High Capacity Transit for the Houston Region –

Creating a Multimodal System Approach for the 21st Century

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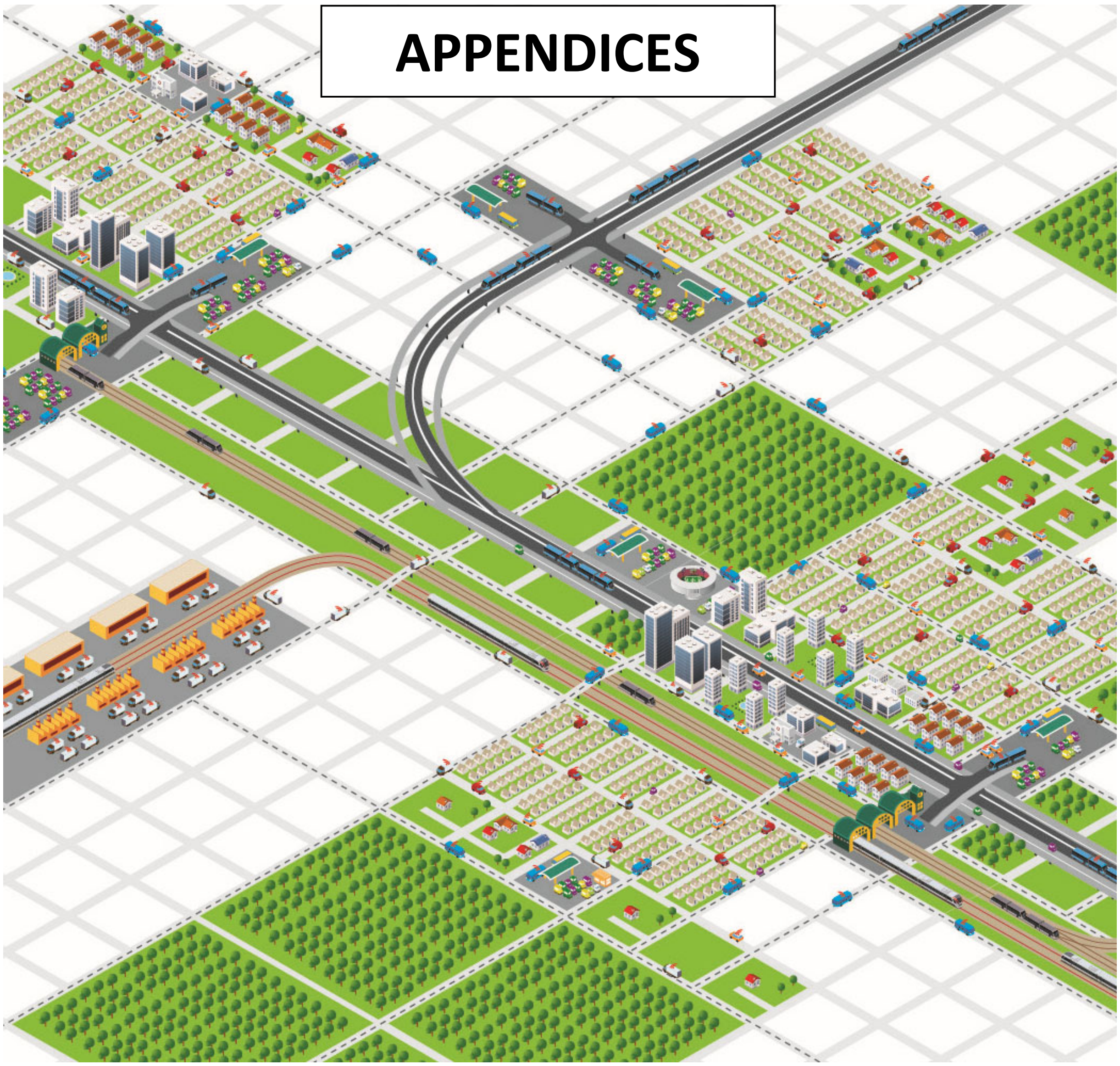
APPENDICES



Source: 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.

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Appendix A

Service Concepts for High Capacity Transit

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This is an Appendix of the Opinion Paper titled:

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

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Appendix A

Service Concepts for High Capacity Transit

Introduction to Service Concepts Workgroup

The Service Concepts Workgroup has been meeting under the auspices of Houston-Galveston Area Council (H-GAC) and its High Capacity Transit (HCT) Task Force, which was appointed by the Transportation Policy Council in mid-2017. This Appendix comprises a summary of the results of the Phase One work by the Service Concepts (SC) Workgroup as of December 2017.

The primary objective of the SC Workgroup is to prepare information and preliminary assessment that will foster the HCT Task Force's development of a 2045 vision for high capacity transit within the H-GAC region based on travel demand forecasts. This vision addresses a multimodal view of existing transit services, potential new applications of existing technologies/services, as well as the addition of future transportation technologies where full automation becomes practical for general use. It should be noted, however, that no particular mode or technology has been endorsed or recommended by the Task Force.

Terminology for Technologies and Service Modes

The following terminology is relevant to the definition of transit applications in specific corridors and districts and any assessment of the overall Service Concepts. Refer also to **Exhibit A-1** in this **Appendix A** for a more detailed set of definitions for service concept types and associated mode and technology applications.

<u>Transit Technology</u> – the class of vehicle technology typically defined by means of:

- Guidance, propulsion and suspension,
- Vehicle configuration (e.g. vehicle size, number of seats and permanent connections through articulation),
- Right-of-Way (ROW) requirements,
- Entrainment (e.g. single vehicle, multiple vehicles coupled together, or virtual entrainment through automated vehicle platoon),
- Methods of vehicle control (e.g., with a human driver, with an automatic train control system, or with a system performing automated driving functions in the vehicle that can replace the human operator).

<u>Service Mode</u> – The way that transit vehicles are operated, typically defined in terms of:

- Alignment of the transit route and stations (e.g., line-haul corridor service, district circulator service, or point-to-point connection of major population/employment nodes or high demand locations).
- Dispatching approach to vehicle trip assignments (e.g., fixed route, demand-responsive flex-routes, or point-to-point demand-response dispatching – advanced reservation or in real-time).

Service Concept Definitions

The SC definitions have been categorized in in accord with the scale and distance over which passengers typically travel on a given technology/mode. In other words, a SC category involves transit travel not requiring a transfer between transit vehicles, thereby providing a "one-seat" ride while using the specific Service Concept. Of course, convenient transferring between different Service Concepts along the travel route is also a consideration of the SC Workgroup, since this connectivity is what comprises the desired integration of a connected and integrated multimodal HCT system.

The basic definitions of Service Concepts have therefore been grouped into these categories:

- Local Service
- Subregional Service
- Regional Service

The following definitions have been developed within each category and sub-category to describe each specific Service Concept being studied.

- LOCAL
  - Local Circulation and Connectivity Service – Conventional Public Transit modes operating with close stopping points along the route
  - Local District Circulator – Conventional and unconventional modes providing circulation within a specific urban/employment District or Major Activity Center
  - Local First-Mile/Last-Mile Service – Connecting service between a High Capacity Transit station and nearby Major Activity Center/District
- SUBREGIONAL
  - Subregional Corridor and Internodal Service – Fixed route transit service (station spacing less than 3 miles) along high-demand corridors and between major trip-generation "nodes"
- REGIONAL
  - Regional Commuter/Express Service – Longer distance express service (station spacing greater than 3 miles) between population centers and high employment/activity centers
  - Mega-Regional Service – Very long distance service (greater than 100 miles) between the centers of two or more large metropolitan regions

Each of these Service Concepts (SC) was further defined in terms of their respective attributes and other factors shaping the SC usefulness and attractiveness as an alternative travel mode to the automobile.

Service Concepts Attributes and Levels of Service

The Service Concepts have been investigated in light of their typical applications in selected major cities/regions of the world. The definitions of the basic Service Concepts have been developed in terms of their functional purpose and characteristics/attributes, organized in accord with specific categories

- Right-of-Way (ROW)
- Speed (mph)
- Ridership Capacity (passengers per hour per direction – pphpd)
- Spacing Between Stops
- Level of Service – High, Medium and Low

Passenger "level-of-service" (LOS) attributes have been further defined for each given technology and mode application in terms of a general "low", "medium" and "high" passenger accommodations. These LOS attributes were evaluated in accord with transit service characteristics of:

- Headways – "Maximum" average frequency (in minutes) of transit vehicle service at a specific location, e.g., shortest wait time between trains/vehicles that a passenger would typically experience.
- Service Period – Portion of the day (in hours) that is provided transit service, typically identified separately for weekday and weekend service
- Days of Week -- Number of days-a-week transit service is provided

Finally, the different SC attributes for each category are uniform for ROW, average speed (mph), average station spacing (miles) and typical directional capacity (pph-passengers per hour) were developed from specific examples, as well as through literature research and expert opinion of the H-GAC staff and consultant team. It should be noted that the LOS attributes of High, Medium and Low are defined differently between the different Service Concepts—i.e., a High LOS for Local District Circulator is defined as 2 to 5 minute headways, compared to a High LOS for a Regional Commuter/Express Service with 15 minute headways.

Peer City Analysis Statistical Data

In order to provide examples of technology and service mode applications within each of the Service Concept categories and sub-categories, a set of peer cities were identified. This designation of "Peer City" was not to represent a holistic comparison of all the H-GAC regional attributes, but rather to represent relevant examples of technology and service modes drawn from other major cities with transportation challenges and environmental characteristics somewhat similar to Houston.

Statistical data has been assembled from the representative Service Concepts in each of the Peer Cities that have been studied. These data are given in the Exhibits at the end of this Appendix A, and comprise an overview of how the various technologies and service modes are typically applied in urban and regional settings similar to the Houston-Galveston Region. Exhibit A-2 provides statistical data from Peer Cities for Local Service, Exhibit A-3 for Subregional Service and Exhibit A-4 for Regional Service Concepts. For comparison with the Houston Region's current transit operations, Exhibit A-5 (two pages) has comparable statistical data for the Local and Subregional operations of Houston METRO for similar service concepts.

Organization of the statistical data in the Exhibits has been made according to:

- Route/Alignment
- Performance
- Passenger LOS
- Capacity

The sources referenced for the statistical data have been a combination of published schedules and time tables by the transit operator (primary information source), supplemented by internet research on vehicles and system suppliers to assess the vehicle size and seating capacities, as well as expert knowledge of the specific city or technology class by individuals within the SC Workgroup, as well as within the H-GAC staff and consultant team.

The average values of the detailed statistical data from the Peer Cities are also shown at the bottom of the tables comprising the respective exhibits, which has provided some guidance to the range of performance and level of service values used for comparison in the discussion below concerning the simplified attributes and characteristics that will be used for the corridor assessments and evaluations.

Service Concept Examples

Each Service Concept in the following **Figures A-1 to A-6** include photographs and typical performance, alignment and service mode characteristics drawn from selected examples of the Peer City transit services. These "examples" of each category of HCT Service Concepts for selected technologies and service modes are drawn from both the existing METRO services in Houston and from other selected Peer Cities.

In the Service Concept figures and in the summary section that follows, simplified metrics have been used to provide a suitably high-level comparison between the different technologies and modes.

- Right-of-Way
    - Street
    - Semi-Exclusive
    - Exclusive
- Operations
    - Speed
    - Ridership Capacity
    - Spacing Between Stops
- Level of Service
    - Low
    - Medium
    - High

The following figures are intended as illustrative examples and not as comprehensive descriptions of the Service Concepts.

Figure A-1 Local Circulation and Connectivity Service

Figure A-2 Local District Circulator Service

Figure A-3 Local First-Mile/Last-Mile Service

Figure A-4 Subregional Corridor and Internodal Service

Figure A-5 Regional Commuter/Express Service

Figure A-6 Mega-Region Service

Local Circulation & Connectivity Service

Bus Rapid Transit Characteristics

Right-of-Way			Operations			Level-of-Service		
Street	Semi-Exclusive	Exclusive	Speed (miles/hour)	Ridership Capacity (1,000s/ hour/ direction)	Spacing Between Stops Low (Blocks), High (5+ mi.)	High	Medium	Low
X	X		15-25	1 – 4 *	Mid	15 Min; 20 Hrs; 7 Days	30 Min; 20 Hrs; 7 Days	60 min; 12 Hrs; 5 Days

* Presence of bypass lanes at Bus Rapid Transit stations can increase ridership capacity, but requires additional ROW

Example taken from Cleveland HealthLine BRT

Source: Wikipedia https://en.wikipedia.org/wiki/HealthLine

Other Examples of Local Circulation and Connectivity Service

Light Rail Transit Example taken from Dallas McKinney Ave. Transit Authority – M Line Trolley	**Local Fixed-Route Bus** Example taken from Los Angeles METRO Wilshire Blvd Bus Line
	
Source: MATA website	

Figure A-1 Local Circulation and Connectivity Service

Local District Circulator Service

Streetcar/Tram

Right-of-Way			Operations			Level-of-Service		
Street	Semi-Exclusive	Exclusive	Speed (miles/hour)	Ridership Capacity (1,000s/ hour/ direction)	Spacing Between Stops Low (Blocks), High (5+ mi.)	High	Medium	Low
X	X		10-15	1 – 8 *	Low	5 Min; 20 Hrs; 7 Days	15 Min; 20 Hrs; 7 Days	Special Events

* Upper end of ridership capacity assumes large trams with full load standing passengers, very close headways and dedicated ROW/stations

Example taken from Dubai UAE, RTA Al Sufouh District Tram
Source: Dubai Roadway and Transport Authority

Other Examples of Local District Circulator Service

Automated People Mover (APM) Transit
Example taken from Miami-Dade Transit
Downtown Metromover

Original Downtown Loop Service Began 1986
North and South Extensions Service Began 1994

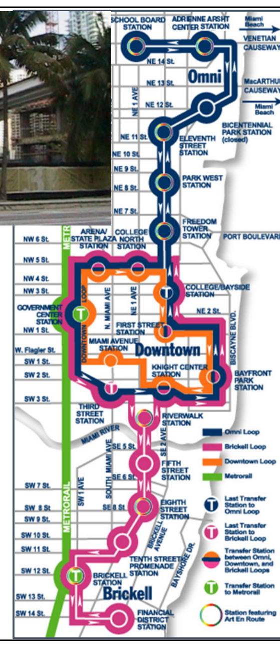


Figure A-2 Local District Circulator Service

Local First-Mile/ Last-Mile Service

APM System

Right-of-Way			Operations			Level-of-Service		
Street	Semi-Exclusive	Exclusive	Speed (miles/hour)	Ridership Capacity (1,000s/ hour/ direction)	Spacing Between Stops Low (Blocks), High (5+ mi.)	High	Medium	Low
		X	15-20	2 – 8 *	Low	2 Min; 20 Hrs; 7 Days	5 Min; 20 Hrs; 7 Days	15 Min; 12 Hrs; 7 Days

* Wide Range of Vehicle Sizes from 24 pass. to 100 pass., very close headways and protected ROW/stations

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

Example taken from Dubai UAE, RTA Metrorail FM/LM Connector to Bluewaters District

Other Examples of Local First-Mile/Last-Mile Service

Bus Line on Special Route with Dedicated Stops
Example taken from Washington DC Circulator –
Typical Route from Union Station To
Navy Yard-Ballpark

Figure A-3 Local First-Mile/Last-Mile Service

Subregional Corridor and Internodal Service

Automated Transit System (ATS)

Right-of-Way			Operations			Level-of-Service		
Street	**Semi-Exclusive**	**Exclusive**	**Speed** (miles/hour)	**Ridership Capacity** (1,000s/ hour/ direction)	**Spacing Between Stops** Low (Blocks), High (5+ mi.)	**High**	**Medium**	**Low**
		X	**25-35**	**6 – 28 ***	**Mid**	**15 Min; 20 Hrs; 7 Days**	**30 Min; 20 Hrs; 7 Days**	**60 min; 12 Hrs; 5 Days**

* Grade separation and train length are variables affecting ridership capacity.

Example taken from Dubai UAE, RTA Metro -- Al Sufouh 2 Line
Source: Dubai Roadway and Transport Authority website

Other Examples of Subregional Corridor and Internodal Service

Bus Rapid Transit Example taken from Los Angeles Metro's Orange Line BRT	**Light Rail Transit** Example taken from Dallas DART Red Line

Figure A-4 Subregional Corridor and Internodal Service

Regional Commuter/Express Service

Commuter Rail

Right-of-Way			Operations			Level-of-Service		
Street	Semi-Exclusive	Exclusive	Speed (miles/hour)	Ridership Capacity (1,000s/ hour/ direction)	Spacing Between Stops Low (Blocks), High (5+ mi.)	High	Medium	Low
	X	X	30-55	2– 7 *	Mid-High	15 Min; 20 Hrs; 7 Days	30 Min; 20 Hrs; 7 Days	60 min; 10 Hrs; 5 Days

* Grade separation and train length are variables affecting ridership capacity.

Example taken from Los Angeles Metrolink Commuter Rail System

Other Examples of Regional Commuter/Express Service

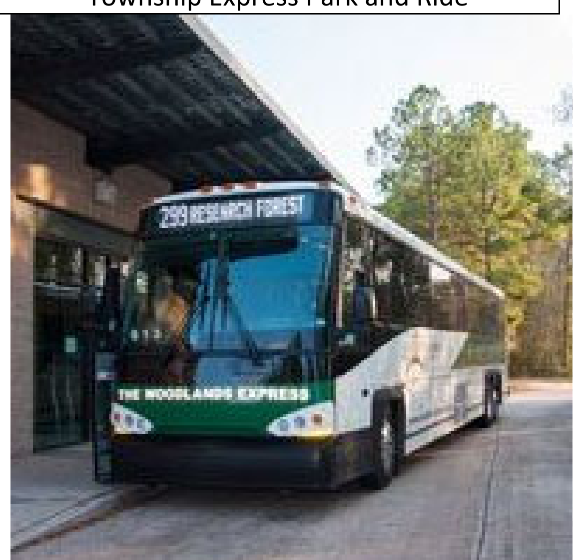
Light Rail DMU Example taken from Austin Metrorail Red Line to Leander	**Express/Limited Stop Bus** Example taken from Woodlands Township Express Park and Ride
	
	Source: Woodlands Express website https://www.thewoodlandstownship-tx.gov/994/Park-and-Ride-Service

Figure A-5 Regional Commuter/Express Service

Mega-Region Service

High Speed Rail

Right-of-Way			Operations			Level-of-Service		
Street	Semi-Exclusive	Exclusive	Speed (miles/hour)	Ridership Capacity (1,000s/ hour/ direction)	Spacing Between Stops Low (Blocks), High (5+ mi.)	High	Medium	Low
		X	125-150	2 – 4	High	30 Min; 20 Hrs; 7 Days	60 Min; 20 Hrs; 7 Days	180 min; 10 Hrs; 5 Days

Example taken from Texas Central Partnership, Japanese Shinkansen Technology
Source: Texas Central Railway website

Other Examples of Mega-Regional Service

Intercity High Speed Rail Example taken from Amtrak Northeast Corridor – Bombardier Acela Train	**Intercity Passenger Rail** Example taken from Amtrak California Service through LA Union Passenger Terminal
 Source: Wikipedia https://en.wikipedia.org/wiki/Acela_Express	

Figure A-6 Mega-Region Service

Overview of Emerging AV Technologies

Finally, the SC Workgroup has also performed an assessment of new, advanced transportation technologies that are now emerging, commonly being referred to as "AV Transit" when applied to non-automotive vehicles. The focus has been on now AV Transit technologies operating under the auspices of public transit agencies will benefit the Houston Region in broad terms, and in particular to assess the implications for High Capacity Transit implementation over the long term.

The following considerations are being given to the assessment of Emerging Technologies.

1. Autonomous technology can be added to all transit modes (both bus and rail) and will make them better:
   - more frequent service
   - greater reliability
   - lower operating costs
   - more precise stopping at stations
   - faster service
   - greater capacity
2. Large Transit vehicles (i.e., heavy rail, light rail, BRT) will get even more efficient
3. Small automated/autonomous shuttles may also be able to serve public transit markets not served today

With respect to the impacts of automated "autonomous" vehicles, the workgroup concluded that transit services will still be more space efficient for moving people along available roadway ROW. Consider the points of comparison between present day and possible future conditions, and note the illustration of these points found in **Figure A-7**.

Overall, the SC workgroup conclusions are that in the future AV Transit technology applications to transit buses will be a more effective transport solution compared to fully automated and connected automobiles for a typical roadway lane.

Overall, the workgroup conclusions are that:

1. Autonomous single occupant cars in the future will still carry fewer people than human operated Bus Transit does today in the same space, and in fact will carry multiple times as many people when comparing automated transit with automated cars, since:

   - ***Future Capacity Advantage:*** Autonomous buses will carry:
     - 23 times as many people as single-occupant autonomous cars
     - 10 times as many as 3-passenger shared-ride autonomous cars
   - ***Unchanging Capacity Limitation:*** "Capacity" of a given transit line is also limited by loading/unloading rates for both cars and transit at stations/stops. This is essentially true because "people won't get faster" when boarding an automated bus, unless the never vehicle technologies have more doors or different kinds of doors.

2. Autonomous vehicles do not automatically make congestion go away
   - If autonomous vehicles ***are not shared***:
     - same number of vehicle miles traveled as today

- same number of parking spaces as today
- ability to do work during commute means people will choose longer commutes
- intersections (shared with pedestrians, bikes, likely non-autonomous vehicles) still limit capacity of roads

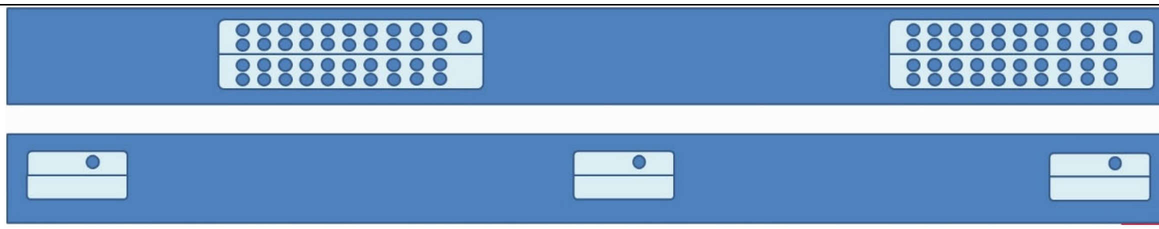
- If autonomous vehicles ***are shared***:
  - more vehicle miles as empty vehicles wait, travel to next pickup
  - more curb space required for loading and unloading (which may mean fewer travel lanes are available)
  - parking still required to store spare vehicles outside rush hour
  - ability to do work during commute means people will choose longer commutes
  - intersections (shared with pedestrians, bikes, likely non-autonomous vehicles) still limit capacity of roads

Summary of Service Concept Assessments of Attributes and Characteristics

The Workgroup has produced a simplified summary table showing typical ROW, operations and LOS values drawn from a combination of the Peer City statistical data as well as literature search and expert opinion for the purpose of facilitating the on-going comparative assessment process. This summary table is found in **Table A-1** on the following page. **Table A-1** is the primary work product of the SC Workgroup's Phase 1 activity, and it provides a very useful high-level comparative assessment of the Service Concepts.

