DALLAS MIDTOWN
**AUTOMATED
TRANSPORTATION
SYSTEM STUDY**

Dallas Midtown Autonomous Transportation System and Shared Parking Feasibility Study

September 2019

North Central Texas
Council of Governments

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Acknowledgements

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- Raymond Douglas Chong, Assistant Director of Transportation/City of Dallas
- Andrew Pagano, Transportation Planner/City of Dallas
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- David Perel, Managing Director, Head of Lodging Investments/Civitas Capital
- Steve Leeke, Asset Manager/2M Companies, LLC

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Autonomous Transportation System Study

Parking Study

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LEA ELLIOTT

COLEMAN ASSOCIATES

Pacheco Koch

TOOLE DESIGN

K STRATEGIES

DeAngelo Rail Services

Executive Summary

Executive Summary

Dallas Midtown is an ambitious master-planned redevelopment site envisioned as a live-work-play district with a cohesive and symbiotic mix of uses, from retail and restaurants to residences, office space, and community parks. An essential component of this vision is mobility—how people enter and move throughout the site. Rather than a traditional framework, wherein single-occupancy vehicles are the primary method of internal circulation, the creators of the Dallas Midtown vision—including the North Central Texas Council of Governments (NCTCOG), the City of Dallas, North Dallas Chamber of Commerce, and many property owners and developers—espoused a pedestrian-friendly, multimodal mobility network, where convenience and connection among uses are elevated above all.

Dallas Midtown exists in a "transit desert"; for it to reach its full potential, it must be connected to the regional transit system.

Mobility and the Dallas Midtown Vision

Without ample and active mobility options within the district, the synergy of Dallas Midtown's many proposed uses and amenities would be lost. Recognizing this, NCTCOG initiated an effort to study how best to create and support a reliable, self-operating, internal circulation system. This work, the *Autonomous Transportation System and Shared Parking Feasibility Study*, assessed the utility and technical feasibility of an autonomous transportation system to achieve larger district-wide mobility and sustainability goals; feasible recommendations for development, support, and management of the system; and projected capital and operating costs. In summary, the following findings and recommendations were developed, by topic:

Establishment of a T/PMA to execute parking and transportation management tools across the Midtown district would be necessary.

The management authority would provide incentives/assistance to businesses to help achieve the mandated reductions, an approach that has been used in other areas to promote alternative modes of transportation.

Setting prices for parking in different areas in a development considers the needs of the various user groups competing for parking spaces and entices users to park where the area needs them to park.

Permits are another pricing tool that entices users to park where they are needed to park. They provide the permit holder with some level of convenience (no need to pay a meter or a parking lot attendant/machine), and often a discounted rate, in exchange for parking in a specific area.

Other incentives and disincentives (carrots and sticks) can be offered to help encourage users to park where desired.

Trip caps, set either by parcel or by zone

Industry best practices and the use of technology can be used to manage parking for increased parking system efficiency and a better user experience.

Parking and Transportation Demand—In most cases, parking is provided on a project-by-project basis, with the amount generally based on use and density. However, this study determined that this traditional method of parking resource allocation would not contribute to, and could even damage, the mobility vision for the Dallas Midtown district. Instead, the study recommends a district-wide shared parking model wherein a number of strategically located structures, closely linked to internal circulation options and

pedestrian infrastructure, would serve the whole. This strategy would be complimented by a series of active transportation demand management initiatives to not only discourage the use of single-occupancy vehicles in traversing the site, but also encourage alternative modes of arrival to the district itself.

ATS Route Alignment and Stations—Of the various route and station alignments considered, the study recommends an elevated system based on projected implementation costs, operational reliability, pedestrian access, and a reduced potential for conflict with vehicles at-grade. Further, the study identifies six potential station locations, with the objective of evenly distributing access, enhancing pedestrian connectivity, and aligning with vehicular and transit access points to the district.

The recommended GRT vehicle and system holds 12 to 21 persons per vehicle on a dedicated route and moves over 15,000 persons each day.

ATS Vehicle Types—The study recommends a group rapid transit (GRT) technology—a vehicle resembling a small bus in outward appearance, able to run on a dedicated looped route with fixed pick-up and drop-off locations. After review of many different vehicle types, this option was selected based on feedback from stakeholders and the public, cost, and its technical performance in the following areas: level of service, technological maturity, and infrastructure requirements.
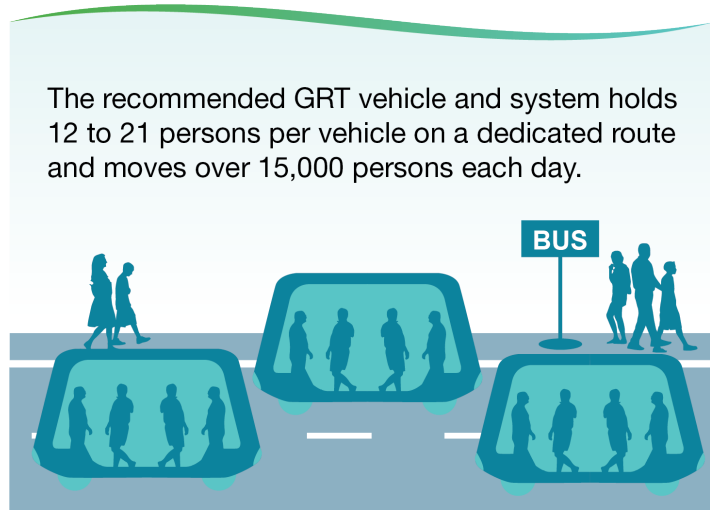
Pedestrian and Placemaking Integration—Mobility in all forms—particularly enhancement of the pedestrian environment through connection and placemaking—is an essential study component. Conceptual ATS station designs, intended to seamlessly integrate the ATS with the pedestrian framework as well as points of entry for other forms of travel (e.g., light rail and vehicle parking), have been developed for further consideration and refinement. From an aesthetic standpoint, these conceptual stations embrace modern and timeless design elements and simple, easily understood wayfinding with a focus on people over vehicles.

Unified Management—Implementation of these initiatives will require uniformity in policy and direction at the executive level. As such, the study recommends the creation of a management entity to provide leadership and oversight over shared parking and transportation demand management, the ATS, and general transportation and mobility infrastructure programs.

Blended Buildout—While full redevelopment of Dallas Midtown will occur over a period of many years, the study recommends completing buildout of the ATS route to ensure district-wide mobility equity. Conversely, the study recommends a phased buildout of shared parking structures—and the use of existing structures to meet initial demand—as development occurs.

Recommended route alignment: **Elevated 2.2-mile loop circulating the Dallas Midtown area in both directions**

Driverless, automated single-vehicle system on a dedicated, grade-separated facility. Fixed route and stops. Up to 18 vehicles circulating.

Vehicle Capacity:
12 — 21 passengers

ATS vehicle:**GRT**

Expected headways:
1 minute

System capacity: **840 persons/hour (15,120 persons/day)**

Implementation Cost

Conceptual estimate based on ROW acquisition, utility relocation, necessary traffic improvements, station and guideway construction, and vehicle procurement.

Capital Cost: Maintenance Cost:
$95M   **$1.4M/year**
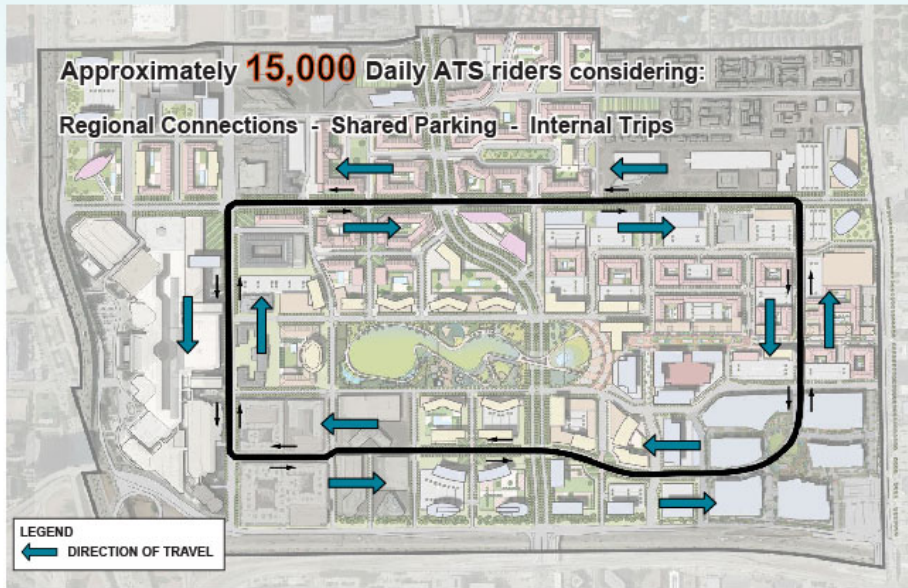
Recognizing Road Blocks

Many of the recommendations described herein diverge from traditional models, which primarily emphasize single-occupancy vehicle usage as the major—and even sole—form of transportation. While these recommendations are essential to creating the cohesive, connected, and highly cooperative mobility network imagined for Dallas Midtown, they come with their own roadblocks, albeit surmountable ones, including:

Administrative and Regulatory Changes—To implement the recommended district-wide shared parking strategy, changes to the zoning code sections governing the off-street parking provision in Dallas Midtown would be required. This, in turn, requires leadership from the City of Dallas Planning and Urban Design departments and support and approval by the Planning Commission and City Council.

Traditional Financing for New Development—Shared parking is a less conservative approach to building parking infrastructure than adhering to simple and additive use-based parking ratios; however, the parking industry, as well as many municipalities including the City of Dallas, have used shared parking publications (primarily the Urban Land Institute's 2005 *Shared Parking* handbook) for decades. As such, while this strategy may be considered modestly unorthodox and require some communication and coordination (particularly with commercial lenders), it is unlikely to significantly hinder the speed or scope of the study area's development potential.

Forecasting Autonomous Travel Demand—Autonomous systems such as the one recommended for Dallas Midtown are an emerging technology that produces a variation in scale that both provides an opportunity for adaptive use and creates challenges in demand modeling based on more traditional travel modes. A model based on transit-oriented developments was created for forecasting ATS ridership potential in Midtown; Midtown will become the first of what can be expected to be many such developments that use autonomous technologies to increase mobility within a dense, diverse district while also connecting to regional networks. Further study of the impacts of the Midtown ATS installation will be vital to providing more information for this emerging market.

Estimated Daily ATS Ridership

Approximately **15,000** Daily ATS riders considering:

Regional Connections - Shared Parking - Internal Trips
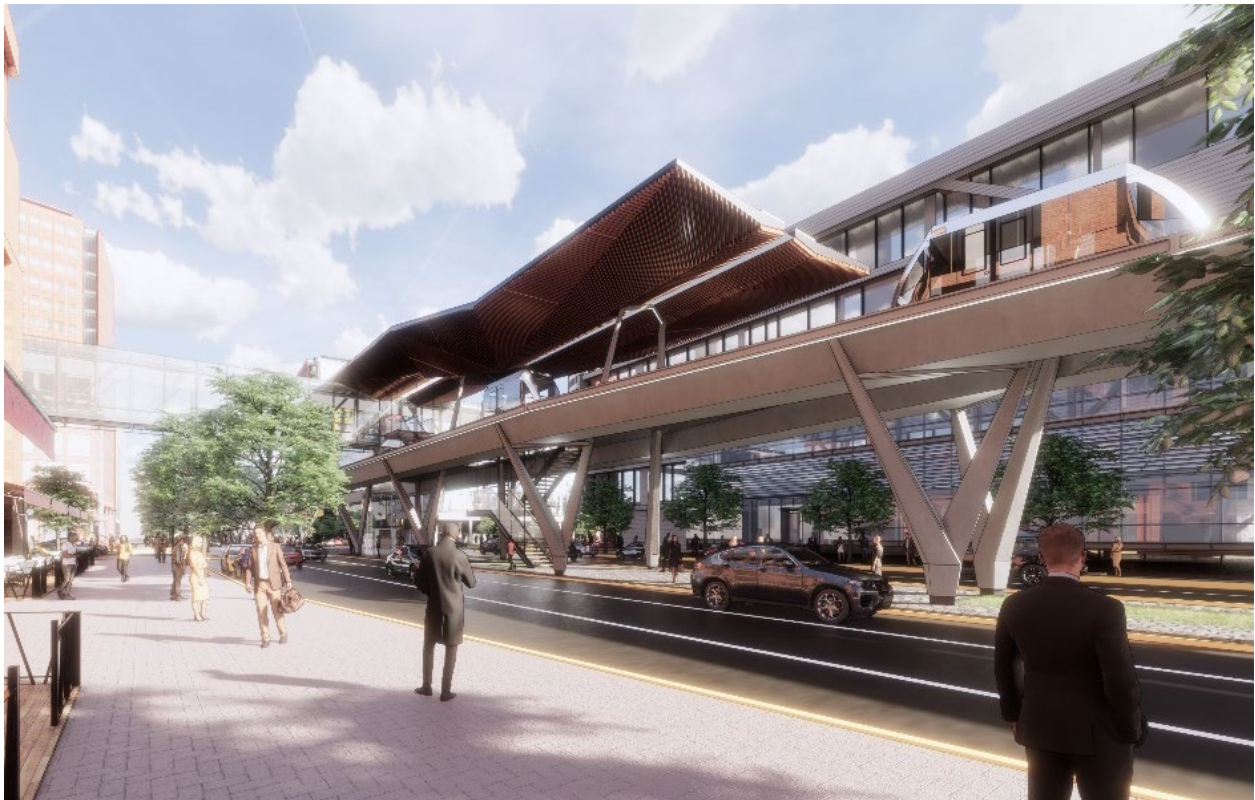
LEGEND
— DIRECTION OF TRAVEL

Next Steps

The recommendations herein form a comprehensive and coordinated solution. If deviations from the recommended solution occur, additional analysis will be required. Some of the recommendations are critical and time-sensitive to this plan advancing into detailed design and implementation and should be approached in the immediate future. These recommended next steps are summarized below and detailed in the full report.

Organization of Management Agency—Organize a coordination meeting among major partners within the first 60 days following acceptance of this report to discuss the creation of a management entity for the Dallas Midtown mobility system.

GRT Vendor Demonstration—Work with a GRT vendor to arrange a temporary vendor demonstration route in the Dallas Midtown area.

Shared Parking Implementation—Evaluate the potential for existing parking structures to accommodate shared parking. Work with developers currently in the planning stages for new developments to assess options to utilize existing parking resources to the extent possible.

Thoroughfare Adjustment—Align the existing *Thoroughfare Plan for Dallas Midtown* to accommodate ATS alignment as proposed in this report. By making some of these thoroughfare alterations before the streets are constructed in the year following the study closure, construction costs may be lower than when the parcels around it are developed and construction time would be shorter, reducing the duration of lost street access and minimizing negative impacts.

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Acronyms and Abbreviations

Acronyms and Abbreviations

%	percent
APGS	Automated Parking Guidance System
APM	Automated People Mover
ATS	Autonomous Transportation System
AV	autonomous vehicle
B	billion (dollars)
DART	Dallas Area Rapid Transit
DFW	Dallas-Fort Worth
ft	foot
FTA	Federal Transit Administration
ITE	Institute of Transportation Engineers
GRT	group rapid transit
M	million (dollars)
mph	mile(s) per hour
NCTCOG	North Central Texas Council of Governments
NDCC	North Dallas Chamber of Commerce
O&M	operations and maintenance
PRT	personal rapid transit
RFP	request for proposal
SOV	single-occupancy vehicle
SRC	study review committee
STOPS	Simplified Trips-on-Project software
T/PMA	Transportation / Parking Management Authority
ULI	Urban Land Institute

Section 1

Introduction—The Dallas Midtown District

1   Introduction—The Dallas Midtown District

1.1   History

The Dallas-Fort Worth (DFW) metroplex has the longest light-rail network in the country (Nicholson, 2016); however, as the region has grown during the age of the automobile, many residents find themselves far removed from a nearby station to reasonably access regional rail service. The "first mile/last mile" concept embraces strategies to provide initial and final links between origin and transit services (and between transit services and destination).

Recognizing the mobility potential of emerging autonomous vehicle technologies, the North Central Texas Council of Governments (NCTCOG) assembled a Regional People Mover Initiative. This initiative included an initial study, the *Last Mile Transit Connections Concept Study* (NCTCOG, 2016), that made the case for using (within a large development) autonomous vehicles (AVs) as a transit service similar to the Las Colinas Area Personal Transit System ("people mover") or Skylink terminal connection service at DFW International Airport. In addition to providing transit circulation within a development, these autonomous services could be used to connect the development to the regional transit network, thereby addressing the first mile/last mile mobility restraint.

The initial study performed by NCTCOG identified regional points of interest that lacked adequate connections to regional transit services. From these potential installation locations, Dallas Midtown was selected as the site for which a framework for implementing an autonomous transportation system (ATS) in the metroplex would be created. The implementation framework includes the goals depicted to the right. Dallas Midtown would serve as the proving grounds for measuring and mapping ATS feasibility in a mixed-use development. Creating a direct link between public and private stakeholders and study progress was essential in consensus-planning efforts to build recommendations based on analytical forecasting and public insight. To properly engage appropriate city, regional, and transit officials as well as the several developers and residential communities in the area, two methods of stakeholder interaction were held throughout the study.

Implementation Framework Goals

- Provide efficient and effective circulation within the proposed development
- Establish connections to the regional rail and transit systems
- Develop a demand forecasting tool that can be applied to future people mover locations in the region
- Perform an alternative analysis of the present and near-future state of autonomous technologies
- Provide alignment, station location, vehicle, and implementation recommendations for an ATS in Midtown

First, a study review committee (SRC) was organized by inviting all city, transit, county, and regional officials who had the Dallas Midtown area in their jurisdiction or who would be required to successfully implement an ATS in the area. Regular contact was kept with SRC members, and project updates were provided on an approximately quarterly basis. This committee included sitting city council member Lee Kleinman, Chairman of the Mobility Solutions, Infrastructure, and Sustainability Committee, as well as representatives from Dallas Area Rapid Transit (DART), the North Dallas Chamber of Commerce (NDCC), the City Planning Commission, and several City of Dallas departments, including transportation and economic development. The SRC also included private developers and agencies who owned property or held development plans in Midtown, including representatives from the Galleria Mall and the current owners of the Valley View Center mall property, Beck Ventures, and Seritage Growth Properties. A full list of the SRC members who participated in these voluntary meetings and provided vital feedback to the study is included in the acknowledgements section of this report.

Second, the study team organized three open house meetings, conducted at major milestones during the study (Figure 1-1) to provide updates to any interested individuals and to receive attendee feedback. These meetings were publicized throughout the Dallas Midtown area, and the content and reactions were included in the *Dallas Morning News*. Summaries of all three public meetings, in addition to summaries of the six SRC meetings, are available on the NCTCOG website.

Figure 1-1. Dallas Midtown Study Timeline

SPRING 2018 — Study of Dallas Midtown development and current and future state of autonomous vehicles begun

Collect data for study including Midtown Plan, roadway infrastructure, and state of ATS industry

SUMMER 2018 — Public Open House and Listening Session No. 1

Develop ATS Ridership Estimation Tool and alternative ATS recommendations

WINTER 2018 — Public Open House and Listening Session No. 2

Select recommended ATS alternative and develop implementation options

SPRING 2019 — Public Open House and Listening Session No. 3

Develop implementation options and recommendations

SPRING 2019 — Final proposed recommendations for a people mover in Dallas Midtown

1.2 History of Dallas Midtown and Proposed Development

In 2012, developer and investor firm Beck Ventures announced plans to redevelop the site of the dilapidated Valley View Center mall area (Figure 1-2). Located 10 miles north of downtown Dallas near the crossroads of two of Dallas's primary regional roadway connections, Dallas North Tollway and the I-635 LBJ Freeway, the regional mall, constructed in 1973, had demonstrated the same struggles as malls across the country and revitalization plans created an opportunity for modernization.

Figure 1-2. Valley View Mall Area, 2017

Source: Dallas Morning News, 2017

1.2.1   Building the Vision for Dallas Midtown

By 2011, with anchor Macy's already closed (Wilonsky, 2011), NDCC began efforts to attract redevelopment to the area. Beck Ventures, along with the NDCC, City of Dallas, and other developers and regional agencies, joined to develop a vision for the approximately 400-acre Valley View-Galleria area.

This district vision was illustrated in the *Valley View–Galleria Area Plan* (NDCC and City of Dallas, 2013) through a collaborative effort in planning a vibrant, mixed-use development with an approximately 20-acre park at its core. The plan in its original design aimed to add 10,000 new residential units, up 10 million square feet of new office space, and mixed retail to supplement the existing regional retail center at the Galleria Mall.

The plan update was the first of many collaborative successes by the SRC and is the basis for fitting appropriate recommendations to the Dallas Midtown area.

However, development plans changed between 2013 and 2018 when the analytical phase of this ATS commenced, causing one of the initial tasks of the study to be rationalizing the updated development plans for the district between the stakeholders and the city.

1.2.2   Updating the Development Plan

Understanding the scale of the development plan in the district was foundational to forecasting travel demand and furthermore, estimating expected travel patterns to/from and within the Dallas Midtown area.

The development plan update was an iterative process with participating members of the SRC providing a rationale for 2013 intentions versus 2018 expected outcomes. Primary developers provided updated plans with their own parcels and the City of Dallas Office of Economic Development provided updates concerning ongoing proposals and targets in the area that had been altered since 2013.

Through the first SRC update meeting as well as several break-out meetings with SRC members, a final plan revision was agreed upon by the SRC in the second update meeting (Figure 1-3). The updated land use plan on Figure 1-3 is intended for ATS ridership estimation purposes for this study only. The plan update was the first of many collaborative successes by the SRC and is the basis for fitting the

recommendations of this study to the Dallas Midtown area. The varying outline colors on Figure 1-3 represent the existing boundaries of transportation analysis zones in NCTCOG's Regional Travel Demand Model; the relevance of these boundaries will be explained further in Section 3.

By providing a rational background for what is planned in the Dallas Midtown area, the land use plan is the first step in building the model of growth for the area and forecasting potential demand for an ATS, should one be implemented. The process of converting the revised development plan into estimated ATS ridership demand is discussed in Section 3.

Figure 1-3. Revised Dallas Midtown Expected Development Plan by Land Use
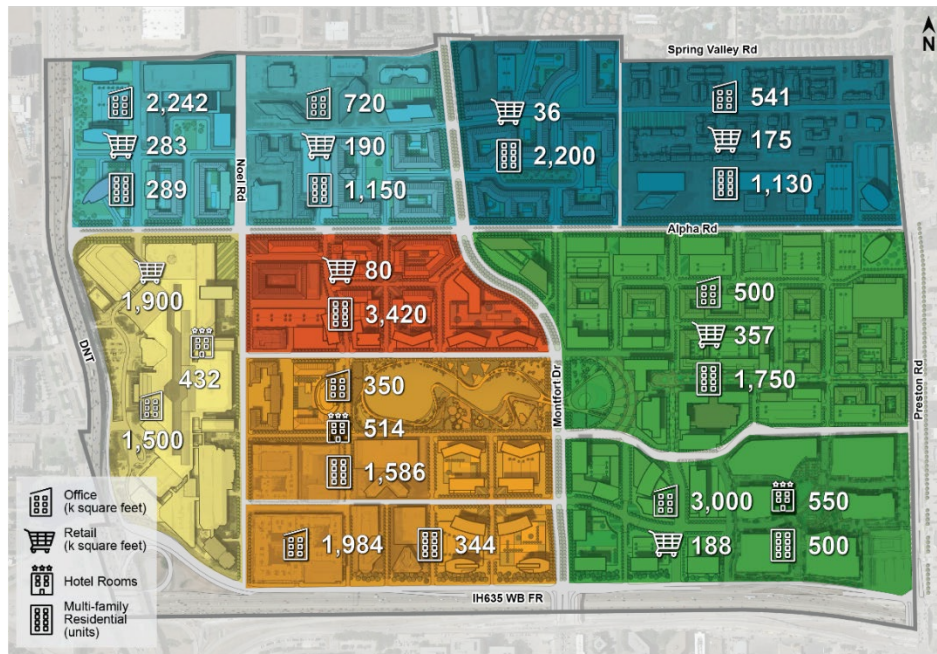
1.3   Regional Connections

The location of Dallas Midtown gives it pivotal access by car, being at the crossing of I-635 and the Dallas North Tollway; however, it sits comfortably in what City of Dallas Councilman Lee Kleinman has referred to as a "transit desert." The recent plans of a new east-west rail line, the Silver Line, running approximately 2 miles north of the Midtown area, will bring regional rail close to the development. Completing the transit perimeter around the north Dallas area, long without adequate regional connectivity, is the DART Green line 5 miles to the west and the DART Red and Blue lines, 3 and 6 miles to the east, respectively.

Dallas Midtown exists in a "transit desert"; for it to reach its full potential, it must be connected to the regional transit system.

Although some of the recommendations in this report are concentrated in reducing single-occupancy vehicle (SOV) trips within the site, connection to the regional transit system must be established for Dallas Midtown to reach its full potential. The impact to the ATS ridership estimation, as well as the connectivity that Midtown has with the metroplex, will be discussed in Section 3. Although the operational feasibility of the ATS internal to Dallas Midtown was the primary

study focus, the impact these regional transit connections would have is significant, and so the connections displayed on Figure 1-4 were assumed for study purposes. Section 5 details the rationale behind these conceptional regional transit alignments.

Figure 1-4. Potential Regional Transit Connections to DART Rail Network

Proposed Midtown ATS Regional Connectivity
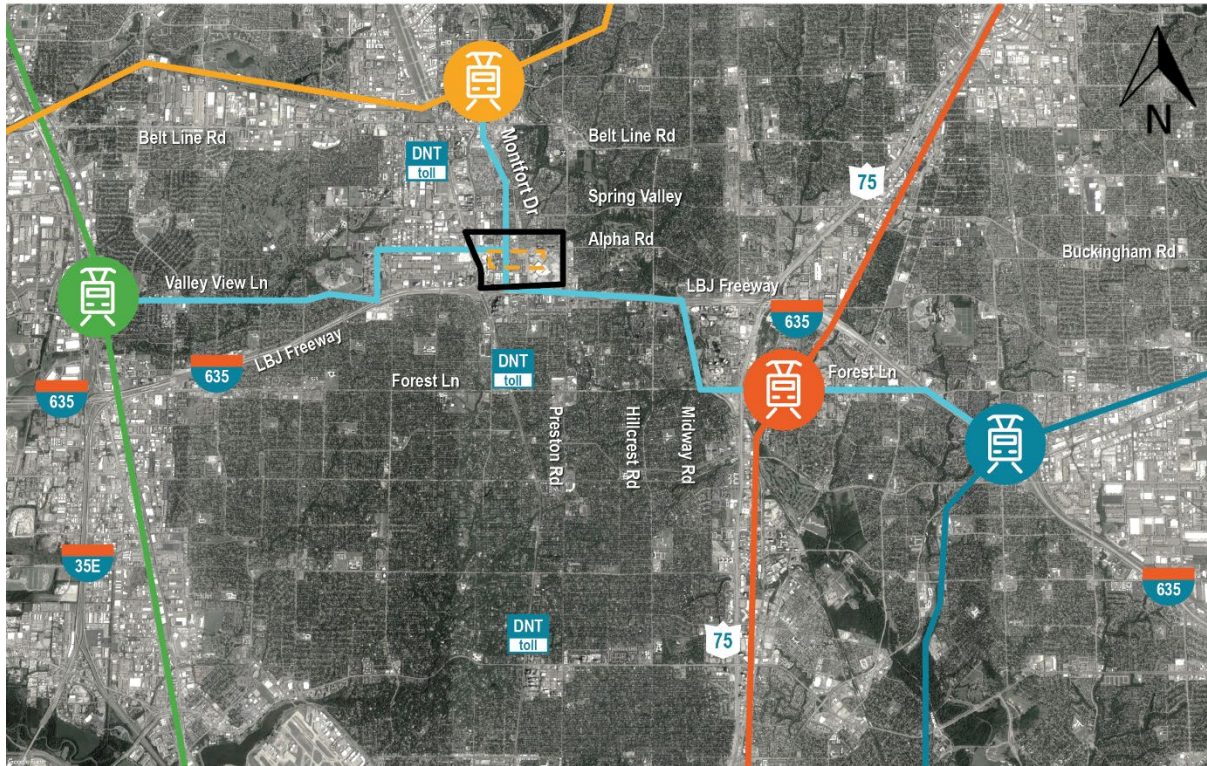
- Cotton Belt Regional Rail
- Proposed Dallas Midtown
- Dallas Midtown Area
- Blue Line LRT
- Red Line LRT
- Green Line LRT
- Proposed Regional Connections

- Knoll Trail
- LBJ/Skillman St
- Farmers Branch
- Forest Lane

Section 2
Parking Demand
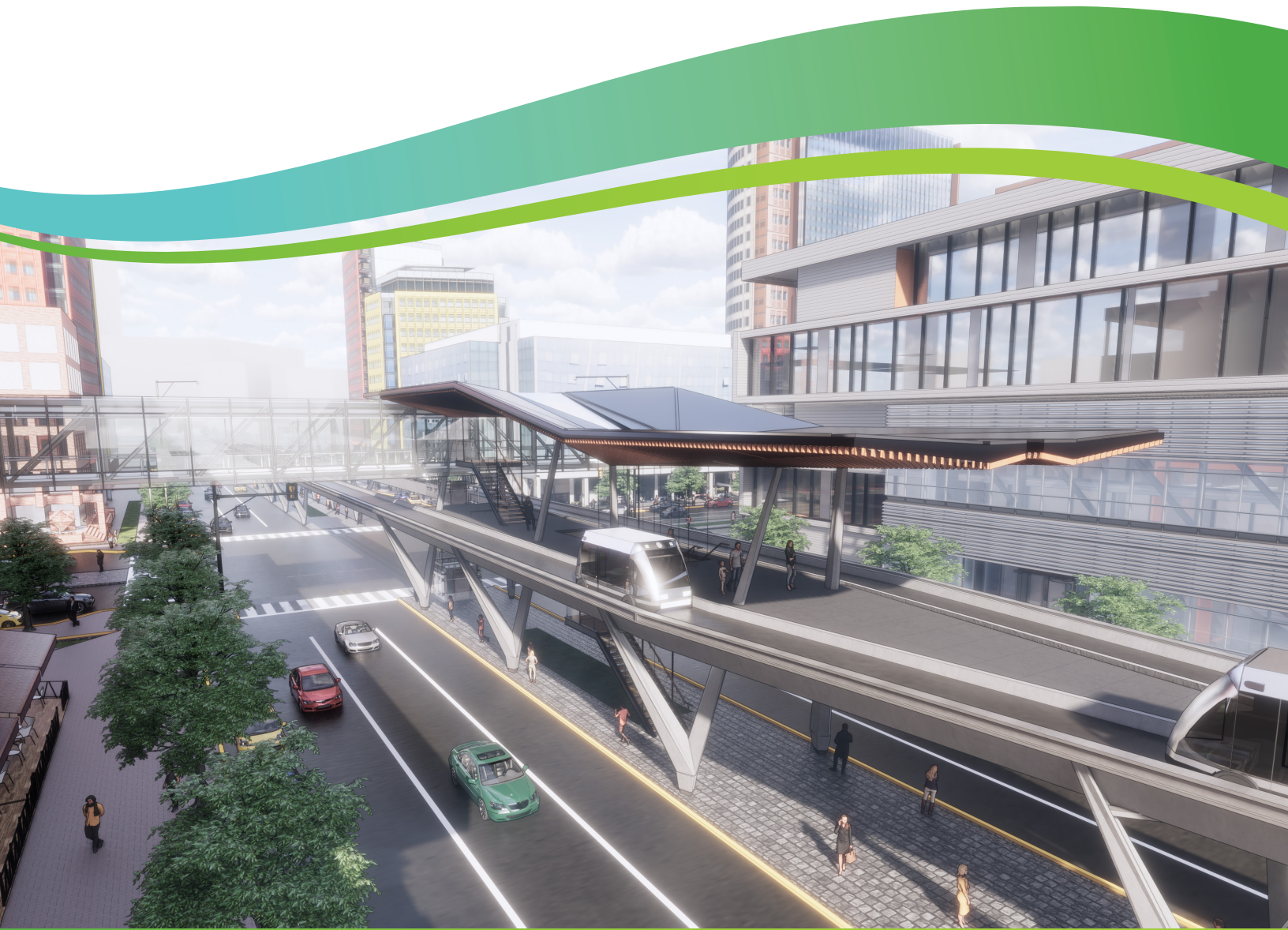
2   Parking Demand

Dallas Midtown is the site of an ambitious redevelopment plan comprising 10 distinctive mixed-use zones and a community park. The vision for this mixed-use district is to minimize internal vehicular circulation and reduce vehicular dependency for movement internal to the site. To achieve these goals, it is essential to develop a parking infrastructure strategy that encourages alternatives to SOVs when circulating through the site and helps the pedestrian-friendly environment envisioned to flourish.

2.1   Why is Parking Important to Mobility?

When each individual use provides its own parking—as is typical in many vehicle-centric mixed-use environments—users are encouraged to drive from place to place, parking their vehicle at each location. If parking were provided individually by all—or even most—of Dallas Midtown's developments, most people would exhibit this behavior and have no incentive to use the ATS as the primary choice for movement around Dallas Midtown.

A primary task was to assist NCTCOG in developing an alternative parking strategy, one that would reduce (if not eliminate) the use of private vehicles as the primary method of internal circulation around Dallas Midtown, thereby supporting mobility goals.

2.2   Existing and Projected Conditions

The parking strategy is based on a series of foundational assumptions, including the boundaries of the study area and the development projections for the study area, on an aggregate basis and by zone. In addition, existing parking assets on the site that will remain after development is completed were assessed, and these may have the potential to serve as shared parking options.

2.2.1   Dallas Midtown Study Area

Similar to the ATS ridership demand analysis, Midtown was divided into 10 distinctive zones, each with its own unique development projections as set forth by the *Valley View–Galleria Area Plan* (NDCC and City of Dallas, 2013). Figure 2-1 depicts these zone boundaries within the study area.

Figure 2-1. Dallas Midtown Study Area Zones
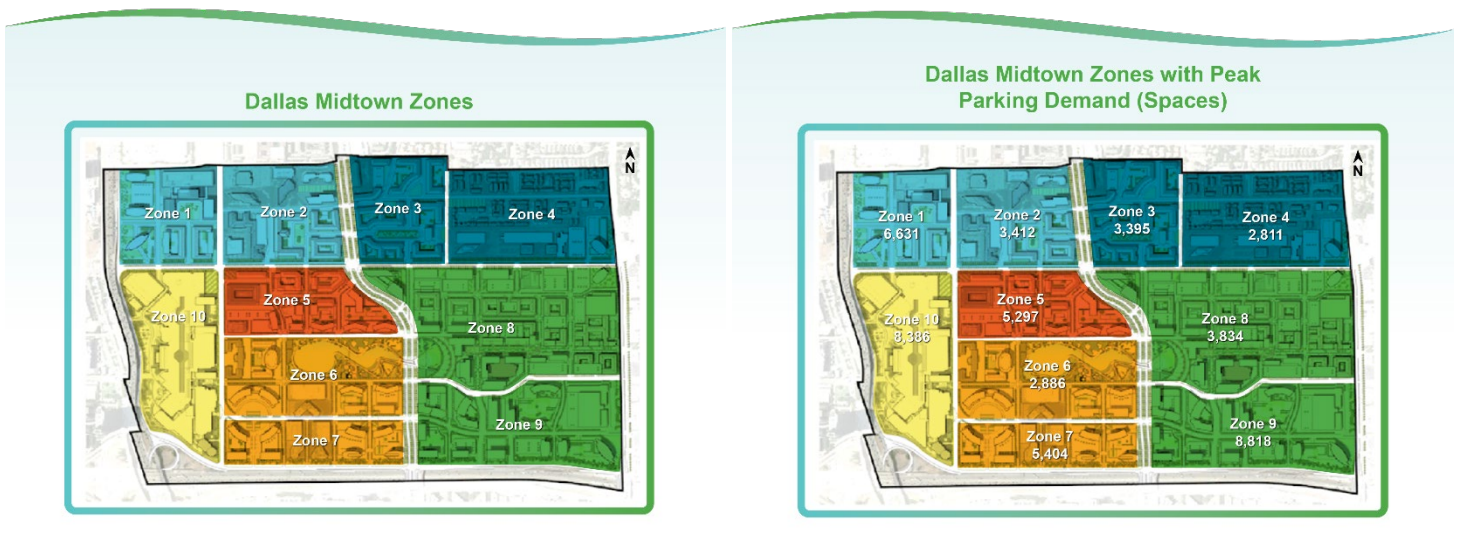
2.2.2   Development Assumptions

Table 2-1 provides an overview of development projections for each zone by use, as utilized in the parking strategy analysis contained in this report. Densities are in the thousands of square feet unless otherwise noted—all densities include both existing (and to remain) development and projected new development. Note that some assumptions were made regarding the distribution of community retail, regional retail, and restaurant development, as each of these uses has different implications from a parking standpoint. These assumptions are further discussed in Section 2.3.

Table 2-1. Dallas Midtown Development Assumptions by Zone per Valley View–Galleria Area Plan

Land Use Type	Density by Zone[a]									
	1	2	3	4	5	6	7	8	9	10
Community retail[b]	233	150	30	140	60	—	—	287	150	—
Restaurant[c]	50	40	6	35	20	—	—	70	38	—
Regional retail[d]	—	—	—	—	—	—	—	—	—	1,900
Hotel (units)	—	—	—	—	—	514	—	—	550	432
Multifamily residences (units)	289	1,150	2,200	1,130	3,420	1,586	344	1,750	500	—
Office	2,242	720	—	541	—	350	1,984	500	3,000	1,500

Source: NDCC and City of Dallas, 2013

— Land-use type not represented in specified zone.

[a] In thousands of square feet unless noted otherwise.

[b] Small-scale retail serving the local community.

[c] Dining options (assumed that 20 percent of total retail development would fall into this category, based on metrics from similar mixed-use districts).

[d] Large-scale retail serving the regional community, such as shopping malls.

2.2.3   Existing Parking to Remain

Roughly 22,000 structured and surface parking spaces are likely to remain intact within the study area at full buildout. Figure 2-2 shows the estimated number of existing parking spaces to remain in each zone once the study area has been developed, based on current development projections.

Figure 2-2. Existing Parking Projected to Remain in Dallas Midtown
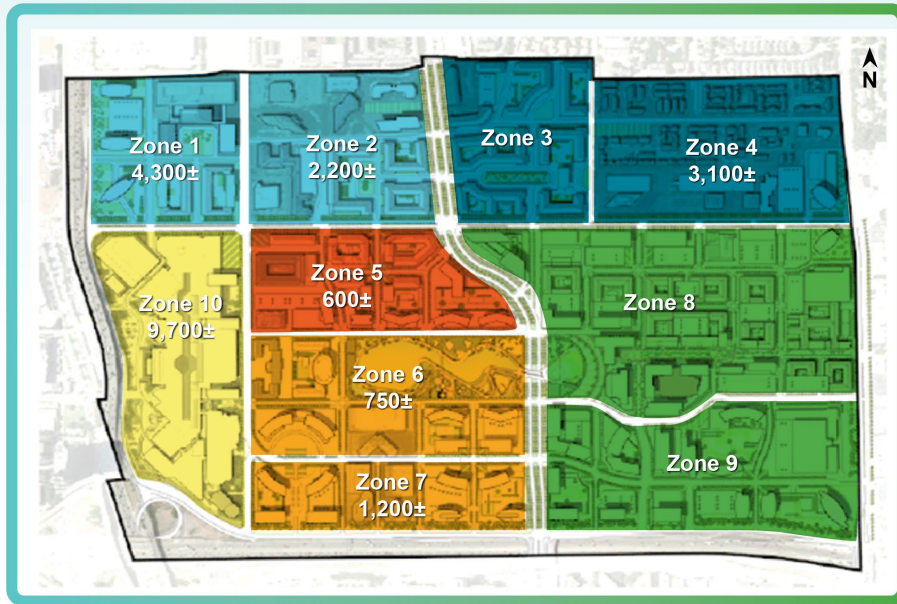
2.3   Status Quo Scenario

2.3.1   Existing Off-Street Parking Requirements (per City Regulations)

New development at Dallas Midtown must currently follow regulations set forth in the Valley View–Galleria Area Special Purpose District regulations (Planned Development 887) (Dallas City Council, 2013). These regulations reference use-based, as-of-right off-street parking requirements set forth in Chapter 51A, Article 13 of the City of Dallas codes, which developers can follow without additional documentation or effort, and a series of alternative options, which require a more vigorous process.

