some of the HCT technologies would have a similar impact on roadway traffic operations as exists with the METRO LRT when the activation of signal priority/pre-emption is combined with a frequent passage of the HCT vehicles/trains. These traffic impacts are discussed in some depth for each technology alternative in the full Opinion Paper.

Table ES-1 shows a summary comparison of headways required for different technologies to meet the Baseline seated passenger capacity of 6,000 passengers per hour per direction – a practical design capacity for a conventional commuter rail line with all seated passengers.

Table ES-1 Comparison of HCT Technology Carrying Capacity and the Associated Signal Pre-emption implications for At-Grade Traffic 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

The table also shows a qualitative assessment of traffic impacts when the technologies operate at-grade (except for the ATS rail technology which must be grade-separated), as well as a comparison of the ultimate maximum capacity for each of the four technologies when complete grade separation is assumed and standing passengers are included.

It is clear from this table that the operational impacts of commuter rail are significant with signal pre-emptions every 10 minutes for a single direction of travel. Realistically, pre-emptions would be more frequent with bi-directional operations in all-day service. In comparison, the signal preemption frequency of 4-car LRT trains would impact traffic operations roughly 3x more than commuter rail, without even considering the impacts of trains traveling in the opposite direction. For AV Bus operations with 4-bus platoons, the impact is 5x greater than commuter rail. In comparison, with full grade separation of automated metro-rail technology at every roadway crossing there would be no impact on traffic operations.

To mitigate unacceptable operational traffic impacts of LRT trains and AV bus platoons for a transit line operating at the benchmark capacity, the comparison above indicates that the alignment would need to have grade-separated crossings at all major roadways. Similarly, the traffic impacts of commuter rail trains would be significant and grade separation at most major roadway crossings may be appropriate.

Because of the heavy impacts to traffic operations for technologies operating at-grade, it therefore becomes highly likely that the capital cost of aerial structures will be required to build suitable high

capacity transit within the Westpark/Richmond Corridor, whatever technology is chosen – based on the 2045 HCT Vision Plan forecast of the highest transit ridership demand of all corridors in the region.

Further, with this reality of high capital costs to resolve these impacts through grade separations, it is the opinion of the author that best alternative would be to build an automated metro-rail system in light of its ultimate capacity being much greater at over twice that of BRT, LRT or commuter rail technologies.

Satisfaction of Typical Corridor Evaluation Criteria – When a HCT corridor study is undertaken, the assessments typically develop a set of evaluation criteria by which the conceptual applications of technologies and service modes are assessed. These criteria provide a framework for uniform assessment of all aspects of the defined HCT regional transportation corridor, as well as the related transit service provided to the associated town centers, urban districts and major activity centers within the corridor.

A typical set of evaluation criteria are applied in the Full Opinion Paper to assess the Westpark/ Richmond Corridor HCT line's benefits necessary to justify the substantial transit infrastructure investments. While the criteria below may resemble criteria stemming from work of the H-GAC High Capacity Transit Task Force, it does not reflect the Task Force's assessment in any way. The Task Force has not endorsed the assessment below.

A selected example from the comprehensive assessment given in the Full Opinion Paper is stated below:

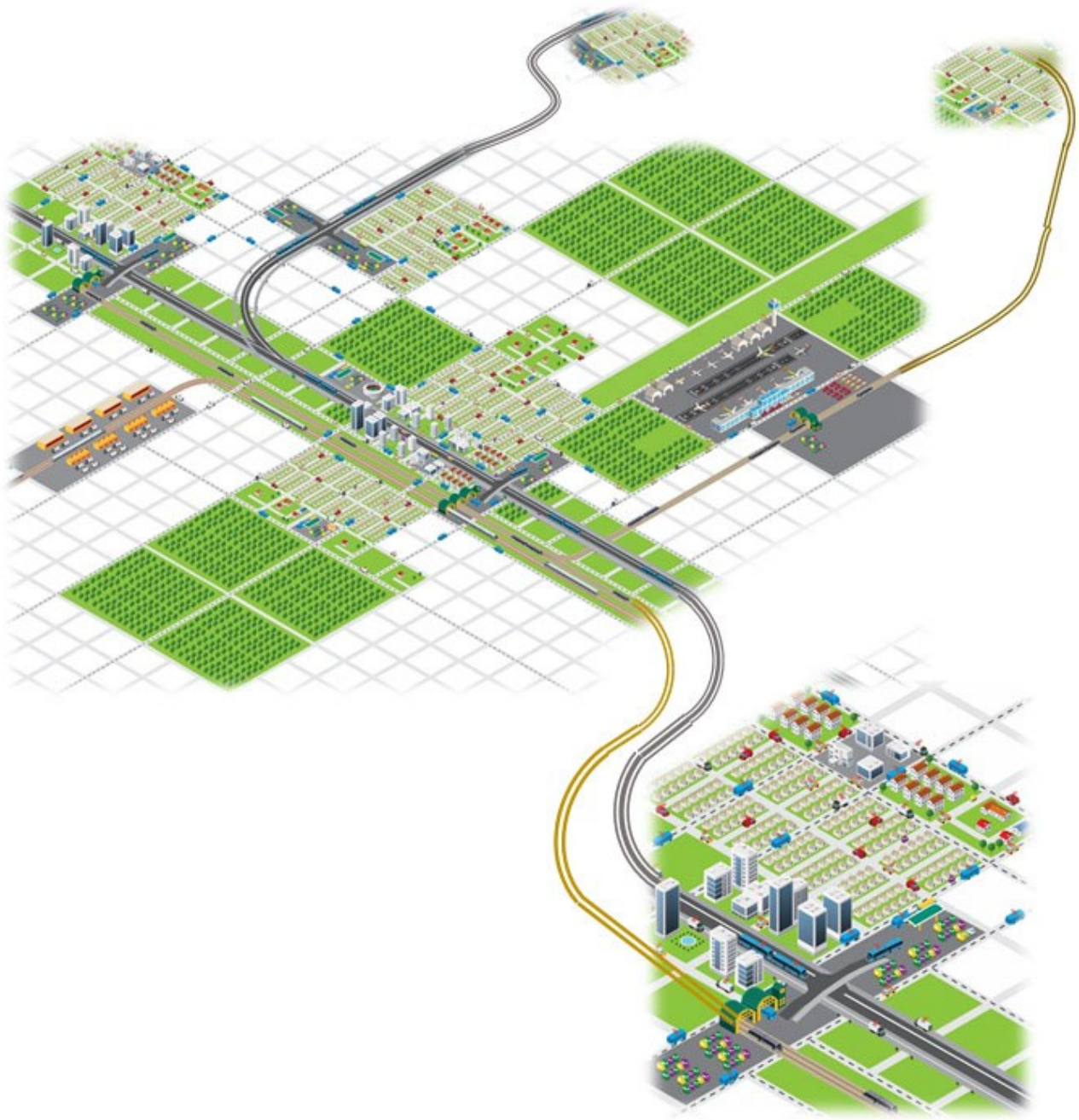
- **The conceptual HCT line should connect within the corridor with town centers, urban districts and major activity centers, as well as provide efficient connections to the integrated multimodal regional HCT system.**

Discussion: The Westpark/Richmond corridor is very well suited to connect with a number of large urban centers and high density residential areas through creation of several major intermodal centers, each of which can also be served by AV Microtransit and AV Bus systems satisfying the Circulation and FM/LM Service Concept. This will be most effective when the proposed Urban Core Transitway System is created as a grade-separated transitway circulation network inside Loop 610.

Overall, the deployment of high capacity transit within the Westpark/Richmond corridor – when combined with the proposed FM/LM and urban district circulation systems within the Urban Core – scores extremely high when analyzed according to the framework of typical evaluation criteria described in the Full Opinion Paper.

Finally, the significance of the H-GAC 2045 HCT Vision Plan's travel demand modeling study results cannot be overlooked with regard to the potential transit demand forecasts along the Westpark/Richmond Corridor. The fact that this corridor had the highest total transit ridership demand of any corridor of 20 miles or less in length, as well as the highest boardings per mile of all corridors in the region, certainly gives it a special status. It should also be noted that this ranking is not the first time that the Westpark corridor has shown this promise when high capacity transit was analyzed to serve the far west side of the region. The 2009 Regional Commuter Rail Connectivity Study also scored this corridor with the highest ridership potential, specifically having the highest home-based work trips per mile among the 16 long-distance radial corridors that were studied³.