Present Day Example with Human Drivers

- <u>100 feet of traffic lane carrying 0.5 people:</u> Single occupant vehicle, 15 feet long at 65 mph, and a 2 second (roughly 200 ft) gap between vehicles
- <u>100 feet of traffic lane carrying 17 people</u>: 40 foot bus, all 40 seats full, 15 feet long at 65 mph, and a 2 second gap between vehicles
- ***Present Day Result:*** B<u>us Transit caries 35 times as many people as single occupant car</u> in the same travel-lane space



Future Example With More Efficient Automated/Autonomous Vehicles

- <u>100 feet of traffic lane carrying 3 people</u>: Single occupant vehicle, 15 feet long at 65 mph, 20 foot gap between vehicles
- <u>100 feet of traffic lane carrying 67 people</u>: 40 foot bus, all 40 seats full, 15 feet long at 65 mph, 20 foot gap between vehicles

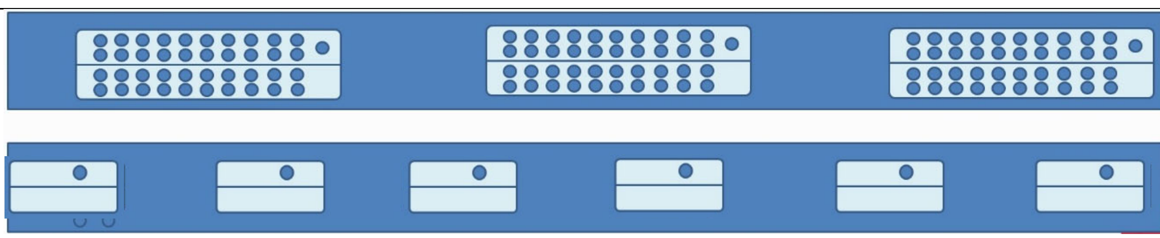


Figure A-7 Comparison of Present Day Transit with Future Automated Transit Technology Benefits

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Table A-1 Overview of HCT Service Concepts – Performance Characteristics and Level of Service

HCT Service Concepts - Performance Characteristics and Level of Service Matrix

	SERVICE CONCEPTS	Modes	Right-of-way: Street	Right-of-way: Semi-Exclusive	Right-of-way: Exclusive	Speed (mph)	Ridership Capacity (1,000s/hr/direction)	Spacing between Stops (Low – Every Block; High – 5+ Miles)	Level of Service: High	Level of Service: Medium	Level of Service: Low
Local	Local Circulation & Connectivity Service										
		Local fixed bus	x			8-15	1-4	Low	Frequent service: 7 days a week, headways of at least every 15 min 6 am to 7 pm or later; nighttime service can be less frequent (See METRO "Red Route") Total span of service: at least 20 hours/day	Basic service: 7 days a week, headways of at least every 30 min 6 am to 7 pm or later; nighttime service can be less frequent (see METRO "Blue Route") Total span of service: at least 20 hours/day	Coverage service : 5-7 days a week, headways of one hour or less; limited evening service (see METRO "Green Route") Total span of service: at least 12-14 hours/day
		Streetcar	x			10-15	1-4	Low			
		Deviated Fixed route	x			15-25	*	Low			
		Paratransit	x			8-15	*	Low			
		Demand-response	x			15-25	*	Low			
		Bus Rapid Transit	x	x		15-25	1-4[2]	Mid			
		Light Rail/Tram	x	x	x	10-25	2-8[1]	Mid			
	District Circulator Service										
		Demand-response	x			15-25	*	Low	Every 5 min, 7 days a week	Every 15 min, 5-7 days a week	Special purpose: peak or special events only
		Streetcar	x	x		10-15	1-4	Low			
		APM			x	10-15	2-8	Low	Every 2 min, 7 days a week	Every 5 min, 7 days a week	Every 15 min, 5-7 days a week
	First Mile/Last Mile Service										
		Demand-response	x			15-25	*	Low	N/A[3]		
		Rapid Bus	x			10-20	1-3	Low	Every 2 min, 7 days a week	Every 5 min, 7 days a week	Every 15 min, 5-7 days a week
		APM			x	15-20	2-8	Low			
Sub-Regional	Sub-Regional Corridor and Internodal Service										
		Express/ Limited-stop Bus	x	x		30-55	1	Mid-High	7 days a week, headways of at least every 15 min 6 am to 7 pm or later; nighttime service can be less frequent Total span of service: at least 20 hours/day	7 days a week, headways of at least every 15 min during peak; at least every 30 min off-peak Total span of service: at least 20 hours/day	Peak focused: rush hour only overlay on local service
		Bus Rapid Transit	x	x	x	10-25	1-4[2]	Low-Mid			
		Light Rail	x	x	x	10-25	2-8[1]	Mid			
		Heavy Rail			x	25-35	6-28[1]	High			
		ATS			x	25-35	6-28[1]	Mid			
Regional	Regional Commuter/Express Service										
		Express/Limited-Stop Bus	x	x		30-55	1	Mid-High	7 days a week, headways of at least every 15 min 6 am to 7 pm or later; nighttime service can be less frequent Total span of service: at least 20 hours/day	7 days a week, headways of at least every 30 min during peak; at least every hour off-peak Total span of service: at least 20 hours/day	Peak focused: frequent sevrice at peak in rush hour direction, limited off-peak
		Bus Rapid Transit	x	x	x	15-35	1-4[2]	Mid-High			
		Light Rail DMU	x	x	x	10-25	2-8[1]	Mid-High			
		Heavy Rail			x	25-40	6-28[1]	Mid-High			
		Commuter rail		x	x	30-55	2-7[1]	Mid-High			
	Mega Region Service										
		Intercity Rail		x		50-60	1-2	High	Frequent: 7 days a week, at least every 30-60 min all day	All-day 7 days a week, every 30-60 min peak, every 1-3 hours offpeak	Basic: 2-5 round trips a day
		High Speed Rail			x	125-150	2-4	High			
		Intercity Bus	x			50-60	1-2	High			

Emerging Technologies - Autonomous Vehicles

Modes	Timing	Street	Semi-Exclusive	Exclusive
Cars	2020-2030	x	x	x
Local Fixed Bus	2020-2030	x	x	x
Express/ Limited-stop bus	2020-2030	x	x	x
Bus Rapid transit	2020-2030	x	x	x
ATS/Automated Rail	present-2030			x

These modes and technologies can serve a variety of service concepts and types; some characteristics of these technologies (such as capacities) are still under analysis and research

Sources and references (available upon request): "Planning and Urban Design Standards" (2006); METRO New Bus Network fixed-route service standards; H-GAC Regional Transit Framework Study; analysis of service concepts and examples from other cities

1. Grade separation and train length are variables affecting ridership capacity: fully-separated systems, such as MARTA in Atlanta or the Washington METRO, are not subject to limitations such as street block lengths or intersection geometries and therefore have higher capacities than systems that are only partially grade-separated, such as DART light rail in Dallas, or systems that operate almost entirely at-grade, such as Houston's METRORail.
2. Presence of bypass lanes at Bus Rapid Transit stations can increase ridership capacity, but requires additional ROW: the Silver Line busway in Los Angeles has bypass lanes tand can therefore accommodate more vehicles providing a variety of services; the Orange Line busways in Los Angeles, however, has no bypass lanes and buses must stop at every station, thereby limiting the number of vehicles and services that can be provided.
3. Highly variable: service provided on demand

* flexible/coverage modes: very low capacities

7-Dec-17

This opinion paper is not endorsed or sponsored by H-GAC's High Capacity Transit Task Force or TSU CTTR, nor does it necessarily represent the opinion of HCT Task Force members or TSU CTTR leadership.

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Exhibits to Appendix A Service Concepts for High Capacity Transit

Exhibit A-1 Definitions of Service Concepts and Operating Mode and Technology Applications

Exhibit A-2 Local Service Statistics from Peer Cities

Exhibit A-3 Subregional Service Statistics from Peer Cities

Exhibit A-4 Regional Service Statistics from Peer Cities

Exhibit A-5 Local and Subregional Service Statistics from Houston METRO Operations

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Exhibit A-1 Definitions of Service Concepts and Operating Mode and Technology Applications

Definitions of Service Concepts

Local Circulation and Connectivity Service -- Conventional Public Transit modes operating with close stopping points along the route

Local District Circulator Service -- Conventional and unconventional modes providing circulation within a specific district

Local First-Mile/Last-Mile Service -- Connecting service between a High Capacity Transit station and nearby Major Activity Center/District

Subregional Corridor and Internodal Service -- Fixed route transit service (station spacing less than 3 miles) along/between high-demand corridors and trip-gen nodes

Regional Express Service -- Longer distance express service (station spacing greater than 3 miles) between population centers and high employment/activity centers

Mega-Regional Service -- Very long distance service (greater than 100 miles) between the centers of two or more large metropolitan regions

Definitions of Operating Mode and Technology Applications

Local Bus -- Local bus routes, operating on-street

Flex-Bus -- Local bus routes with on-demand deviations, operating on-street

D-R Bus -- Demand-Response (D-R) small bus dispatched upon demand-call (e.g., Paratransit services), operating on-street

APM -- Automated People Mover (APM) fixed guideway system, operating on a grade-separated transitway

ATN -- Automated Transit Network (ATN) fixed guideway system, operating on a grade-separated transitway

Aerial Tram -- Automated Urban Aerial Tramway with fixed routes and terminal station stops, operating along cable system between tower structures

Rapid Bus -- Fixed Bus route with traffic signal priority and special station stops, operating on-street

Exhibit A-1 Definitions of Service Concepts and Operating Mode and Technology Applications

Definitions of Operating Mode and Technology Applications (Cont.)

BRT -- Bus rapid transit (BRT) on fixed route with signal priority and rail-like station platforms, operating in a dedicated transitway

Streetcar -- Tram/streetcar with fixed routes, operating on-street in mixed traffic or dedicated lane

Street LRT -- Street Light Rail Transit (LRT) on fixed routes with traffic signal priority/pre-emption and dedicated station platforms, operating on-street

LRT -- Light Rail Transit (LRT) on fixed routes with traffic signal pre-emption and dedicated station platforms, operating in dedicated right-of-way

Heavy Rail -- Heavy-rail mass transit vehicles on fixed routes with defined station stops, operating in grade-separated dedicated right-of-way

ATS -- Automated Transit System (ATS) fully automated heavy rail fixed guideway system, operating in grade separated dedicated right-of-way

Express Bus -- Highway coaches designed for traveling long distances on fixed routes, operating in HOV lanes and in mixed-traffic on-street

Light Rail DMU -- Lighter weight railroad class vehicle configured as DMUs** on fixed routes, operating on heavy-rail network (potentially freight network if FRA certified with Positive Train Control - PTC)

Commuter Rail -- Railroad class vehicles pulled by locomotives (diesel/electric or electric propulsion with overhead catenary), or configured as DMUs** on fixed routes, typically operating on heavy-rail network (potentially freight network with Positive Train Control - PTC) within a single metropolitan area

Intercity Rail -- Railroad class vehicles pulled by locomotives or configured as DMUs** on fixed routes, operating on freight heavy-rail network and connecting several cities/metropolitan areas

HSR -- High speed rail (HSR) trains designed specifically to reach very high travel speeds on fixed routes, operating on exclusive grade-separated right-of-way

** DMU – A **diesel multiple unit** or **DMU** is a multiple-unit train powered by on-board diesel engines. A DMU requires no separate locomotive, as the engines are incorporated into one or more of the passenger vehicles/carriages.

source: Wikipedia – https://en.wikipedia.org/wiki/Diesel_multiple_unit

Exhibit A-2 Local Service Statistics from Peer Cities

Local Service Statistics from Peer Regions

High Capacity Service Concepts -- Performance and Operational Service Parameters

Update: 23 Jan 2018

			Route/Alignment			Performance		Passenger LOS			Capacity					
Service Classification	Service Concepts	Technology Applications and Operating Mode	Route Length (Miles)	Number of Stations	Average Station Spacing (Miles)	Max Travel Time (Min)	Average Speed (mph)	Headway (Min) Pk.	Headway (Min) Off-Pk	Service Period (Hrs/Day)	Vehicle Seating Capacity	Vehicle Capacity (Seated + Standing)	Multi-Vehicle Consists	Line Capacity During Pk. Optns (Pass/Hr./Direction)	Peer Region	Notes/Comments
Local	Conventional Bus/ Rail Service	Local Bus														
		BRT														
		D-R Bus				REFER TO HOUSTON METRO DATA IN APPENDIX A										
		Paratransit														
		LRT														
		Streetcar/Trolley	2.2	25	0.09	30	4.4	11	22	16	25	40	1	218	Dallas	McKinney Ave. Streetcar (Vintage Trolley)
		Deviated Fixed Rt.	11	14	0.85	85	7.8	85	85	11	20	25	1	18	Desoto Co., FL**	Desoto-Arcadia Regional Transit (DART)
	District Circulator Service	APM	2.26	10	0.25	13	10.4	2	5	18	12	100	2	6,000	Miami	Miami Metromover -- Arts District Line
		APM	1.9	9	0.24	12	9.5	2	5	18	12	100	2	6,000	Miami	Miami Metromover -- Financial District Line
		APM	3.4	4	1.13	20	10.2	15	15	13	8	92	3	1,104	Dubai	Palm Jumeirah Monorail
		Streetcar	3.3	10	0.37	23	8.6	8	8	18.5	57	328	1	2,460	Dubai	RTA Al Soufouh Tram
		ATN														
		Rapid Bus				NO PEER CITY OR OTHER EXAMPLES										
		BRT														
		D-R bus														
	First-Mile/Last-Mile Service	APM	1.6	2	1.62	4.5	21.5	0.375	5	20	8	24	1	3,840	Dubai	Bulewaters
		Rapid Bus	3	12	0.27	15	12.0	10	10	15	40	83	1	498	Washington	Blue Route -- Union Station/Navy Yard
		ATN														
		BRT				NO PEER CITY OR OTHER EXAMPLES										
		D-R bus														
		Streetcar	2.45	6	0.49	10	14.7	20	20	18.5	34	103	1	309	Dallas	City of Dallas Oak Cliff Streetcar

Sysems w/ Data	Technology Applications	Rt. Length	No. Station	Station Spacing	Travel Time	Speed	Pk Hdwy	Off Pk Hdwy	Service Period	Veh Seating	Veh Capacity	Consists	Line Capacity	
3	APM-Distric Circ.	2.5	7.7	0.54	15.0	10.0	6.3	8.3	16.3	10.7	97.3	2.3	4368	APM-Distric Circ.
3	Streetcar	2.7	13.7	0.3	21.0	9.2	13.0	16.7	17.7	38.7	157.0	1.0	995.7	Streetcar
1	Rapid Bus	3.0	12.0	0.27	15.0	12.0	10.0	10.0	15.0	40.0	83.0	1.0	498	Rapid Bus
1	APM - FM/LM	1.6	2.0	1.62	4.5	21.5	0.4	5.0	20.0	8.0	24.0	1.0	3840	APM - FM/LM
1	Deviated Fixed Rt.	3.0	12.0	0.27	15.0	12.0	10.0	10.0	15.0	40.0	83.0	1.0	498	Deviated Fixed Rt.

** Example taken from a location NOT designated as a Peer City

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Exhibit A-3 Subregional Service Statistics from Peer Cities

Subregional Service Statistics from Peer Regions

High Capacity Service Concepts -- Performance and Operational Service Parameters

Update: 22 Nov 2017

			Route/Alignment			Performance		Passenger LOS			Capacity					
Service Classification	Service Concepts	Technology Applications and Operating Mode	Route Length (Miles)	Number of Stations	Average Station Spacing (Miles)	Max Travel Time (Min)	Average Speed (mph)	Headway (Min) Pk.	Headway (Min) Off-Pk	Service Period (Hrs/Day)	Vehicle Seating Capacity	Vehicle Capacity (Seated + Standing)	Multi-Vehicle Consists	Line Capacity During Pk. Optns (Pass/Hr./Direction)	Peer Region	Notes/Comments
Subregional	Corridor & Nodal Connectivity Service	Heavy Rail	24	19	1.33	43	33.5	10	20	21	76	166	8	7968	Atlanta	Red Line - North Springs/Five Points
		Heavy Rail	15	15	1.07	32	28.1	10	20	21	76	166	8	7968	Atlanta	Blue Line -
		Heavy Rail	17	16	1.13	33	30.9	7.5	15	19	76	166	4	5312	Miami-Dade	Metrorail Orange -Dadeland/Govmt Cntr/MIA Airport
		Heavy Rail	22.5	22	1.07	47	28.7	15	30	19	76	166	4	2656	Miami-Dade	Metrorail Green L.-Dadeland/Govmt Cntr/Palmetto
		BRT	20	33	0.63	78	15.4	10	15	24	57	80	1	480	Miami-Dade	South Miami Busway-344th St. P&R/Dadeland S.
		Heavy Rail	30	27	1.15	73	24.7	8	12	18.5	76	166	8	9,960	Washington	WMATA Red Line -- Shady Grove/Metro Cntr/Glenmont
		Heavy Rail	19	17	1.19	67	17.0	10	15	21	76	166	8	7,968	Cleveland	GCRTA Red Line -- Cleve. Airport/Dntn/East Cleveland
		LRT	12	24	0.52	39	18.5	15	30	21	76	175	2	1,400	Cleveland	GCRTA Green/Blue Lines -- Green Rd.-Tower City
		BRT	6.8	20	0.36	40	10.2	7	15	24	57	80	1	686	Cleveland	GCRTA Healthline -- Stokes/Windermere-Publ. Sq.
		ATS	32	29	1.14	60	32.0	4	7	20	50	140	5	10,500	Dubai	RTA Metro -- Al Sufouh 2 - Jebel Ali/Union Sta/Rashidya
		BRT	11.2	16	0.75	52	12.9	4	15	24	57	80	1	1,200	Los Angeles	Metro Orange Line
		BRT	26	15	1.86	64	24.4	4	60	24	57	80	1	1,200	Los Angeles	Metro Silver Line -- Harbor Gateway/Dwntn/El Monte
		Heavy Rail	6.4	8	0.91	13	29.5	10	20	17	61	180	6	6,480	Los Angeles	Metro Purple Line
		Heavy Rail	16.4	14	1.26	29	33.9	10	20	20	61	180	6	6,480	Los Angeles	Metrorail Red Line
		LRT	30	26	1.20	73	24.7	7	15	20	68	175	3	4,500	Los Angeles	Metrorail Gold Line -- Azuza/Union Station/East LA
		LRT	25	22	1.19	58	25.9	6	20	20.5	68	175	3	5,250	Los Angeles	Metrorail Blue Line
		LRT	20	14	1.54	34	35.3	15	20	20.5	76	175	2	1,400	Los Angeles	Metrorail Green Line
		LRT	15.2	19	0.84	48	19.0	6	12	22.5	68	180	3	5,400	Los Angeles	Metrorail Expo Line
		ATS	18	20	0.95	40	27.0	2	10	20	33	130	4	15,600	Vancouver	Expo Line -- Waterford to Columbia
		ATS	14.6	17	0.91	34	25.8	2	10	20	33	130	2	7,800	Vancouver	Millennium Line
		ATS	9.4	13	0.78	25	22.6	6	20	20	44	167	2	3,340	Vancouver	Canada Line
		LRT	27	25	1.13	65	24.9	20	30	21	98	198	4	2,376	Dallas	DART Red Line - Parker Rd/Dwntn/Westmoreland
		LRT	28	23	1.27	69	24.3	15	30	21	98	198	4	3,168	Dallas	DART Blue Line - Rowlett/Dwntn/UNT Dallas
		LRT	27	24	1.17	76	21.3	15	30	21	98	198	4	3,168	Dallas	DART Green Line - Buckner/Dwntn/North Carrolton
		LRT	41	29	1.46	92	26.7	10	30	21	98	198	4	4,752	Dallas	DART Orange Line - Parker Rd./Dwntn/DFW Airport

	Sysems w/ Data	Technology Applications	Rt. Length	No. Station	Station Spacing	Travel Time	Speed	Pk Hdwy	Off Pk Hdwy	Service Period	Veh Seating	Veh Capacity	Consists	Line Capacity		Yellow cells represent transit lines that travel through the CBD and continue to another sector of the region. The averaged values should be consdered in this light.
	4	BRT	16	21	0.9	59	15.7	6.3	26.3	24.0	57	80	1.0	891	BRT	Adequate sampling of data -- three systems in optn
	9	LRT	25.0	22.9	1.1	62	24.5	12.1	24.1	20.9	83	186	3.2	3,490	LRT	Large sampling of data and well proven systems
	8	Heavy Rail	18.8	17.3	1.1	42.1	28.3	10.1	19.0	19.6	72	170	6.5	6,849	Heavy Rail	Large sampling of data and well proven systems
	4	ATS	18.5	19.8	0.9	39.8	26.8	3.5	11.8	20.0	40	142	3.3	9,310	ATS	Adequate sampling of data -- three systems in optn

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Exhibit A-4 Regional Service Statistics from Peer Cities

Regional Service Statistics from Peer Regions

High Capacity Service Concepts -- Performance and Operational Service Parameters

Update: 23 Jan 2018

Service Classification	Service Concepts	Technology Applications and Operating Mode	Route/Alignment: Route Length (Miles)	Route/Alignment: Number of Stations	Route/Alignment: Average Station Spacing (Miles)	Performance: Max Travel Time (Min)	Performance: Average Speed (mph)	Passenger LOS: Headway (Min) Pk.	Passenger LOS: Headway (Min) Off-Pk	Passenger LOS: Service Period (Hrs/Day)	Capacity: Vehicle Seating Capacity	Capacity: Vehicle Capacity (Seated + Standing)	Capacity: Multi-Vehicle Consists	Capacity: Seated Line Capacity During Pk. Optns (Pass/Hr./Direction)	Peer Region	Notes/Comments
Regional	Regional Express Service	Comm. Rail	70	18	4.1	120	35.0	20	60	16	160	400	3	1440	Miami	TriRail - Magnonia Park/MIA Airport
		Comm. Rail	74	19	4.1	130	34.2	15	60	17	142	400	6	3408	Washington	MARC - Martinsburg/Union Stn (Brunswick)
		Comm. Rail	59	13	4.9	104	34.0	15	30	12	142	400	6	3408	Washington	VRE - Spotsylvania/Union Stn (Fredericksburg) **
		Express Bus	38	12	3.5	98	23.3	10	10	7	40	40	1	240	Washington	Loudoun County Transit - Leesburg Park & Ride
		Express Bus	29	7	4.8	73	23.8	15	15	6	40	40	1	160	Washington	Loudoun County Transit - Ashburn N. Park & Ride
		Comm. Rail	60	13	5.0	100	36.0	25	90	16	142	400	10	3408	Los Angeles	Metrolink - San Bernadino Line
		Comm. Rail	80	13	6.7	120	40.0	60	90	15	142	400	10	1420	Los Angeles	Metrolink - Orange Co. (Oceanside) Line
		Comm. Rail	60	11	6.0	130	27.7	60	90	15	142	400	10	1420	Los Angeles	Metrolink - Antelope Valley (Lancaster) Line
		Comm. Rail	50	7	8.3	88	34.1	30	180	12	142	400	10	2840	Los Angeles	Metrolink - Riverside Line **
		Comm. Rail	60	12	5.5	112	32.1	45	120	14	142	400	10	1893	Los Angeles	Metrolink - Ventura Line
		Comm. Rail	41	8	5.1	75	32.8	30	30	5	144	400	10	2880	Vancouver	West Coast Express **
		Light Rail DMU	32	9	4.0	55	34.9	30	60	14	108	200	1	216	Austin	Capital MetroRail
		Light Rail DMU	21	6	4.20	45	28.0	30	60	18	108	200	1	216	Dallas	Denton County A-Train
		Comm. Rail	33.2	10	3.7	61	32.7	30	60	20	142	400	4	1136	Dallas	Trinity Railway Express
		Express Bus	33.9	4	11.3	45	45.2	10	15	9	40	40	1	240	Houston	Woodlands Expr - Research Frst/Dwntn **
		Express Bus	36	4	12.0	55	39.3	15	20	6	40	40	1	160	Houston	Woodlands Expr - Sterling Ridge/Dwntn **
		Express Bus	27.8	4	9.3	50	33.4	10	15	9.5	40	40	1	240	Houston	Woodlands Express - Sawdust/Dwntn
															** - a.m. Inbound only; p.m. outbound only	
	Sysems w/ Data	Technology Applications	Rt. Length	No. Station	Station Spacing	Travel Time	Speed	Pk Hdwy	Off Pk Hdwy	Service Period	Veh Seating	Veh Capacity	Consists	Seated Line Capacity	Technology Applications	
	5	Express Bus	32.9	6.2	8.2	64.2	33.0	12.0	15.0	7.5	40.0	40.0	1.0	208.0	Express Bus	Adequate sampling of data -- three systems in optn
	2	Light Rail DMU	26.5	7.5	4.1	50.0	31.5	30.0	60.0	16.0	108.0	200.0	1.0	216	Light Rail DMU	Small sampling of data -- only one system in operation
	10	Comm. Rail	58.7	12.4	5.3	104	33.9	33	81	14	144	400	7.9	2325	Comm. Rail	Large sampling of data and well proven systems

This opinion paper is not endorsed or sponsored by H-GAC's High Capacity Transit Task Force or TSU CTTR, nor does it necessarily represent the opinion of HCT Task Force members or TSU CTTR leadership.