Assuming no changes are made to these regulations, developers will likely use the base off-street parking requirements to determine the number of new spaces they need for their development. Developers are unlikely, or at least less likely, to take advantage of reduction or variance opportunities unless they are significantly incentivized, or even mandated, to do so. As such, the analysis of a status quo scenario in which existing regulations are followed focuses on the use-based, as-of-right requirements rather than assuming a significant portion of new development will incorporate existing reduction opportunities. However, the nature and parameters of these opportunities are outlined in this section and explored further in Section 7.

A status quo scenario—in which existing parking regulations are followed—would require an additional 3 million square feet of land dedicated solely to parking.

2.3.2 Base Off-Street Parking Requirements

As is typical for the vast majority of municipalities across the U.S., the City of Dallas has embraced a use-based methodology to dictate off-street parking provisions for new development, wherein each use type is assigned a required parking ratio. Table 2-2 shows the applicable requirements for the uses included in the Dallas Midtown development vision.

Table 2-2. Existing Base Parking Requirements

Use	Number of Required Parking Spaces [a]
Community retail	4
Restaurant	10
Regional retail	4
Hotel	1.25 spaces per room plus 5 per 1,000 square feet of meeting space
Multifamily residence	1.15–2.00 spaces per unit, depending on number of bedrooms
Office	3

[a] In thousands of square feet unless noted otherwise.

The following are key characteristics of the current base parking requirements for the study area:

- **Use-based** requirements are those based solely on the development's use and do not include any immediate nuance or flexibility to adjust parking provisions based on other factors, like proximity to transit.

- **Additive** requirements are those for mixed-use developments, meaning that developments with multiple uses, such as a residential building with a ground-floor office component, would provide parking based on the sum of the requirements for both uses.

- **Individual** requirements are those applicable to each individual development project and offer no opportunity to provide parking across multiple projects.

2.3.3 Likely Outcomes of Status Quo Scenario

Roughly 68,000 spaces are needed to fulfill the base parking requirements for full buildout at Dallas Midtown as currently conceptualized (Table 2-2).

Figure 2-3 depicts the required parking spaces by zone.

Figure 2-3. Parking by Zone, Status Quo Scenario
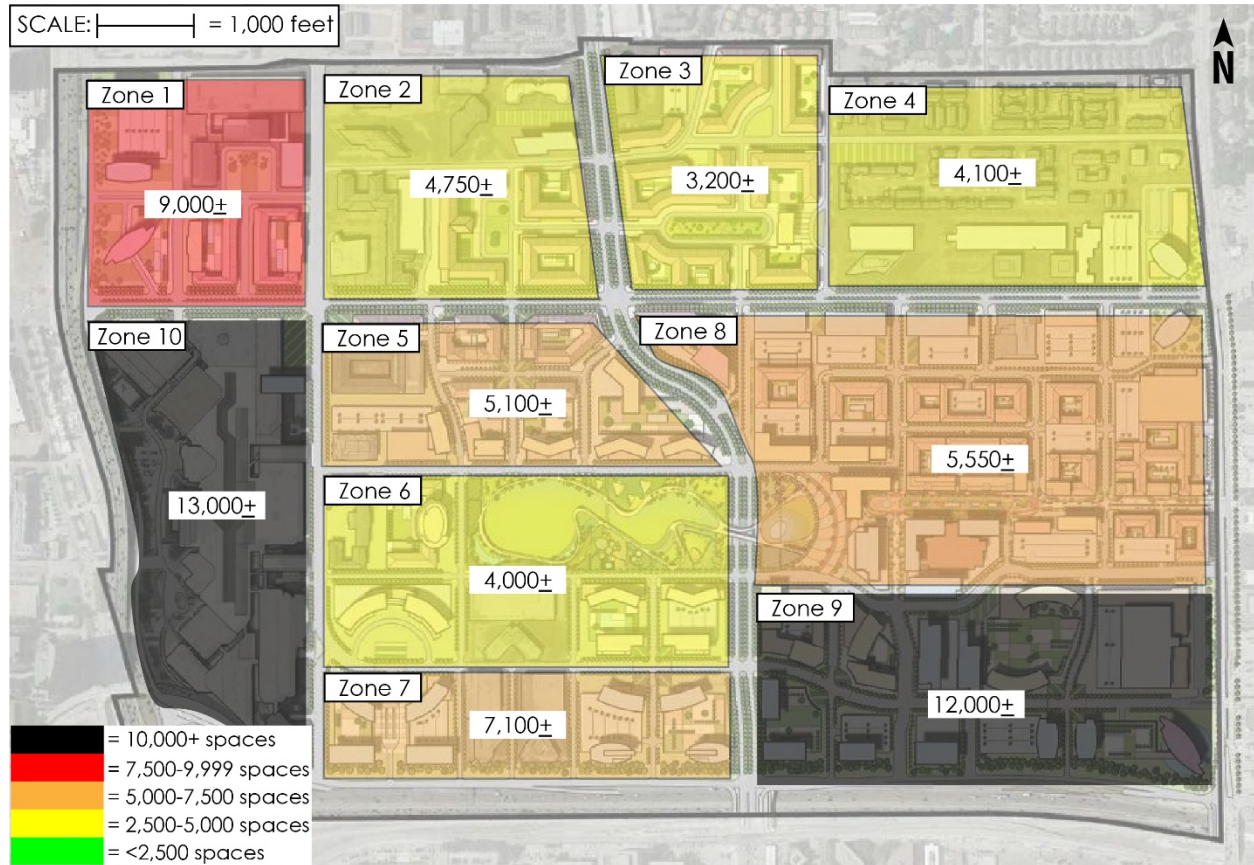
This calculation assumes that developers utilize the base parking requirements to determine how many off-street parking spaces they will build, and build parking for their individual sites, as dictated by the code requirements. Further, this calculation assumes fewer than 10 percent of new developments will deviate from the standard base parking requirements.

2.3.3.1 Benefits

The status quo scenario would yield several benefits; however, they are primarily administrative, and do not generally support the ultimate goal of leveraging parking as a support system for the overall mobility network. Likely benefits are detailed in the image to the right.

Ordinance changes unnecessary: Assumes adherence to the base parking requirements set forth in the existing planned development for Dallas Midtown.

Conservative and standard approach: Avoids pushback from government and financing entities.

Minimal coordination: Avoids the need for extensive coordination and agreement between government authorities and developers.

2.3.3.2 Challenges

The main challenges with the status quo scenario are related to its lack of inherent support for the ATS. Because parking under this scenario would be project based and not district-wide, each project's demand would be met internally, thereby encouraging drivers to drive from one project's parking resource to another's. Likely challenges include the following:

- **Effective elimination of internal ATS ridership:** Because individual projects would provide their own parking under this scenario, use of the ATS as an internal circulator would no longer be a necessity. As such, internal demand for the ATS will be effectively eliminated, as derivation of ridership will rely solely on the personal whims and desires of riders who prefer to take the ATS rather than drive from destination to destination.

- **Capital cost:** In this scenario, where parking is a project-based resource rather than a shared resource, and the base parking requirements are followed, more parking is needed than would be in a shared scenario (68,000 spaces). This results in a projected capital cost of $1.9 billion, excluding land acquisition costs.

- **Square footage dedicated to parking:** Compared to the recommended strategy, this scenario requires an additional 3 million square feet of land dedicated to parking.

2.3.4 Alternative Options Offered in Existing Off-Street Parking Requirements

As stated, the existing regulations do offer opportunities to apply for reductions from the base off-street parking requirements in Table 2-2. These opportunities are discussed herein and further explored in Section 7.

2.3.4.1 Prescribed Reductions

Table 2-3 summarizes the available opportunities for static reductions, for which all projects can receive a predetermined reduction. The maximum cumulative reduction allowed under Chapter 51A, Article 13 is 50 percent of the base requirement.

Benefits of the recommended parking strategy include:

- Reduced number of single-occupancy vehicle trips
- More efficient use of land
- Estimated savings of $940 million in parking construction costs

Table 2-3. Static Off-Street Parking Reductions Permitted under Chapter 51A, Article 13

Reduction Type	Description	Maximum Reduction Permitted
Access to rail/bus/trolley transit	Reduction for sites within a maximum 2,640 feet of a rail, bus, or trolley transit station	Up to 25% depending on proximity to station
Affordable housing	Reduction in number of spaces required per affordable housing unit developed, if unit is within 1,320 feet of an alternate transportation option	50%
Employer transportation demand management	Reduction in number of spaces for uses that institute and enforce a transportation demand management program	25%

Table 2-3. Static Off-Street Parking Reductions Permitted under Chapter 51A, Article 13

Reduction Type	Description	Maximum Reduction Permitted
Underground office parking	Reduction for office uses where parking is built underground	33%
Tree preservation	Reduction for developments wherein protected trees are maintained and preserved; 1 space reduction per protected tree	5% or 1 space, whichever is greater

2.3.4.2 Shared Parking (Project-Based)

The code also allows for developers of mixed-use projects to submit for reductions above and beyond the allowed cumulative 50 percent by using the Urban Land Institute's (ULI) 2005 shared parking model to determine their own project's parking needs, assuming shared parking resources across the project's multiple uses. Note this shared parking option is project based—meaning efficiencies from sharing resources are realized only by a single project—rather than district-based, where multiple projects would share parking resources.

2.4   Alternative Parking Strategy

District-wide shared parking is recommended as an alternative strategy to leverage parking as a tool to support, rather than discourage, use of the ATS. This strategy comprises two key components:

- Projecting actual parking demand generated by the proposed uses at the redeveloped Dallas Midtown site by zone, assuming that parking is a primarily shared resource.

- Identifying areas well suited for shared parking structures/facilities.

Beyond the principal goal of leveraging parking infrastructure to support the ATS, this strategy can achieve the following:

- **Anticipate and accommodate the future of parking and transportation behavior:** The alternative strategy incorporates various transportation mode split targets to create a more realistic projection of what parking demand will look like for the future of Dallas Midtown as transportation behaviors change. These targets are derived from assumptions regarding infrastructure investment, expansion of transportation network companies, and generally increased connectivity over the development period, from inception to full buildout.

- **Right-size parking assets to avoid building too much or too little parking:** The alternative strategy recommends parking supply based on projected demand instead of requirement, thereby ensuring parking infrastructure is a responsive, well-used resource.

- **Integrate parking, multimodal transportation, and community elements:** Parking as a shared resource across multiple developments means the design and location of parking infrastructure can accommodate the needs of many different users, rather than only one type. This strategy offers opportunities to create shared, centrally located parking resources serving as a hub and point of entry for multiple transportation modes.

2.4.1 Shared Parking Demand

A shared parking analysis was prepared using the shared parking model for the Midtown area to supplement the zone-by-zone models developed using the ULI 2005 shared parking model. Two shared parking models were constructed:

- Conventional model: The conventional model takes a conservative approach to projected driving behaviors by assuming that the majority of users will still use a SOV to arrive at Dallas Midtown. In addition, this model assumes a lower "captive" or walk-in ratio among complementary uses (such as office workers eating at local restaurants and residents shopping at local retail). A full set of assumptions is provided in Appendix D.

- Recommended model: The recommended model uses lower driving ratios, operating under the assumption that the multimodal vision for Dallas Midtown is achieved through the recommended strategies included in this document. In addition, this model assumes higher captive or walk-in ratios among complementary uses, projecting a more cohesive, mobility-friendly fabric throughout the district. A full set of assumptions is provided in Appendix D.

2.4.2 Conventional Model Output

Table 2-4 shows the results of the conventional shared parking model for the Midtown area. The output shown in this analysis is for the weekday as the large amount of office uses planned in Midtown result in a weekday daytime peak. Given the scale of office development, the Midtown development could likely support additional night and weekend uses, including special events at the park, as parking facilities dominated by office users would generate peak parking demand at different times.

Table 2-4. Dallas Midtown Conventional Shared Parking Model Output (Weekday)

	Weekday					
	Base[a]	Month Adjustment[b]	Peak Hour Adjustment[c]	Non Captive[d]	Drive Ratio[e]	Demand December
Land Use	Demand	December	2:00 PM	Daytime	Daytime	2:00 PM
Retail–Customer	3,045	100%	100%	50%	95%	1,446
Retail–Employee	735	100%	100%	98%	87%	624
Super Regional Shopping Center–Customer	6,080	100%	100%	50%	95%	2,888
Super Regional Shopping Center–Employee	1,520	100%	100%	98%	87%	1,290
Restaurant–Customer	3,302	100%	90%	0%	95%	0
Restaurant–Employee	583	100%	95%	98%	87%	470
Hotel–Guest	1,496	67%	60%	100%	66%	397
Hotel–Employee	374	100%	100%	98%	87%	318
Residential Guest	1,237	100%	20%	100%	95%	235
Residential Reserved	18,553	100%	100%	100%	100%	18,553
Residential Unreserved	0	100%	70%	100%	100%	0
Office–Guest	2,167	100%	100%	85%	100%	1,842

Table 2-4. Dallas Midtown Conventional Shared Parking Model Output (Weekday)

	Weekday					
	Base[a]	Month Adjustment[b]	Peak Hour Adjustment[c]	Non Captive[d]	Drive Ratio[e]	Demand December
Land Use	Demand	December	2:00 PM	Daytime	Daytime	2:00 PM
Office–Employee	28,176	100%	100%	99%	92%	25,738
Subtotal Customer/Guest	17,327	-	-	-	-	6,808
Subtotal Employee/Resident	31,388	-	-	-	-	28,440
Subtotal Reserved Resident	18,553	-	-	-	-	18,553
Total Parking Spaces Required	**67,268**	**-**				**53,801**
					% Reduction	20

[a] **Base ratio** refers to parking demand, assuming a suburban site where 100 percent of customers/employees drive to the site and that all uses provide parking separately.

[b] **Month adjustment** accounts for the seasonal peaks of each land use.

[c] **Peak-hour adjustment** accounts for the hourly usage pattern of each land use.

[d] **Non-captive** accounts for users already parked onsite for another use (for example, a guest at a hotel with a car patronizing a restaurant nearby while remaining parked at the hotel).

[e] **Drive ratio** refers to the percentage of customers/employees projected to drive to the use and accounts for carpooling and alternative modes of transportation.

Table 2-5 shows the results of the base shared parking model by zone and includes an estimate of existing parking in each zone that will remain in place for the foreseeable future. The surplus/deficit line shows the additional parking supply that would be necessary to support the buildout of the updated Midtown development plan, assuming shared parking principles and agreements are in effect.

Table 2-5. Dallas Midtown Conventional Shared Parking Model Output by Zone (Weekday)

Distribution of Weekday Demand by Zone											
	Zones										
December 2:00 PM	1	2	3	4	5	6	7	8	9	10	Total
Retail–Customer	320	207	41	193	83	0	0	395	207	0	1,446
Retail–Employee	138	89	18	83	36	0	0	171	89	0	624
Super Regional Shopping Center–Customer	0	0	0	0	0	0	0	0	0	2,888	2,888
Super Regional Shopping Center–Employee	0	0	0	0	0	0	0	0	0	1,290	1,290
Restaurant–Customer	0	0	0	0	0	0	0	0	0	0	0

Table 2-5. Dallas Midtown Conventional Shared Parking Model Output by Zone (Weekday)

					Distribution of Weekday Demand by Zone						
					Zones						
December 2:00 PM	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Restaurant–Employee	90	73	11	64	36	0	0	127	69	0	470
Hotel–Guest	0	0	0	0	0	136	0	0	146	115	397
Hotel–Employee	0	0	0	0	0	109	0	0	117	92	318
Residential Guest	6	22	42	21	65	30	7	33	9	0	235
Residential Reserved	433	1,725	3,300	1,695	5,130	2,379	516	2,625	750	0	18,553
Residential Unreserved	0	0	0	0	0	0	0	0	0	0	0
Office–Guest	382	122	0	92	0	59	337	85	510	255	1,842
Office–Employee	5,324	1,710	0	1,285	0	831	4,712	1,188	7,125	3,563	25,738
Subtotal Customer/Guest	708	351	83	306	148	225	344	513	872	3,258	6,808
Subtotal Employee/ Resident	5,552	1,872	29	1,432	72	940	4,712	1,486	7,400	4,945	28,440
Subtotal Reserved Resident	433	1,725	3,300	1,695	5,130	2,379	516	2,625	750	0	18,553
Total Demand	6,693	3,948	3,412	3,433	5,350	3,544	5,572	4,624	9,022	8,203	53,801
Existing Supply to Remain (Estimate)	4,343	2,200	0	3,100	625	750	1,220	0	0	9,671	21,909
Surplus/(Deficit)	**(2,350)**	**(1,748)**	**(3,412)**	**(333)**	**(4,725)**	**(2,794)**	**(4,352)**	**(4,624)**	**(9,022)**	**1,468**	**(31,892)**

Zone 10, comprising the Galleria Mall, is generally built out and has enough parking to support existing uses, including planned changes to the Galleria. Zones 8 and 9, which call for complete redevelopment of existing uses and no parking to remain, would need to build new parking spaces. Other zones, with a mix of existing-to-remain and planned development fall in the middle and could benefit from increased use of existing parking assets with shared parking.

2.4.3   Recommended Model Output

Table 2-6 shows the results of the recommended shared parking model for the Midtown area. The output shown in this analysis is for the weekday as the large amount of office uses planned in Midtown result in a weekday daytime peak. Given the scale of office development, the Midtown development could likely

support additional night and weekend uses, including special events at the park, using office parking facilities during non-peak times with shared parking agreements.

Table 2-6. Dallas Midtown Recommended Shared Parking Model Output (Weekday)

Land Use	Weekday					
	Base	Month Adjustment	Peak Hour Adjustment	Non-Captive	Drive Ratio	Demand December
	Demand	December	2:00 PM	Daytime	Daytime	2:00 PM
Retail–Customer	3,045	100%	100%	30%	85%	776
Retail–Employee	735	100%	100%	98%	50%	359
Super Regional Shopping Center–Customer	6,080	100%	100%	50%	85%	2,584
Super Regional Shopping Center–Employee	1,520	100%	100%	98%	50%	742
Restaurant–Customer	3,302	100%	90%	0%	85%	0
Restaurant–Employee	583	100%	95%	98%	50%	270
Hotel–Guest	1,496	67%	60%	100%	50%	301
Hotel–Employee	374	100%	100%	98%	50%	182
Residential Guest	1,237	100%	20%	100%	70%	173
Residential Reserved	9,277	100%	100%	100%	100%	9,277
Residential Unreserved	9,277	100%	70%	100%	100%	6,494
Office–Guest	2,167	100%	100%	75%	90%	1,463
Office–Employee	28,176	100%	100%	99%	70%	19,583
Subtotal Customer/Guest	17,327					5,297
Subtotal Employee/Resident	40,665					27,630
Subtotal Reserved Resident	9,277					9,277
Total Parking Spaces Required	**67,268**					**42,204**
					% Reduction	37

Approximately 11,600 fewer parking spaces are needed in the recommended model (Table 2-6) than in the conventional model (Table 2-4), a 17 percent decrease.

Table 2-7 shows the results of the recommended shared parking model by zone. Included is an estimate of existing parking in each zone that will remain in place for the foreseeable future. The surplus/deficit line shows the additional parking supply that would be necessary to support the buildout of the conceptual plan for Midtown, assuming shared parking principles and agreements are in effect.

Table 2-7. Dallas Midtown Recommended Shared Parking Model Output by Zone (Weekday)

December 2:00 PM	Distribution of Weekday Demand by Zone										
	Zones										
	1	2	3	4	5	6	7	8	9	10	Total
Retail–Customer	173	111	22	103	44	0	0	212	111	0	776
Retail–Employee	80	51	10	48	21	0	0	98	51	0	359
Super Regional Shopping Center–Customer	0	0	0	0	0	0	0	0	0	2,584	2,584
Super Regional Shopping Center–Employee	0	0	0	0	0	0	0	0	0	742	742
Restaurant–Customer	0	0	0	0	0	0	0	0	0	0	0
Restaurant–Employee	52	42	6	36	21	0	0	73	40	0	270
Hotel–Guest	0	0	0	0	0	103	0	0	111	87	301
Hotel–Employee	(1)	0	0	0	0	63	0	0	67	53	182
Residential Guest	4	16	31	16	48	22	5	24	7	0	173
Residential Reserved	215	863	1,650	848	2,565	1,190	258	1,313	375	0	9,277
Residential Unreserved	150	604	1,155	593	1,796	833	181	919	263	0	6,494
Office–Guest	302	97	0	73	0	47	268	68	405	203	1,463
Office–Employee	4,051	1,301	0	978	0	632	3,585	904	5,421	2,711	19,583
Subtotal Customer/Guest	479	224	53	192	92	172	273	304	634	2,874	5,297
Subtotal Employee/Resident	4,332	1,998	1,171	1,655	1,838	1,528	3,766	1,994	5,842	3,506	27,630
Subtotal Reserved Resident	215	863	1,650	848	2,565	1,190	258	1,313	375	0	9,277
Total Demand	5,026	3,085	2,874	2,695	4,495	2,890	4,297	3,611	6,851	6,380	42,204
Existing Supply to Remain (Estimate)	4,343	2,200	0	3,100	625	750	1,220	0	0	9,671	21,909
Surplus/(Deficit)	(683)	(885)	(2,874)	405	(3,870)	(2,140)	(3,077)	(3,611)	(6,851)	3,291	(20,295)

Zone 10, comprising the Galleria Mall, is generally built out and would have a surplus of parking to share with the rest of Midtown in the recommended model. In the recommended model, Zone 4 also appears to have enough existing parking to remain to support the new development planned in the zone because the existing office building in Zone 4 would likely have excess capacity if recommended mode splits are achieved for office workers. Subject to shared parking agreements, the existing structure could provide parking for planned retail and multifamily and could be a hub for ATS parking. While the shared parking model has been organized into the designated zones, it should be noted that the intent and structure of the shared parking model encourages the sharing of parking across zones because the zones may experience different periods of peak parking demand. For example, a zone dominated by office use will experience peaks between 10:00 a.m. and 2:00 p.m. on weekdays, while zones with more retail, restaurant, and entertainment uses will peak on weekends at lunchtime and dinnertime. An office-centric zone would use some of the parking in an entertainment-centric zone on weekdays, with the reverse occurring on weekends.

The per-zone output is intended as a guide to help distribute parking assets throughout the study area so that most users experience a good level of service. Additionally, in the case of Dallas Midtown, the proposed ATS system affords additional flexibility in the location of the parking supply, as users can park near an ATS stop and use the system to get closer to their destination.

Figure 2-4 depicts parking needs by zone assuming a district-wide shared parking scenario with recommended mode split targets.

Figure 2-4. Parking By Zone—Alternative Parking Strategy (Recommended)
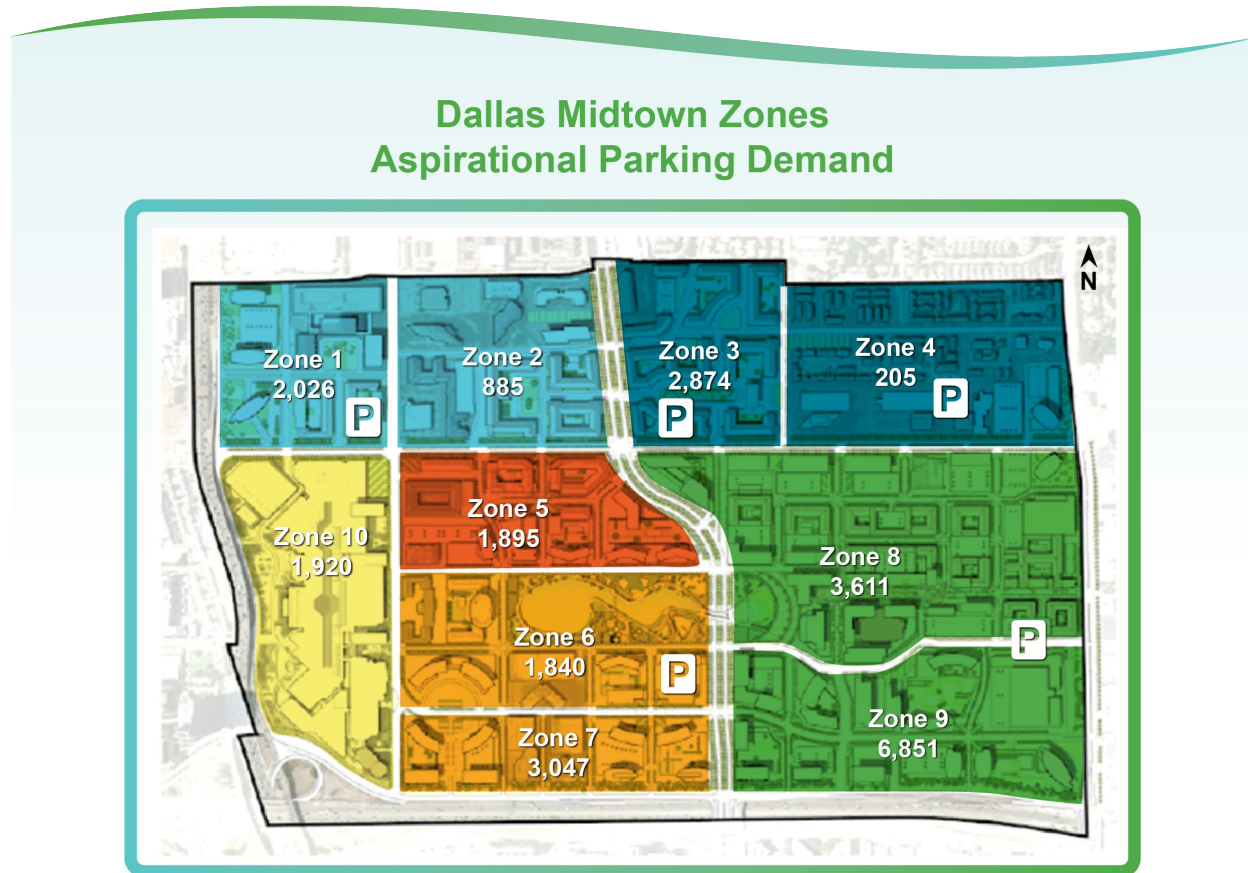
2.4.4   Likely Benefits

The benefits of the alternative parking strategy follow the essential goals of the study: to develop a method to provide parking in such a way that is complementary, rather than detrimental, to the mobility network. Likely benefits include the following:

Material support of the ATS: Internal ridership will be driven by predictable, inherent, and need-based demand rather than individual preference.

Reduced peak-hour SOV trips: Reduction of 50,000 SOV trips at peak hour (as compared to the status quo scenario and assuming achievement of aspirational mode split targets).

Savings for developers, property owners, and investors: Estimated savings of $940 million in basic parking construction costs alone (assuming achievement of aspirational mode split targets).

Increased land use efficiency: Projected 3 million square feet of land available for active uses because parking will be shared, centrally located, and right-sized based on actual need.

More collective control/mutually beneficial decisions: Design of shared parking assets to serve the needs of multiple users and multiple project types rather than the needs of a single property.

2.4.5   Likely Challenges

The main challenges with the alternative parking strategy are administrative. Implementation of the strategy will require extensive coordination and commitment from the governing authorities and the developers. Likely challenges include the following:

- **Amendments to planned development and parking-related ordinances:** Implementation of an alternative parking strategy cannot occur without amendments to the existing planned development and referenced ordinances (such as those set forth in Chapter 51A, Article 13 regarding off-street parking requirements).

- **Management entity:** Collective decision-making regarding parking and transportation infrastructure will require a management authority or entity. A successful management authority will provide simultaneous oversight of the parking infrastructure and the ATS and ensure a symbiotic relationship between them.

- **Less conservative, but still widely accepted approach to parking:** Shared parking is a less conservative approach to building parking infrastructure than adhering to simple and additive use-based parking ratios; however, the parking industry, as well as many municipalities (including the City of Dallas) have used shared parking publications (primarily ULI's 2005 *Shared Parking* handbook) for decades. As such, while this strategy may be considered modestly unorthodox and require some communication and coordination (particularly with commercial lenders), it is unlikely to significantly hinder the speed or scope of the study area's development potential.

Section 3
ATS Ridership Estimation

3 ATS Ridership Estimation

3.1 Limits of Existing Projections' Methods and Purpose behind Estimation Tool Creation

Two ridership modeling software tools were evaluated to conduct the Dallas Midtown ATS ridership estimate: STOPS (Simplified Trips-on-Project software) and a customized Microsoft Excel–based tool.

3.1.1 STOPS

STOPS is the Federal Transit Administration's (FTA) modeling software. This software is typically used for ridership estimation for "New Starts" and "Small Starts" projects as a simplified method to quantify the measures used by the FTA to evaluate and rate projects. STOPS is a limited implementation of the conventional four-step travel demand model but replaces the standard trip generation and trip distribution steps with the Census Transportation Planning Package to describe overall travel markets. It also replaces the traditional coded transit network with standard transit-services data in the General Transit Feed Specification format. The model has been calibrated and validated for multiple transit areas and types of projects.

3.1.2 Microsoft Excel–Based Tool

A customized Microsoft Excel–based tool can include the first three steps (trip generation, trip distribution, and mode choice) of the four-step travel demand model process to create trip tables. The final step (trip assignment) can be done with travel demand model software like TransCAD using a coded transit network with the trip tables from Excel. The model would need to be calibrated and validated using data from similar developments and transit projects.

3.1.3 Evaluation

STOPS was reviewed by the study team and, in coordination with FTA model creators, determined to cover larger areas and transit systems more typical (for example, buses, light rail, commuter rail) than the anticipated Dallas Midtown development and ATS being evaluated.

The study team evaluated the customized Microsoft Excel–based tool and determined that it would require more effort to develop but could be developed in a manner that would allow it to be reused to evaluate other, similar potential projects in the DFW region. It could better include the proposed development by using the *Trip Generation Manual* (ITE, 2017) to generate trips based on the specific proposed development with the existing land uses, and could also be customized for the project-specific types of autonomous systems being considered.

It was decided that a customized Microsoft Excel–based tool would be used for this project so that it could be customized for the proposed development and ATS evaluation.

3.2 Ridership Estimation Methodology

Although a summary of the ridership estimation process conducted for this study is included in this report, a fully detailed estimation methodology is located in Appendix A along with the Estimation Tool User Guide and a validation memorandum in Appendix B.

The potential ridership for an ATS was considered in three parts:

1. Internal demand based on revised development plan (detailed in Section 1)

2. Latent regional transit demand, should proposed regional transit connections be implemented

3. Potential parking demand, should parking capacity be restrained as a district resource as opposed to being available at each land use

Internal demand was based on expected land uses within the development and imported into the Ridership Estimation Tool along with expected parking demand (see Section 2). The demand was projected 20 years into the future to incorporate for development growth (Figure 3-1). Regional transit demand was provided by NCTCOG's regional travel demand model and was combined with the internal output from the Excel tool. These three integrated demand components were then input into TransCAD software to accomplish trip assignment and map total estimated ATS ridership within Dallas Midtown.

Figure 3-1. Dallas Midtown Study Area Demographics Comparison Charts
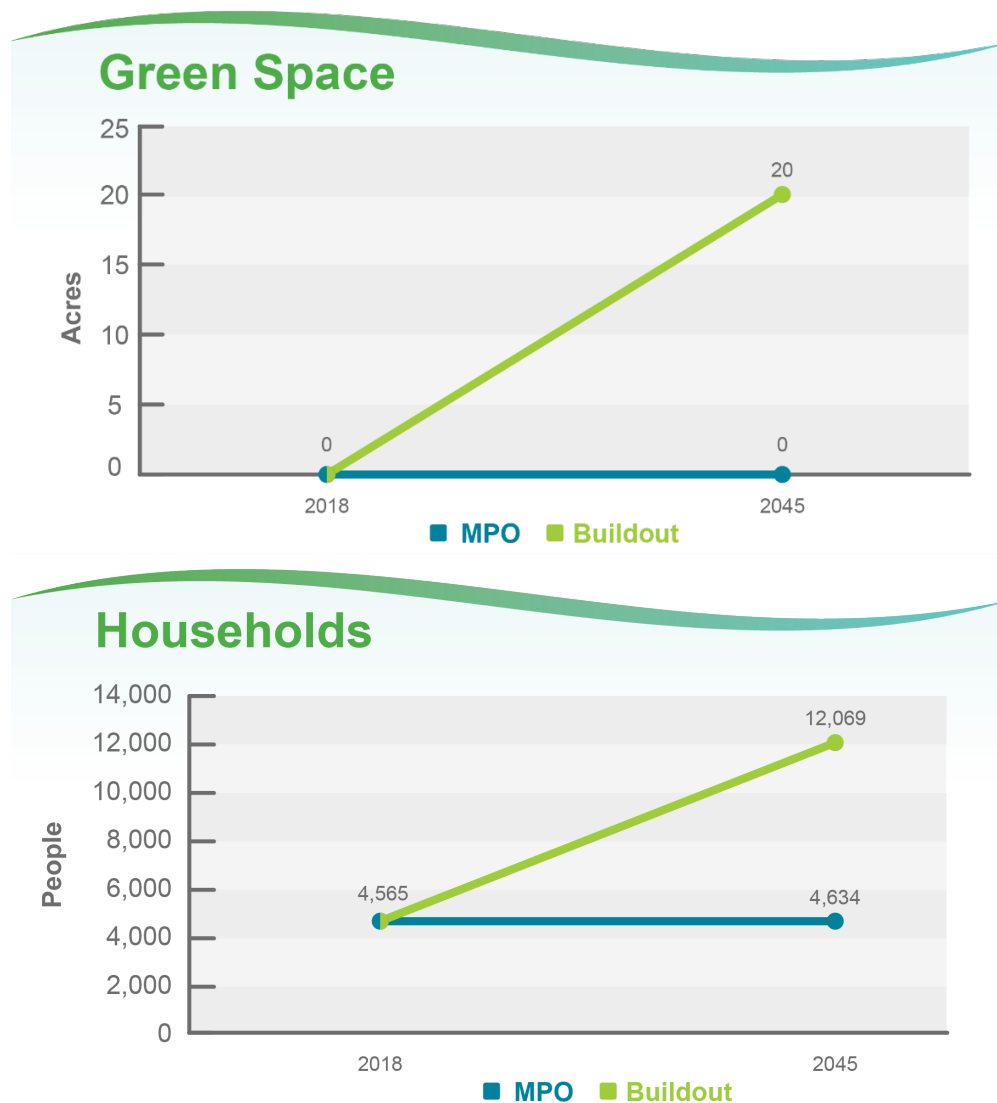
Figure 3-1 Dallas Midtown Study Area Demographics Comparison Charts (Continued)

Employment

Population
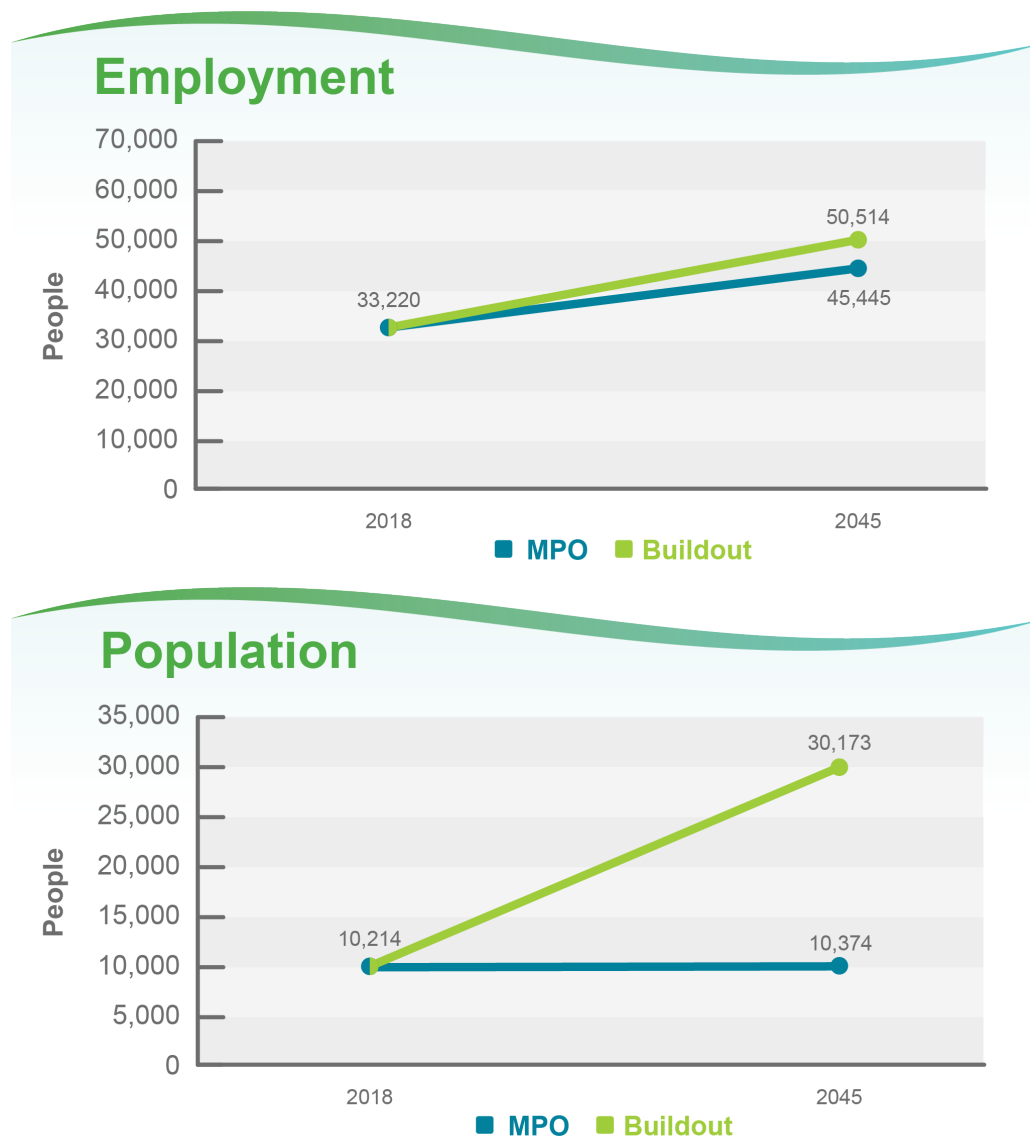
3.3   Ridership Estimation Results

Figure 3-2 shows the results of the ridership estimation for the Dallas Midtown ATS by direction for each segment between approximate station locations. The total ridership estimate includes the internal, regional, and parking ridership. The internal ridership was estimated using the ridership estimation tool. The regional ridership was estimated using the DFX 4.5.3 model (NCTCOG, 2018) to get trips for three regional transit connections to Dallas Midtown, and then those trips were assigned to the Dallas Midtown ATS network. The transfer from the regional transit connections to the Dallas Midtown ATS network was assumed to be at a station near Montfort Drive and Bryce Lane. The parking ridership was estimated by first calculating the internal ridership percentage for an ATS link and comparing it to the total internal demand. Then that same percentage was applied to the p.m. peak hour parking demand, excluding reserved residential parking, to get the parking ridership estimate for each ATS segment.