³ In 2009 a "Regional Commuter Rail Connectivity Study" was led by Kimley-Horn and Associates, with HNTB, Wilbur Smith Associates, and Fregonese Assoc., and performed under the auspices of H-GAC



ES.5 Conclusions on an Integrated Multimodal High Capacity Transit System

Houston is facing a major transportation crisis in the coming years as a result of our huge growth and our inability to build sufficient roadway capacity to compensate for this growth. Travel demand forecasts indicate the roadway demands will be well above the available capacity at critical points within the roadway system, resulting in massive congestion lasting for many hours of the day as we double in size over the next 30 years. Further, growing evidence indicates that the vehicle-miles traveled will actually be larger than travel demand models are able to forecast due to empty vehicle movements through the roadway system as ride-hailing services proliferate, with the resulting dispatching of fleets of autonomous vehicles around the region.

Building a multimodal transit system with efficient connections for transit users from high capacity transit (HCT) corridor systems to AV Microtransit FM/LM circulation systems will significantly enhance the viability of public transit for many Houstonians currently driving their own automobile. In so doing, this multimodal HCT system will attract very large numbers of people to use the transit option for daily travel. However, we are far behind the other largest metropolitan regions of the world with respect to preparing for an extensive high capacity transit system. This fact makes the planning of an integrated multimodal transportation system extremely important to our future quality of life and the region's continued economic development.

The HCT regional transit system will be strongest when combined with a supporting new system of AV Microtransit circulation and FM/LM systems within town centers, urban districts, and especially within the Urban Core where it can be coordinated and connected to the existing conventional local transit services. Advanced technology AV Buses/BRT deployments operating through our extensive HOV lane system will be the backbone of our future HCT system, creating an essential requirement for continued expansion of the HOV lane facilities in the median of the freeway system such that bidirectional HOV service can operate all day long. Added to this should be rail technology applications in both Subregional Corridor and Regional Express types of service for those corridors which analyses show would be beneficially served by these higher capacity technologies. Houston has developed with the largest employment centers configured in a dense cluster within the Urban Core. This means that the radial HCT lines carrying workers to and from their employment in the Urban Core must be the focal point in building the interconnected HCT network, with other HCT lines spanning between the radial corridors.

Creating such transit infrastructure which allows bi-directional, two-way travel throughout the service day will also allow Houstonians the option to use public transit, even if they live in the Urban Core and work in an employment center on the outer edge of the City. This option to "reverse commute" on the HCT as efficiently as those who "commute inbound" every morning to the Urban Core. This is an essential attribute that must be provided by the region's 21st Century multimodal transit system.

In order to create a well-connected high capacity transit system for the region, within the Urban Core a series of AV Microtransit circulation systems serving the major urban districts will be required. Then starting from these urban district circulation systems, a grade separated Urban Core Transitway System can be created which connects these urban districts with multiple large intermodal stations in strategic locations, thereby facilitating a broader circulation between the districts and major activity centers around and inside Loop 610.

Finally, the HCT system will be able to provide a one-seat ride for many transit users at the point when high capacity transit is built around AV Bus operations in many corridors through an enhanced HOV lane system with direct connections into the grade-separated Urban Core Transitway System. This attribute alone will significantly increase transit ridership throughout the region.

The many HCT lines envisioned through H-GAC's 2045 HCT Vision Plan studies could seem daunting to build when considering their scale and their scope. But to reduce the vision to a lower level will encumber the region with insurmountable transportation challenges for future generations of Houstonians. Completion of the HCT Vision Plan is essential in order to inform our policy leadership of the needs and benefits of creating mobility and access through a HCT system extending throughout the region. It is imperative to communicate the urgency of beginning its implementation now and not at a later time.

With the implementation of the envisioned HCT system that includes integrated multimodal components with effective connection and circulation linkages, Houston will be a world-class city on a par with the other largest and most prominent cities of the world. Fulfilling this vision is essential for Houston's future. It cannot wait for the next generation of leadership to act. It must begin now.

The full Opinion Paper, the Executive Summary and the Appendices have been published as separate documents and each is available on request from H-GAC.