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Exhibit A-5 Local and Subregional Service Statistics from Houston METRO Operations (Page 1)

Local and Subregional Service Statistics from the Houston Region

High Capacity Service Concepts -- Performance and Operational Service Parameters

Page One of Two

			Route/Alignment			Performance		Passenger LOS			Capacity					
Service Classification	Service Concepts	Technology Applications and Operating Mode	Route Length (Miles)[1]	Number of Stations	Average Station Spacing (Miles)	Max Travel Time (Min)[2]	Average Speed (mph)[3]	Headway (Min) Pk. / Off-Pk		Service Period (Hrs/Day)	Vehicle Seating Capacity	Vehicle Capacity (Seated + Standing)	Multi-Vehicle Consists	Boardings per Revenue Hour per Vehicle	Region	Notes/Comments
Local	Conventional Bus/Rail Service	Local Bus		Total includes all stops, Transit Centers and P&R	Systemwide Average								Single vehicle routes only	Boarding Averages per revenue hr.[4]		*Data based on Nov. 2017 weekday values. Local bus routes are are allocated to primary frequency color but may have multiple frequency segments.*
		Red (10-15min) 28 total routes	48.5 thousand daily revenue miles (28 red Routes with average length range of 9-26.7mi)	9800*	340' - 2600'	28 routes ranging from 39-121 max travel minutes****	28 routes Avg - speed range: 12 - 24.2 mph	10/15	10/15	15	34 (min. standard) 57 (articulated bus)	(Considering Peak Capacity at 135% of seated capacity) 46 / 77 (articulated)	n/a	25.36 boardings per revenue hr.	Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi); stop spacing is determined by a METRO coverage stanadrd of 800-2600ft.
		Blue (30min.) 20 total routes	27.4 thousand daily revenue miles (20 Blue routes with average length range of 2-27.8 mi.	9800*	340' - 2600'	20 routes ranging from 12-113 max travel minutes****	20 routes average speed range: 11-24.9mph	15-30	30	18	34 (min. standard) 57 (articulated bus)	(Considering Peak Capacity at 135% of seated capacity) 46 / 77 (articulated)	n/a	23.09 boardings per revenue hr.	Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi); stop spacing is determined by a METRO coverage stanadrd of 800-2600ft.
		Green (60min.) 30 total routes	14.2 thousand daily revenue miles (30 Green routes with average length range of 5-23.1mi.	9800*	800'-2600,	30 routes ranging from 25-109 max travel minutes****	30 routes average speed range: 12-20.2mph	30-60	60	14	34 (min. standard) 57 (articulated bus)	(Considering Peak Capacity at 135% of seated capacity) 46 / 77 (articulated)	n/a	17.58 boardings per revenue hr.	Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi); stop spacing is determined by a METRO coverage stanadrd of 800-2600ft. Green routes are slower by route design in order to offer local street coverage.
		~~Deviated Fixed Rt.~~														
		D-R Bus														*Data based on Nov. 2017 weekday values*
		Acres Homes Community Connector	Avg. trip mi= 7 Max trip mi. = 17	2	n/a	25	16.0	n/a on demand service	n/a on demand service	14	12	no standing	n/a	2.64 boardings per revenue hr.	Houston METRO	
		CBD Greenlink	260 (daily revenue mi.)	14	0.05-1.5mi range	12	7.0	7	7	12	28	(25% of seated capacity) 35	n/a	16.88 boardings per revenue hr	Houston METRO	
		CBD Orange Link	31.2 (daily revenue mi)	17	0.07-0.5mi range	15	7.0	7	7	5	28	(25% of seated capacity) 35	n/a	n/a	Houston METRO	
		LRT														
		Red line	13	25	0.52	62	12.6	6	12 weekends	21	64/128**	180/220***	2		Houston METRO	Rail cars are limited to 2 due to current street block dimensions in Downtown
		Purple Line	6.6	10	0.67	45	9.0	12	12	22	64/128**	180/220***	2		Houston METRO	Rail cars are limited to 2 due to current street block dimensions in Downtown Purple line runs with a single car but capable of a 2 car rail if ridership warrants such.
		Green Line	5	9	0.59	34	9.1	12	12	22	64/128**	180/220***	2		Houston METRO	Rail cars are limited to 2 due to current street block dimensions in Downtown Green line runs with a single car but capable of a 2 car rail if ridership warrants such.
		Paratransit														
			61.4 thousand (Avg. total miles/day) avg. trip length = 13.43	4575 (Avg. total daily stops)	n/a	41mins (avg. trip duration)	n/a	n/a on demand service	n/a on demand service	24	10	10	0	16 (avg. occupancy per vehicle) *based on; Total Passengers 1,905,610 / 327 Vehicles Operated in Annual Maximum*	Houston METRO	
		BRT (Quickline)														
			10	9	0.9 - 1.1	42	15.0	15	na	13	39	(25% of seated capacity) 48	0	17.96 boardings per revenue hr.	Houston METRO	

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Exhibit A-5 Local and Subregional Service Statistics from Houston METRO Operations (Page 2)

			Route/Alignment			Performance		Passenger LOS			Capacity					
Service Classification	Service Concepts	Technology Applications and Operating Mode	Route Length (Miles)[1]	Number of Stations	Average Station Spacing (Miles)	Max Travel Time (Min)[2]	Average Speed (mph)[3]	Headway (Min) Pk. / Off-Pk		Service Period (Hrs/Day)	Vehicle Seating Capacity	Vehicle Capacity (Seated + Standing)	Multi-Vehicle Consists	Boardings per Revenue Hour per Vehicle	Region	Notes/Comments
Subregional Corridor/Internodal Service	Park & Ride Commuter/Express Bus	Commuter Bus (P&R)											Single vehicle routes only			*Data based on Nov. 2017 weekday values.*
		IH 10West Corridor	8.9 thousand daily revenue miles (5 Routes with average length range of 19 29.6 mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	5 routes ranging from 48-87 mins.	5 routes Avg speed range: 25 - 35.9 mph	5-15	45(limited route)	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0		Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)
		IH45 South Corridor	5.4 thousand daily revenue miles (6 Routes with average length range of 13 31.3 mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	6 routes ranging from 43-86 mins.	6 routes Avg speed range: 24 - 29.9 mph	5-15	60 (limited route)	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0		Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)
		IH45 North Corridor	5.3 thousand daily revenue miles (5 Routes with average length range of 26 34.6mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	5 routes ranging from 43-78 mins.	5 routes Avg speed range: 26 - 34.6 mph	6-20	60 (limited route)	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0		Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)
		IH69 Southwest Corridor	5.5 thousand daily revenue miles (7 Routes with average length range of 4- 18mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	7 routes ranging from 8-48 mins.	7 routes Avg speed range: 24 - 37.6 mph	5-20	40 (limited route)	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0	25.20 boardings per revennue hr. (peak); 23.87 (off-peak	Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)
		IH 10 East Corridor	0.6 thousand daily revenue miles (2 Routes with average length range of 12 16.37mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	2 routes ranging from 40-61 mins.	2 routes Avg speed range: 25 - 39.9 mph	15-30	n/a	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0		Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)
		IH 69 Norteast Corridor	3.7 thousand daily revenue miles (4 Routes with average length range of 16 29.8mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	4 routes ranging from 44-62 mins.	4 routes Avg speed range: 33 - 34.8 mph	8-10	60 (limited route)	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0		Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)
		US 290 Corridor	5.8 thousand daily revenue miles (4 Routes with average length range of 17 29.5mi)	Origin - Destination (P&R - Activity center containing multiple stops)	Varied 0.06 - 1mi (based on Activity hub density)	4 routes ranging from 46-64 mins.	4 routes Avg speed range: 30 - 37.1 mph	5-15	50 (limited route)	5-10 (average of 7hrs/day)	53-55 (New vehicle are limited to 53 based on ADA compliance)	n/a Total capacity is = to seating capacity. Standing not recommended	0		Houston METRO	CBD and other high density activity hubs will have stops at every block: ± 340ft (0.06mi)

** Total amount of stops and stations within the METRO Service Area served by the bus network.*

*** Seating capacity vary by model. Currently METROrail consists of 3 models (Siemens S70 H1/H2) models and CAF Urbos model). Highest seating capacity represents a 2 car configuration on the Red Line.*

*** Total passenger capacity vary according to the interior layout. Values represent capacity study conducted by METRO and may differ from manufacturer specifications. Values found by METRO represent a comfotable and safe capacity without over capacity.

sources: METRO passenger load testing

**** Max Travel time represents total maximum time taken along the length of a route from start to end points. It is not representative of passenger travel patterns and travel times

[1] METRO Source: Fixed-Route Bus Routes - Weekday Summary of Schedules - November 2017 Totals represent the toal Revenue miles for a full day of service operations for all buses under the frequency color code (representative of level of service).

*[2] METRO Source: Fixed route Bus Route parameter Statistics- January 22, 2018. Values are representative of the **scheduled** max travel time.*

*[3] Average speed (mph) repressnts the range of scheduled speed through the length of the route. Values are representative of the **scheduled** average speed*

[4] METRO Source: https://www.ridemetro.org/Pages/RidershipReport-112017.aspx Revenue hrs. represent avg. passenger amount for full scheduled hours of service and does not represent the level of service or difference between Peak/off-Peak volumes

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Appendix B

Estimation of Peak Passenger Flows at High Capacity Transit Stations for First-Mile/Last-Mile Transit Capacity Assessment

This is an Appendix of the Opinion Paper titled:

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

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Appendix B

Estimation of Peak Passenger Flows at High Capacity Transit Stations for First-Mile/Last-Mile Transit Capacity Assessment

The Conceptual Studies presented in this document were performed by J. Sam Lott under the employment of Kimley-Horn and Associates, Inc. The content is publically available in the many published technical papers and conference/webinar lectures listed in the References.

INTRODUCTION

Conceptual studies of small-vehicle advanced technology transport systems have been undertaken by Kimley-Horn since the 1990s with unique methodology developed to study "personal rapid transit" (PRT) and "group rapid transit" (GRT) systems. In recent years, the more general term of "automated transit network" (ATN) has been broadly applied to the PRT/GRT transit system concept in which fully automated transit vehicles operate in customized routing to provide a personalized service for passengers. In the ATN concept, the "on-demand" dispatching of empty vehicles to pick-up a single travel party and to transport the party directly to their destination has had only a handful of actual systems implemented in a relatively small scale installations – such as the Masdar City PRT system, or the London Heathrow Terminal 5 Pod System.

The conceptual studies by Kimley-Horn have analyzed much more complicated and larger scale ATN systems than any systems deployed to this date. Such analytical work has been performed in order to evaluate the specialized demand-responsive ATN dispatch operations, the passenger service levels and the necessary fleet size for transit system operations involving many small vehicles. As part of these studies, the benefits of shared-ride services has been a key aspect of the analyses. The modeling has also addressed optional configurations of station berthing configurations, particularly when necessary to serve multiple small vehicles for simultaneous boarding and alighting at high-demand stations.

The methodology applied has become internationally recognized for its effectiveness in large-scale ATN concept studies. As a result of the multiple simulation-based studies of ATN concepts, presentations on the technical approach have been made at a variety of international conferences dealing with the topics of ATN operations, station facilities and ridership analyses. See References (2., 3., 4., 8.) for additional information on the methodology and the associated ALPS software[1].

The information in this appendix has been drawn from a number of technical papers and invited presentations, a portion of which are noted below in the section titled "References". In particular, the specific lectern presentations have addressed the applications of small, shared-ride transit vehicles operating in a network confined to a defined "district" and operating under fully automated controls. The features of interest to similar applications of AV transit operating on urban district roadways is the common intent to provide demand-responsive dispatching and customized service between the user's origin and destination stations. This concept, identified above as an automated transit network (ATN)

[1] The methodology described for studying demand-responsive dispatching of small vehicles applies a unique simulation modeling tool called the Advanced Land-Transportation Performance Simulation™ (ALPS™). This software is owned, applied and licensed by Kimley-Horn and Associates, Inc.

system, is well suited to serve as feeder transit for first-mile/last-mile service at large rail stations, BRT transit centers, and similar high capacity transit (HCT) intermodal stations. Several past studies of ATN The example applications have three studies of ATN systems connecting between urban or special major activity center districts to adjacent HCT stations, and one example of a campus environment that has a transportation hub within the campus proper. These prior studies have provided the primary analytical source for the low, medium and high demand station activity levels as a reference for this H-GAC HCT planning process. In addition, one campus district ATN circulator system has been included to represent a district with person-trips primarily between internal origins/destinations as well as to/from remote parking facilities.

The most recent and most comprehensive presentation comparing the results of the multiple studies serves as the basis for this appendix. This comparative look across the various ATN studies addresses the application of ATN small vehicle technology deployed as urban district connector/circulator systems, with a particular focus on their application as First-Mile/Last-Mile systems connecting the urban district to a large HCT intermodal stations. The presentation was given at the TRB 2016 Annual Conference – see References (9.) for additional information.

Note that for all of the following studies the assumption of the fully automated ATN system was that there were no fixed routes in the transit service. Instead, the transit service comprised individual vehicles being dispatched directly from a single origin station to a single destination station. Further, with shared ride service assumption, when people bound for the same destination were in the origin station at any point in time, they boarded the vehicle simultaneously.

Low Activity-Level HCT Intermodal Station – Alameda Island District, BART GRT Study, 2003

A study was performed in 2003 for the Bay Area Rapid Transit (BART) research and development division which utilized the ALPS simulation model to study a conceptual group rapid transit (GRT) system. Conceived as a guideway system that would operate 18-passenger vehicles to connect the Fruitvale Station to ten stations within the redeveloping Alameda Island multi-use district, the first-mile/last-mile (FMLM) system had a total route length of approximately 6 kilometers (3.7 mi.). See References (1.) for additional information on this study.

The specific 18 passenger capacity vehicle technology that was studied was a tracked vehicle system that was prescribed by BART for purposes of the operational analysis. In addition, the ridership estimates on which the concept study of the FMLM system were provided by BART to the study team for use in the simulation-based operational analysis. Further, the distribution of trips between the destinations of the 10 stations on Alameda Island was also provided to the study team by BART, with the stipulation in the study scope that the system be modeled for shared-ride service.

Figure B-1 depicts the ATN system plan, **Figure B-2** shows the simulation model as it was animating the vehicle operations, and **Figure B-3** shows the pattern of ridership demand at the ATN station serving the BART rail line at Fruitvale station. The more recent evaluation of this case study in comparison to other ATN studies has concluded that the vehicle size of 18 passenger capacity was well above the capacity required, as can be observed in **Figure B-2**. The simulation program's annotation of vehicle status on a second-by-second basis shows that almost all vehicles transported less than 5 passengers at a time throughout the day. It has been observed that only a single station on the island generating enough riders to substantially fill a vehicle. This would indicate that most stations could be effectively served by smaller vehicles, and only the higher-demand station pair should be considered for service with a larger vehicle.

From this BART project, a reference can be established for a "low activity" High Capacity Transit station case for consideration by the H-GAC HCT Task Force. The station activity characteristics resulting from the BART 2003 analysis which are referenced in the definition of the HCT low activity station evaluations of FM/LM AV transit are as follows:

Low Activity Level HCT Intermodal Station Benchmarks (BART 2003 Study)

- Daily Boarding Passengers = 1,786
- Daily Total Passenger Trips Using the ATN System = 3,572
- Peak 5 Minute Flow-in (Brdg.+Altg.) = 60 pass.
- Peak 5 Min. Equivalent Hourly Rate = 720 pph

Figure B-1 BART Fruitvale Station ATN System Concept – 2003 Study

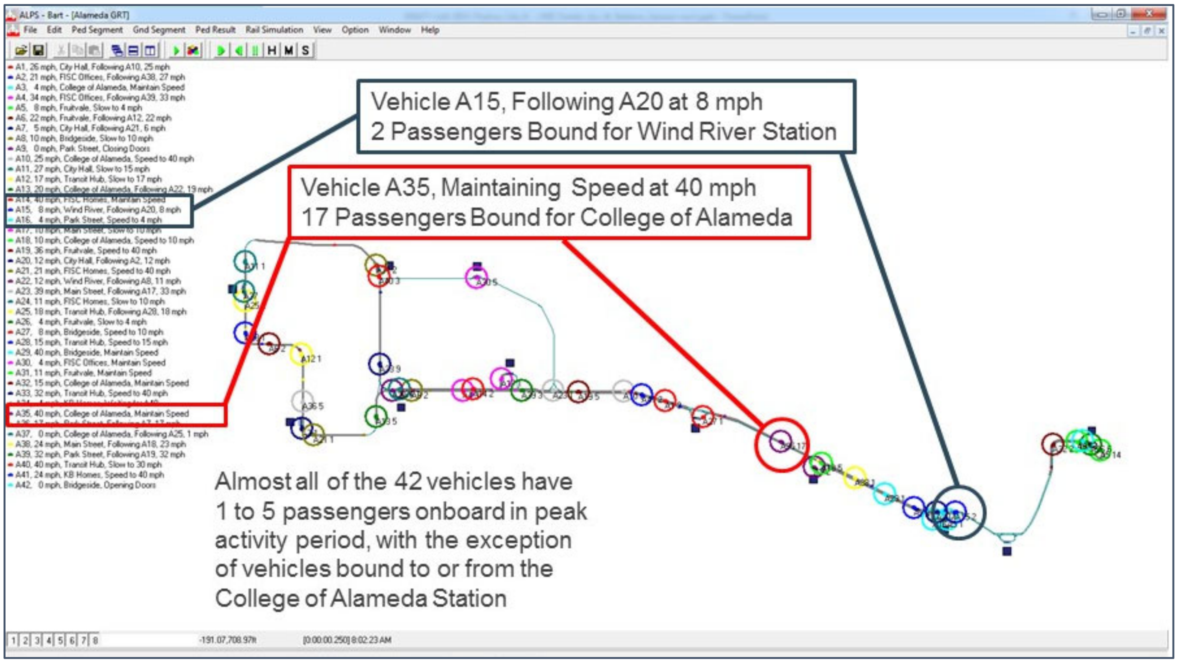

Figure B-2 Alameda Island ATN System at 8:02 a.m. – Listing of Each Vehicle's Operating Status, With Annotation of Vehicle Unit Number and On-Board Passengers Shown Beside Each Vehicle

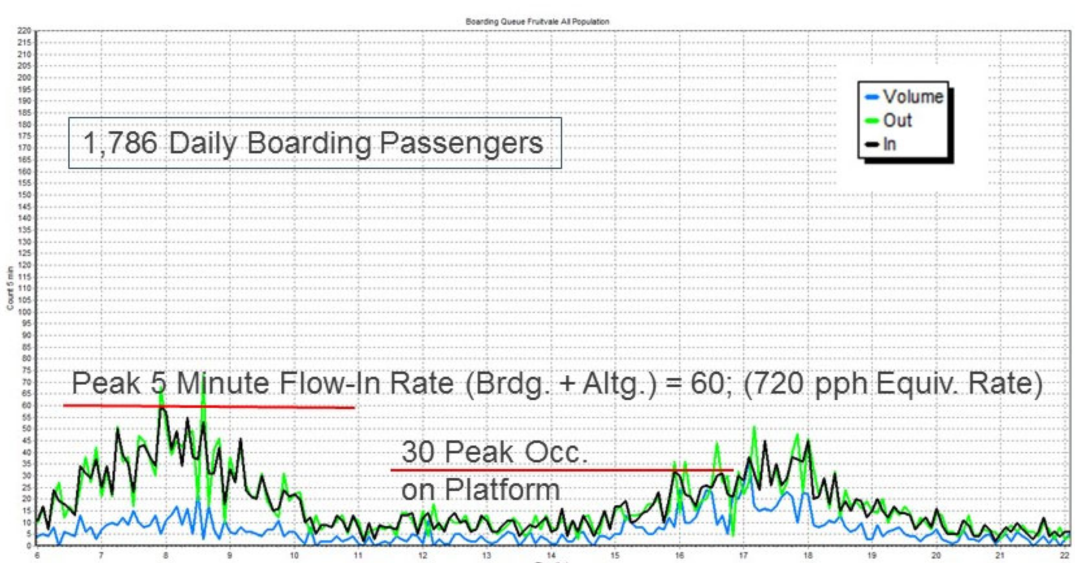

Figure B-3 ATN Station Activity at BART Rail Station – Data in 5-Minute Intervals

Medium Activity-Level HCT Intermodal Station – Newark Airport District, EWR Airport Study, 2009

The second study that provided a reference for the level of passenger activity to be considered a medium level of HCT intermodal station activity was performed in 2009 for the Port Authority of New York and New Jersey (PANY&NJ). The project work evaluated a conceptual ATN system that connected stations at the airport terminals and ground transportation facilities (Newark Airport District) with an ATN station located at the adjacent Northeast Corridor (NEC) rail station – separated from EWR by a major freeway system at a distance of approximately 2.5 kilometers (1.5 mi.) from Newark Airport District (EWR). The analysis was conducted as part of the study which was evaluating different people mover system technology alternatives to provide the FM/LM connections with the NEC station. One of the technologies studied was small, 4-passenger vehicle ATN system using the ATN simulation modeling methodology. See References (5.) for additional information on this study.

The 5.5 kilometer (3.5 mi.) ATN system that was analyzed had 15 stations, with the NEC rail station producing the highest demand conditions due to the surge flow effects as the Northeast Corridor trains arrived with a large number of passengers alighting to transfer to the ATN system. The ALPS model simulated the arrival of the NEC trains, as well as the subsequent progression of the transferring passengers as pedestrians walking through the station. Even with the dispersion of the pedestrians due to their different walking speeds, the surge flow effects at the ATN station were very pronounced.