Figure 3-2. Estimated Peak Demand for Internal Circulation
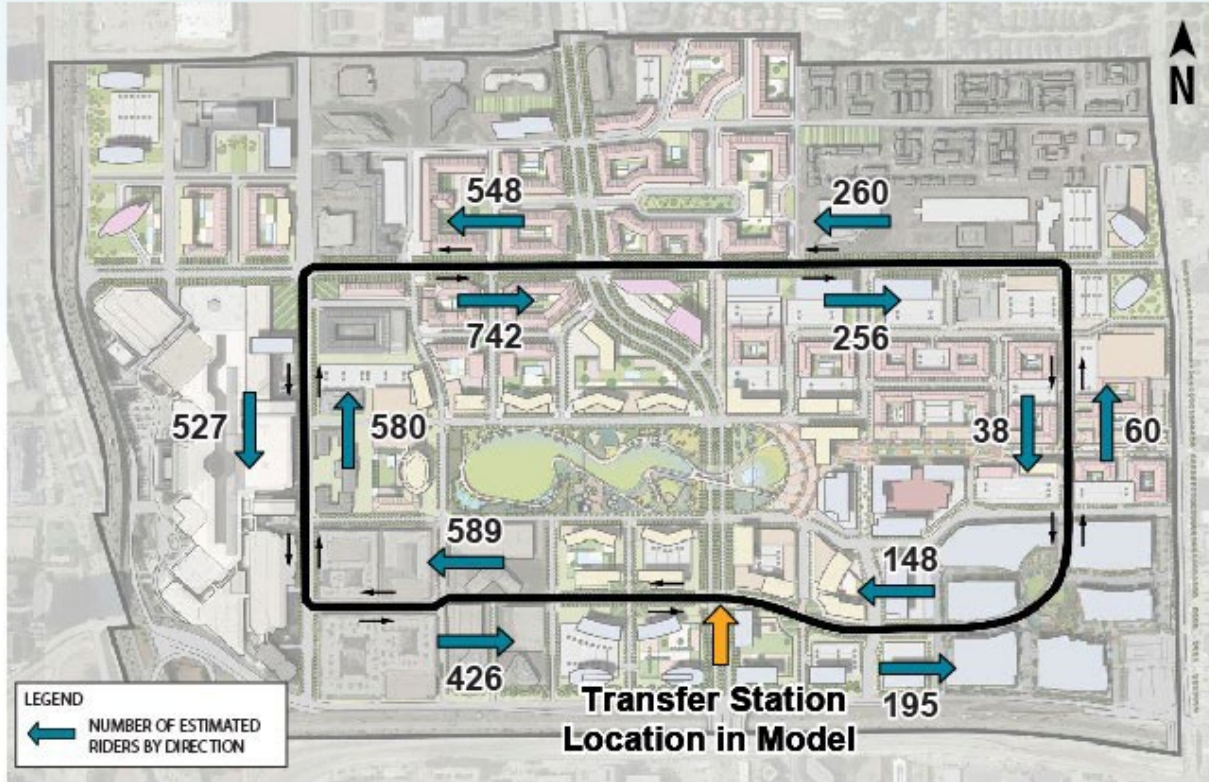
Section 4
Autonomous Transportation System Vehicle Analysis
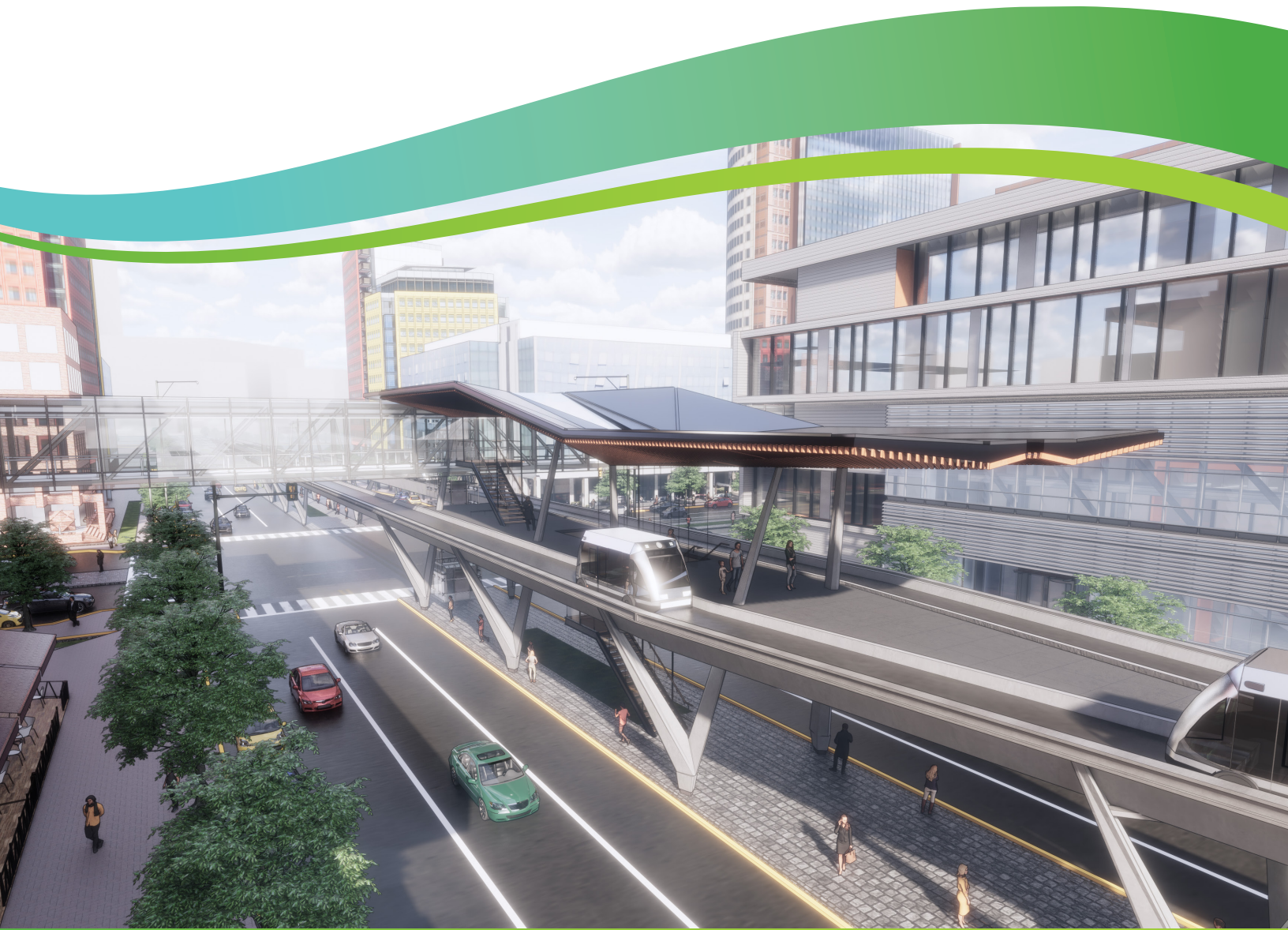
4 Autonomous Transportation System Vehicle Analysis

This section provides an overview of the study's focus on ATS vehicles. The vehicle analysis went through four iterations prior to the final recommendation (Figure 4-1).

Figure 4-1. Progression of Analysis of ATS Vehicles
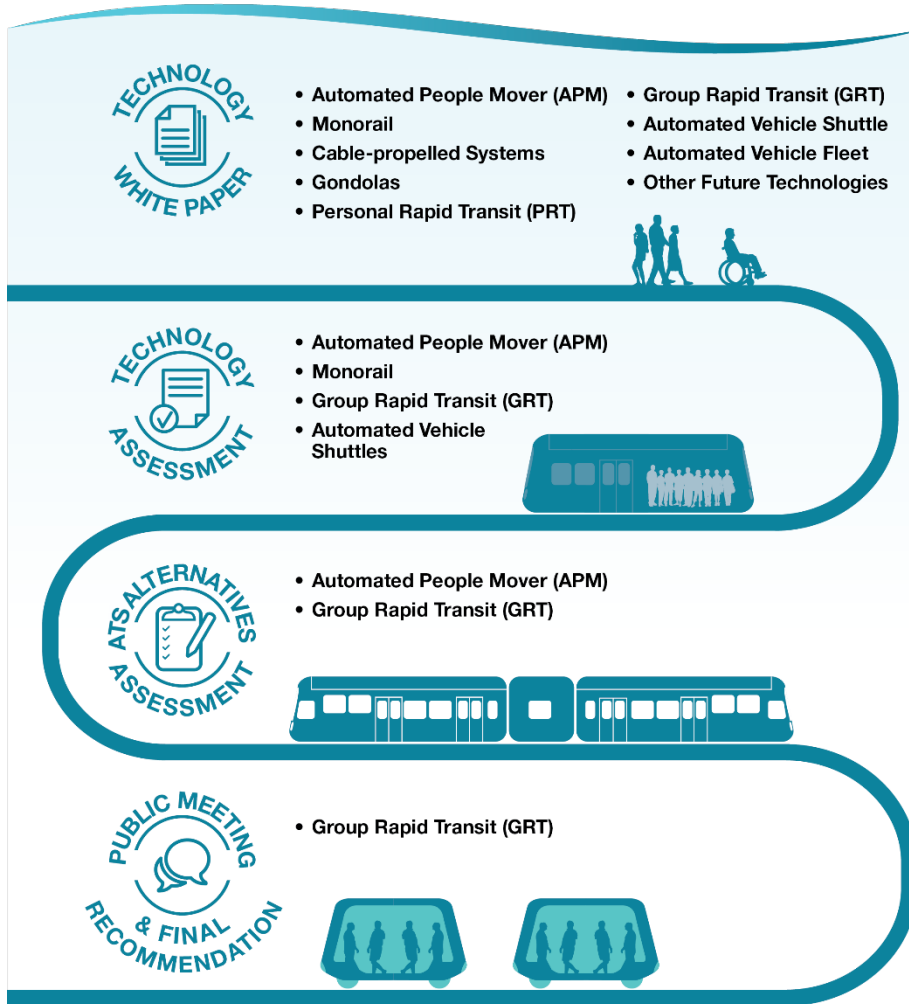
The differing vehicles types and technologies directly impact the alignment options and are discussed in context here with each of the vehicle options as necessary. Alignment options and study analyses are discussed in greater detail in Section 5.

4.1 Current State of Autonomous Vehicles

Early in the project, the study team delivered the final version of the technology scan white paper (Appendix C), which provided a review of current industry usage of public transportation vehicle capabilities. The paper reviewed vehicle characteristics of automated people movers (APMs), monorails, cable-propelled systems, gondolas, personal rapid transit (PRT), group rapid transit (GRT), automated vehicle shuttles, automated vehicle fleets, and other nascent technologies. Table 4-1 summarizes the key points of the technology scan white paper; the full paper is included in Appendix C.

Table 4-1. Autonomous Vehicle Characteristics

Vehicle Category	General Characteristics	Typical Specifications
Automated People Movers (APMs)	Broad class of vehicle not covered in any of the other categories in this table. Vehicles operate without drivers in exclusive right-of-way that can be elevated or dedicated at-grade. Used in major activity centers such as airports and central business districts. Supported by rubber tires or steel wheels on rails. Operates on short headways.	- Vehicle sizes: 20–40 ft long, 8–9 ft wide, 9–12 ft high - Passengers per car: 25–100 - Maximum speeds: 30–50 mph
Monorail	Single concrete or steel beam is straddled by vehicle. Onboard electric motors powered by third rail. High speed and capacity.	- Vehicle sizes: 25–48 ft long, 8–10 ft wide, 14–17 ft high - Passengers per car: 40–95 - Maximum speeds: 35–50 mph
Cable-Propelled System	Propelled by gripping a moving cable traveling between stations. Can be guideway or aerial-based. Guideway systems are supported by rubber or steel wheels on a dedicated guideway.	- Vehicle sizes: 20–49 ft long, 9–10 ft wide, 11–14 ft high - Passengers per car: 50–70 - Maximum speeds: 25–30 mph
Gondolas/Aerial Tramways	Propelled and suspended by moving cable(s). Aerial systems are supported by overhead cable and are usually attended. Susceptible to operational disruption due to high winds.	- Vehicle sizes are widely variable - Passengers per car: 4–120 - Maximum speeds: 15–30 mph
Personal Rapid Transit (PRT)	Small vehicles operating with short headways with non-stop, origin-to-destination travel. Sophisticated network of guideway and AV control. Powered by batteries or third rail. Experience is like a private automobile or taxi.	- Vehicle sizes 12 ft long, 5–7 ft wide, 6–8 ft high - Passengers per car: 4–8 - Maximum speeds: 20–30 mph
Group Rapid Transit (GRT)	GRT is like PRT but with higher-capacity vehicles and grouping of passengers to similar or en route destinations. GRT has been compared to a "horizontal elevator."	- Vehicle sizes 20 ft long, 7 ft wide, 9 ft high - Passengers per car: 18–22 - Maximum speeds: 30–40 mph
Automated Vehicle Shuttle	An AV shuttle is fully automated (driverless and no vehicle operational controls) and typically operates on roadways shared with regular vehicles. Most uses are in pilot stages; AV shuttles are considered emerging and developing.	- Vehicle sizes 13–16 ft long, 6–7 ft wide, 8–9 ft high - Passengers per car: 6–15 - Maximum speeds: 15–55 mph
Automated Vehicle Fleet	Similar to an AV shuttle but operating through an automated and controlled fleet of passenger vehicles. Operates with no driver but with vehicle operational controls available if needed.	- Vehicle sizes 15 ft long, 5–6 ft wide, 5–6 ft high - Passengers per car 4 to 5 - Max speeds 45 to 120 mph

4.2 Preliminary Screening from Technology Assessment

The study team delivered a technology assessment of the eight vehicle categories identified in the Technology Scan White Paper (Appendix C) (aerial tramways were broken out from gondolas and evaluated as a separate, ninth vehicle category). That assessment examined five different characteristics for each vehicle category and ranked the characteristics in terms of risk of meeting a given evaluation criterion. The assessment considered the following characteristics:

- *Performance* and the adequacy or appropriateness of the capacity of the technology regarding the current and potential future ridership requirements and the ability to meet the geometric constraints of the project site.

- *Level of service* provided by the technology, which contributes to the passenger experience.

- *Urban insertion impact* of the technology in terms of impacts to the existing or planned infrastructure and ability to use the existing available space.

- *Cost* of the technology in terms of high-level capital and operations and maintenance (O&M) cost comparisons.

- *Technical maturity* of the technology in terms of whether it is service-proven, has enough manufacturing capability and other commercial considerations.

Table 4-2 shows the technology ranking by category.

Table 4-2. Candidate Technology Evaluation Summary

Evaluation Criteria	Automated People Mover (APM)	Monorail	Cable-Propelled APM	Gondolas	Aerial Tramways	Personal Rapid Transit (PRT)	Group Rapid Transit (GRT)	Automated Vehicle Shuttles/ Autonomous Vehicles (AV)	Automated Vehicle Fleet
Performance	●	●	△	X	X	X	△	△	X
Level of Service	●	●	●	△	●	●	●	△	●
Urban Insertion Impact	△	△	△	●	△	●	●	●	●
Cost	△	■	△	△	△	△	△	●	●
Technology Maturity	●	●	●	●	●	△	△	△	△

●	Provides lower risk for evaluation criterion
△	Provides moderate risk for evaluation criterion
■	Provides higher risk for evaluation criterion
X	Cannot meet evaluation criteria

The ridership estimation conducted in mid-2018 identified capacity needs and passenger demand parameters. These parameters eliminated PRT and AV fleets from further consideration. Gondolas, inclusive of aerial tramways, were eliminated from further consideration as a result of their inability to be expanded.

The study review committee did not want further consideration of cable-propelled system because it was deemed an older technology, not fitting the intentions of the development. It is also difficult to expand a cable-propelled system, which is a priority in a developing area such as the area around Dallas Midtown. APM, monorail, GRT, and AV shuttles were the four vehicle technology alternatives that were considered for further analysis.

4.3   ATS Alternative Analysis

The study team further analyzed the four categories of vehicle that were screened in previous efforts (Figure 4-2). The team's analysis of the operational characteristics, fleet and capacity, and system cost for each vehicle type was presented to the study review committee. Two of the four technologies required specialized infrastructure. All technologies covered the spectrum of existing AV systems that could meet ridership demand. The analyses are summarized in the following subsections.

Figure 4-2. Final Four Vehicle Categories Evaluated

| APM | Monorail | GRT | AV Shuttle Fleet |

4.3.1   Operational Comparison

Key operational characteristics identified for comparison among the four vehicle types are listed in Table 4-3.

For passenger capacity, there is a significant increase in the fixed-track alternatives, but these vehicle types may be excessive given the ridership estimation. Regarding fleet size, in general, more cars would result in higher procurement, maintenance, and storage costs, but the ability to add more vehicles (expandability) increases flexibility and adaptation to new technology innovations.

Analysis assumes all headways were kept under 5 minutes, with the intention of providing near-constant service. Environmental and land use impacts were predominantly from infrastructure-dependent solutions that require construction or buildout. As the four different modes are typically electrical vehicles, no added fuel/emission impacts were assumed.

Table 4-3. Characteristics of Vehicle Types

Characteristics	APM	Monorail	GRT	AV Shuttle
Passenger capacity	105/car	100–150/two-car train set	18–22/vehicle	6–15/vehicle
Fleet size (per direction)	Two 1-car trains each direction plus one spare car—total of five cars	Two 2-car train sets each direction plus one spare—total of five 2-car train sets	Nine cars each direction plus four spares—total of 22 cars	15 cars, but loop size restricts total cars to 13[a] cars each direction plus five spares—total of 31 cars
Headway capabilities and maximum speed	2–4 minute capability 50 mph	2–4 minute capability 50 mph	1 minute 30 mph	1 minute 12–13 mph
System maturity	1971	2005 (small monorail)	2011	2016
Construction Disruptions	Guideway foundations in roadway/median System power utility lines installed along guideway Maintenance facility structure	Guideway foundations in roadway/median System power utility lines installed along guideway Maintenance facility structure	Guideway foundations in roadway/median Maintenance facility structure	Dedicated travel lane Dedicated short-range communications with traffic signals Maintenance facility structure
Environmental Impacts	Guideway, structure, visual impact	Guideway, structure, visual impact	Guideway, structure, visual impact	None (at-grade electric vehicle)
Land use requirements	Specialized infrastructure along alignment Maintenance facility/parking footprint	Specialized infrastructure along alignment Maintenance facility/parking footprint	Can use typical roadway infrastructure[b] Maintenance facility/parking footprint	Can use typical roadway infrastructure Maintenance facility/parking footprint
Expandability	Major construction and vehicle procurement	Major construction and vehicle procurement	Expandable with new construction	Highly expandable

[a] AV Shuttle alternative would not have the space to meet the system demand at full buildout under current ridership assumptions.

[b] GRT is currently operating on specialized infrastructure but is moving to capabilities that will enable it to act like AV on typical roadway infrastructure.

4.3.2 Fleet/Capacity Analysis

To determine the necessary size of the vehicle fleet to match estimated demand with vehicle capacity, a base set of assumptions were considered for each of the four vehicle types.

In addition to the estimated demand (considered in a peak-hour basis), the analysis assumes headways of less than 5 minutes, a dwell time of 20 seconds (typical for this style of system), a system length of 2.2 miles, and six preliminary stations. The basis behind the system length and station count will be detailed in Sections 5 and 6, respectively.

Peak demand of 742 passengers per hour

Desired headway of less than 5 minutes

Dwell time maximum of 20 seconds

System length of 2.2 miles

Six stations

Table 4-4 compares vehicle capacities.

Table 4-4. Capacity Analysis of Vehicle Types

Operational Measures	APM	Monorail	GRT	AV
Full loop duration per load (minutes:seconds)	6:42	6:42	6:42	13:00
Required headway (minutes:seconds)	3:21	3:21	1:30	1:30
Maximum number of revenue vehicles needed	Two 1-car trains each direction	Two 1-car trains each direction	Nine cars each direction	13 cars each direction
Passenger capacity per hour	1,800	1,800	840	720
Operational efficiency (peak hour) (percent)	41	41	88	103 (over capacity)

Operational efficiency was determined during the peak hour and measured as a percentage of the demand that could be addressed by the proposed fleet system. When considering the number of cars and passenger capacity, both GRT and AV had the highest ability to meet ridership estimates while obtaining very low headways.

4.3.3   System Cost Analysis

Both APM and monorail were much higher in vehicle and infrastructure costs than were GRT and AV. Table 4-5 compares system costs.

Table 4-5. System Cost Comparison

Cost Elements	APM	Monorail	GRT	AV
Right-of-way ($M)	0	0	0	13
Utilities ($M/mile)	3	3	3	3
Traffic improvements ($M/mile)	2	2	1	1
Stations ($M/station)	7.5	7.5	7.5	7.5
Vehicles ($/car)	3,000,000	2,500,000	360,000	300,000
O&M cost ($M/year)	5	5	1.4	0.5
Maintenance facility ($M)	2	2	1	1
Construction ($M/mile)	40	50	15	15
Total Capital Cost ($M)[a]	**165**	**184.5**	**94.7**	**190.1**

M = million

[a] Capital cost does not include O&M or maintenance facility cost.

Based on the operational fleet and capacity, and systems costs analyses, the study review committee recommended the APM and GRT alternatives for presentation at the second project public meeting.

4.4   Recommended ATS Vehicle

The recommended GRT vehicle and system holds 12 to 21 persons per vehicle on a dedicated route and moves over 15,000 persons each day.

Based on the feedback received in the second project public meeting and from the study team's deliberation with the study review committee, the study team recommended the proposed ATS be a GRT.

The evolution of GRT has resulted in vehicles that are more like AVs, with the ability to drive in mixed-use facilities if necessary. As GRT technologies adopt AV capabilities, this will allow greater flexibility for the elevated structure to share the facility or for the vehicles to coexist in general traffic in future adaptations of the ATS.

5 Autonomous Transportation System Alignment Analysis

5.1 Alignment Mapping by Vehicle Type

Most of the technologies considered in Section 4 operate on a fixed guideway that can be designed in varying operating configurations. The configuration of the guideway determines how the vehicles navigate it. Examples include single-lane shuttle, single-lane shuttle with bypass, dual-lane shuttle, dual-lane shuttle with bypass, single-lane loop, dual-lane loop, and pinched loop. Some technologies presented in Section 4 do not require a fixed guideway but can operate in the same manner by using a fixed route or can navigate in a network configuration, meaning they can travel anywhere in the system in an order that is not set. The operating configuration also includes the vertical elevation, which falls under one of three categories: elevated, at-grade, or underground.

Several alignment options were developed for the various technology categories. However, for the initial evaluation of each vehicle type, one representative alignment was selected for each evaluation. Although several of these alignments demonstrated the ability to provide the most amount off access to Midtown as a whole and will be detailed further, other loop, radial and grid configuration alignment options were considered and are represented in Figure 5-1.

Figure 5-1. Alignment Alternative Exercise Result
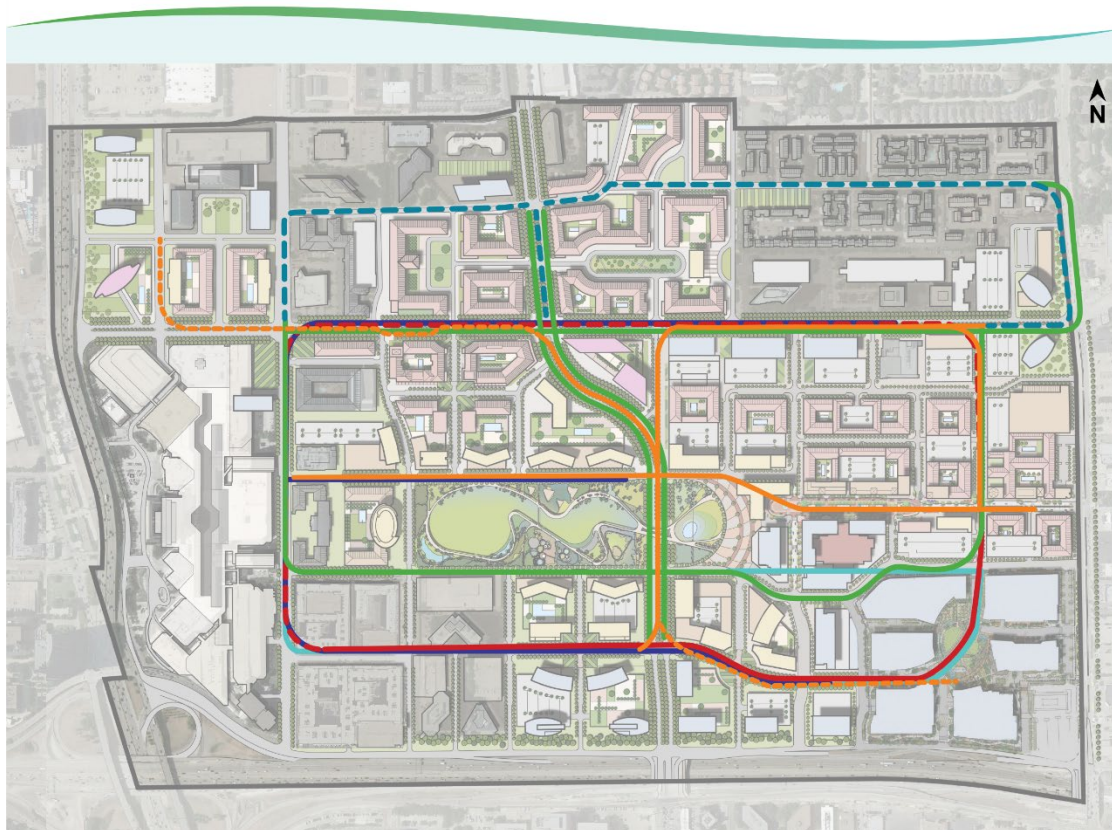
The process to determine the recommended alignment alternative was one that maximized the impact on mobility internally and with regional connections. The needs and constraints of each system (per vehicle technology detailed in Section 4) were weighed based on existing development plans in Midtown as well as the flexibility to implement a base system that could provide immediate mobility improvements and allow for expandable service whether by system extension or a transfer to an at-grade roadway, as GRT is capable of doing.

The system elevation will have a crucial impact on alignment feasibility as sub-grade, at-grade, and elevated systems all have different benefits and challenges. Furthermore, at the stage of development this feasibility study is in, it is assumed that the ATS system will operate within public right-of-way. This assumption allows the study to focus on feasibility and mobility impact as opposed to level of impact to certain parcels, any land requirements, and access and easement coordination. As such, a comparison of the existing roadway network plans and values behind an elevated or at-grade system are detailed prior to the alignment analysis.

Sub-grade ATS implementation was ruled out due to its added negative impact on constructability, implementation coordination, and displacement from the public eye as a mobility alternative.

5.2   Alignment Needs and Constraints

The alignment needs for the proposed system vary based on whether the system is elevated or at-grade. The City of Dallas Thoroughfare Plan (City of Dallas, 2013) includes three types of roadways that would impact the recommended ATS alignment, ranging in right-of-way from 69 feet to 117 feet. To demonstrate the impact of implementing an ATS along these roadways, the required revisions needed in the smallest street type (69-foot right-of-way) as well as the largest (117-foot right-of-way) will be depicted, whether it be an elevated or an at-grade ATS system. The current configurations (without ATS) of the 69-foot and 117-foot streets are shown on Figure 5-2.

Figure 5-2. Current Dimensions of 69-Foot and 117-Foot Streets in Thoroughfare Plan
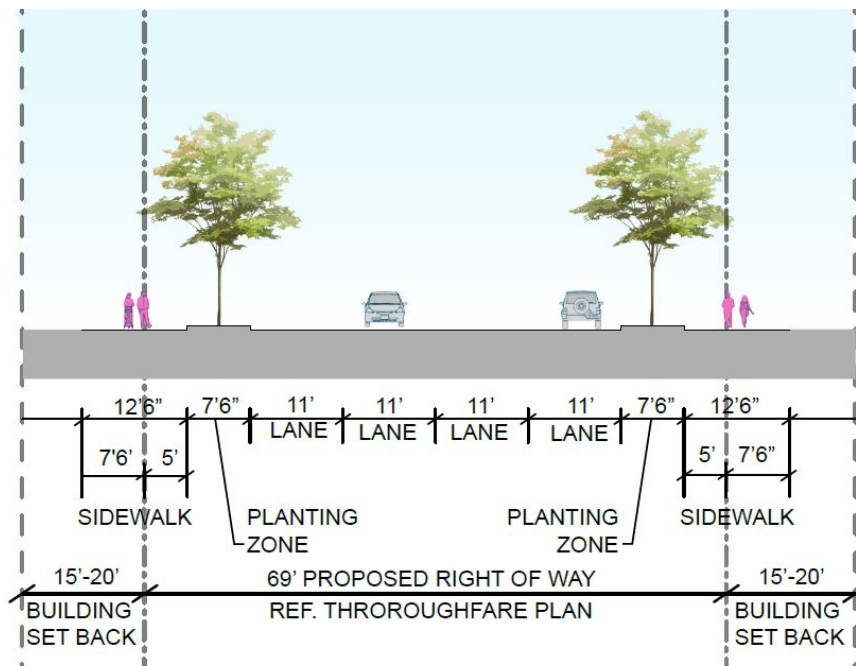
Section 5

Autonomous Transportation System Alignment Analysis

Figure 5-2. Current Dimensions of 69-Foot and 117-Foot Streets in Thoroughfare Plan (Continued)
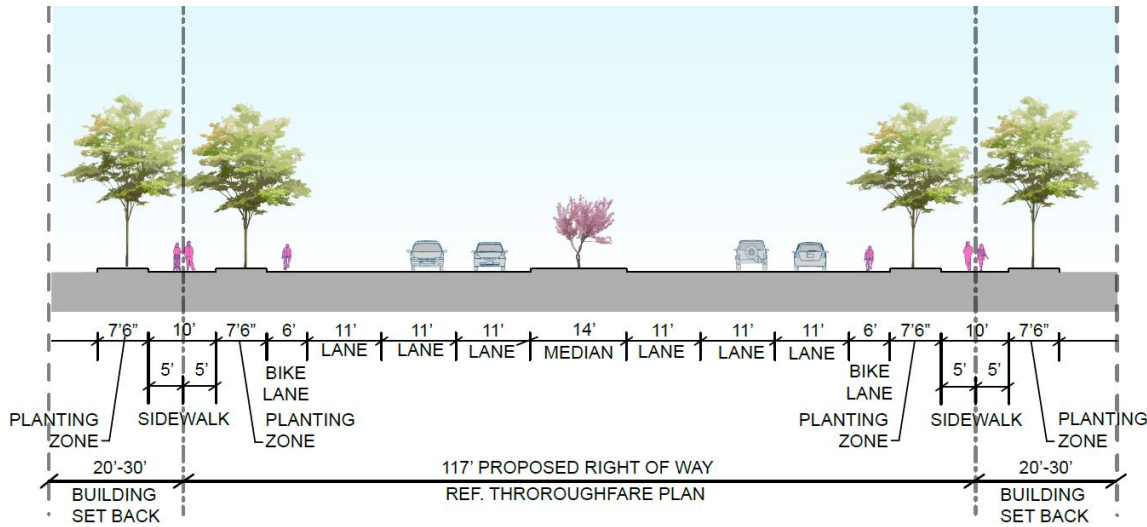
5.3 Elevated System

5.3.1 Alignment Right-of-Way Requirements

To construct an elevated ATS, a 6-foot (minimum) median would be required to house columns for the elevated structure. To maintain the existing/planned right-of-way width in the 2013 Midtown Thoroughfare Plan, 3 feet of sidewalk on each side of the new roadways (designated FN6 and FN8 in the current Midtown Thoroughfare Plan) could be transferred to a new center median. The existing/planned sidewalk would be reduced to 9.5 feet (from 12.5 feet) on streets FN6 and FN8, and the overall right-of-way width would remain unchanged. A median of at least 6 feet is already existing/planned for the Noel Road and Alpha Road segments. As such, the elevated alignment would require no additional right-of-way. See Section 5.3 for right-of-way recommendations at the ATS station (both elevated and at-grade).

The zoning and permitting changes that would be required to reallocate space in the right-of-way planned in the Thoroughfare Plan will be an immediate recommendation from this study, as the new alignment roadways (FN6 and FN8) are set to begin construction in 2019. Making the necessary revisions and constructing the median and roadway curbs in the recommended revised dimensions will save reconstruction costs with future ATS implementation. The median would have an immediate benefit even before ATS implementation by providing landscaping space in the median adequate for trees as well as an ADA-compliant pedestrian refuge at every intersection in this urban district. Figure 5-3 shows the revised dimensions recommended for the 69-foot streets in the Midtown area; as previously mentioned, no revisions are required for the Noel Road and Alpha Road segments.

5.3.2 ATS Stations

Elevated stations for the proposed ATS are also expected to fit within the currently available right-of-way shown in the Midtown Thoroughfare Plan. Elevated stations along the 69-foot right of way streets would be able to fit in the existing right-of-way and maintain projected roadway vehicular lanes if the "planting zone" was reduced from 7.5 feet to 3.5 feet and the sidewalk reduced from the modified 9.5-foot width to a 7.5-foot width for the length of the station. The reduced planting and sidewalk widths could then be

combined with the 6-foot center median in the alignment cross section to form an 18-foot station area in the median.

Figure 5-3. Dimension Revisions Required for an Elevated ATS System in 69-Foot Right-of-Way Streets
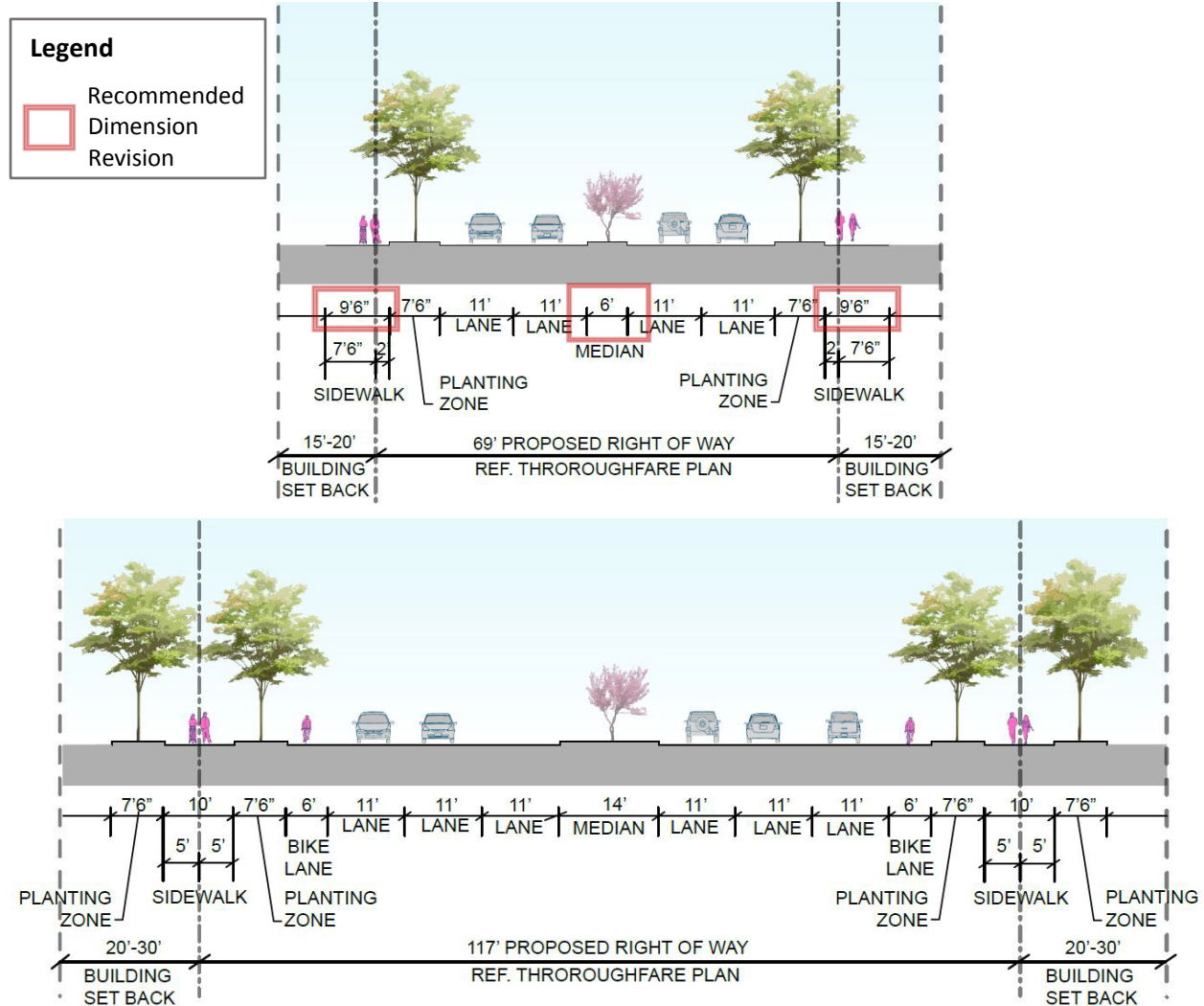
The planned right-of-way of 117 feet along Alpha Road, however, would also accommodate the ATS stations without additional dedication, provided the sidewalk width is reduced. Figure 5-4 shows the revised roadway dimensions required to fit an elevated station in the proposed 69-foot and 117-foot rights-of-way.

Figure 5-4. Roadway Dimensions for an Elevated ATS Station in 69-Foot and 117-Foot Rights-of-Way
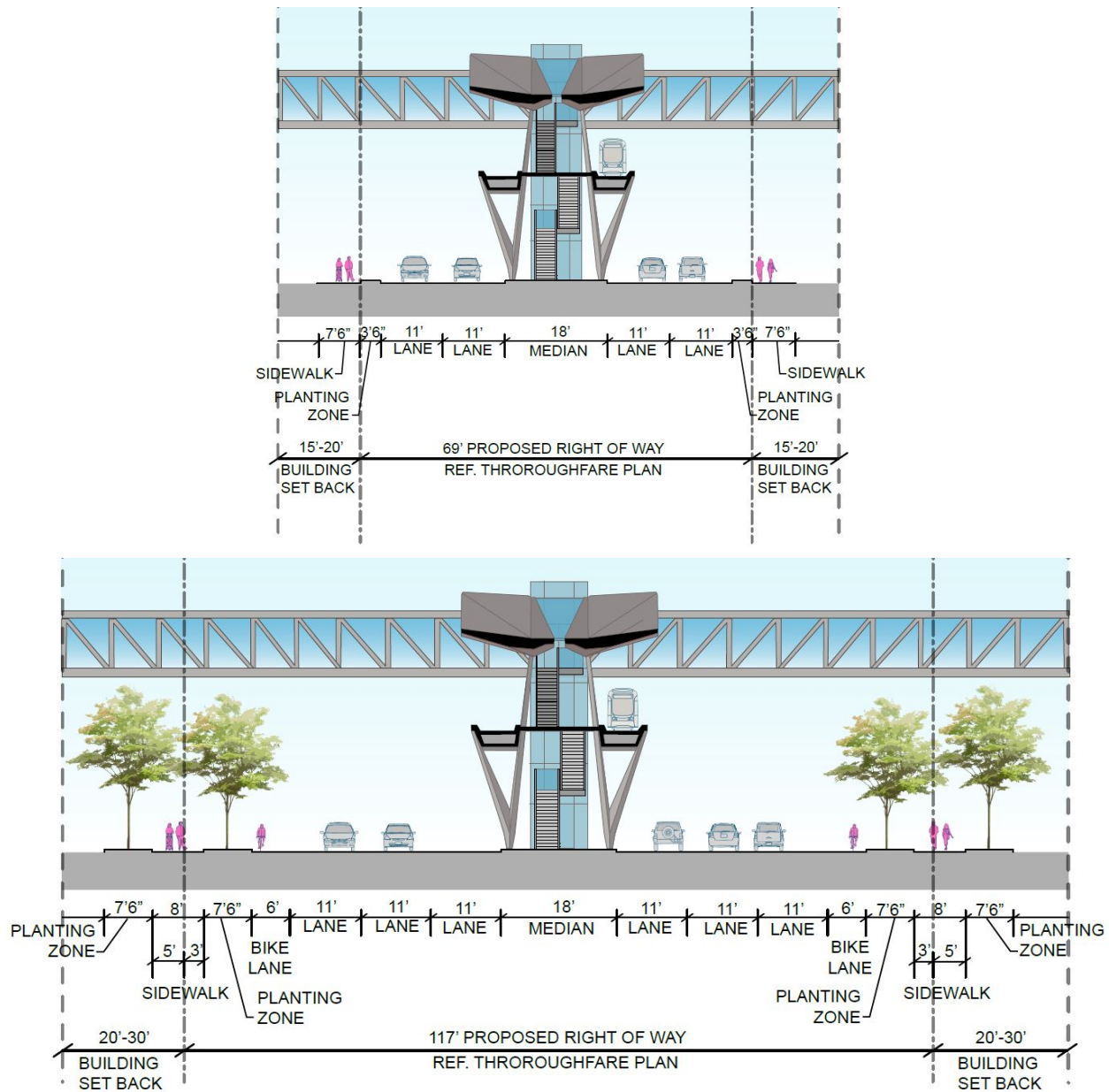
5.3.3 Traffic Impacts

The grade-separated ATS has minimal impact to the surface streets as it is on a fixed guideway elevated above the streets. However, there will be an increase in pedestrian traffic in the study corridor under the buildout conditions. With the anticipated change in traffic patterns with the new developments and the pedestrian activities, the existing signal timings may need to be adjusted at all the signalized intersections to accommodate both the vehicular and the pedestrian traffic. For the grade-separated system, the total ATS travel time for one complete loop is estimated at approximately 5 minutes and 50 seconds, which includes travel time between the stations/stops and dwell time at the stations/stops.

Table 5-1 indicates the required square footage of dedication along each ATS segment using the additional right-of-way dedications.

Table 5-1. Additional Square Footage Required for Proposed ATS Alignment—At-Grade

Roadway ID	Additional Square Footage Required
South leg—Thoroughfare Plan FN8	28,700
East leg—Thoroughfare Plan FN6	12,600
North leg—Alpha Road	0
West leg—Noel Road	12,600

To develop cost estimation values for ROW acquisition, the study team analyzed tax rolls for nearby properties that had been developed to the level anticipated in the project area. By using these tax rolls and converting them to a price per square foot, the properties in question can be expected to be valued at a range of $50/square foot to $400/square foot. The higher-value properties will generally be located closer to I-635 LBJ Freeway or the Dallas North Tollway.

Using a range of square footage values depending on the proximity of each leg to I-635 LBJ Freeway and the Dallas North Tollway, right-of-way acquisition for the selected at-grade alignment is expected to be approximately $8 million.

5.4.2 ATS Stations

At-grade ATS stations are expected to fit within the required dedication described in Sections 5-1 and 5-2. As such, no additional dedication is required for the at-grade stations beyond that previously described. It is anticipated that sidewalk boarding areas with small scaled shelters would be used for the at-grade alignment alternative.

5.4.3 Traffic Impacts

5.4.3.1 At-Grade without Priority

The at-grade ATS without traffic signal priority for the ATS vehicle may have minimal to moderate impact on surface street traffic. When the ATS vehicle does not have signal priority and runs with normal traffic, the arrival patterns for ATS vehicles arriving at the stations will change significantly and may impact ridership. With the anticipated change in traffic patterns as a result of the new developments and pedestrian activities, the existing signal timings may need to be adjusted at all signalized intersections to accommodate ATS, vehicular, and pedestrian traffic. For the at-grade ATS without traffic signal priority, the total ATS travel time for one complete loop is estimated at approximately 9 minutes and 10 seconds. This includes travel time between the stations/stops, dwell time at the stations/stops, and delay at the signalized intersections.

5.4.3.2 At-Grade with Priority

The at-grade ATS with traffic signal priority for the ATS vehicle may have moderate to maximum impact on surface street traffic. With the anticipated change in traffic patterns with new developments and the pedestrian activities, the existing signal timings may need to be adjusted at all signalized intersections to accommodate the ATS, vehicular, and pedestrian traffic. For the at-grade ATS with traffic signal priority, from a high-level traffic analysis, the total ATS travel time for one complete loop could be as short as

6 minutes and 40 seconds, which includes travel time between the stations/stops, dwell time at the stations/ stops, and delay at the signalized intersections.

Implementation of signal priority would introduce significant vehicle delay, as side-street traffic signals would never get the fully allocated green time with the target headway of 1 minute. The ATS vehicle traffic signal priority would also interrupt progression between traffic signals, which will impact the arrival patterns for ATS vehicles at the stations and may impact ridership as well. Because of the number of unknown variables as well as negative impact on thoroughfare system, this alternative is not recommended.

5.5   Elevated System versus At-Grade System

The proposed ATS could be elevated or merged with at-grade vehicular and pedestrian traffic. The study team recommends an elevated system be pursued for the following reasons:

- Travel times on the ATS will be quicker and more reliable on an elevated system, especially during peak hours.

- An elevated system impacts the surrounding environment to a lesser degree than its at-grade counterpart. Pedestrian and vehicular traffic could move freely beneath the elevated system without potential conflict.

The study team recommends the proposed ATS system be either completely elevated or completely at-grade. Transitions from elevated to at-grade pose distinct design and other special challenges that are likely to limit the viability of both the ATS and the surrounding vehicle/pedestrian network. Transitions from an elevated system to an at-grade system are expected to require a minimum of 630 feet of transition length. Pedestrian and vehicular connections across the ATS alignment would not be feasible during this transition length, causing significant disruptions to the local transportation network. Figure 5-6 details the impact of a transition section on the adjacent vehicular network (transition section shown in green).

It would be possible to pre-plan transition areas to coincide with existing/proposed grade changes and therefore minimize the required transition length. However, this type of minimization would require complete buy-in from multiple property owners, intense coordination during buildout of the Midtown development area, and certain property owners might be expected to develop individual sites with the "greater good" in mind. While certainly possible, the study team sees this level of coordination and cooperation as unlikely and therefore advises against such planning. Figure 5-7 is an example of shortened/coordinated transition sections in the area (transition section shown in blue).

Figure 5-6. Potential Impacts of Elevated to At-Grade Transition
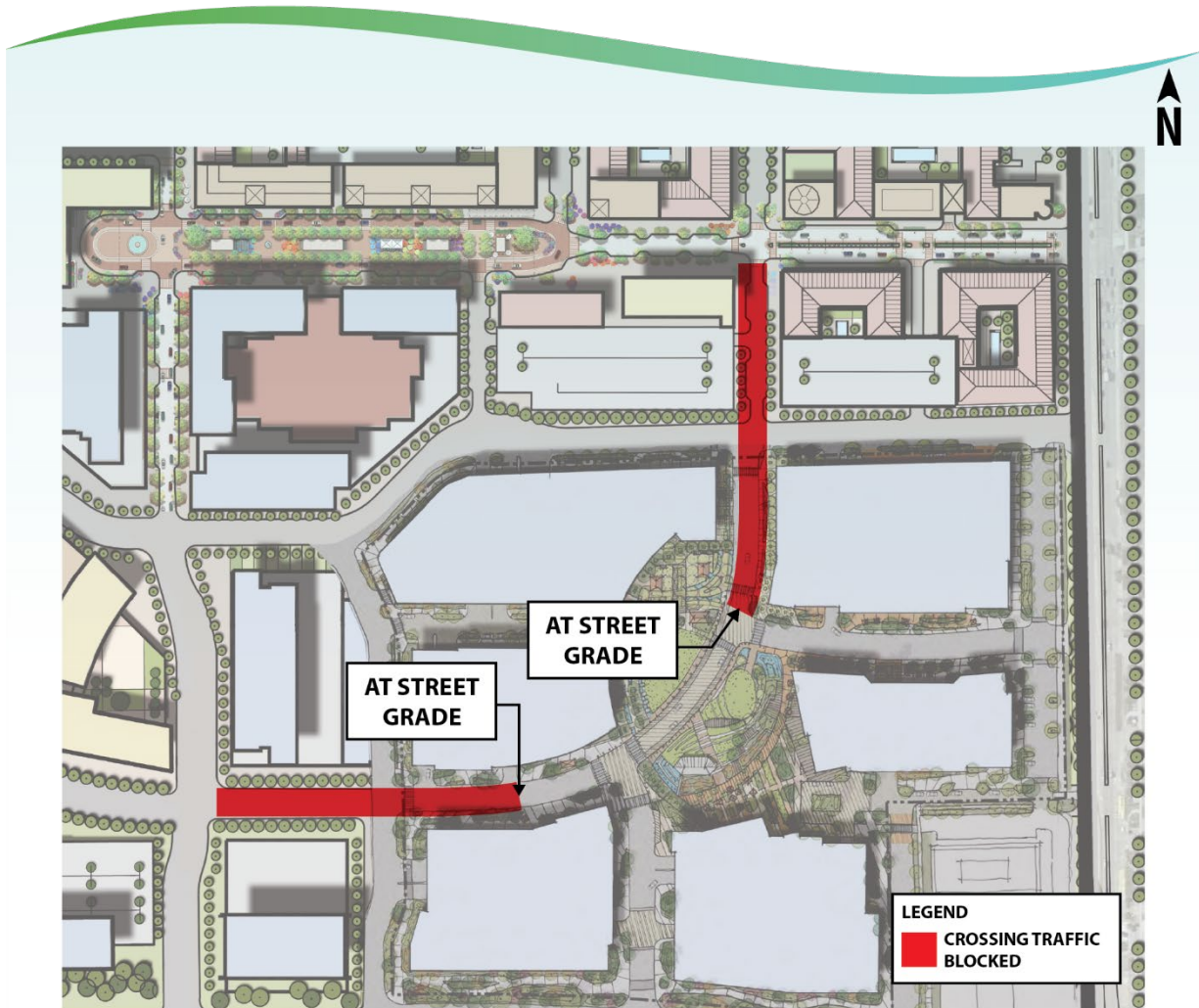
Figure 5-7. Conceptually Feasible Transition Limits with Minimized Impact
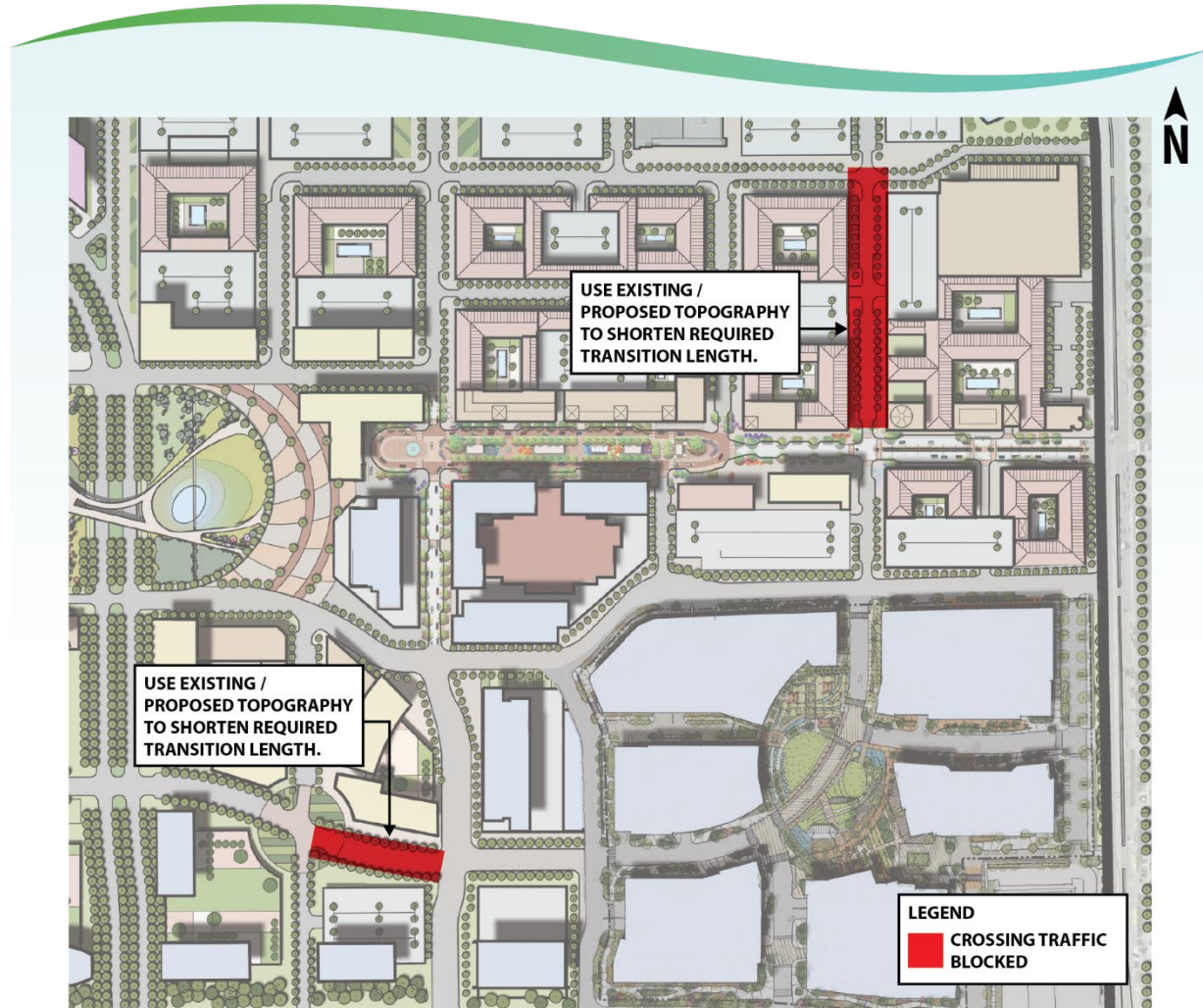
Due to the additional ground-level elements (for example, sidewalks, roadways, landscaping, on-street parking, bike lanes) and the added technical complexity in providing the ATS level of service intended, an elevated system is recommended. Table 5-2 summarizes the comparative characteristics between the two system alternatives.

Table 5-2. At-Grade vs. Elevated System Comparison

Comparative Metrics	At-Grade	Elevated
Additional Right-of-Way Required (ft^2)	53,900	0
Implementation Cost ($M)	108	95
Operational Reliability	**DOES NOT MEET** target headways	**MEETS** target headways
Total Travel Time (minutes:seconds)	9:10[a]	5:50
Connectivity to Sidewalk	Along curb	Stairs and elevators

Table 5-2 continued on next page

Table 5-2. At-Grade vs. Elevated System Comparison

Comparative Metrics	At-Grade	Elevated
Connectivity to Developments	Curb access	Sky bridge connection direct to adjacent building or integrated within building
Impact to Pedestrians	Conflict points created along curb and at intersections	No conflict points created
Impacts to Vehicle Circulation	Frequent traffic could cause signal delays at peak travel times	No impacts created

ᵃ Does not include priority signal implementation.

5.6 Regional Connection Alignment

The assumptions behind the regional connection alignments include having a minimal-impact perspective and a primary focus of bridging the existing regional transit connectivity gap. These alignments are conceptual in nature and although development of the rationale behind the connections was coordinated with DART, they are not currently represented in any DART plan for future service. However, as detailed in Section 3, these regional connections are essential to capturing the full potential of the Midtown ATS.

A key part of this study has been the development of alternative alignments/routes that could interconnect with regional transit connections for various automated transit technologies appropriate for the scale and needs of the Dallas Midtown development. Although the study team also considered a combined regional connector/internal circulator that could use a common technology and shared guideway, after evaluation, a shared regional/internal transit system was not recommended due to challenges in ridership differences, synchronization, impacts/inefficiencies of the ATS, fixed facilities' requirements, and wayfinding. As the needs for internal circulation and regional transit connections are significantly different, the primary focus has been for separate transit systems for the internal circulation component and the regional transit connections.

> "I would call Midtown a TOD [Transit Oriented Development] without the *T*, which is a problem over there. If we're going to add that density, we can't have a ton of cars running in and out of there all the time."
>
> *Source: Lee M. Kleinman—City of Dallas City Council, District 11*

5.6.1 Potential New Alignment Connections

The three regional connections in the ridership estimation exercise include an east–west connection that would link DART's Green, Red, and Blue lines in addition to a north–south connection that would connect Midtown to the proposed Cotton Belt line. Because of Midtown's location along the I-635 LBJ roadway, it is centrally located in a logical intersection of these alignments (Figure 1-4).

A significant design and construction cost could be saved by implementing a system more similar to the recommended GRT technology in an elevated system than with light rail.

5.6.1.1 Cotton Belt Line

The proposed Knoll Trail Station of the Cotton Belt line is directly north of Dallas Midtown and can be directly accessed via Montfort Drive. Noel Road also runs north–south from Midtown toward the Cotton Belt; however, there is currently no median at Noel Road south of Spring Valley Road, and there would

need to be either significant right-of-way acquisition or a sharp turn when the alignment reaches Verde Valley Lane. Montfort Drive, on the other hand, has an existing median that would be adequate for an elevated system and would run alongside the Addison Entertainment District in addition to many residential and commercial uses.

5.6.1.2 Green Line

The connection to the Green line would most logically occur at the Farmers Branch Station. The existing roadway configuration traveling east on Valley View Lane before turning north on Alpha Road includes a median of sufficient width for the majority of this corridor. The length of Alpha Road between Midway Road and Dallas North Tollway is the only segment without an existing median that could be used for the elevated system. This alignment would run alongside Brookhaven Community College, connecting development west of Dallas North Tollway and several north Dallas neighborhoods along Valley View Lane.

5.6.1.3 Red and Blue Lines

The connections to the Forest Lane Station (Red line) and LBJ/Skillman Station (Blue line) will be the most challenging with the lack of an existing thoroughfare link that exists with the other connections. A transit envelope was left alongside I-635 LBJ roadway; however, the transit connection would need to cross over I-635 LBJ roadway to access the Forest Lane Station. The potential connections this east–west alignment would create are significant; however, Medical City, another Dallas limited access roadway (US 75), and a substantial amount of retail and residential destinations are located between Midtown and these two stations. This connection would allow regional transit trips a more-direct connection to central, south, north, and east Dallas.

5.6.2 Immediate Connections

Though these three connections—Cotton Belt, Green, and Red and Blue lines—would provide the most access to the regional transit network, there are options that could be implemented without construction, right-of-way, or significant vehicle-procurement costs. By using the existing roadway infrastructure and an express bus marketed for these significant connections, an immediate and comparatively low-cost connection can be made to regional transit, as the Midtown GRT system and/or development is in early development stages. A comparable major development, Atlantic Station (west of midtown in Atlanta, Georgia) uses this style of connection to consistently provide access to Atlanta's heavy rail transit system.

One such connection already in DART plans would use the LBJ Expressway (tolled lanes of LBJ Freeway) to connect the Forest Lane Station on DART's Red line with Dallas Love Field and DFW airports. By using existing ramps accessing LBJ Freeway (Interstate 635 TEXpress) at Preston Road, this express bus could make an additional stop on Preston Road on the east side of Dallas Midtown without adding significant total trip time to the route.

Similarly, the existing Montfort Road could be initially implemented with an express bus connecting Midtown and the Cotton Belt, upgrading to an elevated system as ridership and demand grows.

5.7 Alignment Selection Analysis

For the technology assessment report (Appendix E), the study team developed 25 different alignment alternatives for nine different alternative technologies. Key factors considered when developing these alignment alternatives included the following:

- **Feasibility of alignment right-of-way**—Considering geometric and spatial constraints of technologies.

- **Constructability**—The complexity of design and surrounding development plans, estimated development schedule, and design that could potentially hinder progress in the implementation of a system.

- **Optimization of alignment/station locations**—The degree to which the alignment/station locations serve the greatest population density areas

  - Transit catchment areas—What are the transit catchment areas around the proposed station locations?

  - Visibility/wayfinding/ease of use—Is it readily visible? Is wayfinding intuitive? Is the system easy to use?

  - Adverse visual impacts—Are there any adverse visual impacts? For example, adjacency to sensitive areas, such as passing through the park, might be an issue to some.

- **Level-of-Service**

  - <u>Operational level-of-service</u>—What is the operational level-of-service provided by the transit system's normal operational configuration on the alignment alternative? For example, a dual-loop configuration allows for frequent service in both directions and the shortest route to destination.

  - <u>Failure management flexibility</u>—How flexible is the vehicle and/or track technology in responding to service failure? For example, a dual-loop configuration provides built-in redundancy: if either loop is out of service, users can still use the other direction loop, and with properly located failure management crossovers, significant failure management operational flexibility would permit continued service.

- **Multimodal connectivity**—Connectivity to regional transit and other ride services.

- **Scale impacts**—Is the scale of the proposed alignment/station locations appropriate for the surrounding context? For example, an elevated ATS along the main "spine" of Dallas Midtown would be an example of something over-scaled and inappropriate for the specific location, given the relatively narrow street and relative proximity of the building facades to the street.

- **Expandability**—Can the alignment be developed and operated in phases, as necessary? Can the alignment be readily expanded in the future?

- **Traffic impacts**—What are the traffic impacts for street-based alignments/routes, such as those for autonomous vehicles?

- **Passenger types**—These vary and can include workers working within Dallas Midtown (who would typically commute in morning and afternoon, along with some usage during lunchtime) versus non-workers (who might come at any time during the day or evening). Passenger types can also vary by their origin/destination (for example, people arriving by private auto to development or parking garages versus people arriving by ride services such as Uber, Lyft, and taxi versus people arriving by regional connection, such as DART buses and future regional connections).

As a result of the process of narrowing down the alignment alternatives, the study team has determined that the optimal alignment alternatives for further consideration are Option 1 and Option 2 (Figures 5-8 and 5-9). Some key parameters, and pros and cons of Option 1 and Option 2, follow each figure.

5.7.1   Option 1

Figure 5-8. Option 1 Alignment

1.9-Mile Dual Loop
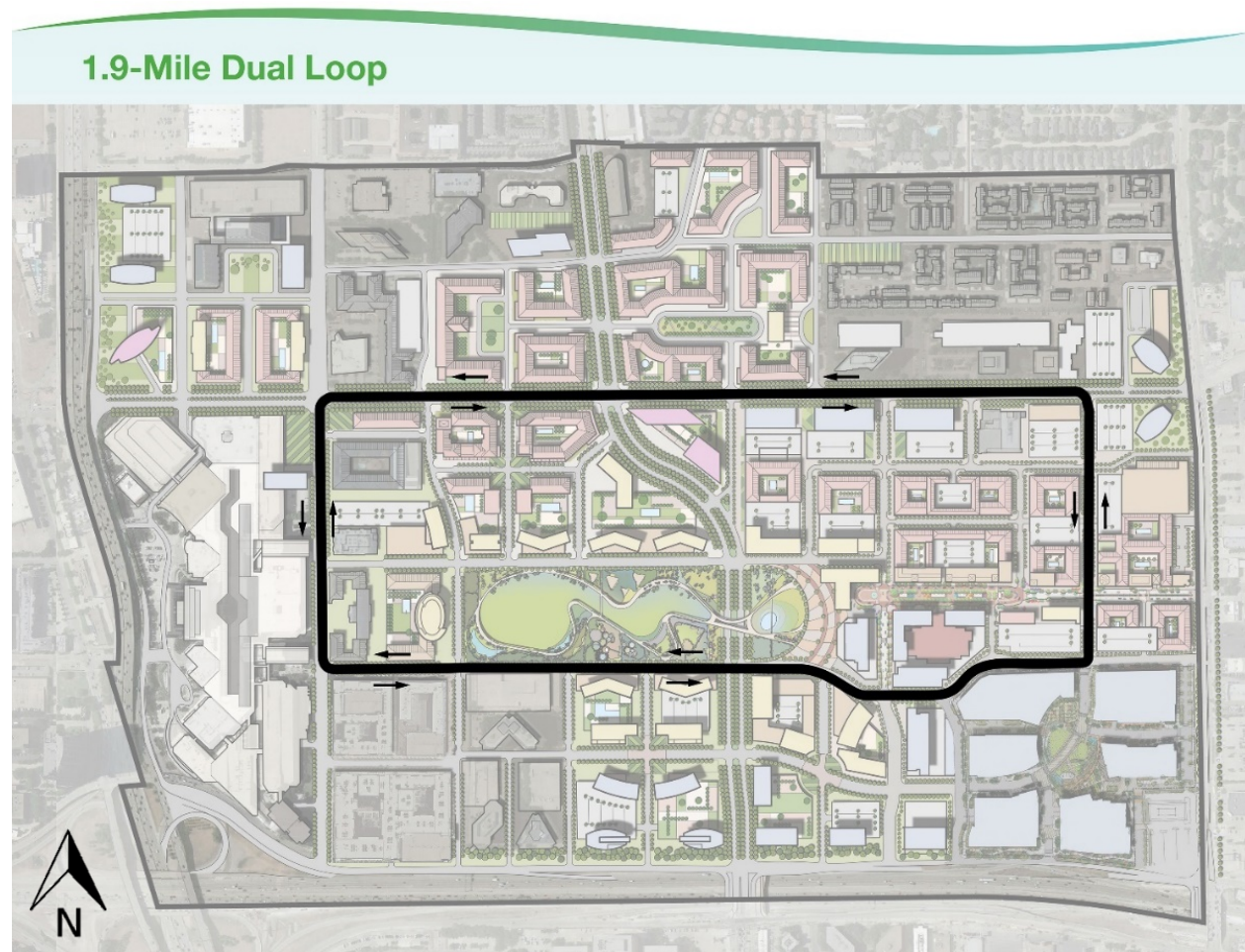
Option 1 has a system length of approximately 1.9 miles. The percent of the total Midtown area within the 1/10-mile catchment area is about 60 percent. The percent of the total Midtown area within the 1/4-mile catchment area is about 99 percent.

- Pros
  - Runs alongside the park; uses the more established James Temple Drive.
- Cons
  - Misses much of the high-density development along I-635 LBJ Freeway.
  - Potential safety conflicts along the park for at-grade technologies.

Figure 5-9. Option 2 Alignment

2.2-Mile Dual Loop
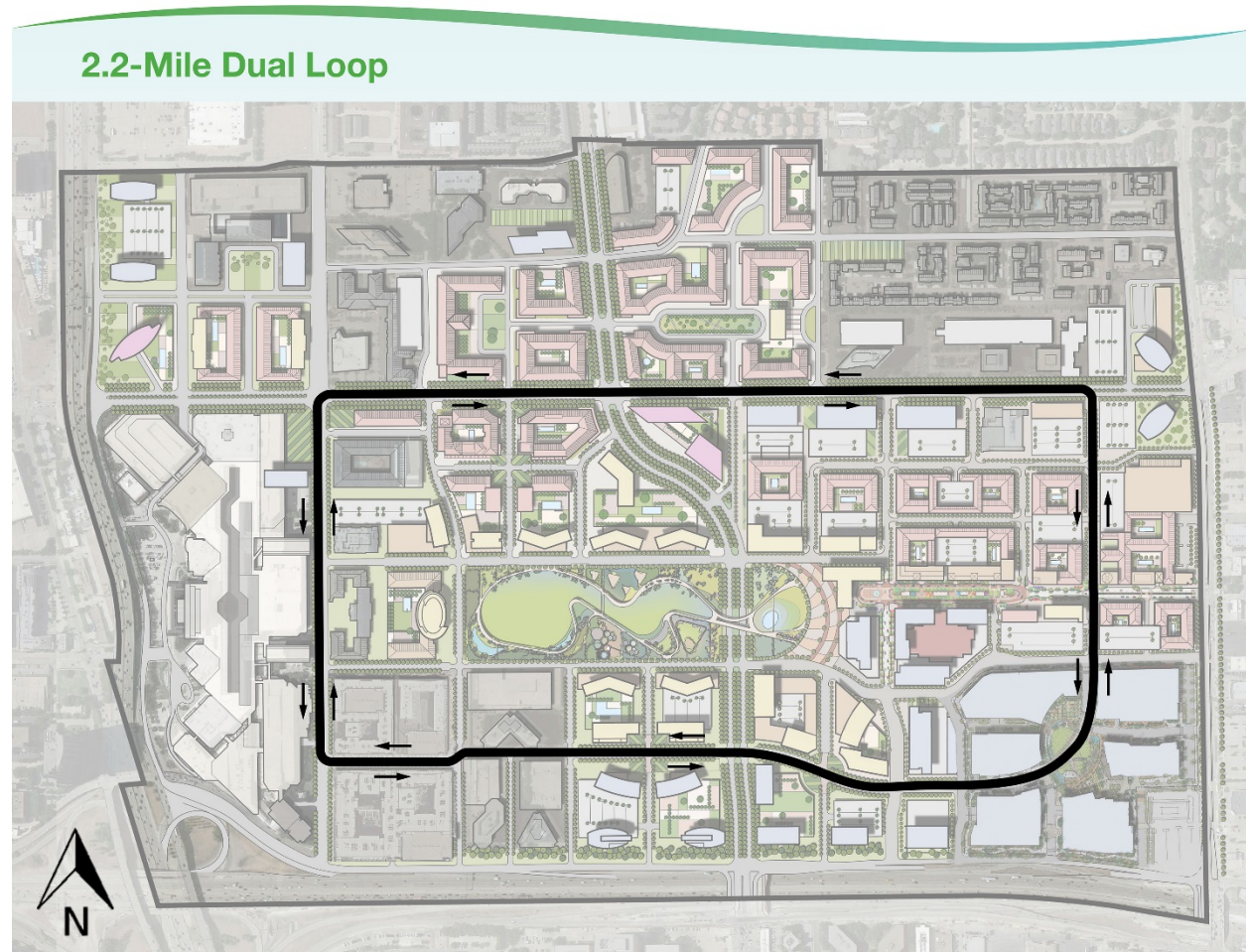
Option 2 has a system length of approximately 2.2 miles. The percent of the total Midtown area within the 1/10-mile catchment area is about 70 percent. The percent of the total Midtown area within the 1/4-mile catchment area is about 99 percent.

• Pros

  – Passes through approximately 5 million square feet of planned development along I-635 LBJ Freeway that could represent about 15–20 percent of the total district development, including the parking catchment area along the southern boundary of Midtown.

• Cons

  – Existing right-of-way pinch along the southern stretch of the alignment.

  – Midtown Park would be a minimum of 800 feet away from the ATS.

5.8   Recommended ATS Alignment

The study team recommends Option 2 as the preferred ATS alignment. Although this option poses right-of-way challenges not present with Option 1, the alignment services a higher percentage of the district development due to its closer proximity to LBJ Freeway. As such, with the driving force of encouraging the highest ridership possible, Option 2 is the preferred choice.

Expanding the dual-loop configuration from a systems-perspective would not be difficult because of the flexibility in the recommended GRT vehicle. With no specialized track or fixed guideway required, the elevated system could be expanded with additional segments or an at-grade access point could allow for GRT to utilize the street network. Figure 5-10 demonstrates potential expansion of the ATS within Midtown should the demand justify the growth.

Figure 5-10. ATS Network Expansion Potential
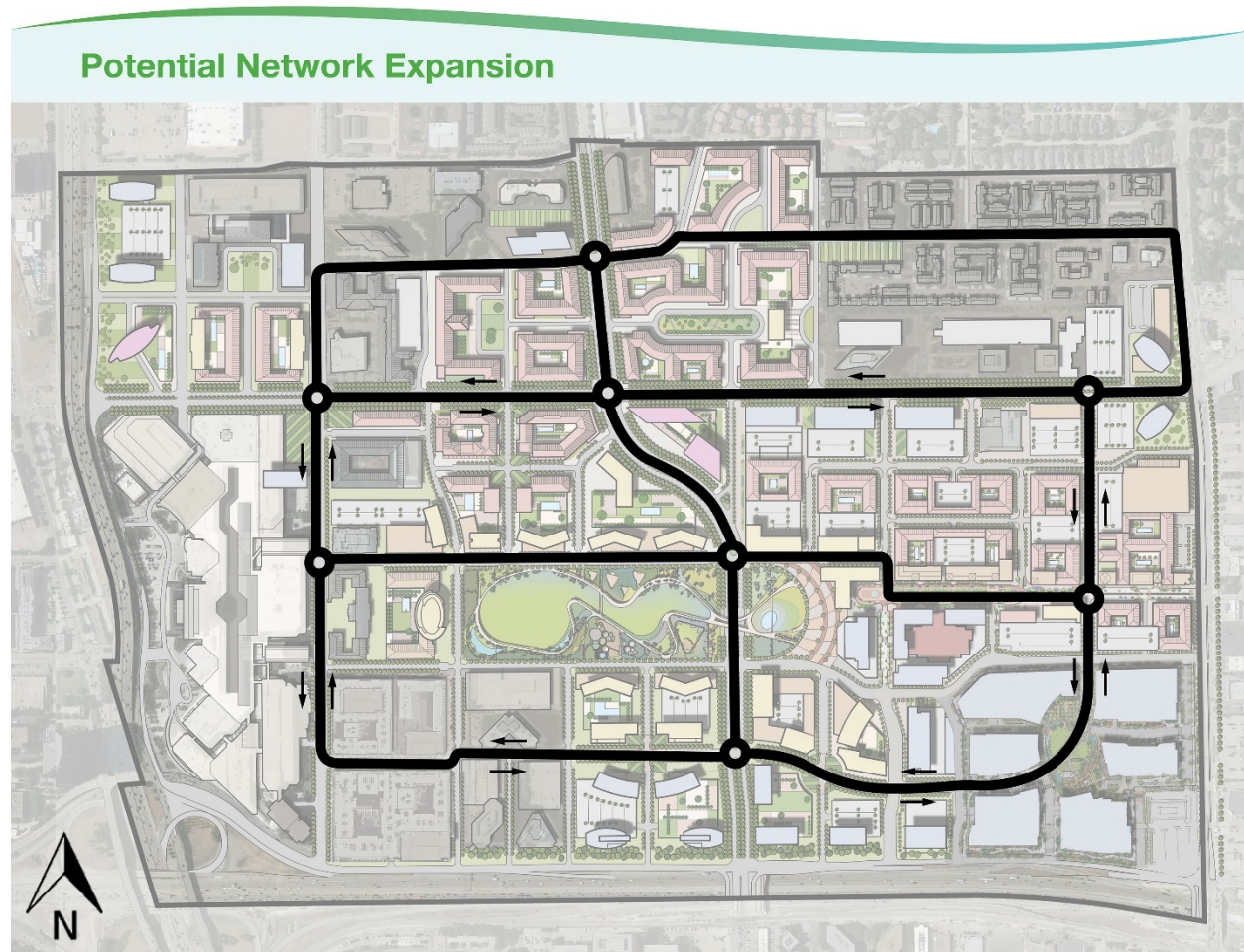
5.9   Summary

No right-of-way acquisition requirement is expected for the projected elevated system alignment and stations. Right-of-way acquisitions for the at-grade system alignment and stations are expected to be approximately $8 million.

Care should be taken to understand the inherent risk of eminent domain valuations in this area. Because most of the subject area is not developed to the level outlined in the proposed zoning/master plan, right-of-way acquisition costs could vary depending on the level of development present at the time of implementation.

There is an opportunity to convert existing (or projected) vehicular travel lanes into space for the ATS, thereby reducing the right-of-way required by eminent domain or other measure. For example, on the south and east legs of the recommended ATS alignment, the projected right-of-way in the Midtown Thoroughfare Plan consists of two 11-foot vehicular travel lanes in each direction with a 12.5-foot parkway

(planting zone and sidewalk treatment alongside the roadway). The at-grade ATS could fit into this planned section by eliminating a travel lane and adjusting the parkway width slightly. The resulting section would be either of the following:

- One 11-foot vehicular travel lane each way, a 10-foot parallel parking lane, two 10-foot ATS sections (7-foot ATS lane with 3-foot buffer), and an 8.5-foot parkway on each side

- One 11-foot vehicular travel lane each way, an 11-foot two-way left-turn lane, the 20-foot ATS median, and an 8-foot parkway on each side

Overall, the proposed alignment is constructible with several qualifications:

- The proposed ATS may need to "swing wide" at each hard corner to avoid existing structures and right-of-way limits. Further analysis is necessary to confirm that existing facilities do not interfere with the ATS alignment. Conflicts at these turning points are not expected for GRT vehicles, assuming a turning radius of 30–40 feet.

- The eastern edge of Noel Road has recently been built out. As such, additional right-of-way is limited. Dedications for this station may need to be made primarily on the western property with an offset station alignment.

- Along the southwest corner, right-of-way may not be readily available due to recent development in this area.

- At the southwest corner of the ATS loop the proposed ATS alignment passes through an existing office tower complex. Although a future roadway is shown at this location on the City of Dallas Thoroughfare Plan, no mechanism exists to require this dedication unless the property is redeveloped. Because redevelopment of the property is not expected by the time of ATS implementation, further coordination, entitlements, and cooperation with the existing property owner may be required to construct the ATS alignment through the subject property.

This analysis and these recommendations make judgements based on overall mobility and feasibility in implementation. Should agencies or developers participate in the alignment selection process after this study has concluded and especially if individual agencies or developers engage in funding the system implementation, the ultimate alignment may change because of the positive impact on constructability. Should the alignment alter from the recommended alignment as stated, however, a similar process of mobility analysis should follow to maximize benefit to the ATS system and surrounding developments.

Section 6

Location of Shared-Use Parking and Automated Transportation System Stations

6 Location of Shared-Use Parking and Automated Transportation System Stations

6.1 Shared-Use Parking Location Criteria

The study team has developed the following guiding principles for parking at Dallas Midtown based on feedback received from study partners and industry best practices for similar developments:

- Encourage a "park once" policy intended to limit internal vehicular circulation within the Dallas Midtown district.

- Develop the efficiency of existing and new parking assets through shared-use parking strategies and strategic locations that maximize the ability of parking structures to conveniently serve as many user groups as possible.

- Develop parking structures that act as multimodal hubs integrated with existing and future active transportation options and the internal ATS.

The location of planned multiuse parking facilities should be determined based on a specific set of criteria (Table 6-1). Note that Figure 6-1 references walking-distance level of service; these categories are shown on Table 6-2.

Table 6-1. Dallas Midtown Parking Garage Site Location Criteria

Criteria	Purpose/Intent
Proximity to ATS stop (less than 1/10 mile preferred)	B+ walking distance level of service or better
Accessibility to main road	Reduce internal circulation and traffic on roads planned to be pedestrian/bicycle friendly
Potential to incorporate with transit	Support ridership goals of planned transit lanes, and provide a flexible, shareable parking supply
Potential for sharing among multiple uses	Efficient use of parking assets, reduction in the number of spaces needed to be built

Table 6-2. Walking Distance Level of Service Categories

Maximum Walking from Parking to Destination	Level of Service D (feet)	Level of Service C (feet)	Level of Service B (feet)	Level of Service A (feet)
Climate Controlled	5,200	3,800	2,400	1,000
Outdoors, Covered	2,000	1,500	1,000	500
Outdoors, Uncovered	1,600	1,200	800	400

In conjunction with projected shared-use parking demand for the subject site at full buildout, Figure 6-1 illustrates several locations that potentially meet the outlined criteria. Because the location of the ATS stops are not finalized, the preliminary discussion below only considers the other three factors shown in Table 6-1.

The locations on Figure 6-1 provide a high-level look at a few locations where parking structures may be more strategic, with the center of each "target" being the most advantageous, given the goal of using parking as a support system for the ATS, and outer, concentric rings less advantageous. The most advantageous locations tend to be along the main roads for easy access and reduced circulation on the internal streets, and near larger conceptual development sites.