Figure B-4 has the pattern of activity at the ATN station connected to the NEC station as the normal sequence of regional commuter rail, intercity and high speed rail trains arrived and departed throughout the simulation day. **Figure B-5** shows the ATN system configuration and the location of the NEC station.

This EWR Airport District analysis provides an important reference point for H-GAC HCT Task Force consideration, since it provides a representative data source for a medium activity-level HCT station. The FM/LM ATN system was specifically analyzed in the simulation study for its operations when applying a small, 4-passenger vehicle technology providing a shared-ride demand-responsive service. It is noteworthy that the configuration of the ATN station shown in the **Figure B-4** activity graphs had four parallel berths in the ATN station. After a series of case studies involving different station berth configurations, the analysis showed that this size of vehicle and station configuration was marginally adequate to service the 5 minute surge flow conditions. The simulation showed an accumulation of 140 people within the station for a brief time around 7:30 p.m.

A key parameter that was identified through the successive case studies performed during the study was that there were conditions where the supply of empty vehicles at the NEC rail station was deficient. For smaller fleet sizes, the system was unable to dispatch sufficient vehicles over the longer distance to adequately serve the rail station demands and very large accumulations of passengers filled the ATN station waiting for service. This situation was mitigated when a storage track is provided on which sufficient empty vehicles could be staged adjacent to the ATN station, as shown in **Figure B-6** which depicts the final station configuration used in the simulation analysis process. It was also concluded that if the ATN technology concept was developed further, there would be a benefit to studying larger vehicles in the fleet – potentially to service a connection between a few high-demand stations within the ATN network.

AV transit system planning activity-levels for consideration in the H-GAC HCT Task Force assessments will reference this 2009 study of an ATN system application to Newark Airport District based on the following statistics:

Medium Activity Level HCT Intermodal Station Benchmarks (EWR Airport 2009 Study)

- Daily Boarding Passengers = 5,879
- Daily Total Passenger Trips Using the ATN System = 11,758
- Peak 5 Minute Flow-in (Brdg.+Altg.) = 200 pass.
- Peak 5 Min. Equivalent Hourly Rate = 2400 pph

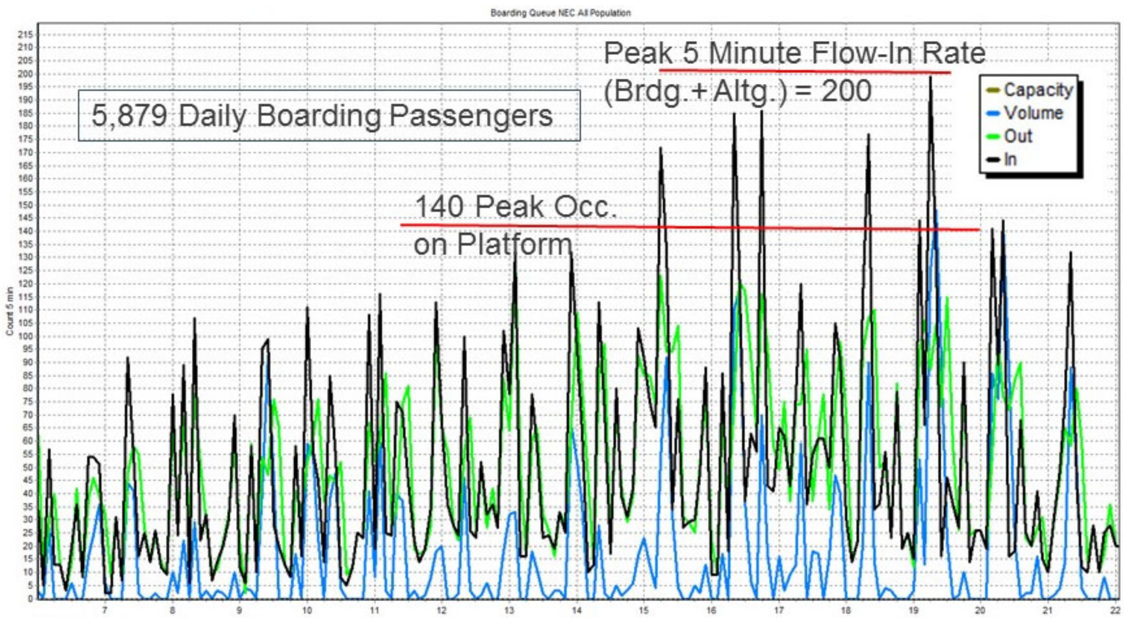

Figure B-4 ATN Station Activity at EWR Northeast Corridor Rail Station – Data in 5-Minute Intervals

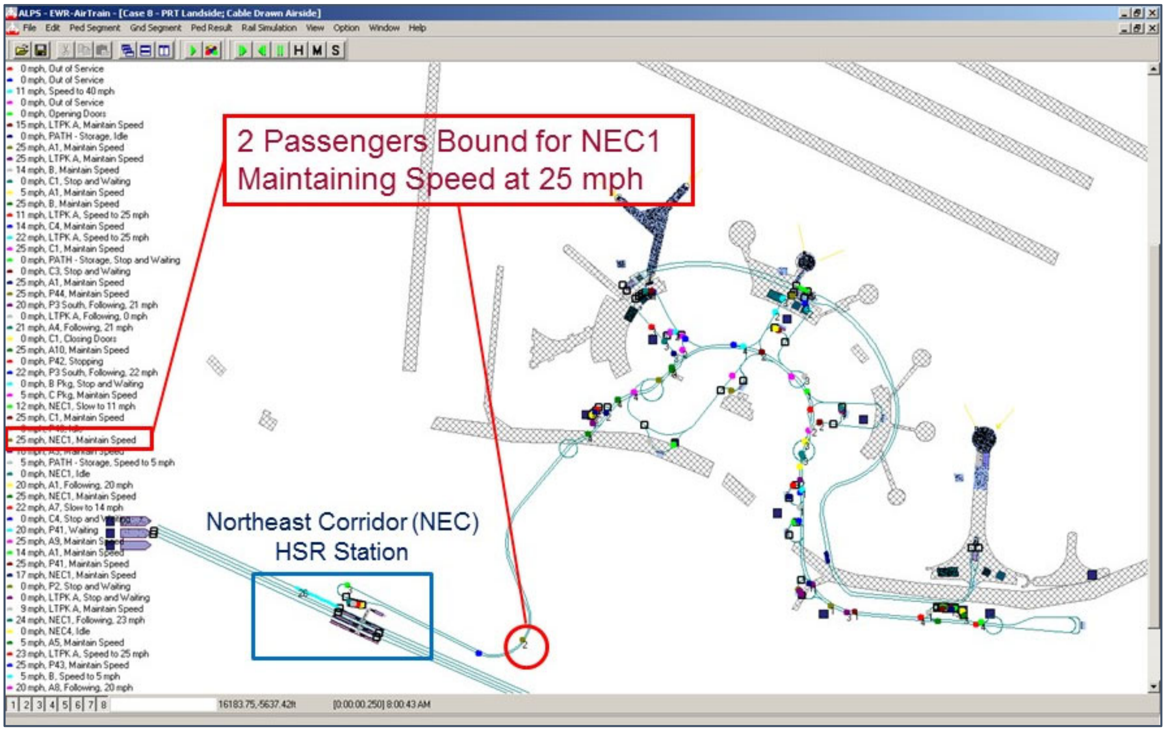

Figure B-5 EWR Airport ATN System at 8:00 a.m. – Listing of Each Vehicle's Operating Status, With Annotation of Unit Number and On-Board Passengers Shown Beside Each Vehicle

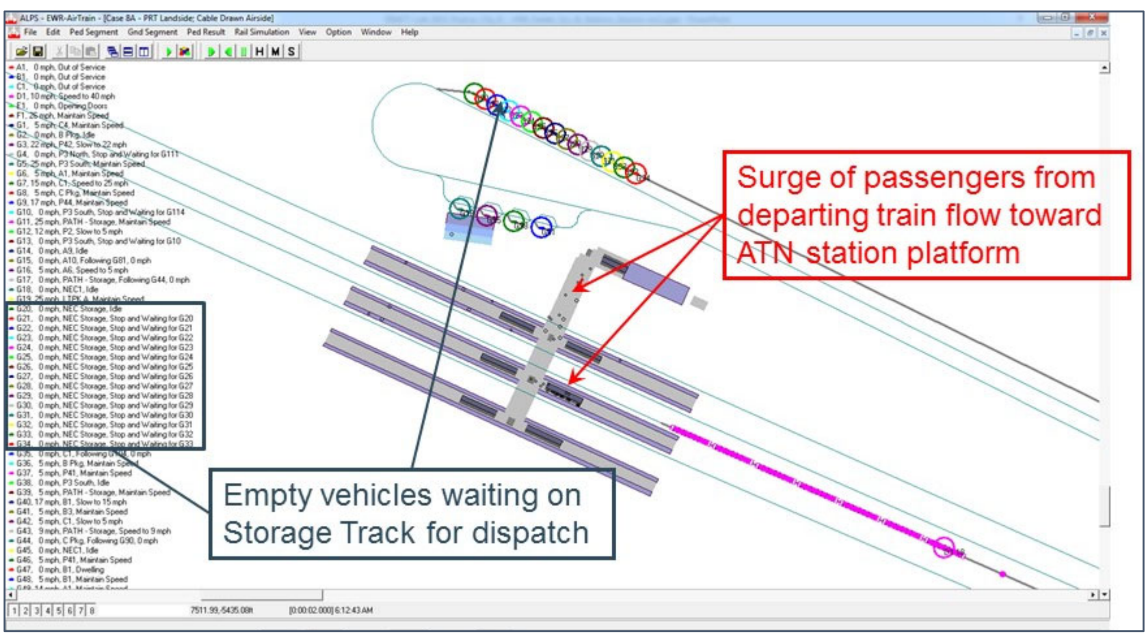

Figure B-6 EWR Study Final ATN Station Configuration Concept With Four Berths and Adjacent Storage Facility

High Activity-Level HCT Intermodal Station – Houston Downtown District, Hypothetical Study of Houston HSR Station, 2012 & 2016

A third study has been referenced which analyzed a large rail station which conceptually would be served by a transit circulator system dedicated to carrying commuters into an adjacent major business district. The core analytical work of station activity was part of a conceptual study of a high speed rail (HSR) system throughout the state of Texas. An element of the study focusing on a HSR station located adjacent to the central business district in Houston, Texas. The very large rail station concept was analyzed using the simulation methodology to study the intermodal station operations as part of the 2012 study for the Texas Department of Transportation (TxDOT).

For the TxDOT study, the HSR station was originally configured in the simulation with a conventional fixed route busing operation for FM/LM distribution of commuters arriving at the HSR station. The daily commuters were arriving at the HSR intermodal station on large regional commuter rail trains used for their daily trip to work in Downtown Houston. A subsequent analysis unrelated to the original 2012 study was performed in 2016 as an academic study of a conceptual ATN system which would perform the FM/LM distribution for the very large intermodal rail station. The results of this academic investigation of an ATN concept for FM/LM connections were presented at the Transportation Research Board (TRB) 2016 Annual Meeting. See References (8.) for additional information on this TRB presentation made during the meeting of the TRB AP040 Automated Transit System committee.

Figure B-7 shows the simulation model that was created to analyze a small, 4-passenger vehicle ATN system operating in a shared-ride, demand-responsive operation. The 10-berth ATN station in the academic study was assessed to analyze whether such a small-vehicle system could be effective in transporting the large surge flows of commuter transit passengers arriving at such a large, high activity intermodal rail station. **Figure B-8** shows the animation of the surge of passengers approaching the ATN station as they transfer from the large regional commuter rail trains during the morning commute period.

For the purpose of defining a high activity-level intermodal station in the H-GAC HCT planning process, the screen capture from the simulation model run provides a graphical representation of the surge flows from the HSR intermodal station to the ATN station as shown in **Figure B-9.** This operational model of the large HCT station provides an important source of statistical data for the high activity-level station benchmark. **Figure B-9** also has the corresponding peak flow rates for the other lower activity examples discussed above for comparison purposes, shown on the graph to illustrate the small, medium and high activity-levels of ATN passengers peak flows that were analyzed.

There is included in the statistical data, however, an adjustment to the total passenger activity-level for a Downtown Houston HCT intermodal station statistics with respect to the 2012 HSR Station Study simulation results. In the 2012 TxDOT study, the local Houston stakeholder group instructed the study team to only include two regional commuter rail lines which had already had ridership studies performed. However, the previous H-GAC Regional Commuter Rail Connectivity Study completed in 2009 had defined 5 lines to serve the downtown district.

Therefore, when considering the use of the Houston study statistics as a reference for the H-GAC HCT study, the assessment was made that the other commuter rail lines planned for the Houston region (or other equivalent high capacity transit mode's service to the CBD) should be also considered to represent a mature multimodal regional rail system. It has therefore been estimated that the total daily passenger activity should be increased by a factor of two for purposes of this HCT planning report. Although the peak 5-minute surge flows of passengers arriving at the ATN station is considered to be the appropriate 5-minute peak demand, the number of times a day when the 5-minute peaking occurs should be significantly increased in frequency. For the reasons noted, the daily passenger activity in the FM/LM AV transit system demand assessment for purposes of defining a "High Activity-Level Station" has also been factored up by approximately two times over the original statics from the original 2012 Houston HSR Station study – this factoring is indicated by the asterisks and the related explanatory note shown below.

High Activity-Level HCT Intermodal Station Benchmarks (TxDOT HSR Houston 2012 Study)

- Daily Boarding Passengers = 5,091 (based on 2012 study's daily commute trip patterns)
- Adjusted Daily Boarding Passengers = 10,250*
- Daily Total Passenger Trips Using the FM/LM System = 10,182 (based on 2012 study)
- Adjusted Total Passenger Trips Using the FM/LM System = 20,500*
- Peak 5 Minute Flow-in (Brdg.+Altg.) = 420 pass.
- Peak 5 Min. Equivalent Hourly Rate = 5,040 pph

* Adjusted to represent an ultimate HCT CBD Intermodal Station (referencing a conceptual regional commuter rail system plan with 5 regional lines connecting at the HSR Intermodal Station), with an assumed doubling of commuters inbound to CBD in the morning commute period.

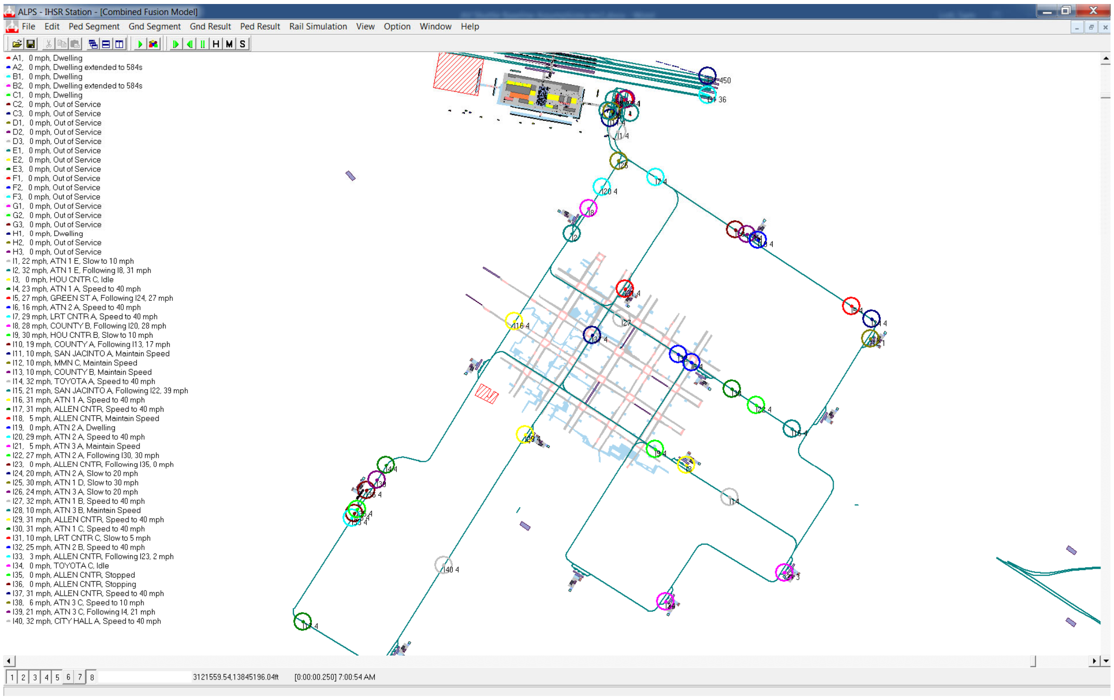

Figure B-7 Conceptual ATN System Providing First-Mile/Last-Mile Connections Between a HSR Intermodal Rail Station and the Houston Central Business District

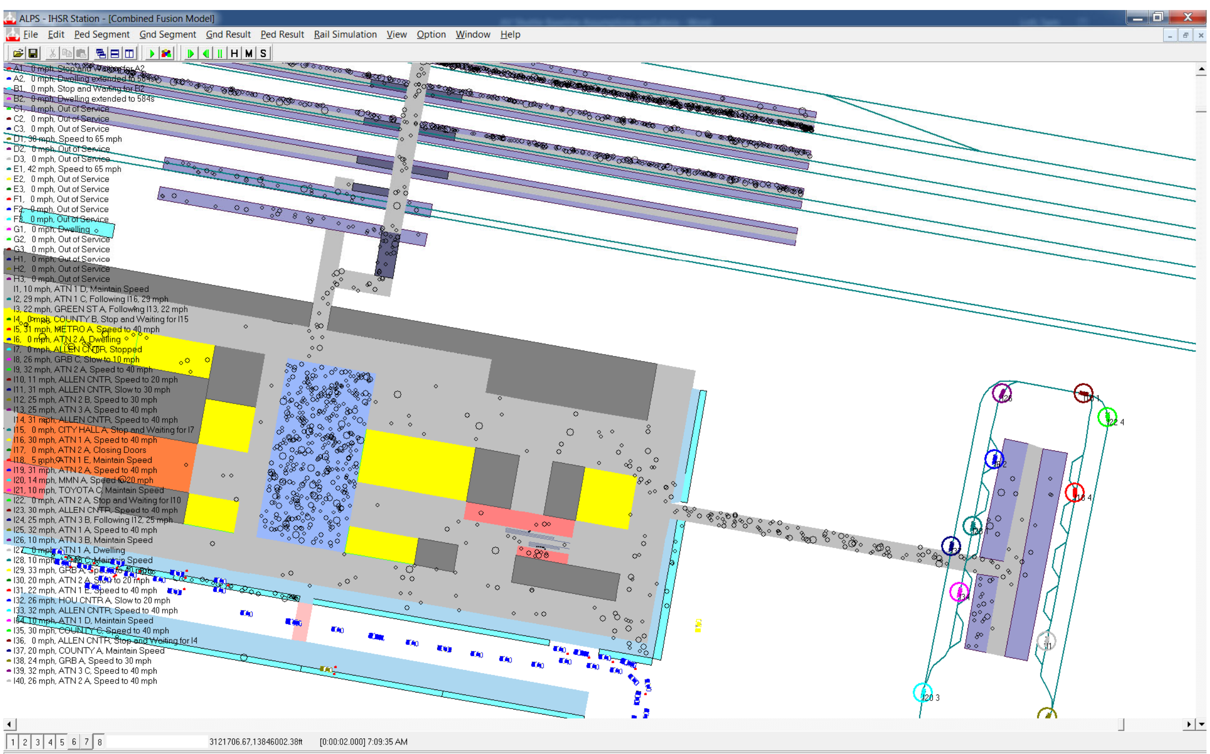

Figure B-8 Passengers Arriving on Large Commuter Rail Trains and Connecting to the First-Mile/Last-Mile Transit System Create Large Surge Flows Conditions at the ATN System Station

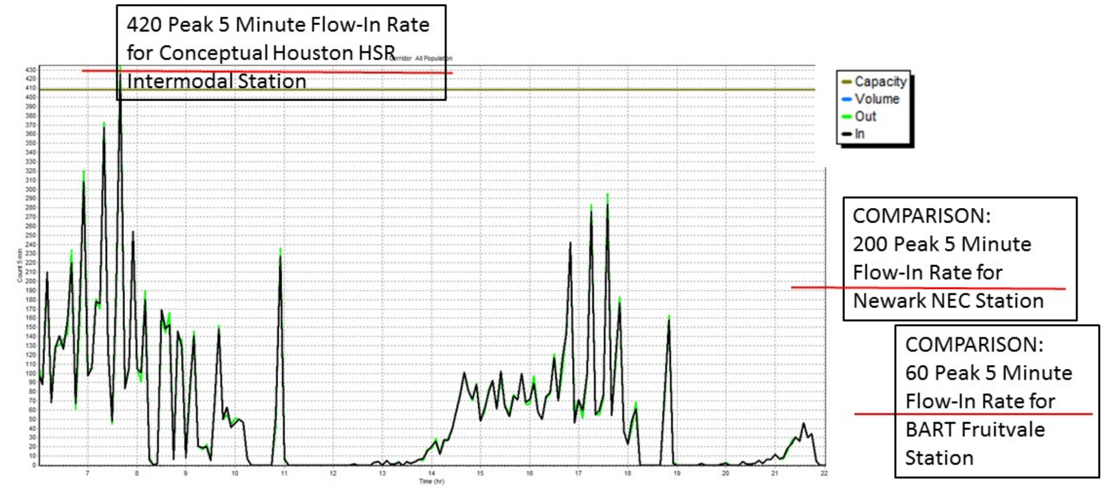

Figure B-9 Peak 5-Minute Surge Flows of Passengers Arriving at a First-Mile/ Last-Mile ATN System for the Houston High Activity HSR Intermodal Station – Compared with the Medium and Low Activity Rail Stations Surge Flows

Large Campus District AV Transit Circulator System – California State University, Fresno (2010)

Another relevant study of a very large ATN system using automated small vehicle technology provides relevant information for reference in a general definition of an urban district or major activity center transit circulator system concept. This conceptual ATN study also applied the analytical modeling methodology using simulation case studies to analyze the operations of a shared ride, demand-response system within a mixed use and university campus environment. The configuration of the transit circulator system is of a configuration that is being called a "network" for purposes of this H-GAC high capacity transit planning study. **Figure B-10** shows one of the configurations studied for the ATN system, with the main campus in the central part of the network, and with the university sports complex on the left and a mixed business development on the right of the image in the figure.