Figure 6-1. Parking Structure Site Selection Analysis

6.2   ATS Station Location Evaluation/Methodology

The placement of stations within the Midtown District is critical to how effectively the system serves future development. The station location analysis is based on the Preferred Alignment (Option 2) assuming an elevated guideway and ATS technology. All land uses in the area are assumed to be transit-supportive and will be enhanced by station proximity. Station spacing was established based on walking distance between stations, with the provision that all parcels in the development be no more than 660 feet, or a 2.5-minute walk, from a station. The number of stations and station spacing was developed to provide the most favorable walking-distance outcome.

Station screening was a macro-level qualitative evaluation with nine basic criteria to highlight major benefits, constraints, and potential fatal flaws:

Station spacing. Stations were spaced to provide even distribution and walkability from adjacent developments with a maximum walking time of 2.5 minutes from any point to a station or 5 minutes between stations.

Parking access/distribution. This was ranked based on access to potential joint-use parking facilities.

Midtown Commons proximity. Pedestrian linkage and proximity to Midtown Commons as the central open space for the district were considered.

Sight lines/visibility. Consideration was given to station visibility from street corridors and sight lines to Midtown Commons.

Multimodal transfer. Station locations were identified to provide a minimum of one location for interconnectivity to future fixed-route transportation or bus modes.

Development density/land use. Based on assumption of future land use, locations were ranked based on their proximity to the highest-density zones of the district.

Right-of-way availability. Sufficient space for the station and associated guideway was considered, and stations were located in areas with sufficient space for station operation.

Civic presence. Stations were located to provide visibility and a civic street presence to allow the station to become a focal point in the development.

Street character/walkability. Street typologies established in the master plan were used to develop station locations based on overall walkability and connectivity via street corridors.

Each criterion was given a corresponding ranking based on the program assumptions mentioned above and on the relationship of the station location to the surrounding area (Figure 6-2).

Figure 6-2. ATS Station Evaluation Criteria and Ranking

Station Location	1	2	3	4	5	6
Criteria	Evaluation Ranking					
1/4 Mile Station Spacing (1/8 Mile Walking Distance)	Good	Good	Good	Good	Good	Good
Parking Distribution/Vehicular Access	Good	Good	–	Good	Neutral	–
Park Proximity (Walking Distance)	Good	Neutral	Neutral	Neutral	Good	Good
Sight Line/Visibility	Good	Neutral	Neutral	Neutral	Good	Neutral
Multimodal Transfer	Good	Good	–	–	–	–
Development Density/Land Use	Good	Good	Neutral	Good	Good	Neutral
Right-of-Way Availability	Good	Good	Good	Good	Good	Neutral
Civic Presence/Open Space	Good	Neutral	Neutral	Good	Good	Neutral
Street Character/Walkability	Good	Good	Good	Good	Good	Neutral

Good   Neutral   Poor   – N/A   ✗ Fatal Flaw

6.3 Station Location Recommendations

Based on the above criteria, six potential station locations were identified to provide the most evenly distributed and accessible fixed-route transit network (Figure 6-3). The six locations provide even distribution of access, pedestrian connectivity, parking, intermodal access, and a high level of connectivity with Midtown Commons. Each station location would be designated by a gateway element at the cross street to identify patron access points to the ATS system. The gateway elements would be reinforced by the street grid and pedestrian linkages. Primary pedestrian linkages between the stations/gateway elements and Midtown Commons are identified to reinforce the need for enhanced pedestrian boulevards at these locations.

Figure 6-3. Recommended ATS Station Location
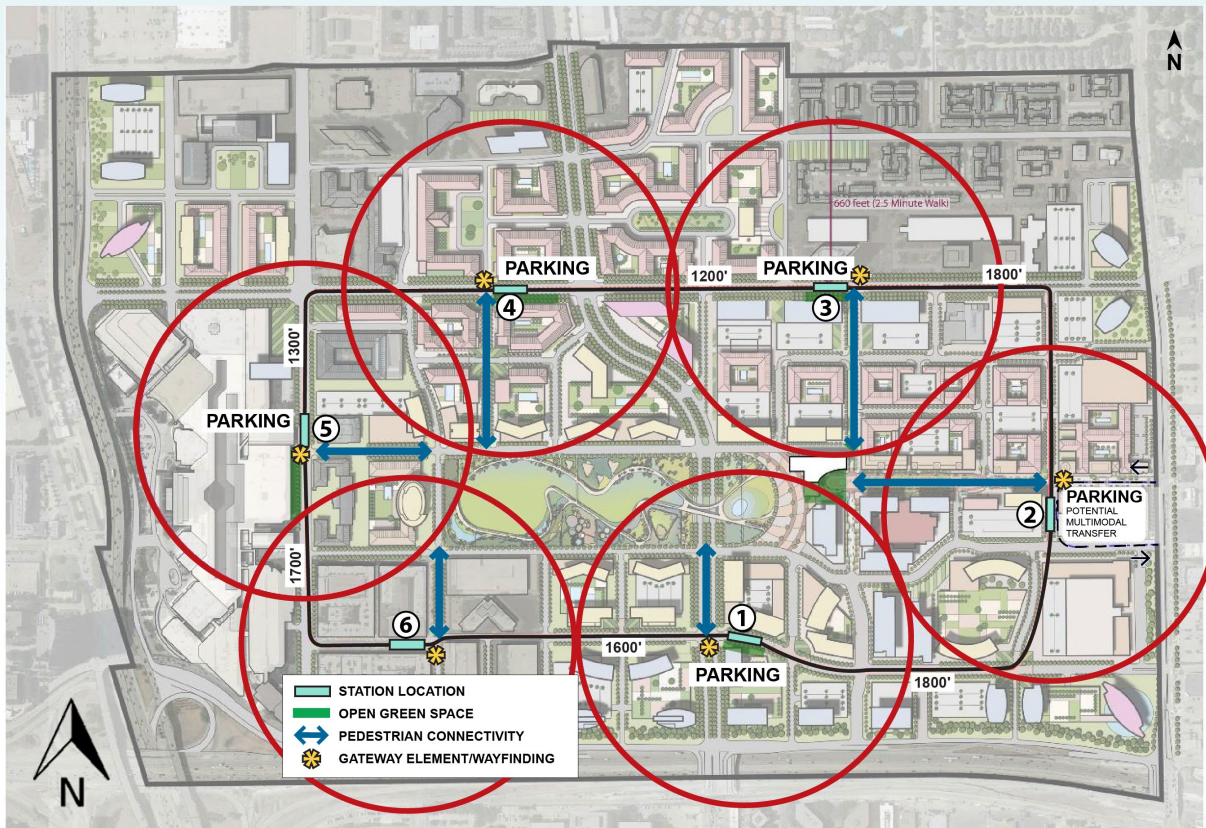
6.4 Pedestrian Linkages/Boulevards

Sidewalks play a critical role in character, function, enjoyment, and accessibility along street corridors to connect neighborhoods, parks, and other community destinations. In addition to providing space for pedestrians, the space between property lines and curbs also accommodates street trees and other plantings, stormwater infrastructure, street lights, and furnishings. This section defines the desired spatial zones for a complete street and comfortable pedestrian environment. The recommendations can be applied to streets based upon the available right-of-way and provide considerations for better activating the streetscape to enhance people's experiences.

6.4.1 Elements

6.4.1.1 Frontage Zone

The frontage zone (Figure 6-4) is the area of sidewalk that immediately abuts buildings along the street. In residential areas, the frontage zone may be occupied by front porches, stoops, lawns, or other landscape elements that extend from the front door to the sidewalk edge. The frontage zone of commercial properties may include such elements as architectural features, outdoor displays, café seating, awnings, and signage. Frontage zones may vary widely in width, from just a few feet to several yards.

6.4.1.2 Pedestrian Zone

The pedestrian (walking) zone (Figure 6-4) is the portion of the sidewalk space used for active travel. For functionality it must be kept clear of any obstacles and be wide enough to comfortably accommodate expected pedestrian volumes (as anticipated by density and adjacent land use), including those using mobility assistance devices, pushing strollers, or pulling carts.

6.4.1.3 Landscape Zone

The landscape, or curbside buffer, zone lies between the curb and the pedestrian zone (Figure 6-4). This area is occupied by transit stop elements such as benches, signage, and shelters. It also contains fixtures such as street lights, trees, bicycle racks, parking meters, signposts, signal boxes, and trash and recycling receptacles. In commercial areas, it is typical for this zone to be hardscape pavement, pavers, or tree grates. In residential or lower-intensity areas, it is commonly a planted strip.

Figure 6-4. Pedestrian-Scale Elements Example Scenario

Frontage Zone	Pedestrian Zone	Landscape/Furniture Zone	Total
desirable width	desirable width	desirable width	desirable width
6' (2' min.)	10' (8' min.)	6' (5' min.)	22' (15' min.)
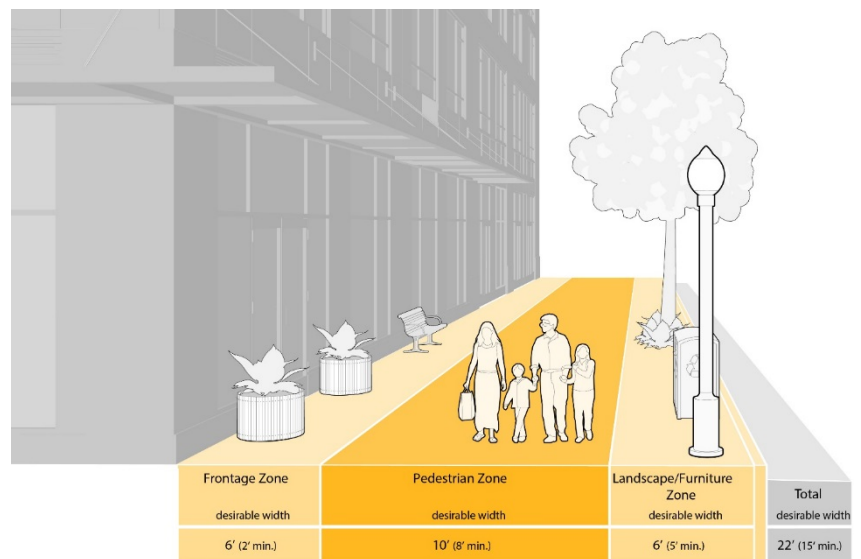
6.4.2 Design Considerations

Vibrant street walls with active uses adjacent to the sidewalk are particularly valuable and are essential to "main street" contexts. Where an active use adjacent to the sidewalk is not feasible, visually engaging walls should be provided adjacent to the street.

Outdoor dining opportunities contribute to a lively street environment and add economic value by enabling private commercial activity to spill into the public street environment. Sidewalk cafés are encouraged in main street contexts and other areas with commercial activity.

Vibrant street walls, outdoor dining opportunities, and landscape structures such as rain gardens are among the design considerations for pleasing pedestrian corridors and streets.

Planting in the public right-of-way typically occurs in the landscape/furniture zone; however, this is not the only place that can accommodate planting. Wherever there is an opportunity for landscape features, street or development projects should also look for opportunities to incorporate best management practices, such as rain gardens. The preferred best management practices for use in the right-of-way are abovegrade systems within the sidewalk that treat stormwater runoff from adjacent roads and sidewalks.

While there are some exceptions, most street furniture is installed in the landscape/furniture zone; on occasion, bicycle parking may be installed in the frontage zone if it is sufficiently wide enough to accommodate it. Regardless, street furniture should not impede movement in the pedestrian zone.

Seating is most commonly located in the landscape/furniture zone of the street, but may also be placed in the frontage zone. Seating in the amenity zone should generally face away from the street and toward the sidewalk or be aligned perpendicular to the curb. Seating in the frontage zone should face the street.

In locations with severely constrained rights-of-way, it is possible to provide narrower frontage and pedestrian zones. Sidewalk width is based on local context; therefore, in retrofit locations where development is not occurring and where existing building are anticipated to remain, 5-foot-wide sidewalks may be adequate.

The provision of tree wells or landscape strip within the landscape/furniture zone will be based on the existing or planned character of the neighborhood.

The widths of the various sidewalk zones will vary given the street type, the available right-of-way, scale of the adjoining buildings, and the intensity and type of uses expected along a particular street segment. A balanced approach for determining the sidewalk width should consider the character of the surrounding area and the anticipated pedestrian activities. For example, is the street lined with retail that encourages window shopping, or does it connect a residential neighborhood to a commercial area where pedestrians frequently need to pass one another? Do the scale of the buildings and the character of the street indicate a need for a wider sidewalk?

6.5 ATS Station Framework

The ATS stations must support the transit technology with an attractive, efficient, clean, safe, and accessible environment. Passenger facilities provide boarding and waiting areas, amenities, and concessions. In addition to accommodating the needs of transit riders, the primary design goal for the system should

be the enhancement of the image of public transportation within the Midtown district and establishment of a brand for the ATS system. A positive community image will result in the enhancement of ridership potential through facilities that provide passenger comfort, safety, and convenience in an easily understood environment. The creation of a positive passenger experience requires effectively integrating the functional elements of the transit technology, site-specific context, and the "transit friendliness factor" of the facility. The primary issues to be considered in design of the stations include the following:

- Community image

- Passenger mode transfers

- Weather protection

- Passenger security (crime prevention through environmental design)

- Passenger safety

- Passenger comfort

- Maintenance and vandalism

- Accessibility

- Employee security

- Code and standards compliance

- Potential parking structure integration

A typical station framework was established to evaluate functional and dimensional needs for the station and included the following programmatic requirements:

- Elevated platform (minimum of 16 feet clear above right-of-way)

- Platform length of approximately 120 feet (may vary depending on the final technology and patronage)

- Center platform configuration with minimum platform width of 22 feet, allowing center vertical circulation

- Elevator, stair, and optional escalator access

- Covered boarding platform

- Considerations of passenger amenities (for example, seating, windscreens, emergency call station)

Provisions should be made to accommodate grade-separated pedestrian access from adjacent development where desired by property owners. This connection would be at a third level approximately 30 feet above the street for an elevated guideway system. Pedestrian connections would also be provided via crosswalks at street intersections.

Figure 6-5. Conceptual Station Design
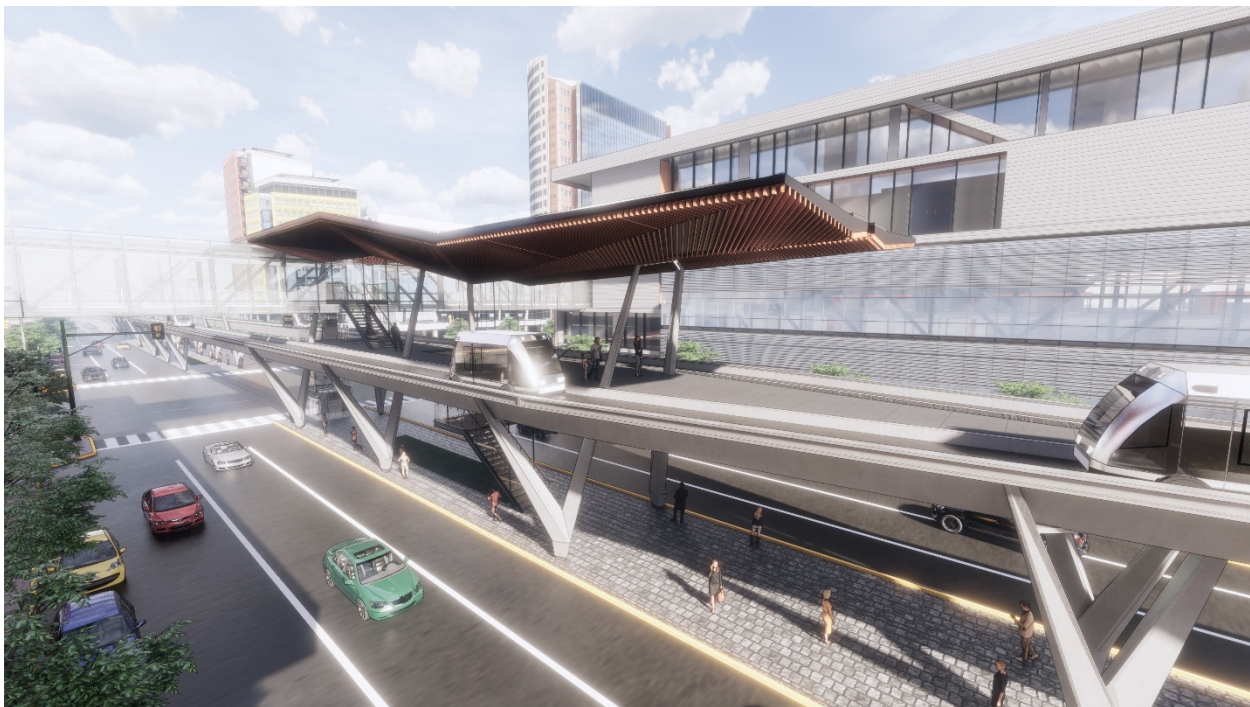
The proposed station design is based on accommodation of the framework requirements for the station platform and concourse within the proposed right-of-way constraints. Vertical circulation is provided by a central stair and elevator from the street-level concourse to the platform above. Escalators may be provided if needed to support the level of patronage. Should a grade-separated pedestrian access be required, the vertical circulation will extend to a pedestrian bridge at a level above the platform. A central canopy covers the platform and concourse below and can be extended to the pedestrian bridge above.

Functionally the station canopy provides protection of the platform, concourse, and vertical circulation elements while also serving as the primary form-giver and image of the stations. While the design of the canopy may evolve as the project and design of Midtown advances, the design concept illustrated on Figure 6-5 is intended to provide a modern and timeless image that establishes an identity and brand of the Midtown ATS. The canopy is aesthetically and functionally integrated with the guideway structure through extension of the guideway columns as canopy supports, further integrating the station into the overall infrastructure and image of the Midtown ATS.

6.6   Connection Parking and ATS Stations

The ATS provides the opportunity to minimize internal vehicular circulation and reduce vehicular dependency for movement internal to the Midtown development. As stated previously, it is essential to develop a parking infrastructure strategy that encourages, rather than discourages, using the ATS as the primary method of internal circulation throughout Midtown. District-wide shared parking leverages parking as a tool to support, rather than discourage, use of the ATS.

To accommodate this concept, station locations have been identified (Figure 6-3) that provide the potential for integrated parking based on adjacency to the street network. This approach allows parking at the most convenient location to the Midtown employee or visitor and use of the ATS as a distribution system within the development. Parking would be provided outside of the street/ATS right-of-way, presumably within a development parcel. Connectivity to the adjacent station would be provided by pedestrian bridge or at the street level with minimized and protected roadway crossing connections. The design of the connection can be flexible; there are comparable examples in DFW at locations such as the DART Cityline/Bush Station. Figure 6-6 shows concept art of a parking structure and the recommended ATS station concepts as outlined in Section 5.

Figure 6-6. Parking Structure and ATS Station Connection Concept

Section 7
Implementation

7 Implementation

The recommendations around the shared-use parking strategy and ATS within Dallas Midtown will require significant consideration into the policies, stakeholders, timeline, and financial support needed for implementation. The following section considers the expected complexities in the implementation process and shares alternative strategies and lessons learned from comparable parking and transportation systems. This will include considering expected cost, potential financing strategies, existing and potential parking regulations, and implementation schedule alternatives.

7.1 Shared-Use Parking System

The vision for Dallas Midtown as laid out in the *Valley View–Galleria Area Plan* (NDCC and City of Dallas, 2013) includes the following:

The area's approach to transportation and parking will have a direct impact on both its ability to achieve the stated vision and the success of the planned ATS.

A parking and transportation management plan for Dallas Midtown would provide a toolbox of strategies to manage the local circulation and parking systems. Additionally, it could serve to reinforce the vitality of the planned ATS by promoting transportation and parking policies and behaviors that complement the ATS as opposed to competing with it.

Both roadway and parking infrastructure consume a valuable asset (land) and have tangible capital costs for construction, in addition to ongoing O&M costs, that are typically not fully recouped through end-user fees. Therefore, encouraging alternative modes of transportation to, from, and within Dallas Midtown; allocating parking efficiently; sharing parking; and implementing parking and transportation demand management measures could have tangible aesthetic and financial benefits for Dallas Midtown as a whole.

- Pedestrian-friendly mixed-use neighborhood
- Vibrant shopping and entertainment district
- Higher density supported by a network of enhanced streets and open spaces
- Central park or regional amenity
- Network of streets with diverse physical characteristics to create an urban fabric

As discussed in Section 6.6, the implementation of a district-wide shared parking strategy will require several core initiatives. This section discusses the recommended initiatives and the different ways and means in which these initiatives can be achieved. These recommended initiatives include the following:

- Establishment of a management authority or entity responsible for the following:

  – **Parking**: Funding, operating, and maintaining parking; monitoring usage; and planning for new capital assets

  – **ATS**: Funding, operating, and maintaining the ATS; monitoring usage; and planning for expansions

  – **General transportation**: Funding, implementing, and monitoring transportation demand management programs to meet SOV goals

- Inclusion of transportation demand management, parking management, and technology initiatives that support ATS ridership (directly and indirectly) limit SOV use, and help drivers

- Changes to existing off-street parking requirements that allow for district-wide shared parking from a regulatory standpoint

This section discusses the rationales for, strengths and weaknesses of, and recommendations for the following:

- Off-street parking requirements

- Parking management authorities

- Transportation demand management, parking management, and technology

7.1.1 Off-Street Parking Requirements

All new development in the Dallas Midtown district is subject to use-based off-street parking requirements set forth in Chapter 51A, Article 13 of the City of Dallas codes. While there are some opportunities for individual projects to receive reductions from standard parking requirements through project-level shared parking or the provision of various desirable attributes (for example, tree preservation), the current parking standard is the industry norm, and there are no options for shared parking district-wide.

7.1.1.1 Why Change the Requirements?

Assuming that no changes are made to these regulations, developers will likely use the base off-street parking requirements to determine the number of new spaces they build for their development. Developers are unlikely, or at least less likely, to take advantage of reduction or variance opportunities unless they are significantly incentivized, or even mandated, to do so.

While changing the regulations will require administrative time and participation from the City Council, not doing so has significant consequences for the ATS, including effective elimination of internal ATS ridership. In addition, building to base parking requirements will result in a projected $1.1 billion to $1.5 billion in additional funds spent on parking and an estimated 3 million square feet dedicated to parking infrastructure.

The most successful district-wide shared parking systems are those supported by a parking ordinance so that new development can contribute to the system.

7.1.1.2 Recommended Strategies

Revisions to off-street parking requirements should accomplish the following goals:

1. Encourage developers to use existing shared-parking resources

2. Discourage developers from constructing significant amounts of project-specific parking for commercial uses

3. Support walkability and other non-vehicular arrival and internal circulation options within Dallas Midtown, including the ATS

Based on these goals, the following initiatives are recommended.

7.1.1.3 District-Wide Parking Management Plan

A district-wide parking management plan should be developed alongside the transportation and parking management authority and include the following components:

District-Wide Parking Management Plan

Overall district vision: What are we trying to achieve with our parking management strategy?

Parking management map and district areas: Graphical and narrative overview of parking management district, including user groups served, locations designated for short-term and long-term parking, and paid parking areas.

Parking enforcement and access: Overview of principles and procedures for parking enforcement, including vision and style of enforcement, technology used, and fee structure.

Pricing structure: Overview of pricing structure for transient and long-term parking, and of rate-increase schedule and method.

Developer exchange: Overview of methods and procedures through which new development can obtain parking in the shared structures.

Event parking management: Overview of any special procedures for events or periods of exceptionally increased activity.

Revenue allocation plan: Overview of uses/allocation split for revenues generated by the parking program.

7.1.1.4 Elimination of Parking Minimums and Exaction of Parking Maximums

The vast majority of municipalities nationwide (including the City of Dallas) utilize minimum off-street parking requirements by use to ensure that adequate parking is provided for new developments. However, in districts trying to foster pedestrian-friendly, transit-centric environments, minimum off-street parking requirements can encourage car-centric behaviors and increase single-occupancy vehicle usage. Conversely, parking maximums (wherein there is a maximum parking allowance by use for new development) are a complementary regulatory framework for districts where mobility, rather than parking, is the primary focus.

7.1.1.5 Case Studies

Several communities nationwide have formally adopted parking maximums to achieve goals akin to those espoused by the Dallas Midtown vision, such as limiting SOV use and encouraging other modes of transportation.

Lloyd District—Portland, Oregon

The Lloyd District is a commercial district in Portland's Central City with several amenities—including the Oregon Convention Center and the Rose Garden Arena—that attract visitors regionwide. The district is served by publicly available, shared off-street parking, as well as metered on-street public parking. In recent years, the district has bolstered its commitment to its "Lloyd EcoDistrict" initiative, defined by a commitment to create a sustainable environment and reduce carbon emissions. A key part of this goal is to boost use of district-supported alternative transportation options, such as electric bikes and bikeshare/carshare opportunities.

Shared parking is supported by city regulations and policies—in the Lloyd District, a key goal of the city is to limit the growth of off-street parking spaces. One way this is being achieved is through the elimination of parking minimums in Lloyd and throughout the Central City, and the exaction of parking maximums for specific uses. Table 7-1 depicts the parking maximums applicable in the Lloyd District, by use.

Table 7-1. Parking Maximum Examples in Lloyd District

Use	Parking Maximum
Residential	1.2/unit
Office and retail	1.5/1,000 square feet
Hotel	1/room

Old Pasadena—Pasadena, California

Old Pasadena is an historic shopping, dining, and entertainment district in Pasadena, California. In the early 1980s, as part of the revitalization of the Old Pasadena neighborhood, a parking strategy was formed wherein shared structures would be constructed along the walkable main corridor to encourage a "park once" policy and discourage vehicle use as an internal circulator. At present, the district manages over 7,500 shared parking spaces, including both off-street and on-street options.

The district's parking vision is complemented by city regulations set forth in the City of Pasadena Zoning Code (Title 17). The City allows for developers to use existing shared spaces as "zoning credit parking spaces" to fulfill their off-street parking requirements and allows the shared parking facilities to oversubscribe up to 50 percent. In addition, the City of Pasadena also requires that base parking requirements be "met but not exceeded," meaning that the minimum parking requirement is also the maximum allowable in most districts, including in Old Pasadena.

7.1.2 Transportation and Parking Management Authority

There are many umbrellas under which to combine parking and transportation management. The most relevant types for the nature and vision of the Dallas Midtown district are the following:

- Public/primarily public: city or transportation authority managed

- Public–private partnerships: transportation and parking management authority (T/PMA) and request for proposal (RFP) and lease/concession agreements

- Private/primarily private: private developer and tax increment financing

7.1.2.1   Why Combined Transportation and Parking Management?

Why Combined Transportation and Parking Management?

The plan for Dallas Midtown, including district-wide shared parking, will be challenging if not impossible to achieve without a defined entity responsible for implementing, managing, operating, and capital planning for both the parking system and the ATS. We recommend that one entity be responsible for both parking and ATS because such an authority:

Has the ability to use parking management tools to encourage ATS ridership both directly and indirectly.

Has the ability to use revenues raised from parking (or from any service) to fund any transportation-related program or need—for example, the authority could use parking meter revenues to subsidize costs for riding the ATS, make pedestrian or bicycle improvements, or develop incentive-based transportation demand management programs.

Can leverage support from champions of the ATS in both the public and private sectors into a singular entity able to advocate for the district and its transportation goals.

The following subsections provide an overview of several methods for combining parking and transportation management as appropriate for Dallas Midtown, and assess the strengths, weaknesses, opportunities, and threats for each entity type. Following these overviews are various case studies focused on entities with a combined goal of managing both transportation (whether in the form of transportation demand management, transit, or people movers) and parking.

In some rare cases, a single private entity or a small group of private entities has acquired land, established a district, and managed parking and transportation collectively, generally for the monetary benefit of the property owners and their tenants, and without extensive managerial oversight from the public. These districts have often been funded by a combination of extensive and aggressive private investment and tax increment financing or urban renewal funds. This strategy was not focused on, as it requires a unique and typically organic combination of circumstances—a wealthy and highly motivated developer, for example—to be feasible. However, Sundance Square (Fort Worth, Texas), an example of this phenomenon, has been included as a case study.

7.1.2.2   Public/Primarily Public: City or Transportation Authority Managed

Overview

This option would entail a municipality or other public body (most likely the City of Dallas or DART) to take full responsibility for constructing, operating, and maintaining the parking and transportation system for Dallas Midtown. Generally, this option has been most common among older municipal parking and

transportation systems that benefitted from federal and state transportation grant funding available in the 1970s, 1980s, and 1990s.

The Los Colinas (Texas) People Mover is a local example of a public governance structure. The people mover service began in 1989 and was operated by a private entity. In 1994, operations were turned over to the City of Dallas Utility and Reclamation District. In 2014, the DART system connected to the Los Colinas People Mover, and ridership on the people mover increased over 500 percent, a testament to the potential impact of establishing connections with the regional transit network.

Strengths and Weaknesses

The following are strengths of this option:

- **Oversight:** This option would allow for strong public oversight from both the agency itself and the constituents it serves, in terms of financing, design, and construction.

- **Service for all:** Given that public agencies are responsible for benefits to their entire service population rather than to specific entities or constituencies, this option would engender an inherent focus on service for all.

The following are weaknesses of this option:

- **Limited revenue opportunities/return on investment:** Large-scale construction projects taken on entirely by public agencies generally have a lower return on investment than those partially or fully built and operated by private entities. In addition, revenue sources would be limited to grant/public funding and end-user payments. There would likely be significant pressure to keep end-user payments low (below market rates) to ensure equity of service.

- **Schedule delays:** Schedules can be delayed or even terminated entirely due to changing priorities of decision makers (for example, City Council or DART board of directors) or even the public itself.

Examples

Examples of public/primarily public operations include the following:

- **Jacksonville Skyway, Jacksonville, Florida:** An automated monorail and park-and-ride system managed by the Jacksonville Transportation Authority, established in 1977.

- **Detroit People Mover, Detroit, Michigan:** An automated light rail and park-and-ride system managed by the Detroit Transportation Corporation.

- **Las Colinas People Mover, Las Colinas, Texas:** An automated guideway transit system managed by the Dallas County Utility and Reclamation District.

7.1.2.3   Public–Private Partnerships: Transportation/Parking Management Authority

Overview

Transportation and parking management authorities are typically incorporated non-profit organizations formed to assist a designated area's commuters and residents in finding and using alternative forms of transportation. Because there is a great deal of overlap between the typical toolbox used by transportation and parking management authorities, the study team recommends that a joint T/PMA be created for Dallas Midtown.

It is recommended that the T/PMA for Dallas Midtown incorporate the additional functions of a parking benefits district to keep revenue from meters, public off-street parking, and other parking fees within the district and used to make various improvements (for example, street sweeping, tree planting/trimming, sidewalk and street repair, street lighting, or graffiti removal). A parking benefit district is created by

charging for parking and dedicating the net revenue towards neighborhood improvements and/or improvements that promote parking alternatives. This may include increased facilities for walking, cycling, and transit use, such as sidewalks, curb ramps, and bicycle lanes.

In addition to or in lieu of being funded by parking fees, the T/PMA could be funded by annual fees paid by property and business owners within the district to fund maintenance of existing parking. There may also be one-time (in lieu of providing parking) or ongoing fees (such as a parking zoning credit) for the provision of existing or future shared-use public parking.

Charging for parking and promoting alternatives can help reduce the number of people parking in the neighborhood, but for those who do park and pay, the area benefits. The board of the T/PMA would make decisions regarding how much to charge and how to manage the parking system. T/PMAs generally have the ability to benefit from a wide range of funding sources, including end-user fees, fees charged to beneficiaries/members (property and business owners that benefit from services, in the form of ongoing or one-time fees), donations, and grant funding.

The creation of the T/PMA and governing body typically sets off a positive chain of events for the area:

- A specific body is created whose responsibility is to maximize the efficiency of the transportation and parking system in the district. As a result, there is also a political constituency that will defend parking rate increases if necessary while keeping in mind the overall health of the district.

- Parking is managed to maximize the efficiency of the parking system, increasing turnover and the use of parking spaces, which allows for an increase in area visitors.

- Traffic could be managed by the setting of district-wide trip caps, setting goals for the reduction of SOV trips, and promoting alternative means of transportation for trips to Dallas Midtown and ATS usage for intra-Midtown trips.

- An incentive is potentially created for charging for parking in residential areas (either through the selling of a designated number of on-street parking permits or even metering streets) as residents can see the money going to direct improvements on their block, such as repaired sidewalks and landscaping.

- There is a byproduct of increased parking revenue throughout the district.

- The T/PMA governing body makes decisions regarding allocation of the additional revenue through such projects as contributing to the funding of off-street parking if necessary, neighborhood beautification projects (such as street trees or attractive benches), or potentially creating funding for employees and others to encourage the use alternate forms of transportations such as bicycles, carpools, or transit, which can ultimately reduce the demand for parking in the neighborhood.

Strengths and Weaknesses

The following are strengths of this option:

- **Alternatives to driving and parking:** T/PMAs promote alternatives to driving and parking for all trips by inherently focusing on a holistic approach to transportation; this may incentivize more people to evaluate alternative transportation to move in and around the area and use the ATS for intra-Midtown trips.

- **Custom-tailored services:** T/PMAs have the ability to create tailored services to a particular district or constituency, rather than simply expanding or augmenting existing services.

- **Flexibility in how to obtain and use revenue:** T/PMAs have flexibility to decide how parking revenue can be used (for example, for neighborhood improvements and amenities or to fund alternative

means of transportation, such as the ongoing O&M costs of the proposed ATS in the case of Dallas Midtown). The T/PMA can help ensure that funds created by visitors and patrons using the meters or public lots stay in the area to help with improvements, landscaping, safety, or lighting. T/PMAs also have flexibility in how revenue can be obtained (for example, through grant funding, donations, assessments of property and businesses, and end-user payments).

The following are weaknesses of this option:

- **Champions are required**: This type of organization typically requires active stakeholder participation to effectively maintain the T/PMA. If there is a sufficient base of enthusiastic and knowledgeable proponents this is not a problem, but in areas without a champion of T/PMAs, this type of structure loses its ability to effect change.

Examples

Examples of T/PMA public–private partnerships include the following:

- **Irvine Spectrum, Irvine, California:** A non-profit transportation management authority focused on increasing usage of multimodal commuting options.

- **Houston Downtown Management District, Houston, Texas:** A management entity focused on collective mobility and access, placemaking, public safety, and more in Houston's Downtown District.

- **Lloyd District, Portland, Oregon (or "Go Lloyd"):** A management entity focused on offering commuting and mobility solutions to residents, visitors, and employees in Portland's Lloyd District, part of the city's downtown core.

7.1.2.4 Public–Private Partnership and Request for Proposal/Concession and Lease Agreement

Overview

This entity type would require that a public entity (for example, the City of Dallas or DART) issue RFPs for construction (Phase 1) and then O&M (Phase 2) of the Dallas Midtown parking and transportation system, then develop and execute a contract with the winning party(ies). The contract would include details such as the following:

- How land slated for construction will be procured and assembled
- Commencement of Phase 1
- Design, construction, and review requirements
- Regulatory requirements
- Public outreach/oversight requirements
- Schedule and nature of payment to private entity during Phase 1
- Certification of completion requirements
- Commencement of Phase 2/requirements to start Phase 2
- O&M requirements
- Schedule and nature of payment to private entity during Phase 2
- Disputes and resolution
- Termination of agreement

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While many public agencies and municipalities issue RFPs for response by qualified private entities, the intensity, length, scope of services, and binding nature of these agreements is fairly novel, and there are few examples of them in the U.S. It is worth noting that the only relevant example found—a long-term partnership between the Regional Transportation District in Colorado and private entity Denver Transit Partners—is currently embroiled in a lawsuit wherein both parties have sued for damages and breach of contract.

Strengths and Weaknesses

The following are strengths of this option:

- **Ability to benefit from private sector efficiency**: This option allows public entities to benefit from the efficiency of the private sector in terms of work requirements, scheduling, training, and technical expertise.

The following are weaknesses of this option:

- **Mutually assured destruction or success:** The public agency remains tied (both practically and legally) to the success or failure of the private entity to deliver assets or service.

- **Lack of knowledge of regulatory requirements:** Private entities often lack the nuanced understanding of federal, state, and local regulatory requirements that public agencies have. This weakness can often be assuaged through extensive vetting of the RFP bids—for example, requiring respondents to provide concrete examples of projects in which they had to apply relevant regulations.

Examples

Examples of public–private partnerships using RFPs/concession and lease agreements are the following:

- **Regional Transportation District and Denver Transit Partners Agreement, Denver, Colorado**: A venture to design, build, finance, and operate multiple heavy-rail commuter lines in the Denver Metro area.

- **Sundance Square, Fort Worth, Texas:** A tax-increment finance district co-funded by a private development company; it includes various internal circulation options and shared parking structures.

7.1.3 Transportation Demand Management, Parking Management, and Technology

The alternative governance strategies detailed in Section 7.1.2 can have a significant impact on the implementation and operational success of an ATS and/or parking system. The potential tools and technology options and their potential impacts on this transportation demand management effort are detailed in the sections below.

7.1.3.1 Primary Transportation/Parking Management Tools

There are several broad categories of parking and transportation management tools available summarized in the graphic to the right and detailed below.

The discussion of parking and transportation management options in this section is intended to provide a broad range of choices, some of which conflict with each other. The tools ultimately selected for the Dallas Midtown area should be based on the goals of the City of Dallas and Midtown stakeholders.

Along with the general strategy, an opinion has been provided with each strategy's ability to complement the area's plans related to the ATS system, and a high-level discussion of costs.

Reduced or Eliminated On-Street Parking

With the relative explosion of alternatives for personal mobility engendered by technology—including electric scooters, bike share (traditional and electric), transportation network companies (Uber, Lyft), and increased deliveries due to online shopping—curb management is becoming a hot-button issue in many areas. Municipalities are increasingly being forced to consider the most valuable use of curb space, and the extent to which static on-street parking may not be the most efficient use of the curbside lane. Additionally, research has indicated that cruising for available on-street parking is a significant cause of congestion in many areas (Shoup, 2007).

The availability of on-street parking in the Dallas Midtown area is a potential impediment to the area's transportation management goals and a potential competitor to the proposed ATS system as it could encourage some patrons to drive from one area of Midtown to another.

Establishment of a T/PMA to execute parking and transportation management tools across the Midtown district would be necessary.

The management authority would provide incentives/assistance to businesses to help achieve the mandated reductions, an approach that has been used in other areas to promote alternative modes of transportation.

Setting prices for parking in different areas in a development considers the needs of the various user groups competing for parking spaces and entices users to park where the area needs them to park.

Permits are another pricing tool that entices users to park where they are needed to park. They provide the permit holder with some level of convenience (no need to pay a meter or a parking lot attendant/machine), and often a discounted rate, in exchange for parking in a specific area.

Other incentives and disincentives (carrots and sticks) can be offered to help encourage users to park where desired.

Trip caps, set either by parcel or by zone

Industry best practices and the use of technology can be used to manage parking for increased parking system efficiency and a better user experience.

- Benefits

  – Potentially allows the City of Dallas to reduce the cross section of roadways within Dallas Midtown, thereby enhancing the overall walkability of the area.

  – Reduces congestion by eliminating cruising for parking—patrons would know that they would either have to park off-street or arrive by another mode.

  – Encourages the use of the ATS for intra-Midtown trips instead of hopping from one short-term parking space to another.

  – Reduces the complexity of on-street parking enforcement.

- Potential disadvantages

  – Potentially reduces revenue compared to having paid on-street parking.

  – Reduces the most convenient access to certain businesses.

  – Costs.

    ▪ Eliminating on-street parking could result in more off-street parking needed to serve Midtown; however, this would be balanced by potential savings related to construction of narrower cross sections on roadways as a result.

Paid Parking

Paid parking in the Midtown area would encourage patrons to weigh the costs and benefits of driving and parking versus arriving via an alternative means of transportation. Paid parking rates could be structured in a way that encourages use of the ATS as opposed to driving to a second location and re-parking for intra-Midtown trips.

An example of an ATS-supportive parking pricing program would be for parking to have a high rate for the first 1–2 hours, and then either be free or severely discounted for additional hours. This would encourage a park-once strategy, as patrons would be encouraged to park in a single location and use the ATS for intra-Midtown trips. Patrons who decide to drive between different locations in the area would be penalized in the form of having to pay twice.

Additionally, if on-street parking is maintained in the Midtown area, it should carry the highest hourly rates, given the convenience it affords. While the presence of on-street parking could negatively affect ATS ridership, the revenue from on-street parking could be put to ATS-supportive use such as funding operations and maintenance.

- Benefits

  - Properly priced parking encourages users to evaluate the true cost of various transportation modes and make the choice that is best for them.

  - Encourages the use of the ATS for intra-Midtown trips instead of hopping from one short-term parking space to another.

  - Is a potential revenue generator to fund ATS O&M as well as district-wide enhancements.

- Potential disadvantages

  - Free parking has a strong cultural cachet.
  - Enforcement would be required.

- Costs

  - There are costs to operate paid parking including installation and maintenance of parking access and revenue control equipment, and parking enforcement; however, paid parking would provide a revenue stream for funding these activities.

Partially Unbundled/Unreserved Residential Parking

Conventional and recommended shared parking models were previously prepared, at the conceptual level, for the Dallas Midtown area as whole. The recommended model assumes that a portion of the residential parking in Midtown would be unreserved and open for sharing. Because residential parking demand peaks overnight and stays at lower levels (50–60 percent) of demand during the day, it is a highly compatible land use to share parking with daytime uses such as office developments.

Additionally, unbundled parking, where a unit's rent does not include parking but where instead a tenant can choose whether or not to purchase the right to park one or more vehicles, would encourage prospective residents of Midtown to factor in the cost of parking into automobile ownership decisions.

- Benefits

  - Reduction in the amount of parking needed to serve Midtown.
- Potential disadvantages

  - Marketability of residential products with unbundled parking in the Dallas area.

Parking Permits

Both residents and employees need parking every day or nearly every day. These users may be best served by a parking permit program that would allow them to pay a fixed monthly fee for parking in a specific parking area. A permit program would offer advantages to permit holders, such as discounted monthly rates and convenience of use (versus paying at a pay station every time they park), while allowing the relevant authority to dictate where they park (that is, not in prime parking spaces).

The use of discounted parking permits should be considered in some instances, including preferred parking for carpools.

Trip Caps

Jurisdictions set trip caps for large, planned developments and development zones. Trip caps usually include an a.m. peak hour cap, a p.m. peak hour cap, and a daily trip cap, which in effect forces developments to consider and promote alternative means of transportation. The a.m./p.m. trip caps target peak hour congestion, while a daily trip cap limits total trips. Trip caps would be highly complementary to the proposed ATS for Dallas Midtown, which, with trip caps, would instantly become an important alternative means of transportation for helping the district meet its goals.

A trip cap would need to be created for the Midtown area as a whole and then broken down to the parcel/development level; it would necessitate the creation of a T/PMA. Trip caps would need to be set by the City of Dallas, and while this study cannot detail the process for setting trip caps, it would likely be a difficult one requiring agreement by most, if not all, of the property owners within the Midtown area.

In some areas, trip caps have been used in place of floor-area-ratio and other development-size caps. In these cases, a property/development is allowed to intensify its land uses as much as it wants, subject to remaining under its set trip cap. This incentivizes the property owner(s) to implement robust transportation and parking demand management.

- Benefits
    - Provides tangible targets for district-wide transportation demand management programs and potential T/PMA.
    - Encourages the use of the ATS for intra-Midtown trips.
- Potential disadvantages
    - Initial set-up and implementation is difficult and likely requires a strong hand by the City of Dallas and buy-in from property owners in the area.
- Costs
    - The cost of implementing and monitoring trip caps would likely be included in the cost of running the T/PMA.

7.1.3.2 Transportation Demand Management

While transportation demand management programs are usually focused on reducing automobile trips, they also have the salutary effect of reducing parking demand at destinations. The following programs should be evaluated and considered for their ability to reduce vehicle trips to, and hence parking demand in, Dallas Midtown:

- Transit service enhancement—increasing level of service for public transit options makes these options more attractive and competitive when compared to single-occupancy vehicle usage.

- Bike sharing and scooters—bike-sharing programs have been gaining traction as a way of solving the first mile/last mile of transit trips, and for short trips in general. Electric scooters have also been gaining in popularity.

- Ample bicycle parking.

- Ridesharing and preferential carpool parking.

- Car sharing—studies indicate that each shared vehicle reduces parking demand by multiple vehicles. The availability of car-share vehicles could induce a household to get by with one personal vehicle knowing that a second vehicle is available to them if needed via a car-share service.

- Dynamic wayfinding and automated parking guidance systems (APGS)—wayfinding and APGS can help reduce congestion associated with the search for parking by providing clear directions to available parking.

7.1.3.3 Technology and Wayfinding Considerations

The Midtown area is well positioned to capitalize on technological advancements that assist with parking wayfinding and management, and provide a high level of customer service to future patrons of the Midtown area. It is recommended that the following be considered as Midtown moves into the implementation/development phase:

- Create a unified, branded, wayfinding system for the Midtown area to direct patrons to available parking resources and reduce cruising for parking.

- Set up and use an integrated APGS to provide real-time space availability at key parking facilities.

- Consider designing for frictionless parking options using a vehicle's license plate as the credential to speed up the ingress/egress process to/from parking facilities.

- Have developers consider a cashless parking system.

- Use and integrate with already established apps for parking and payment so that patrons are not required to download and maintain Midtown-specific apps on their phone.

The cost of parking guidance technology can vary widely based on the complexity and goals of the system. A basic parking access and revenue control system could cost between $200,000 and $300,000 per parking facility, with a technology like space-by-space sensors adding an additional $400 to $500 per space in costs.

7.2 System Cost Overview

This section contains a summary of the expected cost to implement and operate the ATS recommendations and proposed shared-use parking system.

7.2.1 ATS Implementation Cost Overview

The expected cost summary for the ATS as recommended in previous sections will be detailed by specific recommendation to include:

- ATS vehicle

- Recommended alignment

- ATS station

The costs as detailed are based on conceptual design in values consistent with industry expectations in 2018. The primary source for these estimates are based on comparable systems or design utilizing the recommended design principles detailed along with the recommendations. Further conversations with material vendors and detailed design will be required to expand this cost estimate to a level of detail appropriate for procurement and construction.

7.2.1.1 ATS Cost: Recommended ATS Vehicle

The GRT vehicle is essentially a small bus and the vehicle cost is comparable to that with the addition of autonomous technology infrastructure (on the vehicle).

Maintenance costs are an expected annual cost to keep the vehicles in operation and would include any personnel, parts and support in maintaining and operating the vehicle.

Table 7-2. ATS Vehicle Cost

Cost Element	Cost Per Unit	Number of Units	Total Cost
GRT Vehicle	$360,000	22	$7.92M
		Total Capital Cost	**$7.92M**
Maintenance	$1.4M	N/A	$1.4M/year
		Total Maintenance Cost	**$1.4M/year**

7.2.1.2 ATS Cost: Recommended ATS Alignment

The recommended ATS alignment is a 2.2-mile elevated structure as detailed and depicted in Sections 5 and 6. No right-of-way acquisition is required in the elevated recommendation; therefore, no land acquisition costs are included in Table 7-3.
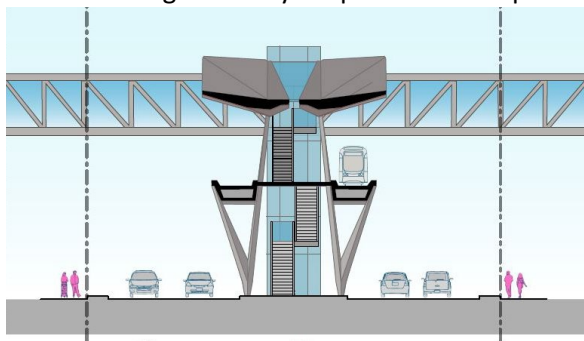
Upon construction, it can be expected that there will be both at-grade and sub-grade improvements needed to implement an elevated system within ROW that has existing pedestrian crossings, traffic signals, utility lines, and other surface-level elements. A conceptual cost per mile to capture those potential costs are included in Table 7-3.

Table 7-3. ATS Alignment Cost

Cost Element	Cost Per Unit	Number of Units	Total Cost
Construction (per mile)	$15.0M	2.2	$33.0M
Utilities (per mile)	$3.0M	2.2	$6.6M
Traffic Improvements (per mile)	$1.0M	2.2	$2.2M
		Total Capital Cost	**$41.8M**

7.2.1.3 ATS Cost: Recommended ATS Station Concept

The elevated station structure is separated from the alignment for purposes of flexibility on the recommended number of stations (six) and the conceptual nature of the station design. Estimated construction cost (Table 7-4) includes the station structure, platform and access points (stairs and elevators).

Table 7-4. ATS Station Concept Cost

Cost Element	Cost Per Unit	Number of Units	Total Cost
Construction	$7.5M	6	$45.0M
		Total Capital Cost	**$45.0M**

7.2.1.4 ATS Cost Summary

The three primary implementation elements are expected to cover all reasonable costs that can be determined from the conceptual design stage. The total capital cost estimated to implement the recommended ATS in Dallas Midtown (Table 7-5) is just under $95 million.

Table 7-5. ATS Cost Summary

Cost Element	Total Cost
GRT Vehicle	$7.92M
ATS Alignment	$41.8M
ATS Station	$45.0M
Total Capital Cost	**$94.72M**
Total Maintenance Cost	**$1.4M/year**

7.2.2 Shared-Use Parking System Cost Overview

This subsection provides an overview of the basic costs associated with building, operating, and maintaining shared parking district-wide in Dallas Midtown. The following assumptions have guided this analysis:

- A significant portion of parking structures will be built partially or fully underground (based on stated preferences of the Dallas community).
- All parking will be actively managed and monitored.
- Industry-recommended standards will be used for general garage maintenance.

7.2.2.1 Parking Costs: Base District-Wide Shared-Parking Scenario

As detailed in Section 2.3.2, projected need (the status quo scenario) was determined to be 53,801 shared parking spaces district-wide, assuming little to no active transportation demand management. Assuming that the existing parking supply of roughly 21,300 spaces can be a shared resource, this results in a total need for 32,501 parking spaces. Table 7-6 provides a general opinion of cost in 2019 dollars for construction of these spaces. Note that this excludes costs to obtain land.

Table 7-6. Opinion of Probable Construction Cost: Base Scenario

No. of Spaces	Cost per Space Range	Total Cost Range
53,801 (total needed)	$28,000–$32,000	$1.51B–$1.72B
32,501 (assuming use of existing supply)	$28,000–$32,000	$ 910.0M–$1.04B

Table 7-7 shows projected annual operations and maintenance costs for the system. General O&M includes labor, utilities, basic general maintenance needs (for example, restriping, repairing minor concrete damage), and other industry standard needs for parking in systems of this size and scope. In addition, it is recommended that $30 to $35 per space per year be set aside for larger repair and maintenance issues, such as structural damage.

Table 7-7. Opinion of Probable O&M Cost: Base Scenario

No. of Spaces	Cost per Space Range (General O&M)	Cost per Space Range (Reserves)	Total per Space Range
53,801	$170–$190 per year	$30–$35 per year	$10.76M–$12.1M per year

7.2.2.2 Parking Costs: Recommended District-Wide Shared-Parking Scenario

As detailed in Section 2.3.3, a need of 42,204 shared parking spaces district-wide is projected, assuming active transportation demand management (the recommended scenario). Assuming that the existing parking supply of roughly 21,300 spaces can be a shared resource, this results in a total need for 20,904 parking spaces. Table 7-8 provides a general opinion of cost in 2019 dollars for construction of these spaces. Note that this figure excludes costs to obtain land.

Table 7-8. Opinion of Probable Construction Cost: Recommended Scenario

No. of Spaces	Cost Per Space Range	Total Cost Range
42,204 (total needed)	$28,000–$32,000	$1.18B–$1.35B
20,904 (assuming use of existing supply)	$28,000–$32,000	$ 585.31M– $668.9M

Table 7-9 shows projected annual operations and maintenance costs for the system. General O&M includes labor, utilities, basic general maintenance needs (for example, restriping, repairing minor concrete damage), and other industry standard needs for parking in systems of this size and scope. In addition, it is recommended that $30 to $35 per space per year be set aside for larger repair and maintenance issues, such as structural damage.

Table 7-9. Opinion of Probable O&M Cost: Recommended Scenario

No. of Spaces	Cost per Space Range (General O&M)	Cost per Space Range (Reserves)	Total per Space Range
42,204	$170–$190 per year	$30–$35 per year	$8.44M–$9.5M per year

7.3   Implementation Schedule

The implementation of a shared-use parking strategy that leans on the synergies of an ATS circulator within Midtown leads to the rationale that the implementation of the two initiatives should be directly coordinated. The most direct way to accomplish this would be to house both the shared-use parking and circulator initiatives under a single management authority similar to that used for Sundance Square in downtown Fort Worth. In addition to management, the funding and strategy of implementation can realize synergies should the two initiatives be taken on together as the Midtown area is being developed.

An alternative implementation strategy analysis was considered to examine some of these potential synergies and challenges.

7.3.1   Alternative Analysis

The team considered three implementation strategies for the recommended approach of an integrated T/PMA, including phased implementation, total build implementation, and blended implementation, as described herein. These strategies were analyzed for their ability to mitigate risk (of development occurring slower than expected), flexibility (to manage demand), cost, and time.

- **Phased implementation:** The use of existing parking spaces to meet existing and initial demand and develop additional parking as development occurs and demand increases. Along the same lines, the ATS circulator would also be developed in segments as development occurs. Though this strategy allows the flexibility to match Midtown development, there is a risk of an incomplete ATS leading to operational challenges and thereby leading to dissatisfaction with the system and governance structure.

- **Total build implementation:** Building out all required parking along with the entire ATS. This would provide operational efficiency of the system because the ATS and parking is available. It would also encourage or expedite development in Midtown. However, there is a risk that macroeconomic changes could lead to lower return on investment if development does not follow as expected, or if future changes in development require reconstruction.

- **Blended implementation:** A combination of the above two strategies in an effort to combine the best of both. This strategy phases the parking development but recommends complete buildout of the ATS so that there are no operational challenges with getting around. Complete buildout of ATS encourages future development and the phased parking can be implemented as demand increases. It would still allow for flexibility if future land uses were modified.

7.3.2   Recommended Implementation

A blended implementation strategy is recommended for the Midtown project (Figure 7-1).

Figure 7-1. Blended Implementation Priorities by Phase

IMMEDIATE ACTIONS

- Organize T/PMA to drive implementation and manage ATS in Midtown
- Change parking requirements to enable shared parking strategy across Midtown
- Revise thoroughfare zoning to avoid precluding future ATS implementation

Legend
- ATS Critical Path Implementation
- Shared Parking Strategy

PRE-IMPLEMENTATION

- Implement demonstration ATS connection to trial vehicle vendor, elevated system, and potential ridership demand
- Develop parking strategy with predetermined locations and private versus shared facilities

IMPLEMENTATION PHASE 1

- Complete recommended 2.2-mile Midtown ATS system
- Initial regional connections to Cotton Belt and LBJ Express implemented
- Construct new parking facilities in predetermined locations as development occurs and demand increases

IMPLEMENTATION PHASE 2

- Green, Red and Blue lines regional connections to DART
- Potential ATS expansion in Midtown beyond 2.2-mile loop

Section 8

Next Steps

8   Next Steps

The recommendations in this report rely on significant initial steps being taken to solidify the project's progression. Additionally, some more immediate actions should be sought so that decisions made prior to system installation do not preclude or further challenge future ATS implementation in Midtown. These actions are based on both meeting development requirements prior to implementation and on SRC discussions on implementation throughout the study.

Next steps and potential opportunities to improve the recommended system are detailed in the following subsections.

8.1   Organization of Management Agency

Within 60 days of the delivery and acceptance of this report, a coordination meeting should be organized that includes NCTCOG, Councilman Lee M. Kleinman, the North Dallas Chamber of Commerce, the City of Dallas Transportation department (and other pertinent city representatives), representatives from DART, Jacobs, and any appropriate developers or stakeholders in the Dallas Midtown area. The Dallas Midtown SRC list of participants at the beginning of this report would be an appropriate contact list for reference.

The purpose of this meeting is to begin the process of organizing a management entity to act as the primary driving force behind the implementation of these recommendations.

The purpose of this meeting will be to begin the process of organizing a management entity to acts as the primary driving force behind the implementation of these recommendations as a whole, with the actions listed in this section as a priority.

8.2   Group Rapid Transit Vendor Demonstration

The most efficient way to demonstrate the potential connectivity a GRT system could provide to the area is by arranging a temporary vendor demonstration route. Such demonstrations have been organized already by autonomous vehicle vendor Drive.ai in the Dallas-Fort Worth metroplex (Figure 8-1).

Figure 8-1. A Drive Demonstration Route in Frisco, Texas, 2018

These demonstrations along temporary routes can aid in the eventual permanent application of an autonomous system in several ways:

- Educate the public and provide a preliminary experience with autonomous vehicles

- Test a route to gauge potential demand and use in a permanent situation

- Test the area for competing implementation options (for example, at-grade versus elevated system)

- Provide a trial opportunity to test vehicle vendor for service reliability

- Provide a "proof of concept" for existing and in-progress development and enticement for potential future development in the Midtown area

As there are no existing transit points of interest on the east side of Midtown at the Valley View site, this demonstration would be most beneficial connecting the Galleria Mall to points of interest north on Montfort Drive. Potential connections include the Village on the Parkway (entertainment/shopping center), several apartment complexes along Montfort Drive, and the future Knoll Trail Station on the Cotton Belt line, which could deliver immediate daily and event-based ridership potential in addition to providing the first regional connection to Dallas Midtown when the Cotton Belt line is completed.

8.3 Parking Requirement Changes

The general purpose of this report is to assess the feasibility of the ATS and related components following full buildout of the Dallas Midtown district. However, given that the construction timeline for full buildout is long (approximately 20 years) and certain developers and property owners are interested in more near-term strategies for accommodating an ATS system, four recommendations for implementation in the next 1 to 2 years has been assembled so that current development does not preclude, and in fact complements, the future vision for the district:

1. **Assess/quantify sharing potential of existing parking structures**: Work with owners of existing parking structures (for example, the Galleria Mall) to assess quantitative and operational sharing potential. Conduct a parking utilization analysis (weekday daytime/evening, weekend daytime/evening), and evaluate the ability of existing access technology to accommodate new users.

2. **Assess/quantify feasibility of sharing new garages**: Work with developers currently in the planning stages for new developments to assess options for garages associated with their developments to act as shared resources.

3. **Require use of ULI's shared parking model**: Require all new development to use the ULI 2005 shared parking model to maximize efficiency of new parking being built until new regulations are in place.

4. **Conduct annual parking utilization assessments**: Conduct annual utilization assessments of parking usage in Dallas Midtown as development occurs.

8.4 Thoroughfare Adjustment

The current dimensions planned in the 2013 Thoroughfare Plan for the streets impacted by the recommended ATS alignment would cause a significant reconstruction of the street when ATS was implemented. Whereas Montfort Drive and Noel Road are planned to have a median in the roadway, the southern and eastern legs of the loop that are in large part set to be constructed soon are not currently planned to have a median. Although there is no need for any additional ROW outside of the 69 feet that is planned for in these segments, constructing a median later would cause the outside curbs, sidewalks, trees, and any utilities or amenities along the curb to be moved/reconstructed.

There is no update needed to the Thoroughfare Plan as the ROW width and roadway classification will remain the same, however the dimensions within the ROW are recommended to be revised to accommodate a raised median (Figure 8-2) when the streets are constructed the first time so zoning and permitting will need to be updated.

The 6-foot median will be more than a placeholder for a future ATS but will increase pedestrian safety in a dense urban environment by providing ADA-compliant refuge space between opposing traffic lanes. This median space can also be used for additional street trees and/or utilities at the time of construction.

Figure 8-2. Recommended Thoroughfare Dimensions for Dallas Midtown Streets
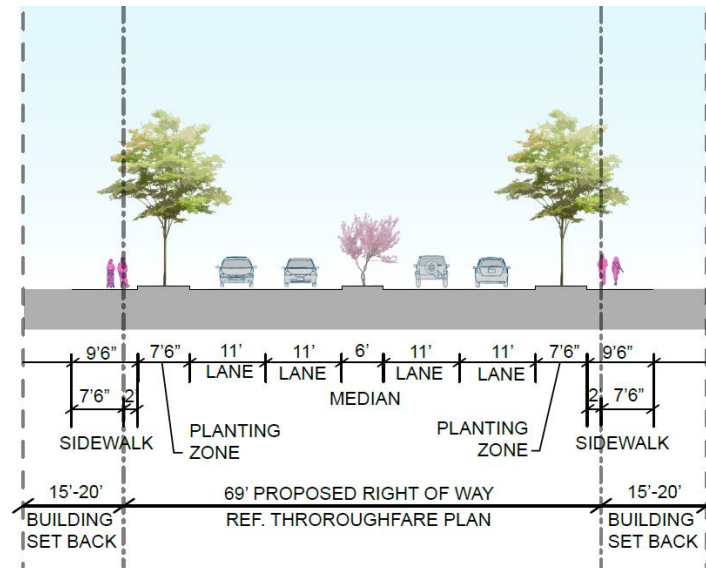
8.5   Innovative Opportunities

Vehicle and infrastructure technology advancements continue to emerge nearly daily. Given the typical timeline that public infrastructure improvements go through—planning, alternatives analysis, agency approvals, design, bidding, and building—technology-dependent implementations can, in some cases, be out of date by the time that initial good idea becomes reality. Anticipating the trajectory of infrastructure technologies is risky, and how cutting-edge innovations are introduced and integrated can affect public acceptance and project success. In fact, in the year since this project was initiated, many events have occurred in the realm of automated vehicles that have had profound effects on how that new technology is advancing in the industry and through policy.

Notwithstanding this caveat, there are newer transportation solutions currently available that may well suit the proposed ATS solution. An exclusive right-of-way, grade-separated roadway facility allows for the deployment of infrastructure that does not necessarily need to accommodate any other uses. However, a roadway that can accommodate both the currently proposed solution and possible other future uses would be optimal.

8.5.1   "Intelligent" Pavement

In 2008, researchers at University of California–Berkeley demonstrated how a roadway that was embedded with a series of magnets was able to automate the steering of a transit bus (Yang, 2008). While the bus's acceleration and breaking were controlled by a human driver, steering into and out of bus stops was done so within an accuracy of 1 centimeter. Today it is very common for traffic signal control systems

to use "cut-loops" or inductive coils of wire to measure the presence of vehicles approaching, leaving, or at a stop bar at an intersection. Battery-powered magnetometers that can transmit via cellular are still widely used by state transportation departments to measure vehicle counts and speeds on roadways.

There have been some recent advancements in putting electronics or other "intelligent" components into pavement. For example, this year, Norway installed wireless charging for its fleet of electric taxis in Oslo (Statt, 2019). This system is using technology by U.S.-company Momentum Dynamics in which plates installed into the roadway are able to inductively (wirelessly) charge vehicles equipped with capable technology. Momentum Dynamics has deployed other similar systems for mass transit and shuttle bus systems in the U.S. Using this type of technology for the proposed ATS solution could simplify charging of the electric-powered fleet while also reducing time off route and costs associated with a dedicated off-route charging station.

Taking this one step further, another U.S. company, Integrated Roadways, has been prototyping a "sensor-rich prefabricated pavement system." These slabs are built offsite for ease of installation and can be used to sense road use characteristics or as a wireless communications network (Figure 8-3).

Figure 8-3. Integrated Roadways' Smart Pavement
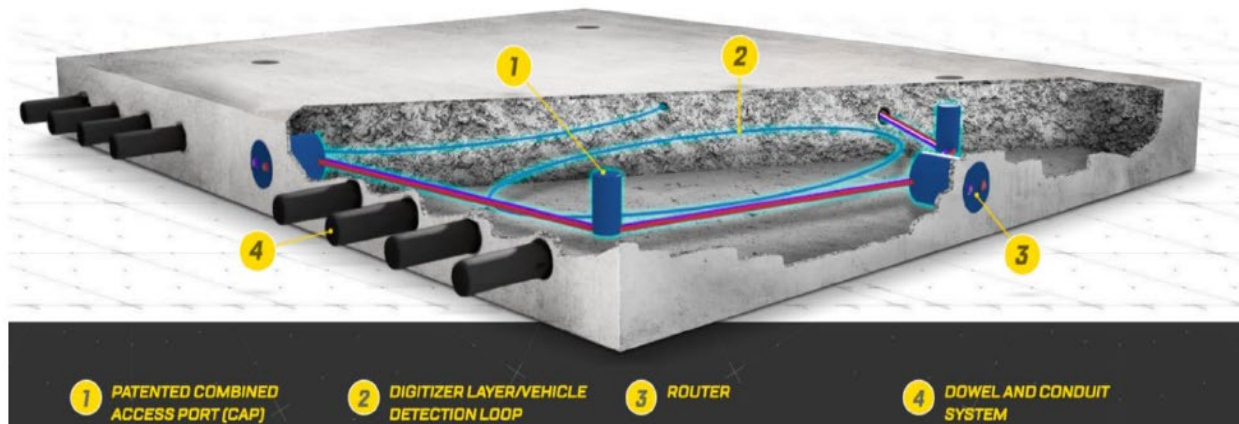
Source: Integrated Roadways

Sensors in the pavement can detect vehicles in real time and are able to determine speeds, weight, and trajectory. Integrated Roadways' Smart Pavement can be adapted for wireless connectivity to street lights, connected autonomous vehicles (CAVs), cellular systems, and wireless in-motion electric vehicle charging. Integrated Roadways' system could also be used as a transit network monitoring and control system that can capture traffic data and road conditions, communicate with transit vehicles, and provide logistics, fleet management, and real-time positioning for automated vehicle operation.

Section 9
References

9   References

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Appendix A
ATS Ridership Estimation Methodology
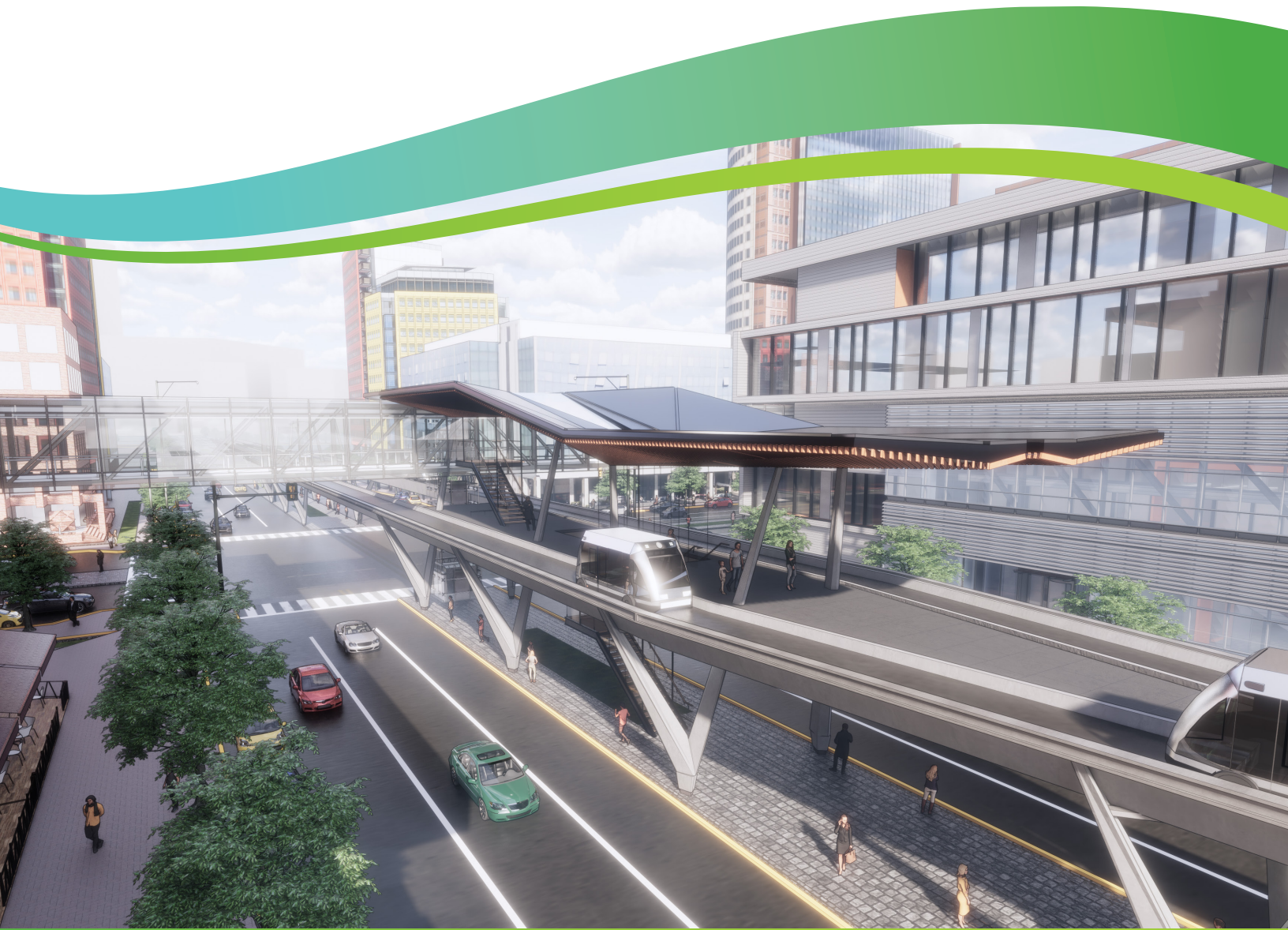
A. ATS Ridership Estimation Methodology

A.1 Internal Site-Capture

The following summarizes the methodology used for the Dallas Midtown Ridership Estimation. Additional details on the ridership estimation tool can be found in Appendix B.

Demographics for the Dallas Midtown study area were provided by NCTCOG's regional travel demand model. The Dallas Midtown study area includes six of NCTCOG's traffic survey zones (Figure 3-1).

Figure A-1. Traffic Analysis Zones in NCTCOG's Regional Travel Demand Model

For comparison, the demographics were pulled for 2018 and 2045 and compared to demographics calculated based on the proposed development for buildout of the Dallas Midtown area. Table 3-1 below compares the demographics.

Table A-1. Dallas Midtown Study Area Demographics Comparison

Demographic Categories	NCTCOG 2018	NCTCOG 2045	Buildout
Population	10,214	10,374	30,173
Household	4,565	4,634	12,069
Employment (Total)	33,220	45,445	50,514
Basic	5,820	8,255	0
Retail	7,415	7,655	6,418
Service	19,985	29,535	44,096

In addition to demographics, the amount of green space within Dallas Midtown was compared between NCTCOG and the proposed development. NCTCOG included no green space in the zones, whereas the Dallas Midtown development includes a 20-acre park. These shifts in the projected make-up of the Dallas Midtown area are depicted in the graphs of Figure 3-2.

Figure A-2. Dallas Midtown Study Area Demographics Comparison Charts

Green Space

Households

Employment

Population
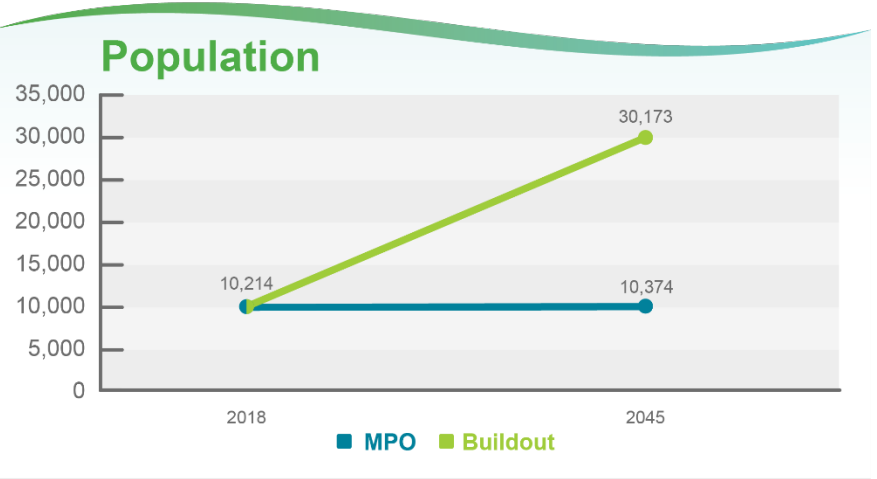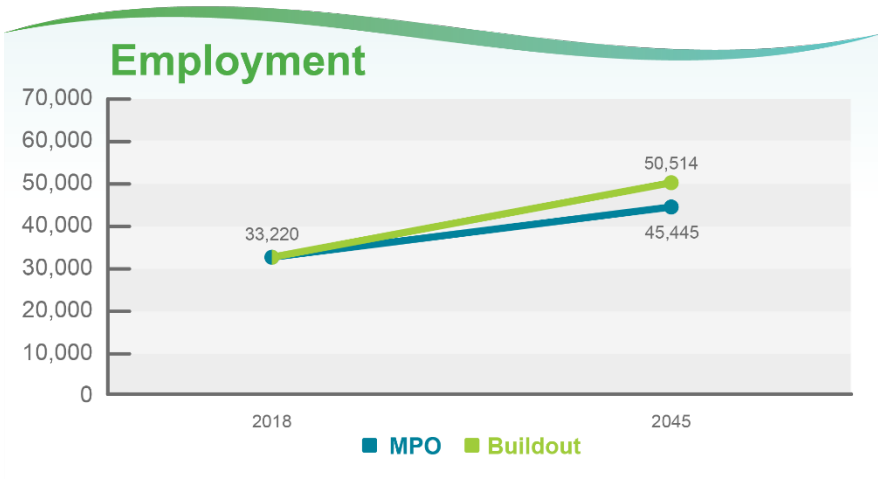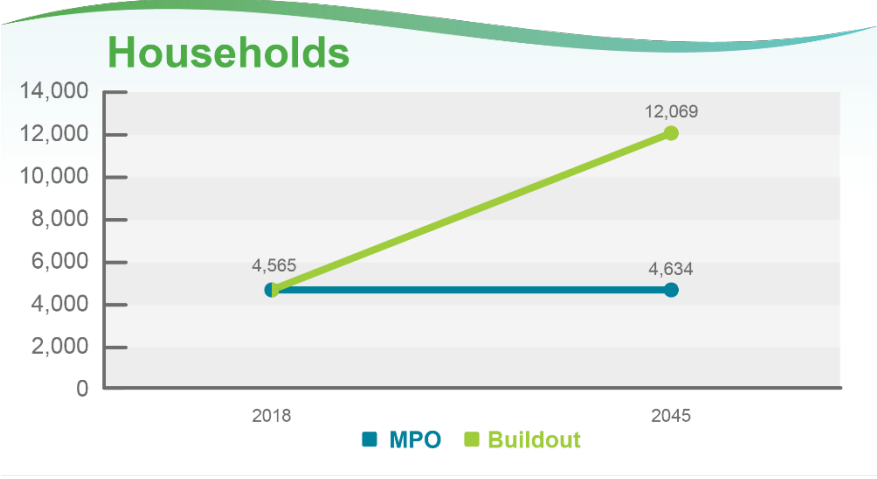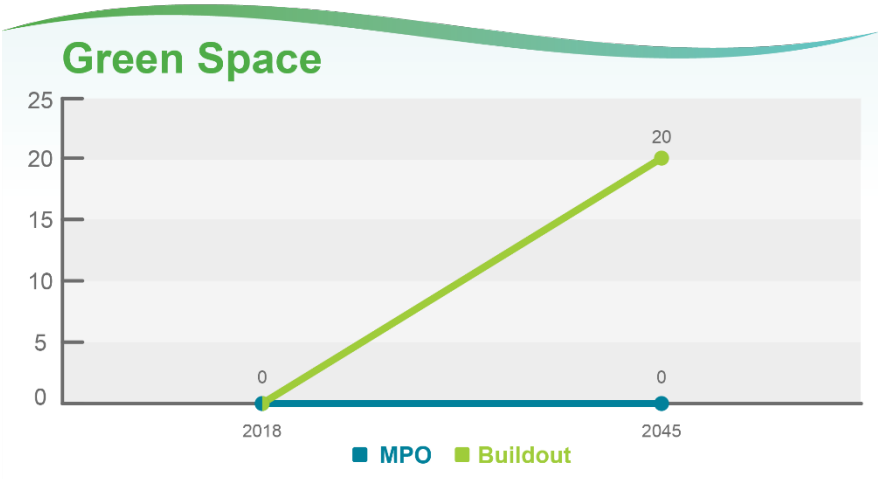
The Dallas Midtown study area was divided into zones based on the assumption of a maximum 5-minute walk time to the boundary of each zone from anyplace within it. The zones were created by splitting NCTCOG's traffic survey zones to create the zones for the study area (Figure 3-3).
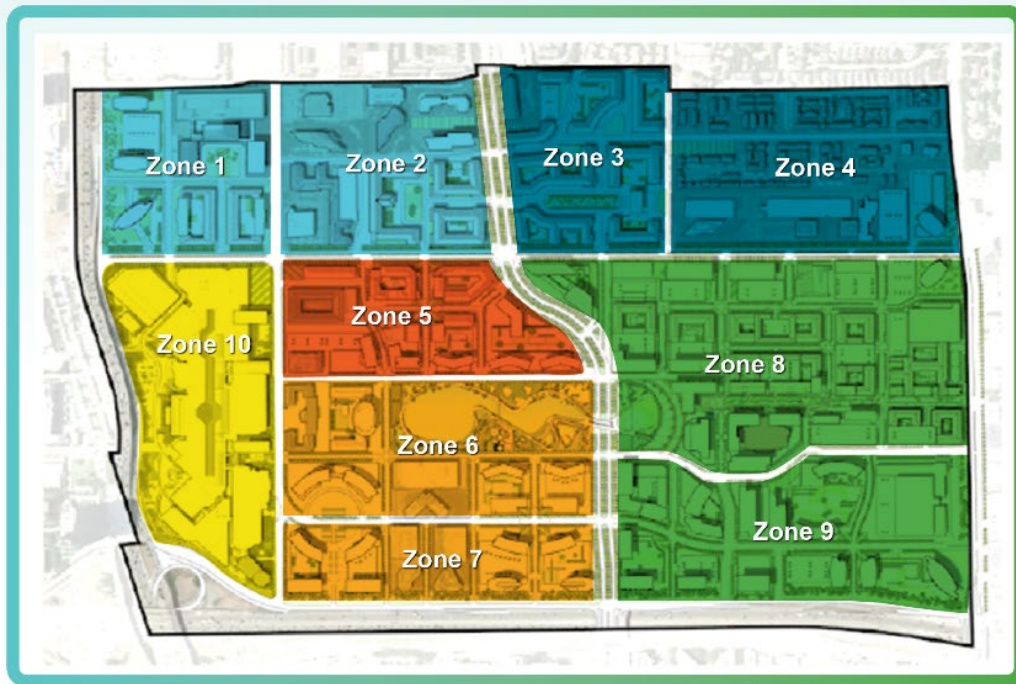
Figure A-3. Dallas Midtown Study Zones

Trip generation for the zones was performed using the *Trip Generation Manual* (ITE, 2017). Multiple land use types were considered, and their respective rates and regression equations were used to generate trips. Land use plans for the development provided by the developers were used to determine the input units for the land uses. Figure 1-3, in Section 1, shows the amount of each land use in each zone for the development buildout. The total development buildout is planned to include 10.8 million square feet of office space, 3.2 million square feet of retail space, 12,069 residential units, and 1,496 hotel rooms.