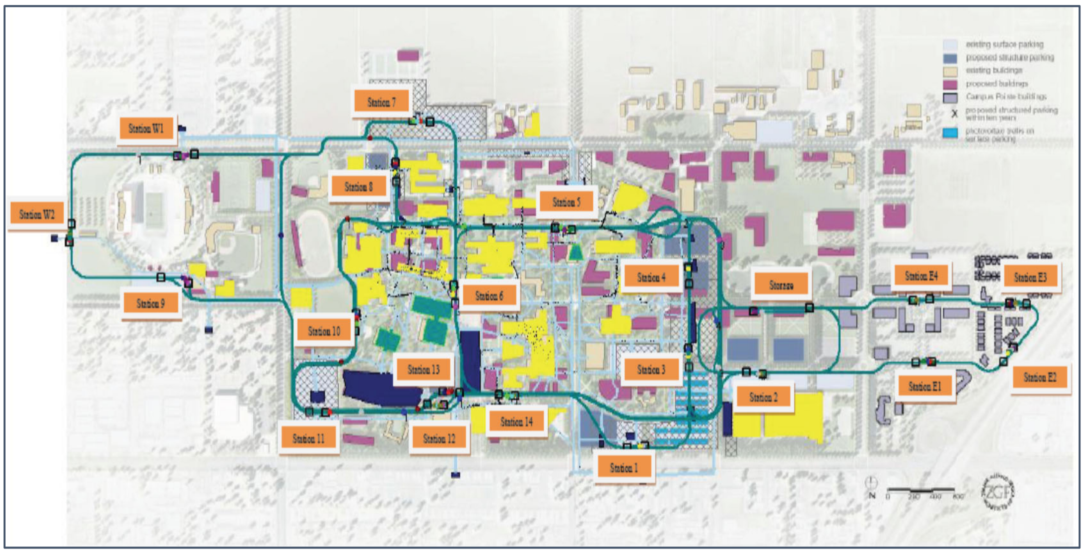

Figure B-10 Network Configuration of a Conceptual Campus ATN System at UC-Fresno

The "length" of the system from end-to-end was approximately 1.5 miles (2.5 km), but due to the network configuration the system was described in the original study report as having 5 miles (8 km) of "route length". There were 20 stations modeled in the simulation of the small 4-passenger vehicle operations, with shared-ride service allowing a group of people who are bound for a common destination and present in the origin station at the time the vehicle was boarded to travel together in a direct trip to the destination station, without any station stops along the O/D travel path. Refer to the References (6.) for more information on this study.

The nature of the university campus with large surge flow conditions during the brief periods of class-change activity created an interesting and very relevant scenario to study, a scenario in which small vehicle limitations to serve these passenger flow conditions. A relatively large fleet of 140 vehicles was determined through the analysis to be necessary in order to bring the average waiting time in the station below 2.5 minutes. The average travel time to each passenger's destination station once they boarded the vehicle was 3.6 minutes. Other configurations, fleet sizes and service concepts were studied as well through the application of the simulation-based tools.

Figure B-11 shows that many vehicles were fully loaded to their 4 passenger capacity during the surge flows of a class change period, as indicated by the number beside each vehicle shown in the animated simulation display screen image capture. One important aspect of study results for this campus circulator operation was the provision of sufficient station berth capacity at certain high-demand stations. Operating conditions resulting from even brief overloading of key stations caused congestion queuing of vehicles which spilled back onto the mainline guideway, resulting in travel delays for all vehicles passing by the station even if they were not bound for the specific high-demand station.

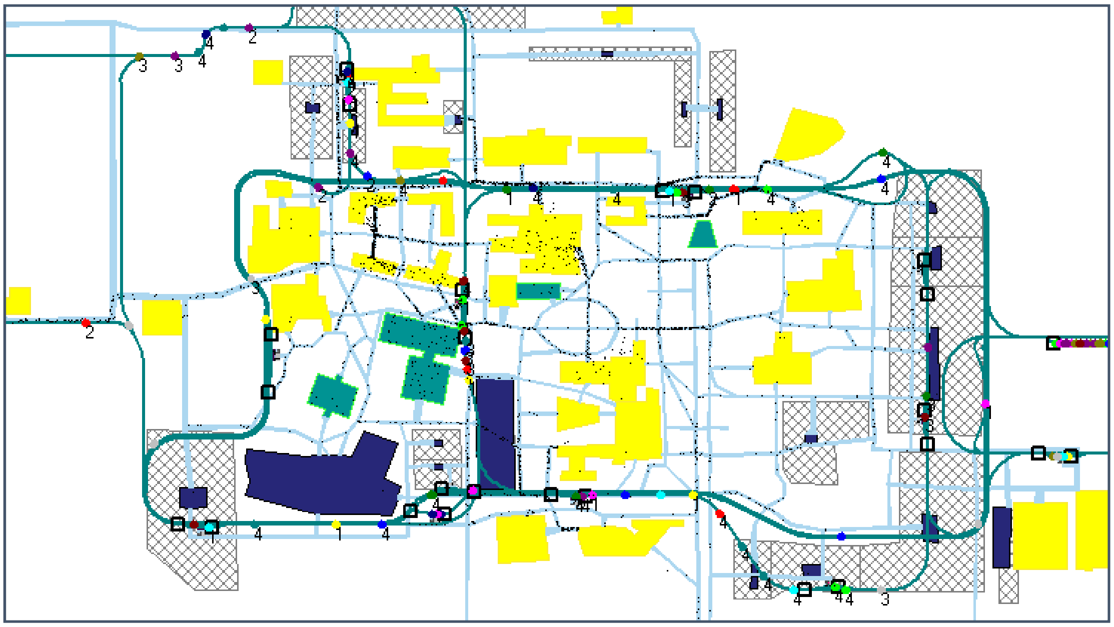

Figure B-11 Peak Class Change Interval With Most Vehicles Loaded to 4-Passenger Capacity

Figure B-12 shows surge flows of student class changes at one station in the middle of the campus. The figure shows flow-in and flow-out graphed minute-by-minute (black and green graph lines), as well as station occupancy "volumes" indicating the accumulation of people on the platform (orange graph line). The "capacity" value (red line) is a platform occupancy limit for the assumed platform dimensions in the model, which is based on 15 sq. ft. per person. Results indicate a larger platform would be beneficial.

Figure B-13 illustrates the distribution of waiting times as a percentage of the passengers boarding at each of the station locations throughout the day. A variety of system configurations and demand scenarios were studied during the course of the work, and average station waiting times across all passengers throughout the day ranged from 2.3 to 2.9 minutes for the various case studies. For the longer wait time of 2.9 minutes shown in the figure, there were some stations at which 10 percent of the passengers had waiting times of between 10 and 12 minutes. This illustrates the system design considerations that must be given to the fleet when establishing the vehicle size and the associated impacts on passenger waiting time, since many vehicles were completely full (4 passengers onboard) during the peak intervals.

As discussed in the example study described above (see Medium Activity-Level Intermodal Station; Newark Airport District), a starvation of available empty vehicles can occur in certain parts of a large network when operating fleets are undersized and when strategically placed storage locations are not included in the system design. This results in time delays as some passengers must wait in the station until additional empty vehicles can be dispatched to serve their specific origin-to-destination trip.

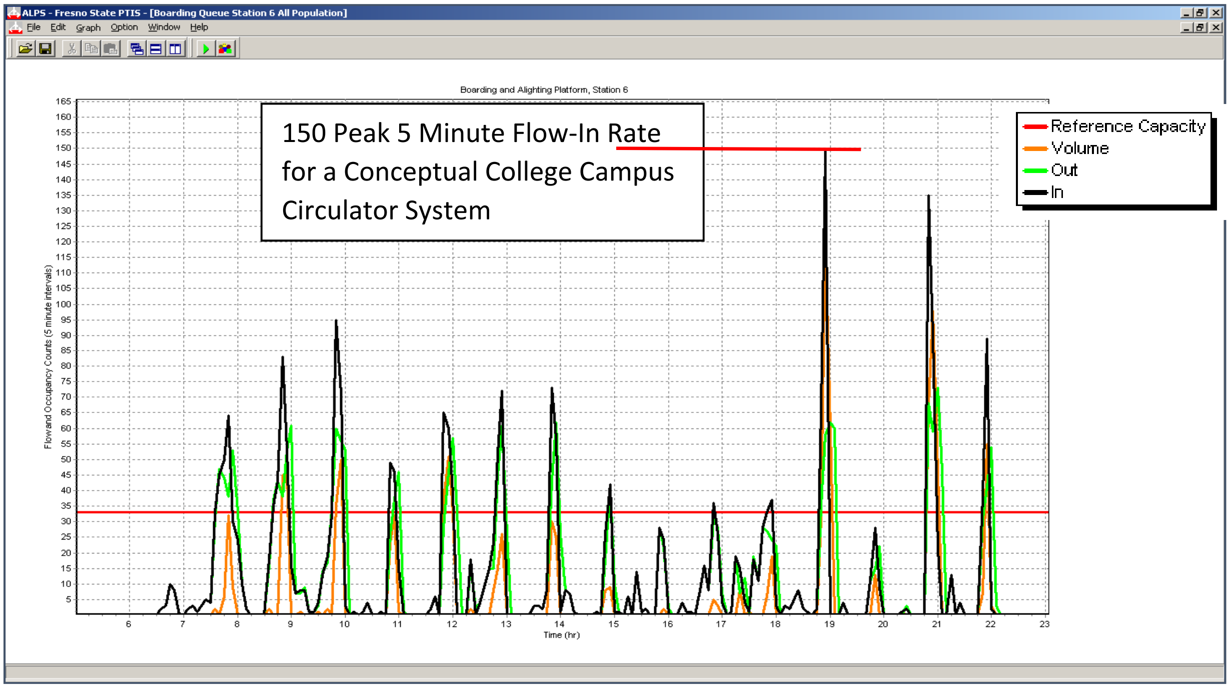

Figure B-12 Central Campus Ridership Surges Flow in 5-Minute Intervals – Station "Flows" are Combined Boarding/Alighting Movements and Station "Volumes" are People on the Platform

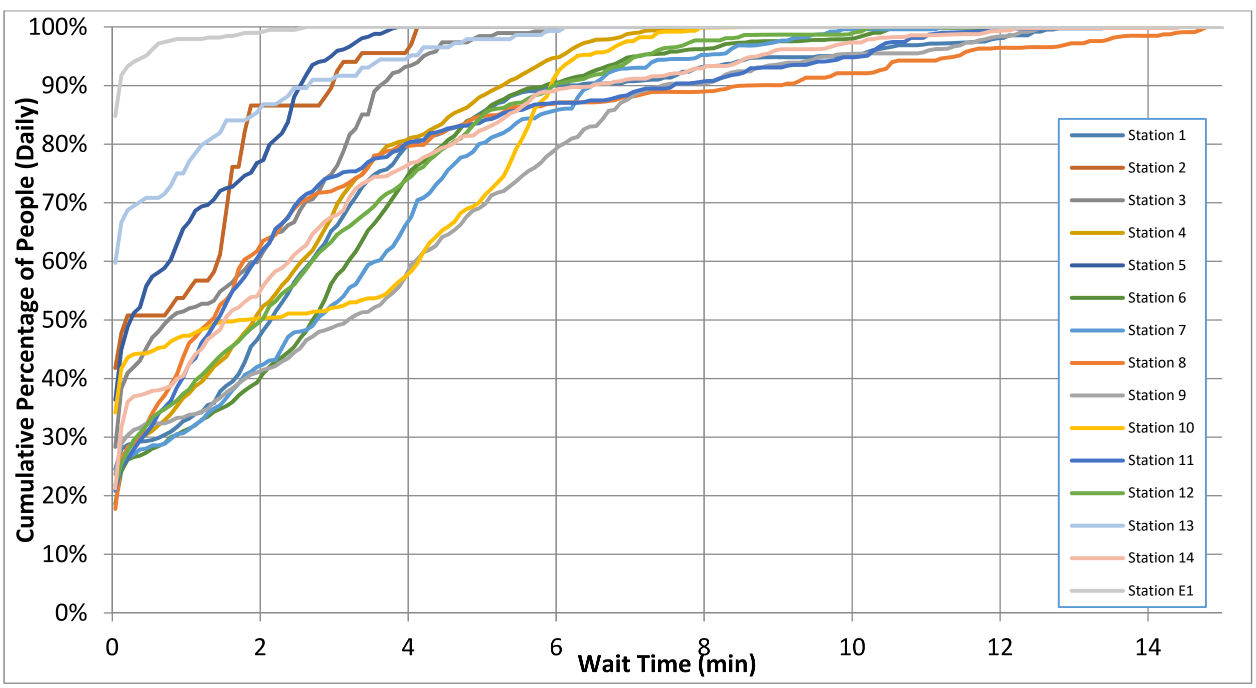

Figure B-13 Distribution of Station Waiting Times for All Stations in Selected Case Study With Small 4-Passenger Vehicles (2.9 Min. Avg. Station Waiting Time Over the Simulation Day)

Conclusions on AV Transit Technology Applications for HCT First-Mile/Last-Mile and District Circulator Systems

The simulation-based operational analysis methodology gives insight into a definition of an important part of the H-GAC HCT multimodal system. These example planning studies provide allow a preliminary assessment of smaller size vehicle technologies applied as AV transit systems serving in FM/LM and district circulator system applications. The multiple studies of a variety of demand-responsive, small-vehicle automated transit systems give reference points for variables such as vehicle size, operating fleet, ride-sharing options, route and station configurations. This methodology has allowed such variables to be tested and the resulting passenger service parameters to be evaluated comparatively across multiple system alternatives.

Three specific studies which have analyzed ATN system applications as first-mile/last-mile systems for different size rail stations comprising low, medium and high-activity ridership levels. The rail station FMLM studies have provided a statistical benchmark from which the three scales of AV Transit systems can be defined. Further, the ATN studies using the simulation-based methodology have also provided insight into the increasing complexity of system configurations as corridor, loop circulator and network concepts evolve through transit service expansion over time.

Use of these reference data and operational insights from the prior ATN studies allow the AV Transit Circulator and FM/LM services concepts to be assessed as generic concepts for preliminary HCT Multimodal Transit System planning purposes. In particular, the use of smaller vehicles (4 passenger to 25 passenger vehicle capacities), when combined with full automation allows a very high level of service to be maintained. The viability of implementing a transit circulator and FM/LM system service plan which satisfies the new FTA model of Mobility-on-Demand will be determined in many applications more by the surge flows within 5 to 10 minutes than by the overall hourly ridership demands.

Therefore, the following peak surge flow conditions are proposed as relevant planning values for ridership demand estimation in the H-GAC High Capacity Transit planning exercises. For purposes of a definition of First-Mile/Last-Mile AV transit connector systems servicing High Capacity Transit intermodal stations, the following benchmarks are recommended.

Low Activity Level HCT Intermodal Station Benchmark

- Peak 5 Minute Flow-in (Brdg.+Altg.) = 60 pass.
    - Peak 5 Min. Equivalent Hourly Rate = 750 pph

Medium Activity Level HCT Intermodal Station Benchmark

- Peak 5 Minute Flow-in (Brdg.+Altg.) = 200 pass.
    - Peak 5 Min. Equivalent Hourly Rate = 2,500 pph

High Activity-Level HCT Intermodal Station Benchmark

- Peak 5 Minute Flow-in (Brdg.+Altg.) = 420 pass.
    - Peak 5 Min. Equivalent Hourly Rate = 5,000 pph

For general definition of typical urban districts and/or special use campus AV Transit Circulator Systems, the following benchmark is recommended.

Medium Activity-Level Internal Campus Station Benchmarks (TxDOT HSR Houston 2012 Study)

- Peak 5 Minute Flow-in (Brdg.+Altg.) = 150 pass.
    - Peak 5 Min. Equivalent Hourly Rate = 1800 pph

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Appendix C

Urban District Automated Circulator and FM/LM Systems Deployed on Grade-Separated Transitways

This is an Appendix of the Opinion Paper titled:

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

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Miami Metromover

Singapore's Sengkang and the Punggol Districts

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Appendix C
Urban District Automated Circulator and FM/LM Systems
Deployed on Grade-Separated Transitways

There are several relevant examples of transit circulator systems in major urban districts which should be considered as models for a grade-separated transitway system within the Urban Core. The Downtown Miami Metromover System and the Jacksonville Downtown Automated Skyway Express (ASE) people mover system which are discussed in this appendix were originally deployed as part of the downtown automated people mover program that was initiated in the 1970s by the Urban Mass Transit Administration (now the Federal Transit Administration).

Also highly relevant as an example of existing technology applications are Singapore's two urban district automated circulator systems. Although the systems are referred to as "automated light rail" systems by Singapore's Land Transport Authority, the vehicle system technology is also operating as an automated people mover system in several major U.S. airports.

All of the example technologies are on aerial structures which are similar to the grade-separated transitway that is envisioned for the AV Microtransit circulation and FM/LM transit systems in the largest and densest urban districts. But in particular, the examples are believed to be highly relevant to the extension of certain district systems to a larger concept of an interconnected Houston Urban Core Transitway System on which full-sized automated buses would operate.

The ***Miami Metromover*** began operations in 1986, and was expanded in 1994. This fully automated, rubber-tire vehicle system has had complete renovations of the vehicle system technology and controls, and has recently been studied for further expansion. The aerial guideway transit system shown in **Figure C-1** connects to two different heavy rail mass transit stations in the proximity to the Central business district and the adjacent Omni extension that is known for its concentration of performing arts venues and the Brickell extension that service a major financial districts. The properties around the Metromover stations have experienced major growth in office and residential tower development, especially over the past 15 years, as can be seen in **Figure C-2**.

Singapore's Sengkang and the Punggol Districts each have "light rail" systems operated by the Land Transport Authority. **Figure C-3** has photographs of the fully automated guideway transit systems in which rubber-tired vehicles operate along an aerial transitway by which people connect between the districts' residential and office towers to regional transit. **Figure C-4** shows the route maps for the two urban district circulator and FM/LM systems carrying riders to nearby stations at the end of the MTR North East Line – an automated heavy rail system operating in a 12 mile long corridor with 16 stations.

The Miami and Singapore examples have guideway system technologies of a vehicle size similar to that of a 40 passenger bus, but designed for standing passengers capacities of between 80 and 100 people. The Houston circulator systems can be envisioned to carry AV buses along a similar type of transitway.

Both of these examples are currently operating as automated technologies that cannot be brought to grade and exposed to street traffic operations or even at-grade traffic crossings. However, the third example addressed below of the Jacksonville downtown people mover system is a prospect for conversion to AV Microtransit technologies which can be brought to grade for mixed traffic operations.

Government Center is a multilevel intermodal station with the Metrorail platforms on the top level, the automated Metromover platforms at mid-level, and connections to buses and city street and pedestrian access facilities at-grade.

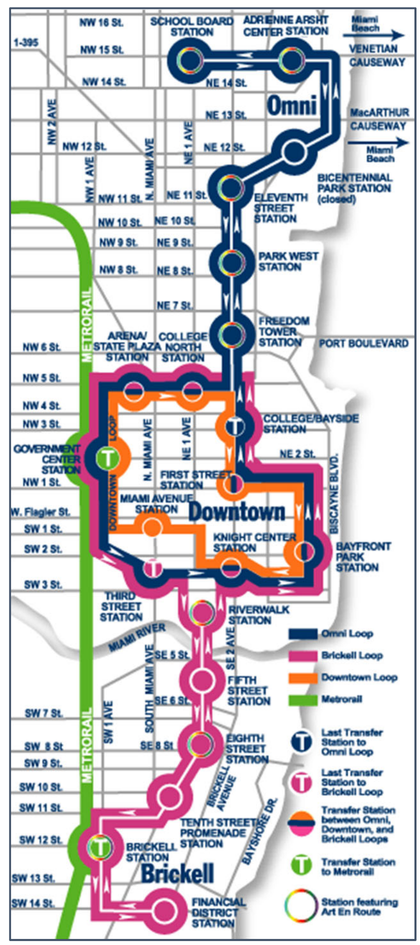


Figure C-1 Miami Metromover Provides FM/LM Connectivity and Downtown Circulation for Transit Passengers Arriving at the Edge of the CBD on the Regional Metrorail System

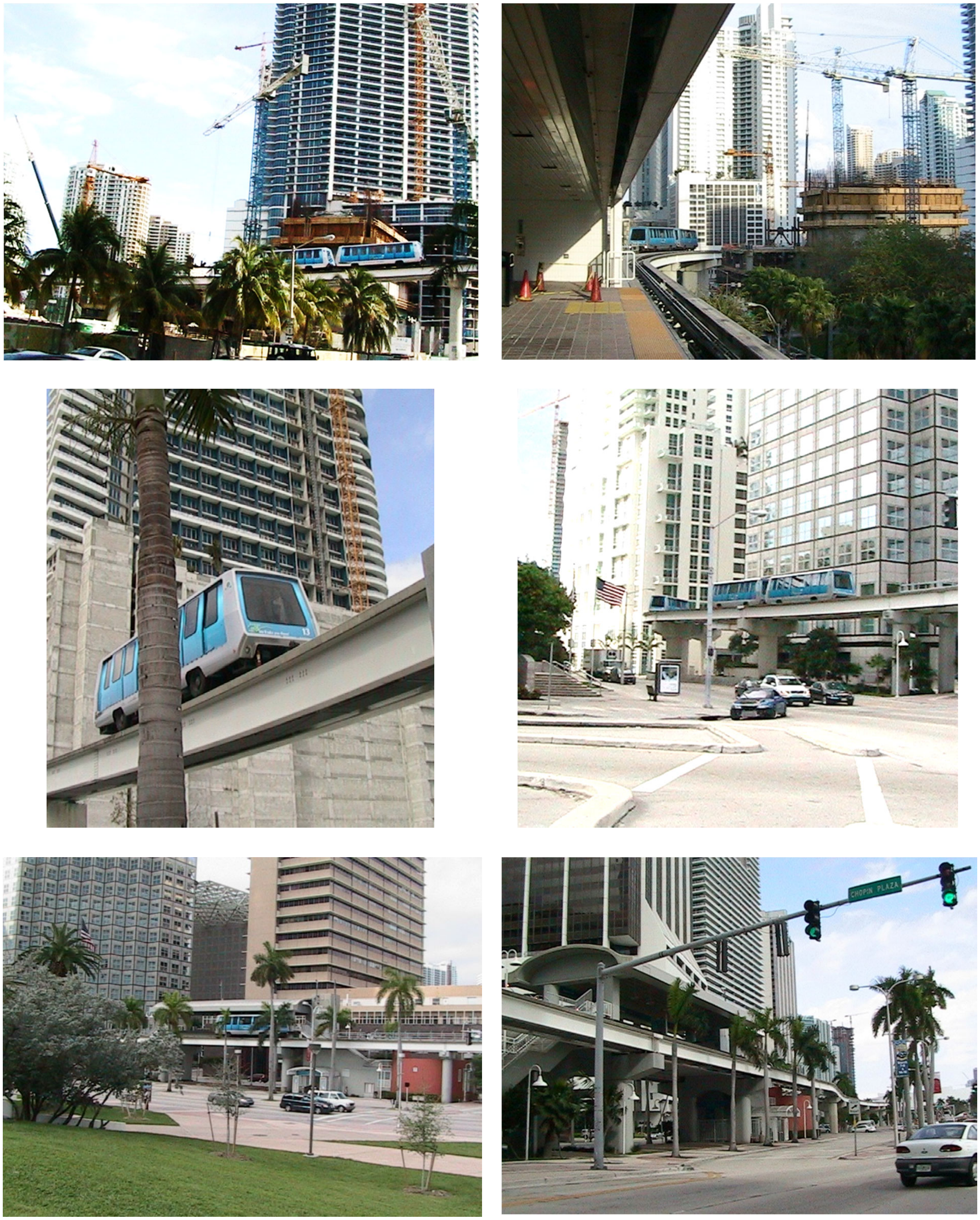
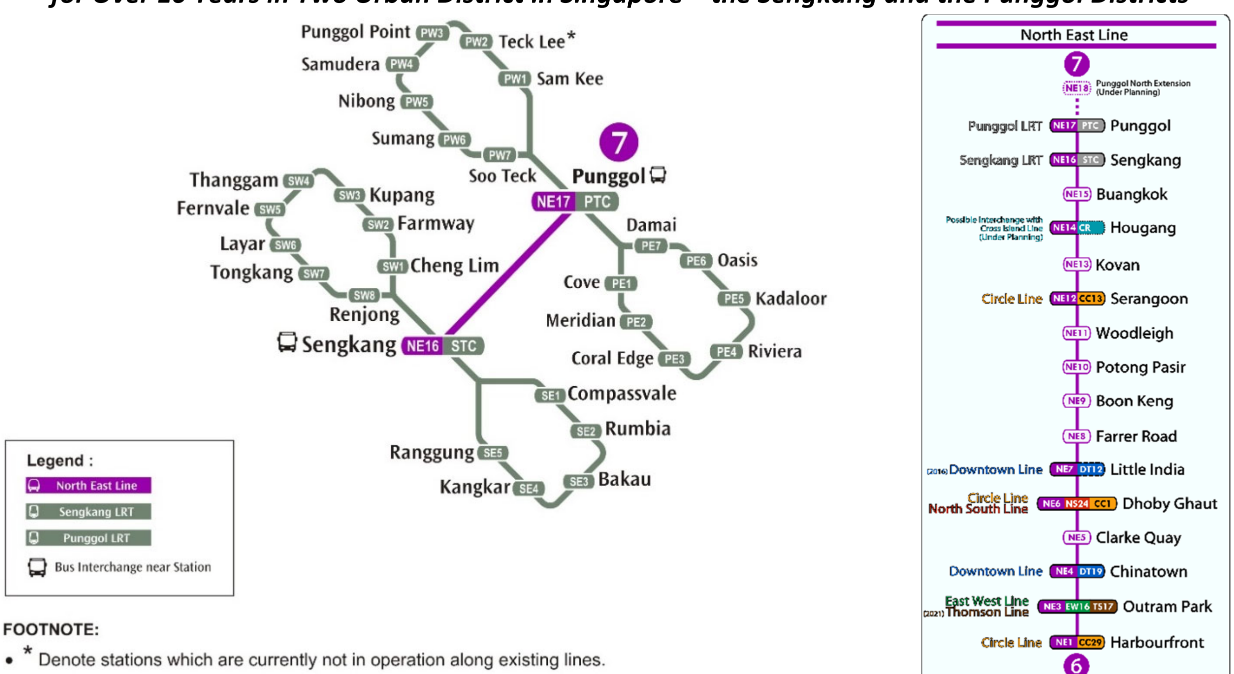


Figure C-2 Miami Metromover Alignment and Station Locations Originally Built in Perimeter Locations Around Downtown Miami Have Seen Major Development in Recent Years

Figure C-3 Automated Transit Circulator System Providing FM/LM Service Along an Aerial Transitway for Over 10 Years in Two Urban District in Singapore – the Sengkang and the Punggol Districts



FOOTNOTE:

- * Denote stations which are currently not in operation along existing lines.

Figure C-4 Route Map of Singapore's Urban District Automated Circulation and FM/LM Systems

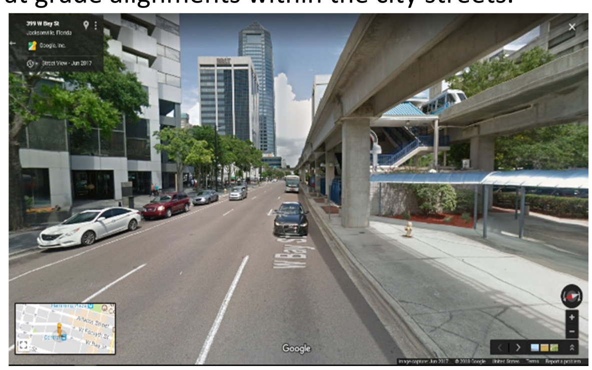
Jacksonville's Automated Skyway Express (ASE) is a case study of particular interest because the legacy downtown people mover system has elevated guideway structure with a fairly generic design. This structure has already supported two completely different vehicle technologies since the 1980's. Design studies are currently underway for conversion of the structures to operate AV Microtransit technologies.

Jacksonville Transportation Authority (JTA) has announced their plan to convert the transitways to flat "roadway" type running surfaces which will allow vehicles of the new AV Microtransit technology class to travel along the aerial alignment. The transitway structure's cross-section showing this flat structure can be seen in upper-left image of **Figure C-5**. Also visible in lower-right photo of the end-of-line station is the existing monorail "box" beam on which the existing "straddle-beam" monorail currently operates. This beam is mounted on top of the basic structure and would be removed in the conversion for AV technology. The aerial structures are located through the heart of the downtown CBD as well as crossing the river to reach the San Marco District.

To accommodate the AV Microtransit capabilities of operating at-grade in mixed traffic, the plan is to build vertical transition segments down to street level. This will allow same AV Microtransit vehicles operating on the aerial alignment to also serve parts of the downtown and San Marco district service area at-grade in locations where congestion would not hinder the AV operations.

Figure C-6 shows the ultimate system plan for the transit circulator system. In the graphic map, the existing ASE aerial transitway system is shown with yellow lines, and the planned new extensions that will transition to an at-grade alignment are shown with blue lines. The renderings in **Figure C-7** are typical to those being used in JTA's public presentations to illustrate the utility that advanced AV transit vehicles will have as they travel along both aerial and at grade alignments within the city streets.

Cross-Section – Flat Surface Transitway Structure



Central Station on West Bay Street in Downtown

River Place Station in San Marco District

Intermodal Facility at Rosa Parks Station

Figure C-5 Examples of Jacksonville ASE Transitway Structures Source: Google Maps, Street View

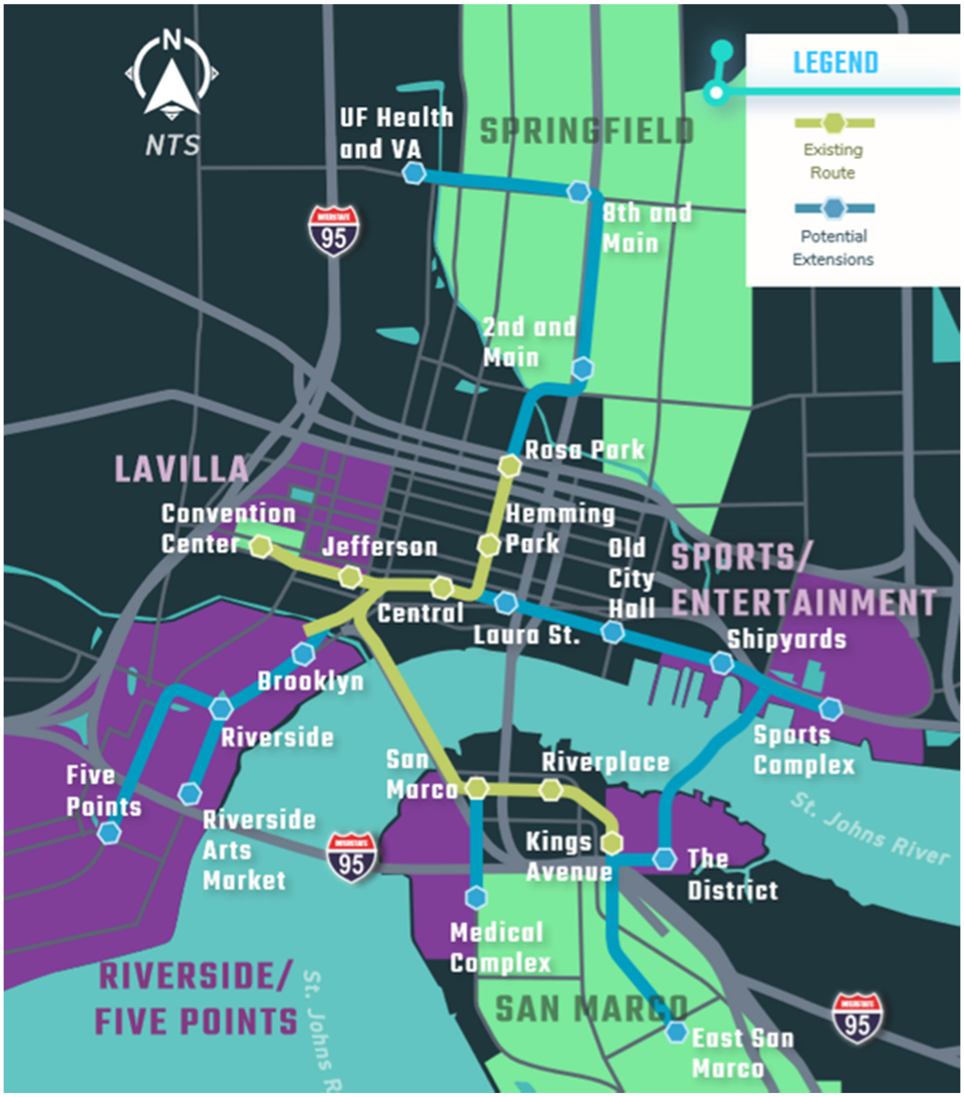


Figure C-6 JTA System Expansion Plan for the Ultimate Urban Circulator (U^2C) System

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

Figure C-7 Illustrations of U^2C Transitway Transitions from Aerial to At-Grade Segments

Appendix D

Conceptual Station Configurations Suitable for New Dynamic Operating Concepts With AV Transit Service

This is an Appendix of the Opinion Paper titled:

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

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Transit Station Facilities

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- Safe Boarding and Alighting
- Station Configurations

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- Empty Vehicle Management
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Appendix D
Conceptual Station Configurations Suitable for New Dynamic Operating Concepts With AV Transit Service

Adapted Excerpt from a Technical Paper[2] Published in the Proceedings of the ASCE Intl. Conference on Automated People Movers and Automated Transit Systems

*In this extract, the term "**AV Transit**" will refer to fully automated and connected roadway vehicles of all sizes, spanning the spectrum of full-size buses to small "Microtransit" vehicles.*

AV Transit technology will be very disruptive to both conventional fixed guideway transit systems and to "rubber-tire" roadway vehicle transit systems, as well as to their station and maintenance facilities. As shown in **Figure D-1**, when each vehicle is capable of operating autonomously from the rest of the vehicles and each vehicle can easily maneuver without physical guidance, then off-line stations will become much more cost effective since there will be no guideway switches involved in accomplishing the merge/diverge operations. This is a radical change to the equipment currently needed in today's fixed-guideway systems. Further, vehicles will be able to maneuver into independent vehicle berths – even if as shown in **Figure D-1** they enter the off-line station as a "virtual train". We believe this virtual coupling and dynamic entrainment is a fundamental component of achieving with AV Transit the level of service of today's existing fixed-guideway systems, or even greater when using more frequent smaller vehicles with higher passenger load factors.

Transit Station Facilities in the future world of AV Transit will change from the conventional fixed guideway transit station configurations. The conventional on-line station at which all trains passing through the guideway segment must stop to allow any passengers to board or alight each train will be replaced by off-line stations. The supervisory control system will inform vehicles on a moment-by-moment basis if any passengers need to board or alight the vehicle, and most vehicles (or virtual trains of vehicles) will bypass many stations without stopping. **Figure D-2 s**hows this type of off-line station configuration as it was designed for the 2005 Aichi Expo. As a result of the tremendous flexibility from the new AV/CV system equipment and facility configurations, wholly new operational paradigms will be possible.

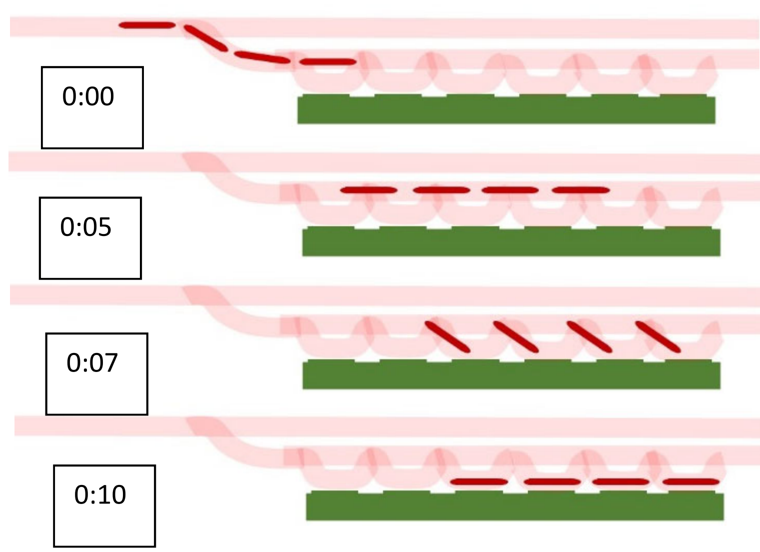

Figure D-1 Virtual Coupling and Uncoupling of Vehicles Allows Individual Vehicle Berthing in Stations

2 *Preparing for Automated Roadway Technology Impacts on Guideway Transit;* J. Sam Lott and Douglas Gettman, PhD, ASCE International Conf. on APMs and ATS; Toronto, April 20, 2016

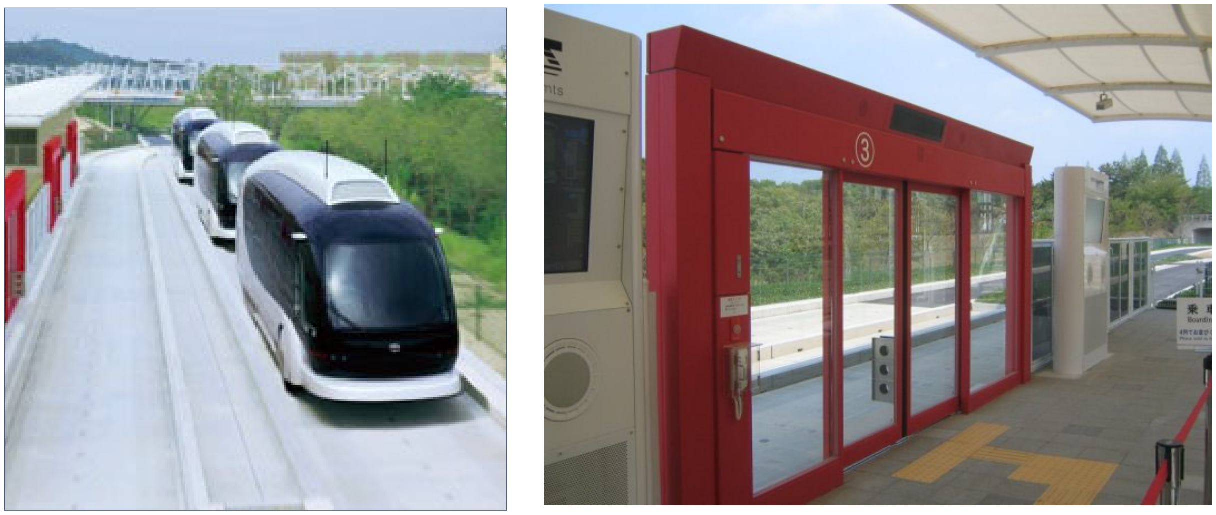

Figure D-2 Off-Line Station With Platform Edge Doors Deployed by Toyota for the Automated Buses at the 2005 Aichi Expo

Source: Wikimedia

Off Line Stations have functionality that has already been addressed in the ASCE Automated People Mover Standards. A specific section is now included in the current version of the standard (ASCE 21-13) concerning train control provisions for off-line station operations. The standard allows vehicles to enter and exit independently of other vehicles which are also occupying the same station. This flexibility (and higher cost-effectiveness) becomes complete when the removal of guideway switches is accomplished by the driverless, self-steering vehicle design.

Another change to the station configurations will be the beneficial provision of independent berths for each vehicle that stops at a given station. This configuration has been called “parallel berths”, as compared to “serial berths” in which any vehicle can only advance when the vehicle in front advances. Illustrated in **Figure D-1**, the flexibility provided by parallel berthing becomes most effective with the new operational concepts discussed in the following section.

Safe Boarding and Alighting of all passengers, especially those with disabilities, the elderly and small children is an important aspect of automated vehicles and other system equipment which involves the station and related equipment designs. It is noted that typical station equipment for AGT/APM transit systems has generally incorporated fixed platform edge partitions and automated station doors. Worldwide, several notable metro systems with automated train operations have recently begun retrofitting platform edge doors into stations originally built without these functional elements. As shown in **Figure D-2** the Toyota IMTS automated bus system at the 2005 Aichi Expo operated with buses making precise stops at each station, aligned with platform edge doors. Safety analyses and the ability of the robotic vehicles to actually monitor and safely confirm that all passengers have fully entered or exited the vehicle will determine the need for such platform edge protection in the future world of AV automated transit systems.

Station Configurations of the future will be driven by the number of guideway lanes, with the associated station footprints growing wider due to the benefits of the mainline bypass of the off-line station. This is even more significant when combined with the provision of a station passing lanes around parallel berths.

However, with the changes to operating concepts as described below, *most station lengths will shrink to a fraction of their current fixed guideway platform lengths*. The operating concept described above will allow individual vehicles and shorter groups of entrained vehicles to provide sufficient capacity to serve the same or even greater ridership demands at any given station location. When service patterns are changed to fit specific station demand patterns using fully automated trains, we have discussed in previous work that short trains on close headways are a much more efficient way to operate a transit system (Lott, Nishinaga). Stations with platforms that currently serve long trains will evolve to be configured more like those shown in **Figure D-3**.

With respect to the number of transitway lanes, the mainline lanes that bypass the off-line station could be at a different level above or below the station service lanes and platforms. This "stacking" of transitway and station levels is of course dependent on the built-environment of each station's surroundings.

Maintenance Facilities for AV automated transit systems will be configured much like conventional bus maintenance facilities, whereas the storage facilities can be located anywhere that is accessible to the route. Storage areas placed in locations away from the maintenance facility will be dynamically utilized throughout the day. Each storage facility's strategic placement and capacity will be designed to hold a portion of the operating fleet in a "hot standby" mode, until such time each vehicle is dispatched back into passenger service. And with the operating concepts described below, removal of a large number of vehicles from operation during periods when passenger demand lags will be efficient and cost effective.

There will still need to be storage in or near the maintenance facility, since each vehicle will need a pre-service checkout and test, as do automated guideway transit systems today. However, remote diagnostic checkout of all functions of vehicles will likely be possible, thus eliminating the need to size the maintenance facility storage areas to hold the whole operating fleet.

Overall, the near term planning of dedicated transitways through an urban context should begin to consider these changes to the transit facilities as radically different systems begin to be deployed. The long term adaptation of the facilities and the necessary land and 3-dimensional space that will be needed by the AV transit systems of the long term future are important to include in the near and medium term assessments of right-of-way requirements within each high density transit corridor, major activity center and business district.

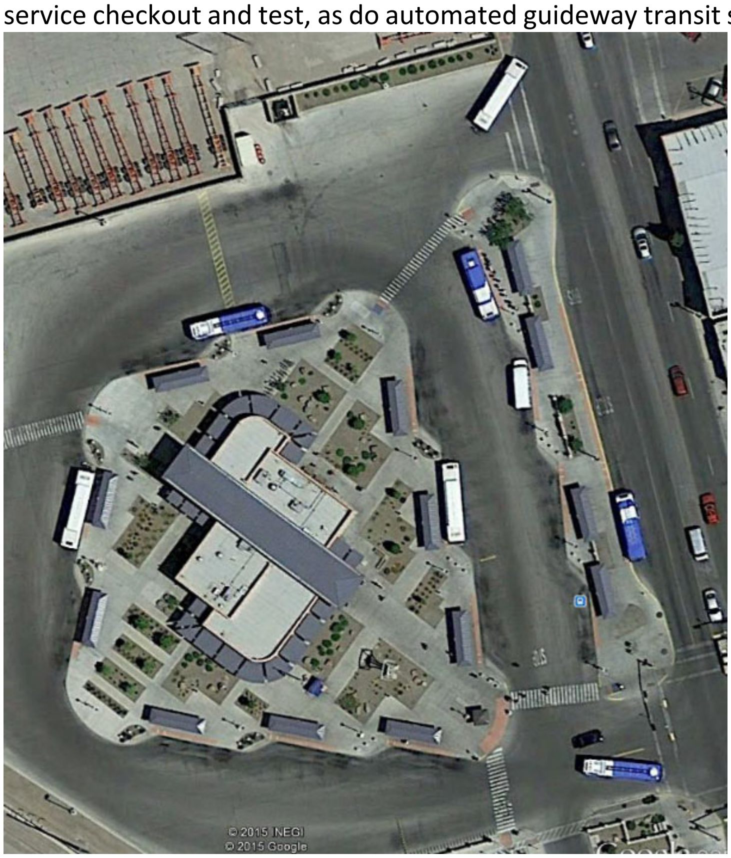

Figure D-3 Off-Line Station Configuration With Individual Vehicle Berths

Source: Google Earth, El Paso Texas

Operating Concepts will pass through a complete paradigm shift during the long term development of AV Transit applications. In fact, the flexibility of future transit systems that respond dynamically to changing demand patterns will gradually begin to replace many, if not most fixed route transit operations.

Demand-Response Dispatching has been performed for many years as part of transit bus services for rural and for transit patrons with disabilities. These demand-response services typically have required a 24-hour advance reservations, although computer aided dispatching has significantly reduced these response times utilizing internet and smartphone applications. However, in the future world when many hundreds of transit vehicles of all sizes are in service and there is a need for "real-time" dispatching, the conventional methods with a "man-in-the-loop" will be replaced by completely automated dispatching systems. As in automated fixed guideway systems, the Operations Control Center staff will act as a monitor for safety and security of existing services, will manage vehicle removal from service for repair activities, and will provide customer service responses to passenger calls from stations or within the transit vehicles. The automated supervisory control system will manage the vehicle dispatching to match the trip patterns of pick-up and drop-off for all riders, make route assignment of vehicles, and constantly communicate with all connected transit vehicles moving through the network or on-standby in storage areas.

The concepts of real-time demand-response service within automated guideway transit systems has been primarily advanced as the operational concept of automated transit network (ATN) technology (or as known for many years – a "personal" or "group" rapid transit. The ATN operational concept is based on a very rapid response of the system when a transit patron arrives at the station, either with a vehicle waiting in the station berth to which the patron is directed for boarding or by the system initiating an immediate vehicle dispatch to pick-up the patron upon their indication of their destination station – conceptually at a payment kiosk in the station or with a mobile phone.

It is likely that the typical transit services during busy times of the day will include multiple riders bound for the same destination from the same origin or with a limited number of stops for pick-up or drop-off on a common route. As a large part of typical fixed route operations used today evolved to be the direct origin-to-destination station service, transit will have travel times that approach those of the automobile.

This type of on-demand service is also being called "Mobility-on-Demand" in many current discussions within the industry, and the transport of multiple patrons between specific origins and destinations is being referred to as "shared-ride" service. Most people are familiar with the operating concept provided by the popular ride-hailing services of Lyft and Uber, which will be emulated by the automated AV Transit operational control systems. In this High Capacity Transit paper, AV Transit operations is envisioned in the form of "Microtransit" where smaller vehicles operate in real time with on-demand service between a person's origin and destination, providing very rapid response at transit pickup/drop-off locations.

Empty Vehicle Management is a corollary to real-time demand-response dispatching, since during significant periods of time throughout the 24-hour day there will typically be many fewer trip requests than during the peak periods. During those off-peak times the automated supervisory control system will send empty vehicles into storage locations placed throughout the transit network, typically near the portions of the transit network where high demands will arise during the next peak. Then as trip requests are received, the supervisory system will dispatch a nearby and available empty vehicle to pick up the transit patron(s). It is this functionality that optimizes the use of energy and vehicle-miles by automatically removing vehicles from service as ridership demand drops.