Internal trips were categorized into two types: intrazonal and interzonal. The intrazonal trips were calculated based on percentages from the *Trip Generation Manual* (ITE, 2017), and the interzonal trips for the Dallas Midtown development were based on the site capture of similar developments and engineering judgment. The site capture is the percentage of the total trips that will stay inside the mixed-use development. The total site capture includes both the intrazonal trips and interzonal trips.

Trip distribution was performed using the gravity model like the one used for trip distribution in the DFX (Dallas–Fort Worth Expanded) 4.5.3 model (NCTCOG, 2018). Parameters from National Cooperative Highway Research Program's (2012) Report 716 were used for the gamma function to create an impedance matrix for the gravity model.

The distributed vehicular trips were converted into person trips using a vehicle occupancy factor of 1.25. Modal split using a multinomial logit model was then performed among three modes: walking, ATS, and passenger car. Generalized cost was used in modal split based on travel time, delays, and fare associated with each mode.

Trip assignment was performed using TransCAD to assign the trip table for the ATS system to an ATS network. The results of the assignment are a ridership estimate between ATS stations.

A.2 Regional Connection Analysis Methodology

For regional ATS ridership, the NCTCOG regional travel demand model was modified to include potential connections between Dallas Midtown and DART's Red, Blue, Green, and Cotton Belt lines. Figure 3-4 shows the connection with preliminary stations. The connections were coded as light rail transit, like the existing DART system. The connections comprise of three interlined route alignments through the Dallas Midtown development: Cotton Belt to Red/Blue Lines, Green Line to Cotton Belt, and Red/Blue Lines to Green Line. These connections are conceptual and for modeling purposes only in order to gauge the expected impact should these regional connections exist.

Figure A-4. Regional Connections with Midtown Development
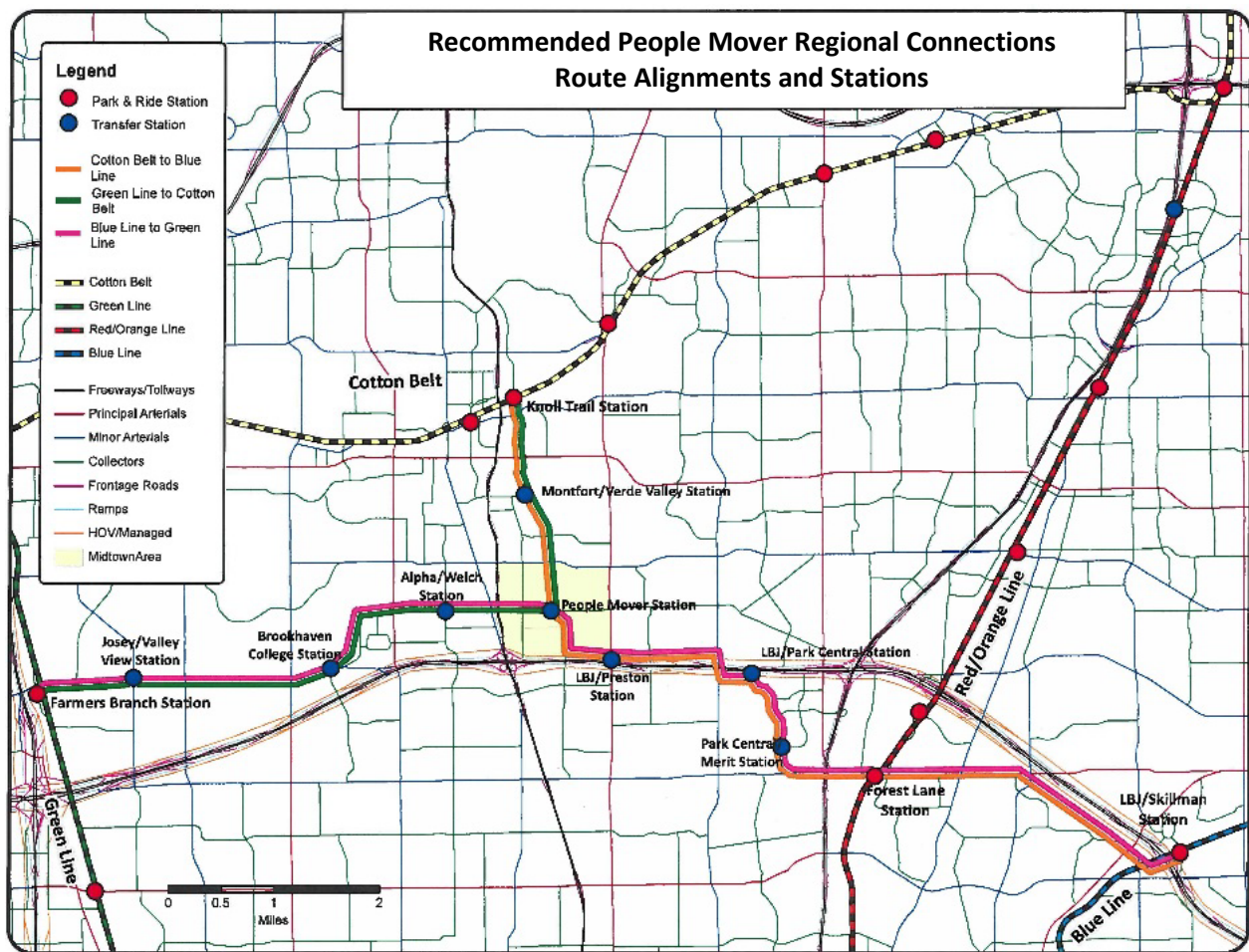
The demographics in the DFX 4.5.3 model (NCTCOG, 2018) were updated with the Dallas Midtown buildout demographics in 2045, and ridership estimates were forecast for each of the connections.

Figure 3-5 shows the ridership estimates for each of the connections and the ridership on each of the connections to the Dallas Midtown development.

Figure A-5. Dallas Midtown Daily Regional Connection Ridership Estimate
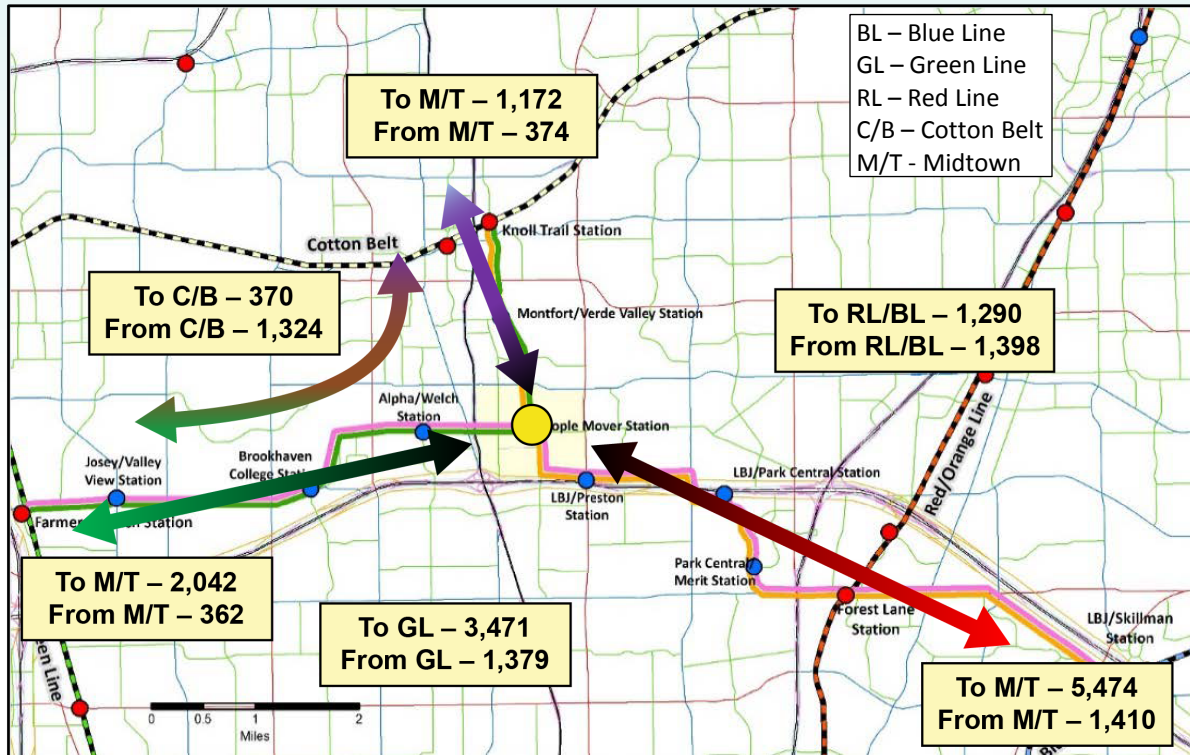
The ridership from the regional connectors was also assigned to the Dallas Midtown ATS as part of the total ridership estimate for the ATS. Select link analysis was conducted on the regional connectors to create a trip table for the trips to and from each of the zones within Dallas Midtown. This trip table was then modified to match the zone structure for the Dallas Midtown ridership estimation tool and assigned to the same ATS network as the internal ridership using the transfer station between the regional connectors and the ATS network as an additional zone.

A.3 Combined Internal and Regional Demand

Figure A-6 shows the results of the ridership estimation for the Dallas Midtown ATS by direction for each segment between approximate station locations. The total ridership estimate includes the internal, regional, and parking ridership. The internal ridership was estimated using the ridership estimation tool. The regional ridership was estimated using the DFX 4.5.3 model (NCTCOG, 2018) to get trips for three regional transit connections to Dallas Midtown, and then those trips were assigned to the Dallas Midtown ATS network. The transfer from the regional transit connections to the Dallas Midtown ATS network was assumed to be at a station near Montfort Drive and Bryce Lane. The parking ridership was estimated by first calculating the internal ridership percentage for an ATS link and comparing it to the total internal demand. Then that same percentage was applied to the p.m. peak hour parking demand, excluding reserved residential parking, to get the parking ridership estimate for each ATS segment.
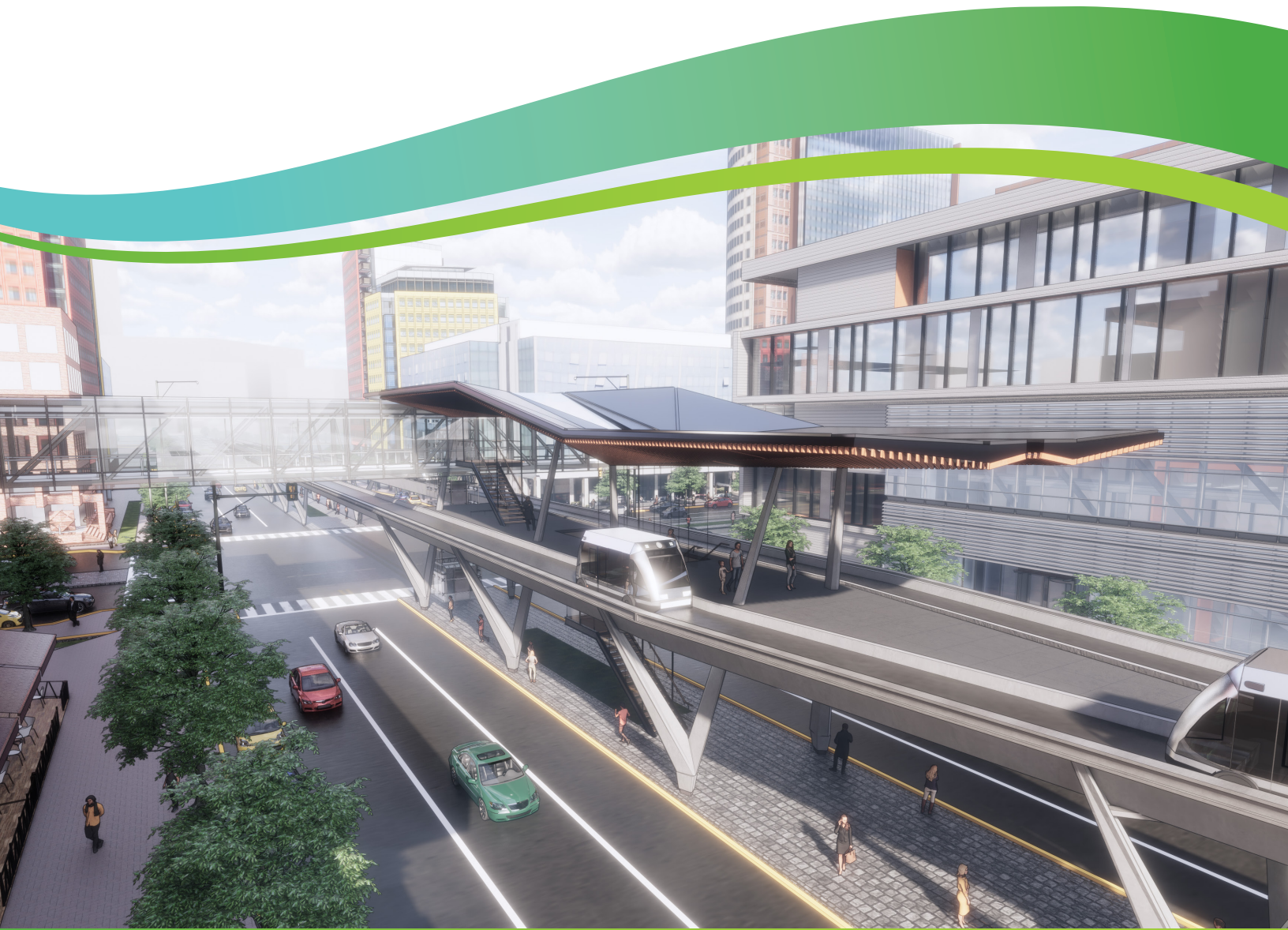
PM Peak Ridership Estimate Alternative 18

548
260
742
256
527
580
38
60
589
148
426
Transfer Station
Location in Model
195

LEGEND
NUMBER OF ESTIMATED
RIDERS BY DIRECTION
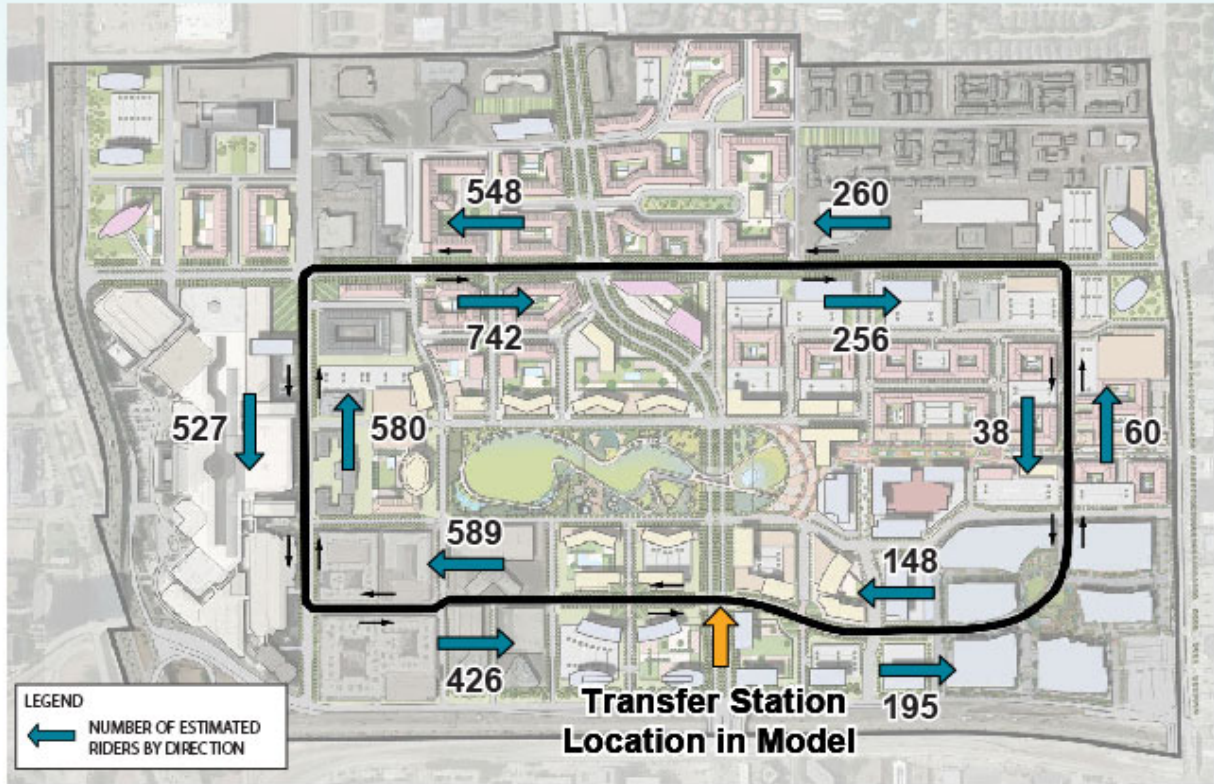
Appendix B
ATS Ridership Estimation Tool User Guide and Validation Memorandum

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Dallas Midtown Automated Transportation System Conceptual Engineering Study

North Central Texas Council of Governments

ATS Ridership Estimation Tool Users Guide

January 18, 2019

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Dallas Midtown Automated Transportation System Conceptual Engineering Study

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Author: Adam Garms, Aasish Khadka
File Name:

Jacobs Engineering Group Inc.

1999 Bryan Street, Suite 1200
Dallas, Texas 75201
United States
T +1.214.638.0145
F +1.214.638.0447
www.jacobs.com

Document history and status

Revision	Date	Description	By	Review	Approved

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Contents

Appendix A. Trip Assignment in TransCAD

Appendix B. Dallas Midtown Ridership Estimation Tool Validation Methodology

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ACRONYMS AND DEFINITIONS

NCHRP - National Cooperative Highway Research Program

ATS - Automated Transportation System

MXD - Mixed-use Development

ITE - Institute of Transportation Engineers

HBW - Home-Based Work

HBN - Home-Based Non-work

NHW - Non-Home-Based Work

MUTCD - Manual on Uniform Traffic Control Device

MPO - Metropolitan Planning Organization

NCTCOG - North Central Texas Council of Governments

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PURPOSE OF THIS GUIDE AND THE TOOL

This user's guide and the *Ridership Estimation Tool Version 1.1* described in it was developed by Jacobs Engineering in collaboration of North Central Texas Council of Governments (NCTCOG) to estimate internal ridership for the Dallas Midtown Mixed-Use development (MXD). This user's guide explains the methodology and logic used in *Ridership Estimation Tool version 1.1*. If any assistance is needed regarding the use of estimation tool, please contact Jacobs.

This Ridership Estimation Tool Version 1.1 was developed to estimate the internal Automated Transportation System (ATS) ridership within relatively large mixed-use development. This tool can be used as supplement to other forecasting tools to estimate ATS ridership. This tool was developed to estimate the ATS ridership within the proposed Dallas Midtown Mixed-use Development (MXD) located in Dallas, Texas. This tool was developed in a manner that it could also be used for other mixed-use developments located in the Dallas/Fort Worth Metropolitan Area. This tool has been setup for developments with maximum of 25 zones.

The Ridership Estimation Tool Version 1.1 is built upon excel platform and uses macros to perform some of its task. The user of this tool should have at least a basic knowledge of excel and macros must be enable within excel for proper use of this tool.

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1. INTRODUCTION

In this chapter, we will summarize the logic used in *Ridership Estimation Tool version 1.1*. This *Ridership Estimation Tool Version 1.1* was developed to estimate the internal ridership within a relatively large mixed-use development using empirical rates and equations. This tool follows the typical four-step modelling procedure but only three of the four-steps are done in this estimation tool. The final step (Trip Assignment) is done using other traffic analysis software like TransCAD or PTV Vistro. The result of the estimation tool is the trip matrix between zones by each mode of transportation in consideration. Users can use the trip matrix as an input for Trip assignment step in other Trip Assignment software.

The parameters, equations, coefficients, and model used in this tool are extracted from the following sources:

- 10th Edition of the Institute of Transportation Engineers (ITE) Trip Generation Manual

- National Cooperative Highway Research Program (NCHRP) Report 684: Enhancing Internal Trip Capture Estimation for Mixed-Use Developments

- National Cooperative Highway Research Program (NCHRP) Report 716: Travel Demand Forecasting: Parameters and Techniques

- Dallas-Fort Worth Regional Travel Model (DFWRTM) from NCTCOG

Ridership Estimation Tool Version 1.1 has eleven tabs. Each tab is linked to other tabs and relies on references between the tabs to perform calculations. The following tabs are present in the tool in the order they are listed below:

1. Instructions
2. Land use Inputs
3. Multi-Modal inputs
4. Trip Generation
5. Intrazonal Trips
6. Community (Site) capture
7. Trips Distribution
8. Trip Distribution Results
9. Modal Split
10. Modal split Results
11. Visual output

Even though this estimation tool has eleven different tabs, the four-step travel demand modelling process is the core of this estimation tool. Extra tabs in this tool are for informative, data entry, and output display purpose. The core four-step logic used in *Ridership Estimation Tool Version 1.1* is summarized below and will be expounded on in further detail in later sections.

1.1 TRIP GENERATION:

Trip generation is the first step in four-step ridership estimation procedure. The trip generation is used to convert land use data into the number of trips using the trip rates or regression equations from the *ITE Trip Generation Manual 10th Edition.* The land use types included in the tool to generate trips are Residential, Retail, Lodging, Office, Recreational, Medicine, Institutional, and Service. These land uses are categorized into sub categories to estimate the trips more accurately.

The inputs for the trip generation step are the expected numbers of units for each land use inside the mixed-use development and output from this step is the total number of entering and exiting trip ends.

1.2 INTERNAL TRIP ESTIMATION:

Internal trips are the trips which start and end inside the mixed-use development. Internal trips have no impact outside the mixed-use development. The number of internal trips depends upon the magnitude and combination of different land uses inside the mixed-use development. For this tool, internal trips are categorized into two types: Intrazonal trips and Interzonal trips. The trips internal to each zone are categorized as intrazonal trips.
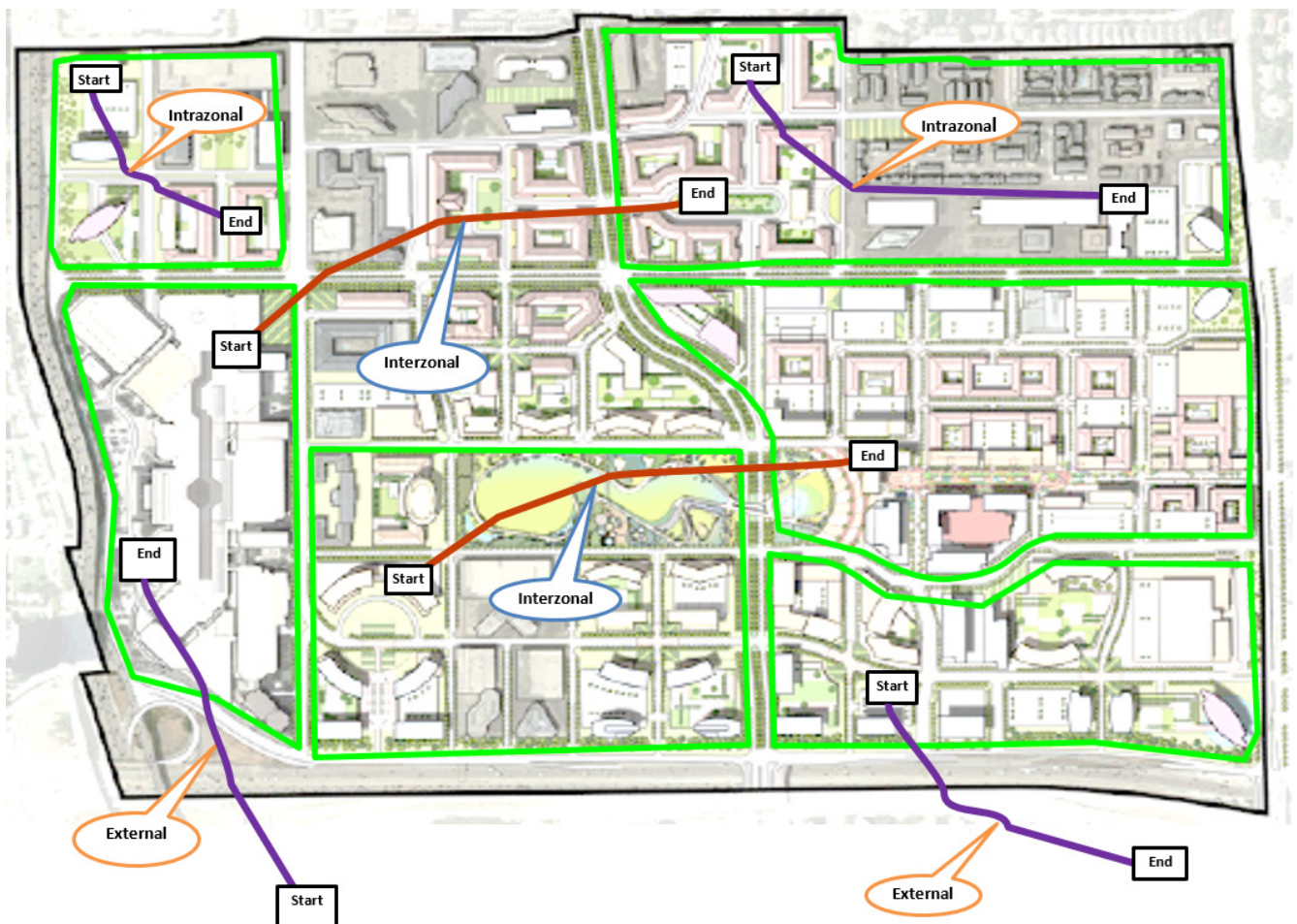

Figure 1: Mixed-use development with different types of trips

The trips that are internal to mixed-use site but are not internal to each zone are categorized as Interzonal trips. **Figure 1** above show the different types of trips in relation to the zones (green boundary) and study area. The Intrazonal trips are estimated based on the percentages from *ITE Trip Generation Manual 10ᵗʰ Edition*.

1.3 COMMUNITY (SITE) CAPTURE ESTIMATION:

The site capture of mixed-use developments is defined as the portion of the total trips that stay inside the mixed-use development and will not cross the boundary of the mixed-use development. For this estimation tool, site capture is estimated by the summation of the intrazonal trips and interzonal trips. Site capture percentage is based on characteristics of the mixed-use development and is affected by the interaction of the land uses present in mixed-use development. There is no maximum or minimum percentage limits for community/site capture since each of the mixed-use developments are unique.

The input for this step is the estimated site capture percentage and the output from this step are the site captured trips.

1.4 TRIP DISTRIBUTION:

The second step in the four-step modeling process is trip distribution. The trip distribution step determines the number of trips between each origin and destination zones. In this tool trip distribution is done by using the gravity model. The gamma function is used as a friction factor to create a friction factor matrix for the gravity model and the parameters for the gamma function are referenced from the NCHRP report 716. Trip distribution is done assuming all trips are vehicular trips. In this tool trip distribution can be done for thee time periods (AM, PM and Daily) and three trip purposes (HBW, HNW, and NHB). In the tool, the trip distribution step uses macros to change the inputs and copy the results to the trip distribution results tab.

The input for this step is a matrix having total trips origins and destinations for each zone and the output from this step is an OD trip matrix between zones.

1.5 MODAL SPLIT:

The third step in the four-stop modeling process in the ridership estimation tool is modal split/mode choice. Modal split estimates the portion of the total trips that will use other modes once introduced due to generalized cost associated with each mode. In this tool, three modes of transportation are considered: Walking, Automated Transportation System (ATS), and Personal vehicle/Passenger car and modal split can be done for the three time periods (AM, PM and Daily). A multinomial logit model is used to perform modal split. Generalized cost is used in modal split based on travel time, delays and fare associated with each mode.

The input for this step is OD trip matrix from trip distribution and the output from this step are the OD trip matrices for each mode of transportation considered.

1.6   TRIP ASSIGNMENT:

Trip assignment is the final step in the four-step modeling process but is done in a separate application from the ridership estimation tool. This step is not build into this tool because it is more efficient to use a software program that has geographic capabilities like TransCAD or PTV Vistro for the networks needed for traffic assignment. Traffic Assignment was performed for only the ATS trip matrix and network for this project. The steps used in TransCAD to do traffic assignment are included in **Appendix A**.

The input for this step is OD matrix by mode and the ATS network. The output from this step are the link volume in each link of ATS.

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2.   ESTIMATION TOOL DETAIL DESCRIPTION:

As stated earlier, this estimation tool is organized into 11 different tabs to assist with the process of building the model. Each tab is designed to serve specific purpose in the model process. Cells in each tab are linked to cells in other tabs and calculations in each tab depends upon the values in other tabs. Each of the tabs has an informative green ribbon located at top of the worksheets to guides user about how to use that specific tab.

Land Use Inputs: Please select appropriate land use type in each MXD zone and enter the expected number of units for each land use in the users input boxes below. We recommend dividing the study area into multiple zones to accurately capture interactions between land uses.

The light orange color cells are for user input and users should enter their inputs in these cells.

The detail description and user guidance for each of the tabs can be found below.

2.1   INSTRUCTIONS:

The instructions tab gives users general information about the *Ridership Estimation Tool Version 1.1.* This tab gives user information about the purpose, potential uses, cautionary notes, version information, definition of acronyms, and contact information. It is recommended the user read these instructions and become familiar with the estimation tool.

⚠️   *Please don't delete any rows or columns in this tool. Deletion of any rows or columns can create problems in the cell references and could produce error in results.*

2.2   LAND USE INPUTS:

The land use inputs tab includes the land use information that is used for the internal ridership estimation. Institute of Transportation Engineer's (ITE) *Trip Generation Manual 10th Edition* land use categories are used. Most of the land use information that can be found in suburban and urban settings are included in the estimation tool. A total of 8 land use categories which include Residential, Retail, Lodging, Office, Recreational, Medicine, Institutional, and Service and approximately 98 sub-categories are included in this tool. This tab also includes the ITE code, units type, trip generation rate, regression equation, and directional distribution percentage used in estimation tool.

Expected number of units for each land use are entered into the light orange color cells.
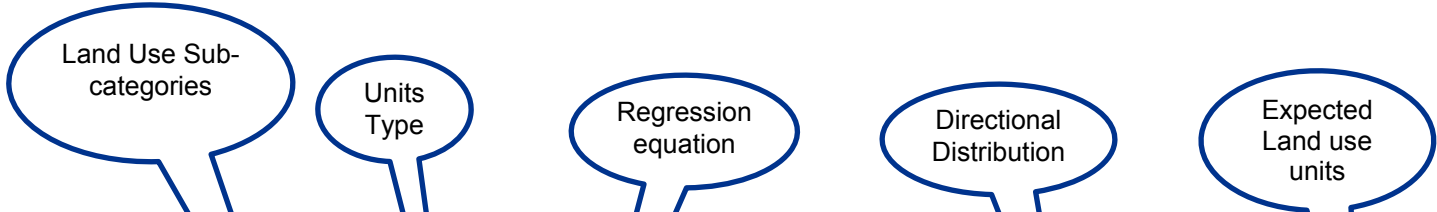
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Land Use Sub-categories

Units Type

Regression equation

Directional Distribution

Expected Land use units

Land Use Inputs: Please select appropriate land use type in each MXD zone and enter expected number of units for each land use in the users input boxes below. We recommend dividing the study area into multiple zones to accurately capture interactions between land uses.

ITE Land Use	Land Use Sub Categories	ITE Code	UNIT	AM		PM		DAILY		Directional Distribution						Zone 1 Expected Units	Zone 2 Expected Units
				AVG	Regression Equation	AVG Rate	Regression Equation	AVG Rate	Regression Equation	AM ENTER	EXIT	PM ENTER	EXIT	Daily ENTER	EXIT		
Residential	Single family Detached Housing	210	DU	0.74	T = 0.71(X) + 4.80	0.99	Ln(T) = 0.96 Ln(X) + 0.20	9.44	Ln(T) = 0.92 Ln(x) + 2.71	25%	75%	63%	37%	50%	50%		
	Multifamily Housing (Low-Rise)	220	DU	0.46	Ln(T) = 0.95 Ln(X) - 0.51	0.56	Ln(T) = 0.89 Ln(X) - 0.02	7.32	T = 7.56(X) - 40.86	23%	77%	63%	37%	50%	50%		
	Multifamily Housing (Mid-Rise)	221	DU	0.36	Ln(T) = 0.98 Ln(X) - 0.98	0.44	Ln(T) = 0.96 Ln(X) - 0.63	5.44	T = 5.45(X) - 1.75	26%	74%	61%	39%	50%	50%	289	1150
	Multifamily Housing (High-Rise)	222	DU	0.31	T = 0.28(X) + 12.86	0.36	T = 0.34(X) + 8.56	4.45	T = 3.94(X) + 211.81	24%	76%	61%	39%	50%	50%		
	Off-Campus Student Apartment	225	BR	0.12	T = 0.10(X) + 5.31	0.25	T = 0.24(X) + 2.90	3.15	T = 3.03(X) + 54.26	41%	59%	50%	50%	50%	50%		
	Mid-Rise Residential with 1st-Floor Commercial	231	DU	0.30		0.36		3.44		28%	72%	70%	30%	50%	50%		
	High-Rise Residential with 1st-Floor Commercial	232	O DU	0.31		0.21											
	Senior Adult Housing - Detached	251	DU	0.24	Ln(T) = 0.76 Ln(X) + 0.21	0.30	Ln(T) = 0.78 Ln(X) + 0.28	4.27	Ln(T) = 0.88 Ln(X) + 2.28	33%	67%	61%	39%	50%	50%		
	Senior Adult Housing - Attached	252	DU	0.20	T = 0.20(X) - 0.18	0.26	T = 0.24(X) + 2.26	3.7	T = 4.02(X) - 25.37	35%	65%	55%	45%	50%	50%		
	Congregate Care Facility	253	DU	0.07	T = 0.05(X) + 2.13	0.18	T = 0.14(X) + 5.10	2.02		60%	40%	53%	47%	50%	50%		
	Assisted Living	254	1000 sqft	0.39		0.48		4.19		78%	22%	30%	70%	50%	50%		
	Continuing Care Retirement Community	255	U	0.14	Ln(T) = 0.85 Ln(X) - 0.82	0.16	Ln(T) = 0.89 Ln(X) - 0.99	2.4	T = 2.01(X) + 715.56	65%	35%	39%	61%	50%	50%		
	Residential Planned Unit Development	270	DU	0.57	Ln(T) = 0.88 Ln(X) + 0.26	0.69	Ln(T) = 0.97 Ln(X) - 0.14	7.38	Ln(T) = 0.94 Ln(X) + 2.43	22%	78%	65%	35%	50%	50%		
Lodging	Hotel	310	R	0.47	T = 0.50(X) - 5.34	0.60	T = 0.75(X) - 26.02	8.36	T = 11.29(X) - 426.97	59%	41%	51%	49%	50%	50%		
	All suites Hotel	311	R	0.34	T = 0.51(X) - 29.37	0.36	T = 0.45(X) - 14.07	4.46	T = 5.20(X) - 119.26	53%	47%	48%	52%	50%	50%		
	Business Hotel	312	R	0.39	T = 0.35(X) + 4.40	0.32		4.02	T = 2.90(X) + 151.69	42%	58%	55%	45%	50%	50%		
	Motel	320	R	0.38	T = 0.36(X) + 2.56	0.38	T = 0.35(X) + 3.53	3.35	T = 3.62(X) - 29.43	37%	63%	54%	46%	50%	50%		
	Resort Hotel	330	R	0.32	T = 0.38(X) - 28.58	0.41	T = 0.52(X) - 55.42			72%	28%	43%	57%				
Recreational	Public Park	411	Acres	0.02		0.11	T = 0.06(X) + 22.60	0.78	T = 0.64(X) + 88.04	59%	41%	55%	45%	50%	50%		
	Campground/Recreational Vehicle Park	416	Acres	0.48		0.98				42%	58%	69%	31%				
	Multipurpose Recreational Facility	435	1000 sqft			3.58						55%	45%				
	Bowling Alley	437	1000 sqft	0.81		1.16	T = 1.01(X) + 4.92			95%	5%	65%	35%				
	Movie Theater	444	1000 sqft	0.22		6.17		78.09				94%	6%	50%	50%		
	Multiplex Movie Theater .	445	1000 sqft			4.91						62%	38%				
	Arena	460	1000 sqft			0.47						36%	64%				
	Ice Skating Rink	465	1000 sqft	0.17		1.33				37%	63%	55%	45%				
	Casino/Video Lottery Establishment	473	1000 sqft			13.49						56%	44%				
	Amusement Park	480	Acres	0.21		3.95		53.41		88%	12%	61%	39%	50%	50%		
	Tennis Courts	490	Courts			4.21		30.32						50%	50%		
	Health/Fitness Club.	492	1000 sqft	1.31		3.45	Ln(T) = 0.67 Ln(X) + 2.44			51%	49%	57%	43%				
	Athletic Club	493	1000 sqft	3.16		6.29				61%	39%	62%	38%				
	Recreational Community Center.	495	1000 sqft	1.76	Ln(T) = 0.54 Ln(X) + 2.73	2.31	Ln(T) = 0.76 Ln(X) + 2.00	28.82	Ln(T) = 0.98 Ln(X) + 3.42	66%	34%	47%	53%	50%	50%		

Land Use Categories

ITE Code

Average Rate

⚠️ *Please make sure you are using right ITE land use sub-categories. The simplest way to do this is to match Land use sub categories name and ITE code.*

2.3   MULTI-MODAL INPUTS:

Multi-modal inputs section has input related to different modes of transportation considered in this study. Inputs entered here are used to calculate the modal split between the modes of transportation. In this tool, mode split is performed between three modes: Walking, Automated Transportation System (ATS) and Personal Vehicle/Passenger Car. Mode split is performed using a multinomial logit model and generalized cost as utility function. To make mode split simple we considered three kinds of variables associated with generalized cost for each mode: speed, delay, and cost. Generalized cost is the cost associate with each mode that include direct and indirect cost. Direct cost is the actual cost (fare, parking) associated with each mode and indirect cost includes the factors other than direct cost that will affect the user's decision to choose a mode. Speed and delay are used to calculate the indirect cost. Speed and delay are converted into total travel time for each mode and multiplied by the value of time used in the NCTCOG regional travel demand model to get indirect cost associated with each mode. The direct cost and indirect cost are added together to get final generalized cost.

Generalized cost = Indirect cost + Direct cost

Indirect cost = Travel time*NCTCOG value of time

Travel time (walking) $= \dfrac{Centroid\ distance\ between\ zones}{speed}$ + Intersection delay

Note: MUTCD recommends average walking speed of 3.5 to 4 ft./sec

Travel time (ATS) $= \dfrac{Centroid\ distance\ between\ zones}{speed}$ + ATS Headway or Total ATS travel time

Travel time (Passenger Car) $= \dfrac{Centroid\ distance\ between\ zones}{speed}$ + Intersection delay + Parking delay
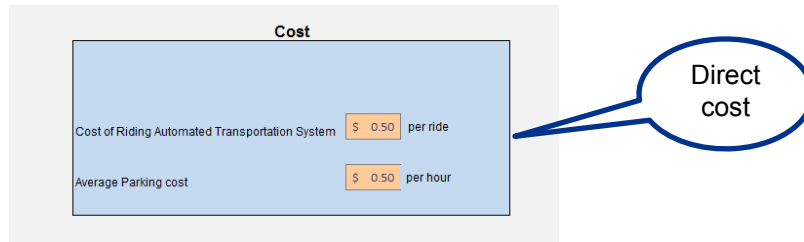
Direct cost = fare or parking

Direct cost (ATS) = fare for riding ATS

Direct cost (passenger car) = parking cost

DESCRIPTION OF EACH COMPONENT OF MODAL INPUT TAB

 Increasing the walking speed of average person may add more trips for this mode by decreasing the travel time and vice versa

 Increasing ATS speed may add more trips for ATS mode by decreasing the travel time and vice versa

 Increasing personal vehicle speed may add more trips for personal vehicle mode and vice versa

 Increasing maximum walk time may increase walking trips share and vice versa.