Dynamic Route Reconfiguration is envisioned to utilize the flexibility of virtual coupling to reconfigure "trains" of vehicles (i.e., platoons) as they enter or exit a station. **Figure D-4** shows a vehicle that arrived at the station as an independent vehicle (see also **Figure D-1**), and then it is automatically entrained with other vehicles by virtually coupling the new consist "on-the-fly" as the vehicles exit their station berths. This type of dynamic reconfiguration of routes and vehicle pairing provides high flexibility by which the automated supervisory control system will continually optimize operations.

Mixed Route / Dispatching Operations allows the mixed service of demand-response, fixed route, and dynamic route reconfiguration, as well as various vehicle sizes to all be served from a common station. **Figure D-4** illustrates a station with vehicles of several sizes, the smallest vehicle (black) having arrived with a single party onboard that traveled directly from an origin station within the network to this final destination station. The larger independent vehicle (green) has also arrived in a demand-response mode, but with multiple travel parties onboard. The vehicles that are entraining (i.e., platooning) (red) are all bound for a common station stop downstream in the network, but not necessarily the very next station on the line since the entrained vehicles may bypass that station stop.

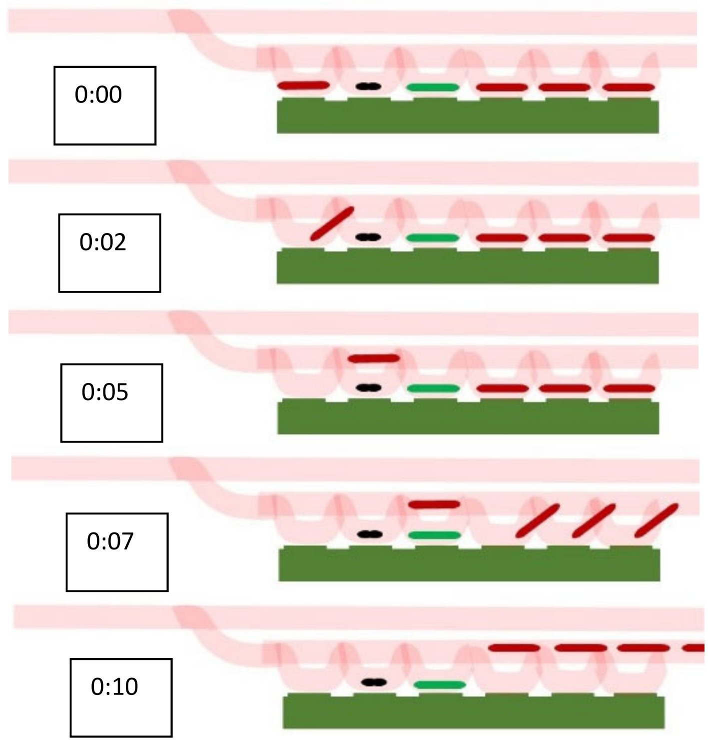

Figure D-4 Concept of Dynamic Reconfiguration of Trains

Conclusions

The advent of AV Transit technology will transform all aspects of transit service over the next few decades. The positive implications of these changes for high capacity transit service in the Houston region are of major importance, but only if the full capabilities of the operational service concepts are incorporated into the planning process for stations and storage facilities. In particular the dynamic routing changes and the automated dispatching of vehicles in response to changes in ridership trip patterns and trip-demand conditions must be included in the long range planning process if the transit facilities are not to hinder or prohibit the most beneficial capabilities of future advanced-technology transit operations.

GLOSSARY OF TERMS

ADA – Americans with Disabilities Act

ATN – automated transit network

AV **–** automated (or autonomous) roadway vehicle

CV – connected roadway vehicle

IMTS – Intelligent Multimodal Transit System, a Toyota brand name

V2I – vehicle-to-infrastructure communications

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Appendix E

Capacity Improvements to the Railroad Network Necessary for Passenger Rail Service

This is an Appendix of the Opinion Paper titled:

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

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Appendix E

Capacity Improvements to the Railroad Network Necessary for Passenger Rail Service

Houston's Railroad Legacy – Our early history is tied to the railroad network and the region's economic foundation was built upon the freight railroad industry. This cannot be lost in the current discussion of moving passengers on the railroad network, since the priority of moving adequate freight is also paramount to the region's future.

The symbol identifying the City of Houston in the official logo is a steam locomotive, and the early slogan of the City is said to have been "where 17 railroads meet the sea." So a suggestion of moving passengers on the railroad has to include discussion of not only how capacity could be added to allow passenger rail to operate, but more importantly to ensure critical freight rail operations are unimpeded over the long term.

Figure E-1 shows the railroad network as it was depicted in the 2007 TxDOT Houston Region Freight Study[3], with the color coding indicating both active railroad lines as well as abandoned/sold right-of-way (ROW). The color coding also shows the owner/operator of the different portions of the network. This railroad network is currently the third largest "terminal operation" in the U.S., with the associated massive freight train traffic activity concentrated in the very center of the Urban Core – primarily as a result of the location the Port of Houston and the petrochemical industries along the Houston Ship Channel and the northern edges of Galveston Bay. The rail lines become increasingly capacity constrained as they merge within the core of the railroad network.

Also, important to the terminal operations is the location of strategic yards within the Urban Core, although UP has recently begun a process to relocate much of their classification yard activity outside of Houston's Urban Core. However, the movement of containerized freight to and from the Port remains a large part of the activity that will always be critical to the Houston economy.

Figure E-2 shows an enlarged view of the railroad network within the Urban Core, in which most freight rail "subdivisions" (sections of the railroad network identified with certain railroad companies) are currently operating at or near their capacity. One specific line that passes through or adjacent to Uptown, Greenway Plaza, and Downtown is color-coded as a green line. This line is called the Union Pacific (UP) Terminal Subdivision, and it serves most of the trains heading to the UP yards to the north of Downtown, in the vicinity of IH-610 North Loop. UP stages many trains along the Terminal Subdivision, holding them on the mainline as they wait for clearance to progress toward the UP yards, or to continue toward the Port of Houston and its associated industries.

Railroad Network Capacity Constraints – Limitations to the existing railroad network's capacity have been well documented, such as in the 2007 TxDOT study. It reported, for example, that the Terminal Subdivision has an average freight train operating speed of about 10 mph. **Figure E-3** shows a common example of several freight trains of a length up to a mile being held for an extended period of time on the Terminal Subdivision. In this particular situation photographed several years ago, the train-hold order involved both a UP train as well as a Kansas City Southern (KCS) train also operating along the UP facility.

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[3] TxDOT Houston Region Freight Study, prepared in 2007 and led by HNTB https://ftp.dot.state.tx.us/pub/txdot-info/rail/freight/houston_study.pdf

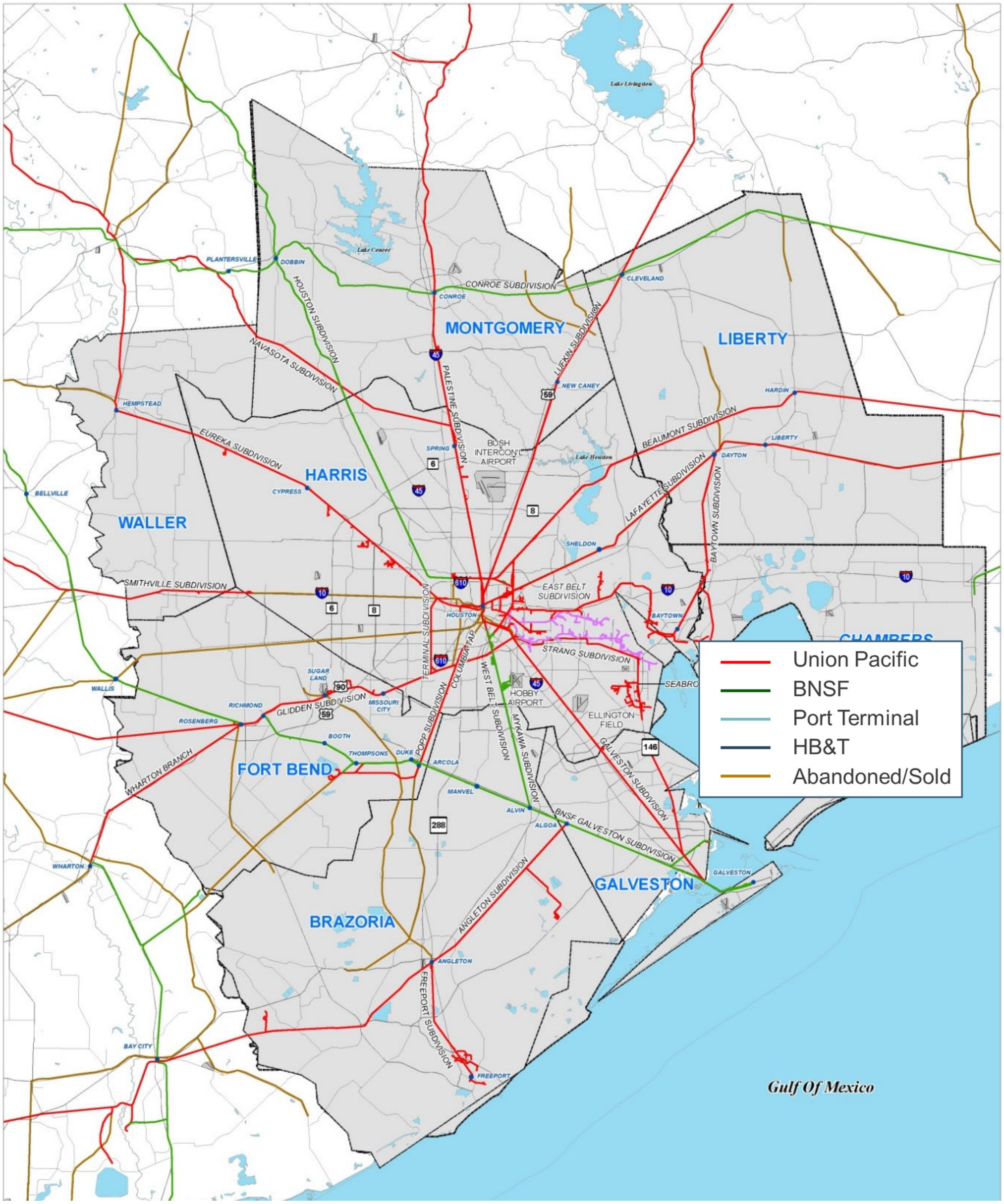

Figure E-1 Freight Railroad Network Within the Houston Region

Source: TxDOT Houston Region Freight Study, by HNTB

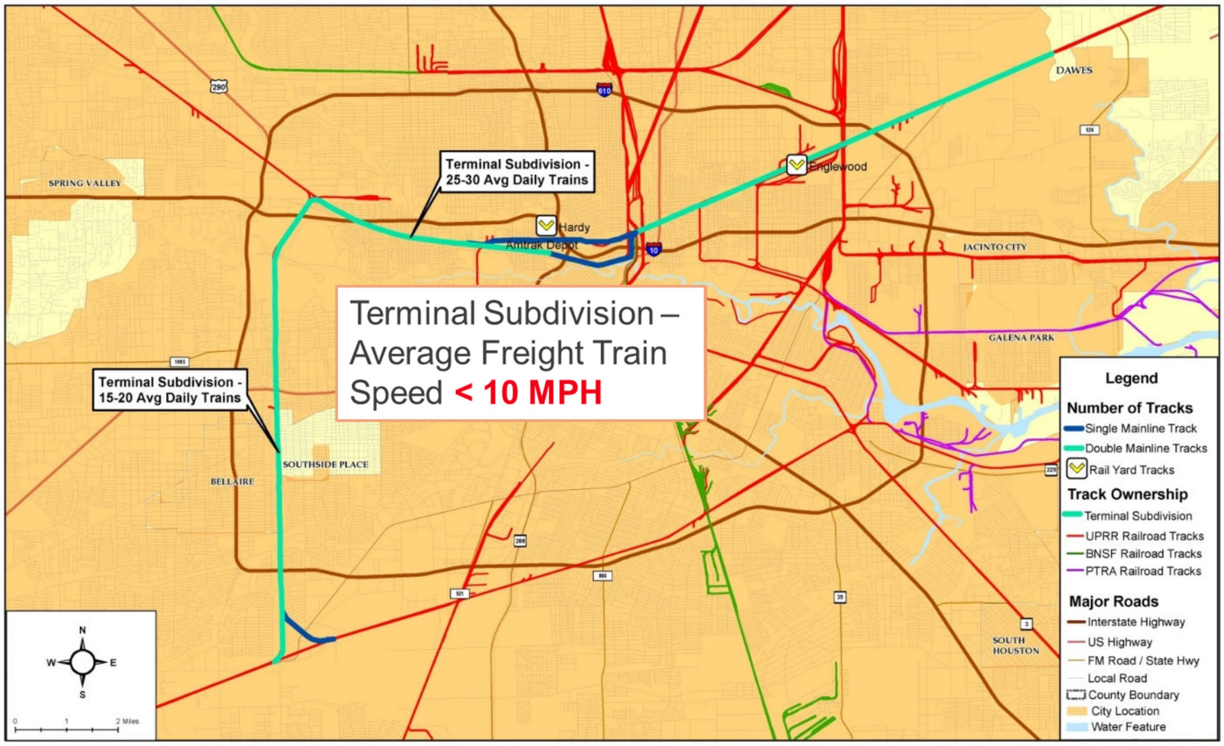

Figure E-2 Capacity Constrained Terminal Subdivision of the Freight Railroad Network

Source: 2007 TxDOT Houston Region Freight Study, by HNTB

Figure E-3 Example of Freight Trains Frequently Held on Mainline Track of the Terminal Subdivision

Photographs taken looking South from Bellaire Blvd.

This operational paradigm of holding/staging trains on the main line is the primary cause of the reported "10 mph" average operating speed along this segment of the railroad. This is one of the key challenges to providing passenger rail service along portions of the railroad network where freight trains are commonly held on the main line. Trains waiting as a result of line congestion due to capacity constraints downstream from their hold locations will only be allowed to proceed when congestion clears sufficiently for them to continue their progress through the network. These characteristics of "terminal operations" are not conducive to passenger trains moving unimpeded along a route through the same corridor when there is a requirement to provide a reliable schedule of service on reasonably close headways.

The Gulf Coast Rail District has been investigating options for providing commuter rail services within the region as part of their basic mission and charter when created by the State of Texas, and a particular corridor of interest to GCRD with respect to moving both freight and passengers is the US 90A corridor stretching from the Urban Core into Fort Bend County. GCRD studies of this particular part of the network will be discussed briefly here as a model for capacity improvements throughout the railroad network such that a high capacity freight rail corridor system could be created across the region.

Fort Bend Bypass Case Study [4] – The key design feature maintained throughout the multiple studies of a freight train bypass through Fort Bend County has been to provide for a completely grade-separated freight rail corridor having sufficient ROW width to allow a triple-tracked mainline capacity at some point in the future. This attribute defining the Fort Bend Bypass would accomplish the goal of completely separating freight train activity from surface traffic by having no at-grade roadway crossings anywhere along its length. This feature would also accomplish another attribute of creating a "quiet zone" classification along the entire length of the corridor. The financial and societal benefits of this complete grade separation from roadways would be quite substantial.

One of the examples that has been referenced in the original concept for the Bypass is the Alameda Corridor Project in Los Angeles. **Figure E-4** is a photograph of this 10 mile long, grade-separate triple-tracked corridor that connects the Downtown River Corridor (a grade separated rail corridor serving both freight and passenger rail trains) with the Port of Long Beach.

The 2015 "Phase 2" investigated alignment options completed in late 2015 for the Gulf Coast Rail District analyzed the railroad network and the growth trends of freight train activity, concluding that freight train activity will double by 2040. **Table E-1** presents the results of the freight train activity forecasts which would be accommodated within the new FBB corridor, which when triple-tracked would have a capacity of approximately 133 trains per day. Of particular importance not indicated by the table is the fact that the FBB concept would still preserve the original capacity of the UP Glidden and the BNSF Galveston Subdivisions to allow passenger trains and freight trains to continue operation along those corridors which pass through dense urban areas.

The alignment options analyzed in the Phase 2 Fort Bend Bypass Study are shown in **Figure E-5**, along with the estimated total cost for the three primary alternative alignments. Each of these options would provide sufficient capacity to serve the expected growth of freight train activity well beyond the 2040 time-frame addressed in the study.

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[4] Gulf Coast Rail District, Fort Bend Bypass Study – Phase 2; 2016, Led by R.L. Banks & Associates, with Kimley-Horn, Brown & Gay Engineers, CDS and AIA Engineers

The study assessed how the Bypass solutions could provide increases to the overall rail network capacity on the southwest side of the region. As a key objective, the Fort Bend Bypass (FBB) would provide not only capacity increases for the freight rail operations, it would also provide sufficient capacity to operate passenger rail trains on the railroad network during portions of the day when home-to-work commuter trips were the predominant activity within the region, as shown in **Figure E-6**.

10 Mile Alameda Corridor Connects the Port of Long Beach to Grade-Separated River Corridor Located Adjacent to Downtown LA

Figure E-4 Los Angeles Alameda Corridor Example

Table E-1 Projected Train Volumes: Base Case (Fort Bend County) from the GCRD 2015 Fort Bend Bypass Study, Phase 2

Railroad Lines	Train Type	Base Case (Average Trains per Day)		
		Current (2014)	Projected (2040)	Practical Capacity of Main Line Railroad, Assuming Mutliple Train Types
UP - Glidden Sub	Freight	35.3	67.5	
	Amtrak	0.9	0.9	
	Commuter	0.0	0.0	
Total UP - Glidden Sub		36.2	68.4	75.0
BNSF - Galveston Sub	Freight	14.6	28.1	30.0
UP - Popp Sub	Freight	0.9	2.0	-----

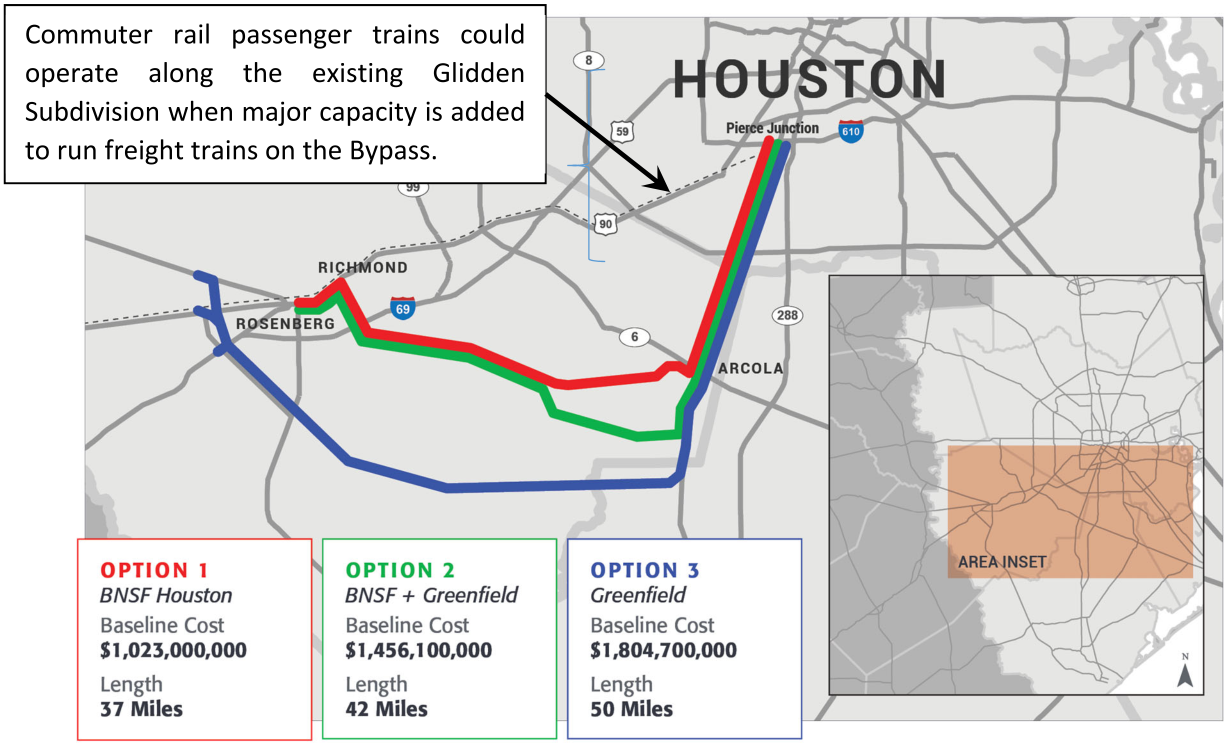


Figure E-5 Options for a Conceptual Fort Bend Freight Rail Bypass with Commuter Rail in the US 90A Travel Corridor Operating on the Existing Glidden Subdivision Railroad

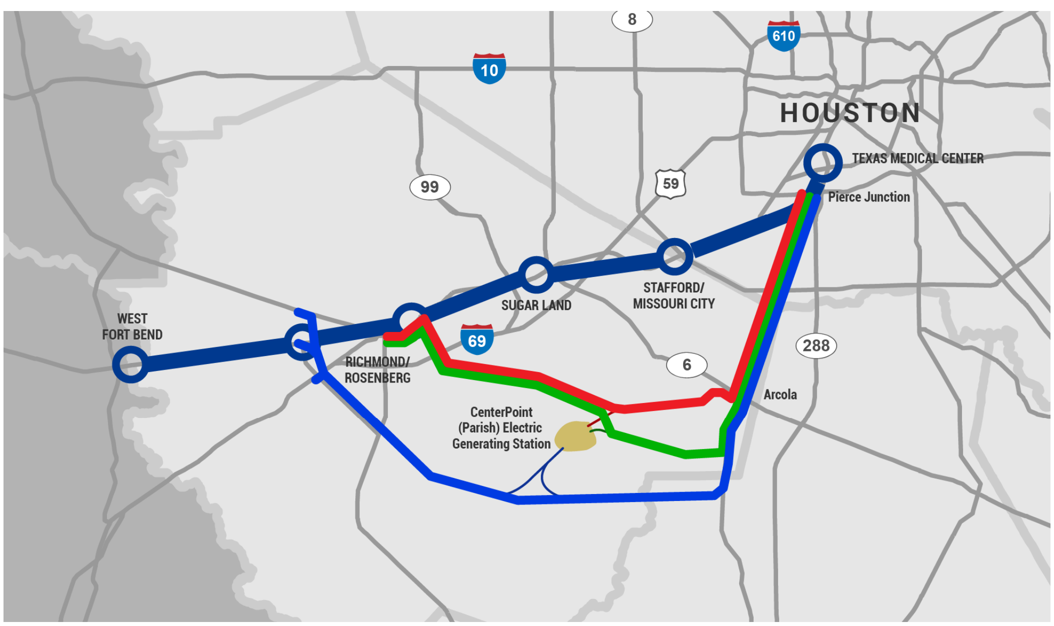


Figure E-6 Fort Bend Freight Rail Bypass plus Commuter Rail on <u>Existing</u> Glidden Subdivision ROW

One of the major motivations for GCRD to address this particular part of the rail network in early studies was because the existing Glidden Subdivision passes through the middle of Sugarland, Richmond and Rosenberg, Texas. The Glidden Subdivision is the main line railroad for UP freight trains traveling west from the region, and it passes through these important suburban areas on the southwestern edge of the Houston Region which are rapidly densifying in population. This combination results in substantial interaction between freight trains and local traffic in these areas.

Immediately prior to the Phase 2 Bypass Study, GCRD had looked at the option of creating a commuter rail line through the US 90A corridor on new ROW adjacent to the existing Glidden Subdivision as part of the Regional Commuter Rail Feasibility Study (refer to footnote 14.). The result of the alignment studies was that a major portion of the line would need to be elevated, and the estimates cost of this approach to passenger rail in the 90A corridor was in the order of $ 2.225 Billion for a 44 mile line to the western edge of Fort Bend County.

Subsequently, the when the Bypass study was performed, it used the costs from the Commuter Rail Feasibility Study with tracks on exclusive ROW option to assess the comparative costs and benefits of building the Bypass such that commuter rail passenger trains could operate on the existing double-tracked railroad track through the US 90A corridor when most freight trains shifted to the Bypass.

Also analyzed were the non-monetized impacts for factors that cannot be quantified in dollars, with both an assessment of the Public impacts as well as the Private Railroad Company impacts. **Tables E-2** and **E-3** show these comparative impacts. Although a final decision on which option to build for the Bypass alignment will involve considerations that include both the monetized and the non-monetized parameters, for purposes of this discussion the Option 3 strong advantage in non-monetized Public and Private benefits will be the basis for using the higher Option 3 capital costs in the comparison.

When the comparison of the “No Build” Case for the Fort Bend Bypass with Commuter Rail on <u>New</u> Track and <u>New</u> ROW (per the previous GCRD Commuter Rail Feasibility Study) to the GCRD FB Bypass Study’s “Build” Case with Commuter Rail operating on the Glidden Subdivision, the resulting Benefit/Cost Ratio is a strong 1.54 value. This <u>equates to a +$1 Billion Benefit for building the Bypass project</u> versus not building the Bypass and instead building the new commuter rail alignment. These costs and benefits assume the Greenfield Option 3 capital costs are used, combined with a net present value (NPV) calculation of Public and Private benefits and costs.

Equally important for the purposes of the overall benefits to the region is that the final combination of the Bypass with the existing UP Glidden Subdivision and the BNSF Galveston Subdivision (both of which would remain in service for Option 3) results in an ultimate railroad network that provides a total overall capacity two times greater than the existing railroad network.

This benefit-cost analysis derived “cost savings” for building the Bypass represents a better, and much more sustainable freight rail facility while retaining the original UP Glidden Subdivision and BNSF Galveston Subdivision as a part of the overall railroad network. Therefore, the “model” of the Fort Bend Bypass that is suggested for broader application suggests that similar benefits would be found throughout the rest of the railroad network.

Table E-2 Public Non-Monetized Impacts, 2014 – 2040 Qualitative Comparisons

Bypass Option Number	No- Build	1	2	3
Commuter Rail Operating Scenario	New ROW	UP Glidden	UP Glidden	UP Glidden
Freight Rail Operating Scenario	Galv. & Glidden	Galv. & Popp	Galv., Greenfield & Popp	Greenfield & Popp
Public Impact #1 -- Economic Growth and Investment Potential	Adequate	Good	Good	Very Good
Public Impact #2 -- Noise	Very Poor	Adequate	Adequate	Good
Public Impact #2 -- Vibration	Poor	Adequate	Adequate	Good
Public Impact #3 -- Traffic Access and Circulation	Adequate	Good	Good	Very Good

Glidden -- UPRR Glidden Subdivision; Galv. -- BNSF Galveston Subdivision; Popp -- UPRR Popp Subdivision

Very Good ● Good ◕ Adequate ◑ Poor ◔ Very Poor ○

Table E-3 Railroad Non-Monetized Impacts, 2014 – 2040

	Bypass Option		
Non-Monetized Railroad Impacts:	1	2	3
Railroad Impact #1: Ease of Access to Capacity Expansion	Very Good	Very Good	Very Good
Railroad Impact #2, Elimination of Diamond Crossing at Rosenberg	Very Good	Very Good	Good
Railroad Impact #3, Elimination of Diamond Crossing at Arcola	Very Poor	Very Good	Very Good
Railroad Impact #4: Reducing Train Delays which Result from Grade Crossing Accidents	Very Good	Very Good	Very Good
Railroad impact #5: Mitigation of Risk of Encroachment upon Railroad ROW	Poor	Poor	Adequate
Overall (Assumes equal weighting)	Adequate	Good	Good

Very Good ● Good ◕ Adequate ◑ Poor ◔ Very Poor ○

200 Mile High Capacity Freight Rail System – The studies of the proposed Fort Bend Bypass corridor as conceived gives insight into how creating a high capacity corridor system with similar features throughout would then allow greater capacity and higher freight train operating speeds throughout the region. **Figure E-7** illustrates the concept of the freight rail corridor system.

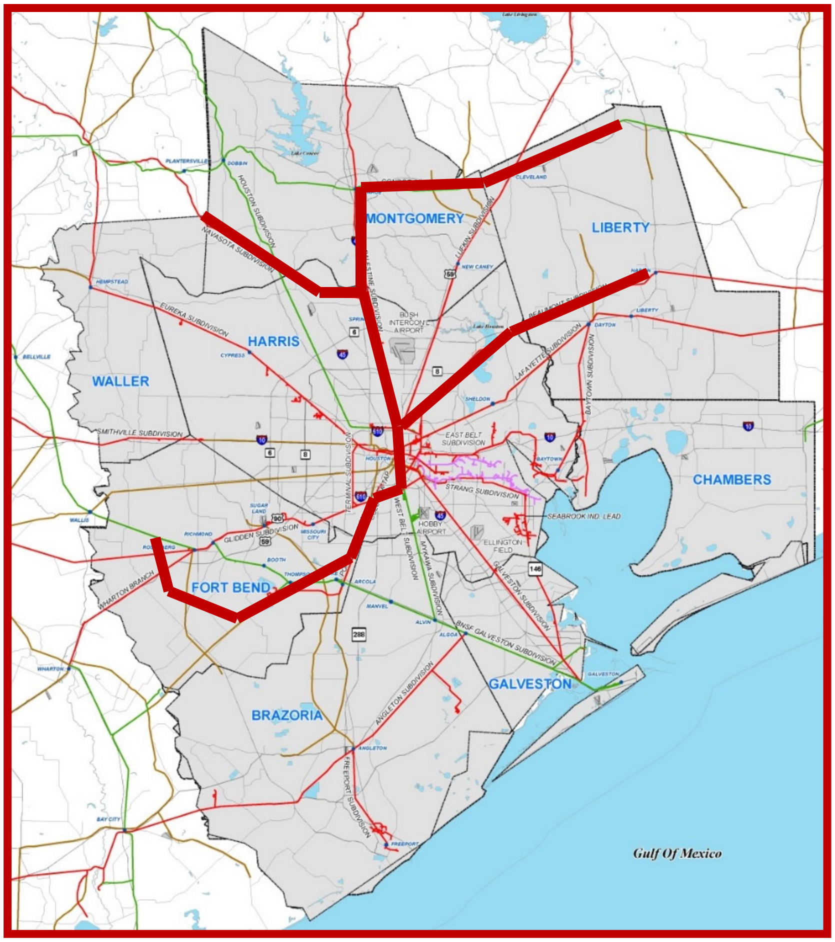


Figure E-7 Sealed Corridor System Provides for Major Growth of Freight Movement

It is important to note that – as in the case of the Fort Bend Bypass – the portions of the railroad network not included in the grade-separated corridor system would still remain active and available for moving freight trains, and in some existing travel corridors also moving passenger trains over a portion of the day. The key features of the conceptual High Capacity Freight Rail Corridor System would be:

1. ROW sufficient for triple tracked mainline facility.
2. Grade separations of all roadway crossings throughout the 200 mile system.
3. Establishment of a new Operational Paradigm where no trains are held on the Main Line for extended periods of time (see discussion below on Strategic Holding Yards).

Currently, the initial phases of what would create the proposed 200 mile corridor system are underway with the improvements now in a process of design and implement for the West Belt Subdivision, as shown in **Figure E-8**. The proposed 50 mile Fort Bend Bypass, as well as the existing 20 mile Palestine Subdivision form the initial heart of the regional High Capacity Freight Rail Corridor System.

Palestine – Existing
20 Miles
West Belt – In Design
9 Miles
Fort Bend Bypass – Concepts Studied
50 Miles

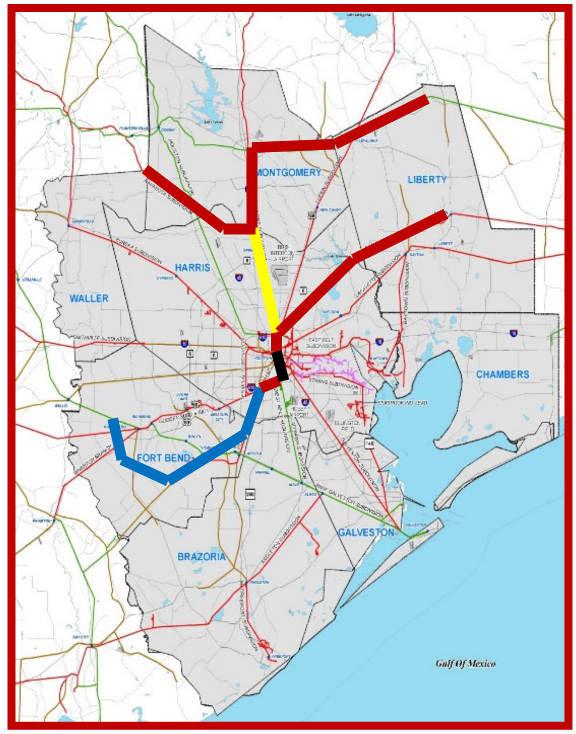


Figure E-8 Grade Separated Segments Already Conceived for This 200 Mile Corridor System

Creation of this conceptual freight system would accomplish the following benefits throughout the high capacity corridors, while also providing for sustainable growth of freight movement through the region:

1. <u>Increased capacity</u> throughout the rail network
2. <u>Quiet zone</u> throughout the corridor system length
3. <u>Higher speed operations</u> in the corridor system
4. <u>Safe and efficient</u> freight train passage, unimpeded by automobile traffic

These benefits accrue for each corridor where incrementally created, even without the entire system being fully implemented.

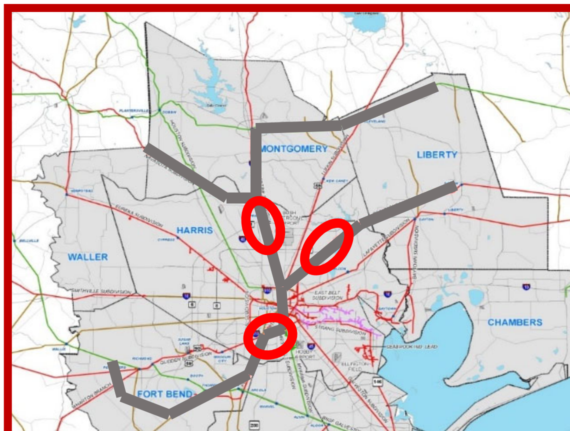


Figure E-9 Strategic Placement of Holding Yards for Temporary Train Staging Could Alleviate Operational Issues Caused by Holding Trains on the Main Line Railroad

<u>Storage Facilities for Holding Trains</u> – The mention above of the new operational paradigm in which trains are no longer held on the mainline railroad track will also require train holding facilities to be created. There are valid situations throughout any day in which access into a destination yard has been temporarily prevented. These conditions will require trains to be held somewhere, and the proposal shown in **Figure E-9** of a series of holding yards would provide these at strategic locations.

From the Freight Corridor System mainline track, the concept would provide a holding yard design configured with direct access to/from 6 to 10 sidings having sufficient length to park one mile long trains. Other features of the holding yard would be crew facilities within the holding yard, and yard locations quickly accessible to railroad operations centers allowing efficient crew changes when necessary.

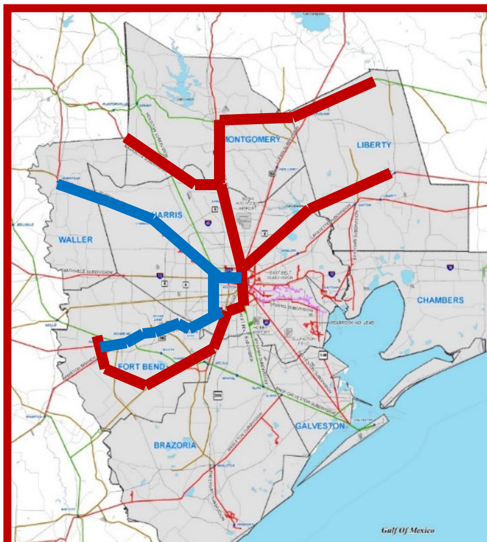


Figure E-10 Creation of a High Capacity Freight Corridor System Allows Opportunities for Passenger Rail Service in Corridors Relieved of Extensive Freight Train Operations

<u>Passenger Rail Operations</u> – Based on the conceptual High Capacity Freight Corridor System discussed above and shown in the preceding figures, most of the freight train activity during the peak travel periods of the day could be removed from the Glidden, the Terminal and the Eureka Subdivisions. This would provide opportunities to run passenger trains on the west side of the region along these particular railroad subdivisions.

Figure E-10 shows these portions of the railroad network that would become operationally suitable for passenger rail when the movement of freight trains are concentrated in the Corridor System. Freight train movements would still occur on these portions of the railroad and local clients would still be serviced along these subdivisions, but freight train movements could be restricted to occur only during off-peak times of the 24 hour day when passenger trains are inactive.

Further, passenger train service reaching well beyond the boundaries of the metropolitan region could be provided by Amtrak in a manner similar to what is described above for Southern California.

<u>Challenge of Implementing Passenger Service in Incremental Corridors</u> – The challenge comes with the fact that a regional freight rail corridor system as described above is created segment-by-segment. At a point when only the first "piece" of the Corridor system – such as the Fort Bend Bypass project – has been built, substantial capacity constraints will still exist within the existing freight terminal network (within the Urban Core). In other words, the justification of substantial passenger rail operations on the Glidden Subdivision can only be accepted by the Class One railroads when the existing freight rail network is improved enough to allow suitably free-flowing freight train operations to come off of the Bypass into the terminal portions of the network.

The terminal railroad network in the center of the region where the Bypass would connect must have existing capacity constraints mitigated either before the Bypass is built or concurrently with the Bypass project construction. This challenge inherently requires a public-private partnership (PPP) between the governmental agencies within Houston and the Class One railroad companies.

The Fort Bend Bypass project is actually a very good "prototype" project by which the region could formulate how public-private partnerships can be used to not only create the passenger rail infrastructure, but as importantly to also address capacity constraints of the existing freight rail system inside the Urban Core. With the proper mitigation of the freight network's existing capacity constraints through a an effective PPP participation, passenger service of the type described in this opinion paper can then begin to be operated through selected corridors within the railroad network.

A freight rail corridor segment that has similarities to the Fort Bend Bypass example, but which does not require the creation of a wholly new corridor where one doesn't exist today, is the Navasota Subdivision. At one time in the past, UPRR was actually considering undertaking the upgrade of freight rail capacity on the north side of the region by constructing substantial capacity improvements along the Navasota Subdivision. At that time, it was thought that operations of freight trains on the Eureka Subdivision could be somewhat curtailed south of Navasota, with most freight trains being diverted along the Navasota Sub.

The Navasota Subdivision spans east and west between the UP Eureka Subdivision at Navasota to the Palestine Subdivision running north from downtown Houston. If the Navasota Sub was upgraded to a form similar to that of the proposed Fort Bend Bypass, then it would be possible to operate passenger rail service along the Eureka Subdivision adjacent to U.S 290.

The two passenger rail lines discussed above – one running northwest through the U.S. 290 corridor on the Eureka Sub and the other line running southwest through the U.S. 90A corridor on the Glidden Sub – can be seen as blue lines in **Figure E-10** above.

<u>Freight Container Automated Transport System</u> – Finally, further reduction in freight train movement through the rail network passing through the Urban Core could be accomplished if an automated container transport system were to be created. The author has discussed this concept in past lectures and presentations through the illustration in **Figure E-11**. Creation of intermodal yards within the large land areas owned by the Class One Railroads in Fort Bend County is feasible, and one intermodal yard already exists in this area.

The concept shown of an automated transport system connecting such intermodal yards with the large Container Ports on Galveston Bay would place the container transport guideway system along the proposed green field alignment of the Fort Bend Bypass. This would allow it to be well integrated with the freight corridor's design, and the remaining length of the system could also be aligned along existing portions of the railroad network.

Figure E-12 shows transport vehicle technologies now in development which could operate along grade-separated guideways adjacent to the freight corridor system. This transport system could carry containers quietly and continuously throughout the day, and transfers of containers to truck and rail could be accomplished on the edge of the region. This concept would thereby substantially reducing the placement of trains and trucks within the heart of the region, providing more capacity on the railroad network for moving people in passenger rail trains. A similar concept could be created to serve freight intermodal yards on the East and the North sides of the region, as well.

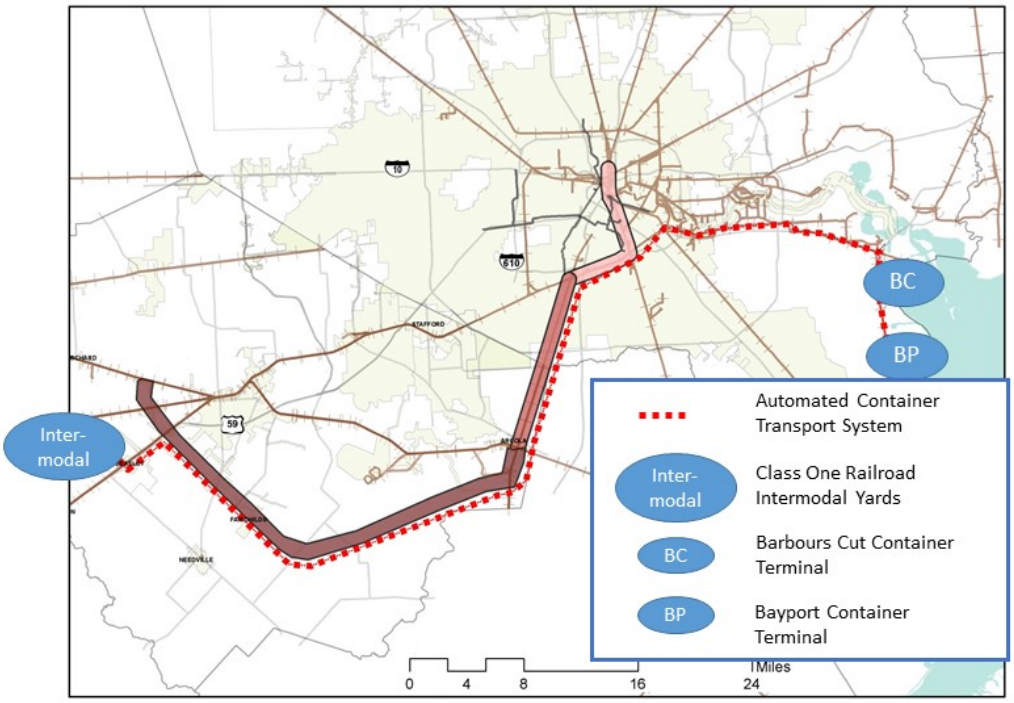


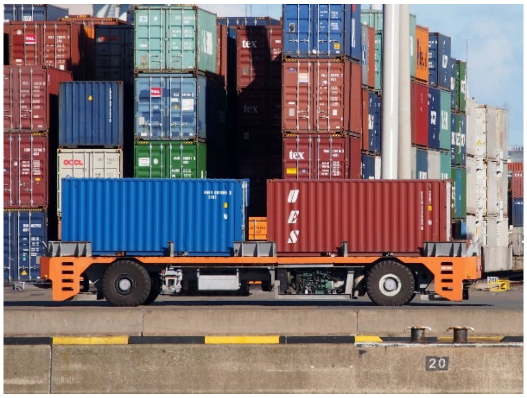
Figure E-11 An Automated Freight Container Transport System Between Intermodal Freight Yards and Port of Houston Container Terminals Would Further Reduce the Movements of Freight Trains

EMMI Maglev Container Transport System
Source: Used by Permission of EMMI Logistics Solutions LLC

Freight Shuttle System – Texas Transportation Institute
Source: https://tti.tamu.edu/freight-shuttle/

Figure E-12 New Technology Container Transport Systems are in Development Which are Designed to Travel on Elevated Guideways with Fully Automated Operations

And finally – in the spirit of advanced technology application in the coming decades – at each end of the guideway transport system AV technology could move the containers within the seaports and within the freight intermodal yards. **Figure E-13** shows photographs of automated guided vehicle (AGV) technologies currently offered in the cargo industry, which are forerunners of the AV technology application in this field.



Source: Universal Cargo Website: https://www.universalcargo.com/is-port-automation-finally-coming-to-the-u-s/ ; Posted March 29, 2016 *In Container Shipping & Transport, ILWU, International Shipping, ports*

Source: VDL Containersystemen http://www.vdlcontainersystemen.com/?news/1093402/New+product+VDL+launched+at+the+TOC+Europe.aspx#.W3obMehKg1I

Figure E-13 Automated Vehicle Technology Can Transport Containers On the Ground Within the Intermodal Yards and the Container Ports

Conclusions on Improvements to Allow Passenger Rail Services – A conceptual High Capacity Freight Rail Corridor System has been described which would dramatically increase the capacity of the railroad network within the region. In addition, concepts for moving containers with an alternative means from container trains currently operating within the heart of the region. Both of these concepts have been proposed for a number of years by the author, and this Appendix E summarizes the ideas from lectures and presentation given over more than five years' time.

The creation of a High Capacity Freight Rail Corridor System is proposed as an evolution of studies and designs which have been completed in the past or are currently underway, with a logical extension of the concept into a system throughout the whole region. In fact the first piece of the proposed corridor system already exists in the Palestine Subdivision running north from downtown, and the improvements soon to be implemented in the West Belt Subdivision will extend the grade-separated corridor through the center of the Urban Core. Adding to these sections are the capacity improvements that have been studied for the Fort Bend Bypass, providing a model in the design concepts for a triple-track configuration with suitable ROW, combined with full grade-separation of all crossing roadways.

But is essential for public investments to be made for the purpose of mitigating capacity constraints of the privately owned railroad network if passenger rail service on the railroad network is to occur. For this to be accomplished, the overall goal and purpose of these public investments along with the nature of the investments must be understood and embraced by our regional decision makers. Further, financial plans must be developed and governmental commitments must be made first in partnership with the private

Class One Railroads, before the process of passenger rail infrastructure design, construction and operations can be fully engaged.

If this public partnership with the Class One private railroads can be fully engaged, then creation of the Freight Corridor System could begin in earnest. And if the corridor concept is combined with other means to reduce freight train activity – such as provided by the conceptual container transport system – there would be sufficient capacity to operate passenger trains along portions of the existing railroad network during the peak travel periods of the day. These passenger train operations would then become an important part of the overall high capacity transit solutions needed by the Houston Region in the decades to come.