Tool checks "if condition" based on walking time first before doing modal split. If travel time between zones is less than waking time, mode split is performed for three modes and if travel time between zones is more than walking time mode split is performed between two modes assuming nobody will walk beyond assumed walking time.

 Increasing headway between ATS system may decrease ATS trips share by increasing travel time and vice versa.

 Increasing average parking delay may decrease personal vehicle trips share by increasing travel time and vice versa

 Increase in cycle length will add more delay for walking and personal vehicle mode and eventually decreasing their modal share and vice versa

Cost of Riding Automated Transportation System | $ 0.50 | per ride

Increasing ATS riding fare may decrease ATS mode trip share by increasing its generalized cost and vice versa.

Average Parking cost | $ 0.50 | per hour

Increasing the parking cost may decrease the personal car trip share by increasing the generalized cost and vice versa.

Number of Zones | 10

Number of zones in study area depend upon size of study area, land use, and engineering judgement. In this tool the number of zones can vary from 2 to 25.

⚠️ *Ridership Estimation Tool Version 1.1 can handle maximum of 25 zones only.*

Value of Time in $ proposed by Region Planning Organization | $0.23 Per min

NCTCOG value of time from the regional model was used for this study. NCTCOG value of time for Dallas midtown mixed use development was $0.23 per minute.

	AM	PM
Vehicle Occupancy Factor	1.25	1.25

Vehicle occupany factor is used to convert vehicular trips to personal trips. Vehicle occupancy factor of 1.25 for both AM and PM was used for Dallas midtown mixed use development.

Scroll down to enter more required data

Scroll down sign: Scroll down to enter more data or view more results

Distance Between Zones (ft)

Note: Distance between zone is the approximate distance between the centroid of two zones. Size of distance matrix depend upon number of zones in consideration. All other cells remains empty.

Zones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		1500	3000	4000	1750	2000	3000	4000	4800	1350															
2	1500		1700	3000	1100	2100	2600	2800	3700	2100															
3	3000	1700		1500	1700	2100	2700	1700	2700	3000															
4	4000	3000	1500		3000	3500	3800	1700	2500	1600															
5	1750	1100	1700	3000		800	1600	2300	3000	1500															
6	2000	2100	2100	3500	800		900	2400	2600	1500															
7	3000	2600	1700	3800	1600	900		2800	2500	1700															
8	4000	2800	2700	1700	2300	2400	2800		1300	3800															
9	4800	3700	2700	2500	3000	2600	2500	1300		4000															
10	1350	2100	3000	1600	1500	1500	1700	3800	4000																
11																									
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The Distance Between Zones (ft) matrix is an approximate centroid distance between the zones. The user enters the centroid distance in the input cells in light orange for top half of matrix only, the bottom half of the matrix will populate automatically. Dark grey cells have no input. The size of matrix depends upon number of zones in consideration. All other cells remain empty.

Number of Major Signalized Intersections Between Zones

Note: Number of major signalized intersection between zones depend upon locations of zones and most likely path traveler will adopt. Size of intersection matrix depend upon number of zones in consideration All other cells remains empty

Zones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		1	2	2	1	2	2	3	3	2															
2	1		1	1	1	2	2	1	2	2															
3	2	1		1	1	2	2	1	2	3															
4	2	1	1		2	2	2	0	1	3															
5	1	1	1	2		0	1	1	1	1															
6	2	2	2	2	0		0	1	1	0															
7	2	2	1	2	1	0		1	0	0															
8	3	1	2	0	1	1	1		0	2															
9	3	2	2	1	1	1	0	0		2															
10	2	2	3	3	1	0	0	2	2																
11																									
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In the Number of Major Signalized Intersections Between Zones matrix the user enters the total number of major signalized intersection between zones. This information is used to calculate delay for pedestrian and personal vehicle mode. The size of matrix depends upon number of zones in consideration. All other cells remains empty.

The ATS Travel Time matrix includes the total time spend travelling from one zone to another zone when using the ATS system. This matrix can be copied from TransCAD shortest path calculations for the ATS network. **Appendix A** includes instructions for producing the input for this matrix. Inputting data into this matrix is optional and the tool will use the ATS speed and distance between zones to calculate travel time if this matrix is left empty. The size of matrix depends upon number of zones in consideration. All other cells remain empty.

ATS Travel Time = Time from centroid to ATS station (getting on the ATS) + Time spent travelling on ATS + Time from ATS station to centroid (getting off the ATS)

2.4   TRIP GENERATION:

The ridership estimation tool uses *ITE Trip Generation Manual 10th Edition* to perform trip generation. This section of the estimation tool does not require any inputs from the user and displays the output from the trip generation calculations. The tool performs a conservative trip generation and reports the maximum number of trips between using the average rate or regression equation. If either the average rate or regression equation is missing, trips are generated using either one available. If both average rate and regression equation are missing there is no trips generation for that land use and tool will report empty cells. This tool generates trips for three times of the day (AM Peak, PM Peak, and Daily). Trips generated in this step are vehicular trips. Number of total trips produced by this tool were validated according to procedure outlined in Dallas Midtown Ridership Estimation Tool Validation Methodology included in **Appendix B.**

For convenience, this section has buttons with macros built into them located in the top ribbon bar. The user can use these macro buttons to navigate to the desired zones. At the bottom of the trip generation table there is a summary of each zones. The user can navigate to the summary by using the summary button.

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Zone 25	Navigation button: Button used to navigate to desired zones.
Summary	Summary button: Button used to navigate to summary section
Home	Home button: Button used to bring users back to home on this tab.

PLEASE NOTE *There are no inputs in this section. Trip generation tab is output only.*

Trip Generation output window

Trip Generation: Total trip ends generated are based on the rates and regression equations found in ITE Trip Generation Manual, 10th edition. Trip ends have one end (either origin or destination) located in MXD. Trip ends are expressed in **Vehicular Trips.**

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 17	Zone 18
Zone 19	Zone 20	Zone 21	Zone 22	Zone 23	Zone 24	Zone 25	Summary	

		Zone 1							
		AM Peak			**PM Peak**			**Daily**		
ITE LAND USE	**Land use Sub-Categories**	**TRIP ENDS**	**ENTER**	**EXIT**	**TRIP ENDS**	**ENTER**	**EXIT**	**TRIP ENDS**	**ENTER**	**EXIT**
Residential	Single family Detached Housing									
	Multifamily Housing (Low-Rise)									
	Multifamily Housing (Mid-Rise)	104	27	77	127	78	49	1573	787	786
	Multifamily Housing (High-Rise)									
	Off-Campus Student Apartment									
	Mid-Rise Residential with 1st-Floor Commercial									
	High-Rise Residential with 1st-Floor Commercial									
	Senior Adult Housing - Detached									
	Senior Adult Housing - Attached									
	Congregate Care Facility									
	Assisted Living									
	Continuing Care Retirement Community									
	Residential Planned Unit Development									
	Base Trips	104	27	77	127	78	49	1573	787	786
	Intrazonal Trips	4	1	3	62	39	23	0		
	Trips External to Zone	100	26	74	65	39	26	1573	787	786

2.5   INTRAZONAL TRIPS:

Intrazonal trips have both a starting and ending point within the same zone. The intrazonal trips are estimated based on the internal capture percentages from *ITE Trip Generation Manual 10th Edition.* Intrazonal trips are calculated for AM and PM peak Period. For each pair of land uses, Intrazonal trips are estimated by taking minimum number of trips between outbound and inbound trips. **Figure 1** shows illustration of Intrazonal trips. Intrazonal trips are subtracted from the base trips since they stay within the zone. **Table 1 and Table 2** below show unconstrained internal capture rates for different land use pairs for the AM and PM Peak period. These internal capture percentage rates are from *ITE Trip Generation Manual 10th Edition.*

Table 1: Unconstrained Internal Capture Rates for Trips originating within MDX

		WEEKDAY	
		AM Peak Hour	PM Peak Hour
From OFFICE	To Retail	28%	20%
	To Restaurant	63%	4%
	To Cinema/Entertainment	0%	0%
	To Residential	1%	2%
	To Hotel	0%	0%
From RETAIL	To Office	29%	2%
	To Restaurant	13%	29%
	To Cinema/Entertainment	0%	4%
	To Residential	14%	26%
	To Hotel	0%	5%
From RESTAURANT	To Office	31%	3%
	To Retail	14%	41%
	To Cinema/Entertainment	0%	8%
	To Residential	4%	18%
	To Hotel	3%	7%
From CINEMA/ENTERTAINMENT	To Office	0%	2%
	To Retail	0%	21%
	To Restaurant	0%	31%
	To Residential	0%	8%
	To Hotel	0%	2%
From RESIDENTIAL	To Office	2%	4%
	To Retail	1%	42%
	To Restaurant	20%	21%
	To Cinema/Entertainment	0%	0%
	To Hotel	0%	3%
From HOTEL	To Office	75%	0%
	To Retail	14%	16%
	To Restaurant	9%	68%
	To Cinema/Entertainment	0%	0%
	To Residential	0%	2%

Source: Bochner, B., K. Hooper, B. Sperry, and R. Dunphy. NCHRP Report 684: *Enhancing Internal Trip Capture Estimation for Mixed-Use Developments*. Washington, DC: Transportation Research Board, Tables 99 and 100, 2011.

Table 2: Unconstrained Internal Capture Rates for Trips Destination within MDX

		Weekday	
		AM Peak Hour	PM Peak Hour
To OFFICE	From Retail	4%	31%
	From Restaurant	14%	30%
	From Cinema/Entertainment	0%	6%
	From Residential	3%	57%
	From Hotel	3%	0%
To RETAIL	From Office	32%	8%
	From Restaurant	8%	50%
	From Cinema/Entertainment	0%	4%
	From Residential	17%	10%
	From Hotel	4%	2%
To RESTAURANT	From Office	23%	2%
	From Retail	50%	29%
	From Cinema/Entertainment	0%	3%
	From Residential	20%	14%
	From Hotel	6%	5%
To CINEMA/ENTERTAINMENT	From Office	0%	1%
	From Retail	0%	26%
	From Restaurant	0%	32%
	From Residential	0%	0%
	From Hotel	0%	0%
To RESIDENTIAL	From Office	0%	4%
	From Retail	2%	46%
	From Restaurant	5%	16%
	From Cinema/Entertainment	0%	4%
	From Hotel	0%	0%
To HOTEL	From Office	0%	0%
	From Retail	0%	17%
	From Restaurant	4%	71%
	From Cinema/Entertainment	0%	1%
	From Residential	0%	12%

Source: Bochner, B., K. Hooper, B. Sperry, and R. Dunphy. NCHRP Report 684: *Enhancing Internal Trip Capture Estimation for Mixed-Use Developments*. Washington, DC: Transportation Research Board, Tables 101 and 102, 2011.

If user like to use internal capture percentage other than the rates from *ITE Trip Generation Manual 10th Edition*, the user can input the internal capture percentage in user input cells. Enter N/A if internal capture percentage is not available. For each time period (AM or PM) two types of percentage are required: Inbound percentage and Outboud percentage.

Internal Capture Percentage are based on ITE Trip Generation Manual 10th edition						
	Outbound Trips for AM Peak Hour					
Origin Land Use From	**Destination Land Use To**					
	Residential	**Hotel**	**Cinema**	**Office**	**Retail**	**Restaurant**
Residential	N/A	0%	N/A	2%	1%	20%
Hotel	0%	N/A	N/A	75%	14%	
Cinema	N/A	N/A	N/A	N/A	N/A	N/A
Office	1%	0%	N/A	N/A	28%	63%
Retail	14%	0%	N/A	29%	N/A	13%
Restaurant	4%	3%	N/A	31%	14%	N/A

Internal capture percentage input area
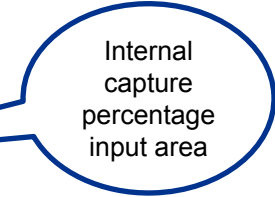
The internal capture percentages from *ITE Trip Generation Manual 10th Edition* are the result of reseach over many years. These precentages can be adjusted if local knowledge or more recent data is available. Caution should be used when changing these percentage as they can greatly affect internal capture of the mixed-use development.

Inbound Percentage: These percentages are applied to base trips of the land use from where trips are entering.

Outbound Percentage: These percentages are applied to base trips of the land use from where trips are exiting.

For each pair of land uses, intrazonal trips are estimated by taking minimum number between outbound and inbound trips.
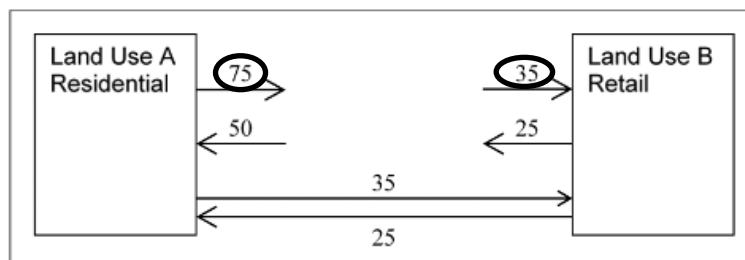
Source: Bochner, B., K. Hooper, B. Sperry, and R. Dunphy. NCHRP Report 684: *Enhancing Internal Trip Capture Estimation for Mixed-Use Developments*. Washington, DC: Transportation Research Board, Figure 19, 2011.

Figure 2: Internal capture calculation between two land use pair

In **Figure 2** above outbound trips of 75 are calculated by applying outbound percentage to the base exiting trips for residential land use and inbound trips of 35 are calculated by applying inbound percentage to the base entering trips for the retail land use. 35 Intrazonal trips are estimated by taking minimum number between outbound and inbound trips.

Each zones has intrazonal trips for AM and PM peak period. N/A indicate no internal capture due to lack of information.

Zone 1							
	Internal capture for AM Peak Hour						
Origin Land Use From	Destination Land Use To						Exiting/ Origin
	Residential	Hotel	Cinema	Office	Retail	Restaurant	
Residential	N/A	0	N/A	2	1	0	3
Hotel	0	N/A	N/A	0	0	0	0
Cinema	N/A	N/A	N/A	N/A	N/A	N/A	0
Office	0	0	N/A	N/A	58	0	58
Retail	1	0	N/A	32	N/A	0	33
Restaurant	0	0	N/A	0	0	N/A	0
Destination/ Entering	1	0	0	34	59	0	TRUE
	Internal capture for PM Peak Hour						
Origin Land Use From	Destination Land Use To						Exiting/ Origin
	Residential	Hotel	Cinema	Office	Retail	Restaurant	
Residential	N/A	0	0	2	21	0	23
Hotel	0	N/A	0	0	0	0	0
Cinema	0	0	N/A	0	0	0	0
Office	3	0	0	N/A	45	0	48
Retail	36	0	0	12	N/A	0	48
Restaurant	0	0	0	0	0	N/A	0
Destination/ Entering	39	0	0	14	66	0	TRUE

Green indicate balanced trips

There are no internal capture percentages for daily trips in the ITE Trip Generation Manual 10th Edition. To calcuated the intrazonal trips for daily trips, the same percentage as PM peak was applied to the daily base trips to obtain daily intrazonal base trips.

Number of intrazonal trips produced by this tool were validated according to procedure outlined in Dallas Midtown Ridership Estimation Tool Validation Methodology included in **Appendix B.**

2.6   COMMUNITY (SITE) CAPTURE:

Site capture is estimated by summation of Intrazonal trips and Interzonal trips. Site capture percentage is based on the characteristics of the mixed-use development and is affected by the interaction of land uses present in the mixed-use development. Intrazonal trips calculated in the previous step are added to the interzonal trips to get the total site capture.

Interzonal trips are the trips that are internal to the mixed-use development but are not internal to each zone. Interzonal trips move between the zones inside study area.
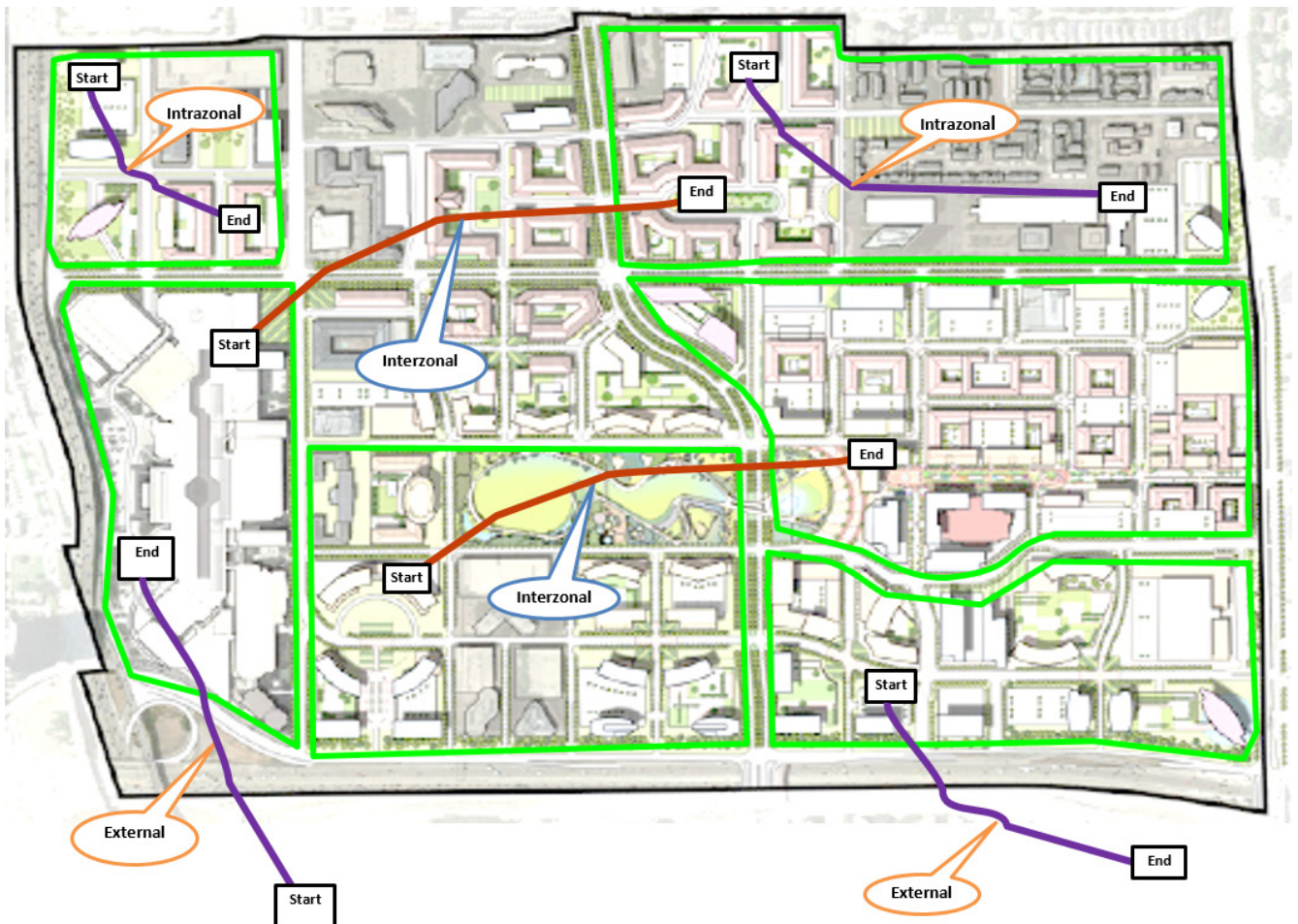
Figure 3: Mixed-use development with different types of trips

Interzonal trips are estimated based on the interzonal capture percentage. Interzonal capture percentage is based on the types of land use, distribution of land use, their proximity to each other, and size of the mixed-use development. To calculated interzonal trips, first total site capture is estimated by referencing similar mixed-use developments and using engineering judgment. Then interzonal capture percentage is entered in the user input box by subtracting intrazonal trips from site capture. This process is used to attain the percentage of site capture.

There is no maximum or minimum percentage limits for community/site capture since each of the developments are unique. Typically, site capture ranges from 10% -50% depending upon characteristics

Interzonal capture user input area

Referenced document

of the mixed-use development. The internal capture percentage for Dallas midtown were primarily referenced from Legacy Town Center in Plano, Texas, Mockingbird Station in Dallas, Texas and Atlantic Station in Atlanta, Georgia, studies all of which are included in NCHRP 684. For Legacy Town Center the average AM internal capture was approximately 13%, for Atlantic Station it was approximately 15% and for Mockingbird Station it was 27%. For PM peak period average internal capture was higher for all three development approximately around 35%, 41%, and 37% respectively for Legacy Town Center, Atlantic Station, and Mockingbird Station.

> **PLEASE NOTE**
> *Trip balancing indicator must turn green in this step to move forward to another step. Green indication means exiting and entering trips are equal*

There are reference pdfs document attached in some sections within the estimation tool. The user can visit referenced documents to get additional information about how and what information from referenced document are incorporated in this tool.

> **PLEASE NOTE**
> *A pdf reader is required to open pdf documents attached in this tool.*

The vehicle occupancy factor entered in multimodal input section is used in this tab to convert vehicular trips to personal trips. Total site capture percentage for Dallas midtown mixed use development was validated according to procedure outlined in Dallas Midtown Ridership Estimation Tool Validation Methodology included in **Appendix B.**

2.7   TRIP DISTRIBUTION:

This tool performs trip distribution using the gravity model like NCTCOG uses for trip distribution in the Dallas-Fort Worth Regional Travel Model. The gamma function is used as a friction factor to create friction factor matrix for the gravity model and the parameters for the gamma function are referenced from the NCHRP report 716.

Trip distribution connects where trips start and end. The gravity model outputs are trips matrices indicating where trips are coming from and where trips are going to for different trip purpose during different times of the day. The trip purposes used in this tool are HBW, HNW, and NHB. The times of the day used are AM peak, PM peak, and Daily.

The gravity method used to distribute trips is explained below,

Gravity Model

$$T_{ij}^P = P_i^P * \frac{A_j^P * f(t_{ij}) * K_{ij}}{\sum\limits_{j' \in Zones} A_{j'}^P * f(t_{ij'}) * K_{ij'}}$$

where:

T_{ij}^P = Trips produced in zone i and attracted to zone j;

P_i^P = Production of trip ends for purpose p in zone i;

A_j^P = Attraction of trip ends for purpose p in zone j;

$f(t_{ij})$ = Friction factor, a function of the travel impedance between zone i and zone j, often a specific function of impedance variables (represented compositely as t_{ij}) obtained from the model networks; and

K_{ij} = Optional adjustment factor, or "K-factor," used to account for the effects of variables other than travel impedance on trip distribution.

K_{ij} was assumed to be 1 for this tool.

Friction factors were calculated using the Gamma function. The Gamma function is stated as follows

$$F_{ij} = a \times t_{ij}^b \times e^{c \times t_{ij}}$$

where

F_{ij} = the friction factor between zones i and j,

a, b, and c = model coefficients; both b and c should, in most cases, be negative; a is a scaling factor and can be varied without changing the distribution,

t_{ij} = the travel time between zones i and j, and

e = the base of the natural logarithms.

t_{ij} is travel time from one zone to another zone using person vehicle/pas   . a is a constant scaling factor which doesn't change the shape of the gamma function curv   set to any value or may be omitted. In our case a is assumed to be 1. Coefficient b and c are referenced from table below which is taken from NCHRP 716. For this tool values for large MPO are used assuming Dallas-Fort Worth as a large MPO having population more than 1,000,000.

	Home-Based Work		Home-Based Nonwork		Nonhome Based	
	b	c	b	c	b	c
Large MPO 1	−0.503	−0.078	−3.993	−0.019	−3.345	−0.003
Large MPO 2	−1.65	−0.0398	−1.51	−0.18	−1.94	−0.116
Large MPO 3	−0.156	−0.045	−1.646	−0.07	−2.824	0.033
Medium MPO 1	−0.81203	−0.03715	−1.95417	−0.03135	−1.92283	−0.02228
Medium MPO 2	−0.388	−0.117	−2.1	−0.075	−1.8	−0.16
Medium (a) MPO 1	−0.02	−0.123	−1.285	−0.094	−1.332	−0.1
Small MPO 1	−0.265	−0.04	−1.017	−0.079	−0.791	−0.195

Source: MPO Documentation Database.

Table 3: Trip distribution gamma param   for different types o

Time of the day

Trip purpose

Macro button

Referenced document

Trip distribution output

Green indicate within

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 PLEASE NOTE Interzonal trips are only distributed in his tool. Intrazonal trips are not distributed because they stayed inside each zone are assumed to be walking trips.

 Click on input cell first to activate drop down menu.

The user has the flexibility to distribute trips manually by selecting the time of the day and the trip purpose from each drop-down list. This manual distribution is only for information purpose only. For further calculation or to move to next step in the ridership estimation tool the user must run trip distribution using macro button shown below.

 Trip distribution macro button. User must run trip distribution using this macro button to populate the results tab.

 User must run trip distribution using macro button available in trip distribution section to advance to next step.

Trips distributed by gravity method were validated according to procedure outlined in Dallas Midtown Ridership Estimation Tool Validation Methodology included in **Appendix B.**

2.8   TRIP DISTRIBUTION RESULTS:

This section is to view the trip distribution results. It has total of 12 matrices, considering three-time periods (AM, PM, and Daily), three trip purposes (HBW, HNW, NHB) and total. Total is summation of all trip purposes.
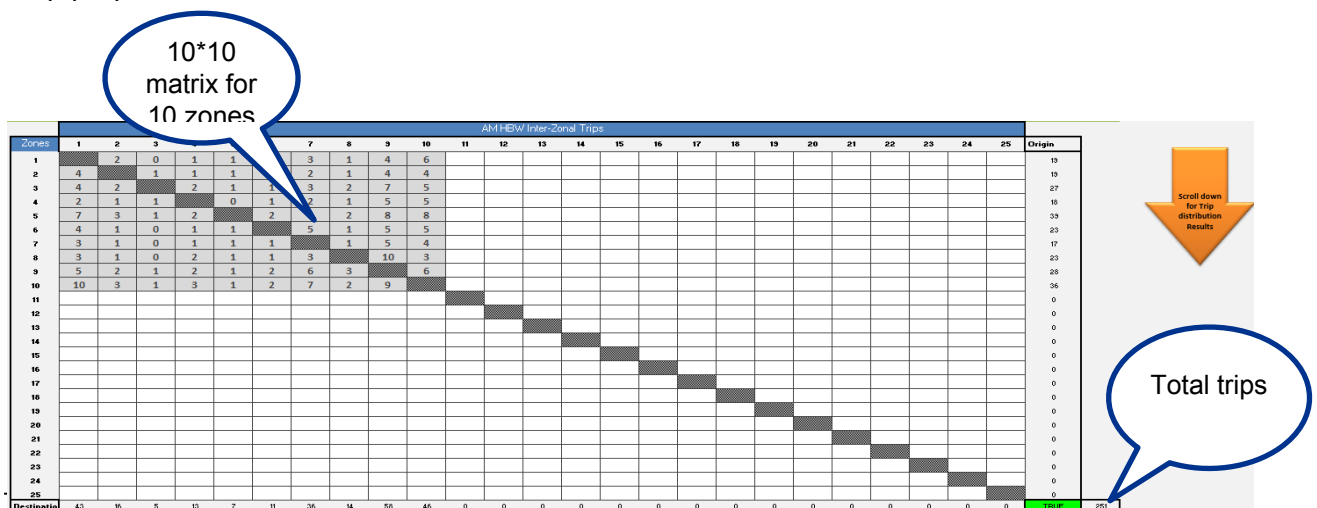
 PLEASE NOTE Size of distributed matrix depend upon number of zones.

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2.9 MODAL SPLIT:

The modal split step determines the portion of vehicular trips that will be attracted towards other modes included in the mixed-use development based on generalized cost associated with each mode. In this ridership estimation tool, three modes of transportation are considered: Walking, Automated Transportation System, and Personal Vehicle. In this tool mode split is done for thee time periods (AM, PM and Daily). Multinomial logit model is used to perform modal split using generalized cost. The generalized cost used in modal split is calculated using travel time, delays and fare associated with each mode. Refer to section 2.3 "Multi-modal inputs" to get more information on inputs.

The equation for multinomial logit model is

$$P_{ij} = \frac{e^{-\beta c_{ij}}}{\sum e^{-\beta c_{ij}^m}}$$

Where,

P_{ij} = proportion or probability of trips by mode

B = Parameter for calibration, assumed as 1 for this tool.

C_{ij} = Generalized cost for mode

$\sum e^{-\beta c_{ij}^m}$ = Summation of negative exponent of generalized cost of all modes

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The user can view the mode split results manually by selecting the time of the day from drop down list. This manual distribution is only for information purpose only. To move to the next step in ridership estimation tool user must run mode split using macro button.

⚠️ User must run modal split macro button to advance to next step.

Modal split done by using multinomial logit model was validated according to procedure outlined in Dallas Midtown Ridership Estimation Tool Validation Methodology included in **Appendix B.**

2.10   MODAL SPLIT RESULTS:

This section is to view mode split results from the modal split step. It has a total of nine matrices, considering three-time periods (AM, PM, and Daily) and three modes (Walking, ATS and Personal Vehicle). The user can use the macro buttons to navigate to the desired mode split results in this section.

PM Trips	AM TRIPS	DAILY TRIPS
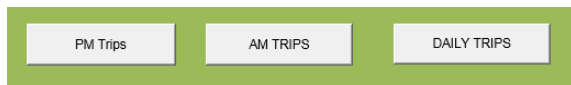
By selecting any of macro button user can navigate to desired mode split section.

2.11   VISUAL OUTPUT:

This section is to view result from *Ridership Estimation Tool Version 1.1* in visual format. Pie charts are used for visual representation of data for different time of day and trip purposes.

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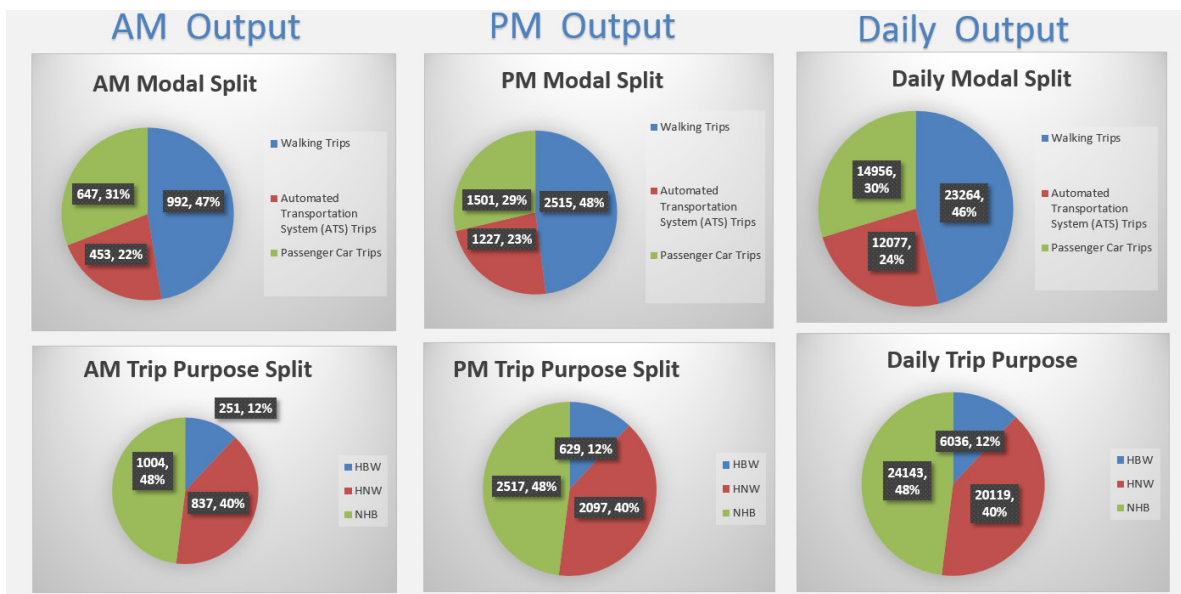
Appendix A. Trip Assignment in TransCAD

The following steps are used to perform trip assignment in TransCAD. Trip assignment was only performed for the Automated Transportation System (ATS) for this study. The network for trip assignment was setup with centroids for the zones for this study, the ATS network with nodes for each stop location, and links from the centroids to the stop location nodes coded as walk links. TransCAD version 5 and 6 were tested and produced the same results for this assignment.

1. Create new gdb file for the ATS system network with the following fields.
   Link_Type (ATS or Walk)
   Type (1 for ATS, 0 for Walk)
   Speed (in mph, 15 mph for ATS, 2 mph for walk)
   Travel_Time (fill column using formula (Length/Speed)*3600)
2. Draw ATS system network with nodes at station locations.
   Connect stations to zone centroid use type walk. Connect centroid to 2 stations as needed so all zones have a route that uses the ATS system.
3. Create Centroid Selection Set (with nodes layer active)
   Selection – Settings – Add Set – Rename Set "Centroids"
   Selection – Select by Condition – "ID < 7" – Set Name "Centroids"
4. Create Network
   Network/Paths - Create Network
           Inputs
               Create From – Entire Line Layer
               Length Field – Length
               Type Field – Type
   Network Fields
           Choose Link Fields – "Type, Speed, and Travel_Time"
   Save Network File
5. Update Network Settings
   Network/Paths - Settings
   General Tab – Centroids - Select "Create from selection set" and drop down "Centroids"
   Link Type - Select "In use"
   Penalties - select "Turn"
   Turn Penalties Tab - Global Penalties - check Turn Prohibited under U-Turn
   Link Type Penalties - select "File Open" and open Link Type Turn Penalties.bin (this file prohibits turns from Link Type 0 to Link Type 0)
6. Output Network Travel Times
   Network/Paths – Multiple Paths
   Settings – Minimize "Travel_Time" – From "Centroid" – To "Centroid"
   Input travel times into ATS Ridership Estimating Tool Spreadsheet
7. Import ATS Trip Table
   Can copy trip table into existing matrix or create new matrix from trip table.
8. Run Assignment
   Planning – Static Traffic Assignment – Traffic Assignment
   Method – select "All or Nothing"
   Matric File – "ATS Trip Table Matrix"
   Matrix – "ATS Volume"
   Parameters – Time – "Travel_Time"
   Save file in same folder as model files

Appendix B. Dallas Midtown Ridership Estimation Tool Validation Methodology

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1999 Bryan Street, Suite 1200
Dallas, Texas 75201
United States
T +1.214.583.8500
F +1.214.638.0447
www.jacobs.com

|	
Date	January 18, 2019
To	North Central Texas Council of Governments (NCTCOG)
From	Jeremy Wyndham, P.E.
Subject	Dallas Midtown Ridership Estimation Tool Validation Methodology

North Central Texas Council of Governments (NCTCOG) has asked Jacobs to conduct the feasibility study for an Automated Transportation System for the Dallas Midtown area. The limit of the study area is approximately 0.7 square miles. The study area is located in Dallas County and is surrounded by Preston Rd to the east, Interstate 635 to the south, Dallas North Tollway to the west, and Southern Blvd to the north. The study area location map is shown in **Figure 1**.

This memorandum describes the validation methodology for Dallas Midtown *Ridership Estimation Tool Version 1.1* developed by Jacobs to estimate the internal ridership for the planned Dallas Midtown mixed-use development for the full build out within the study limits.

SOURCES

Jacobs used following data sources to develop validation methodology for *Ridership Estimation Tool Version 1.1*:

- 10th Edition of the Institute of Transportation Engineers (ITE) Trip Generation Manual

- National Cooperative Highway Research Program (NCHRP) Report 684: Enhancing Internal Trip Capture Estimation for Mixed-Use Developments

- National Cooperative Highway Research Program (NCHRP) Report 716: Travel Demand Forecasting: Parameters and Techniques

- Dallas-Fort Worth Regional Travel Model (DFWRTM)

- Land use maps provided to Jacobs by Omniplan, Beck Venture, and land use plan from previous study in the same area

- The City of Dallas

- Model Validation and Reasonableness Checking Manual, Federal Highway Administration (FHWA)

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Dallas Midtown Ridership Estimation Tool Validation Methodology
Jeremy Wyndham, P.E.
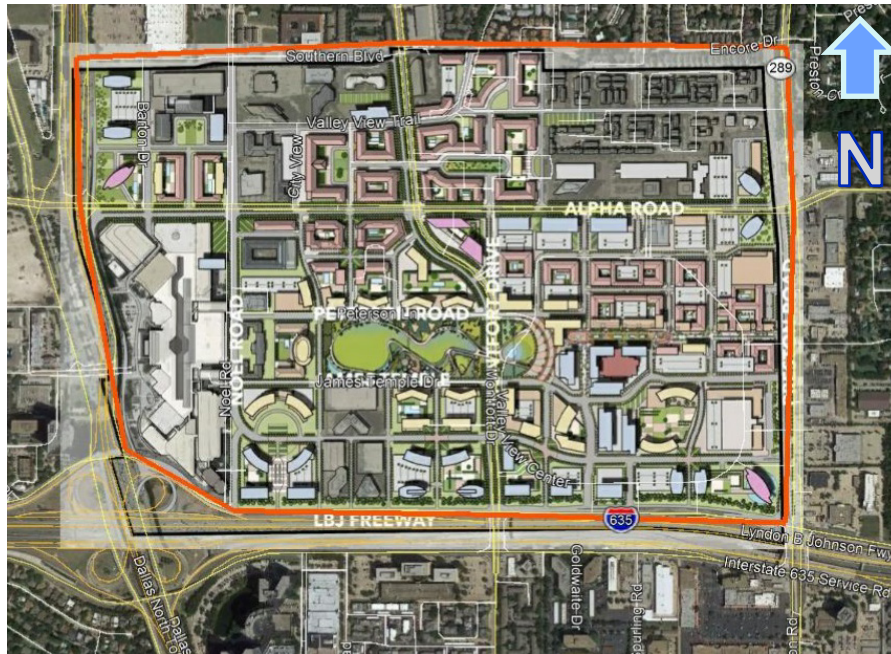
**Figure 1: Dallas Midtown Study Area**

METHODOLOGY

The validation for Dallas Midtown *Ridership Estimation Tool Version 1.1* was carried out by validation of each section of Dallas Midtown *Ridership Estimation Tool Version 1.1* and their results. The results and the parameters used in each of the section of estimation tool were compared with the result and parameters of previously validated tools used in industry and currently available in the market. This approach of validation was adopted to ensure each component is properly interfaced and the modelling error won't propagate through the model. Reasonableness checks were also done simultaneously for each component as well as for the data entry tab as model validation was carried out.

Dallas Midtown *Ridership Estimation Tool Version 1.1* has following components/sections

- Instructions
- Land use Inputs
- Multi-Modal Inputs
- Trip Generation
- Intrazonal Trips
- Community (Site) Capture
- Trip Distribution
- Trip Distribution Results
- Modal Split
- Modal Split Results
- Visual Output

Memorandum

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Jeremy Wyndham, P.E.

Dallas Midtown was divided into several zones to accurately estimate the trips to and from Dallas Midtown area. Study area was divided into zones such that our divided zones are located within the NCTCOG's traffic survey zones (TSZ). The study area zones are shown in **Figure 2** and the NCTCOG's traffic survey zones (TSZ) are shown in **Figure 3**. **Table 1** below shows the locations of zones with respective to NCTCOG's traffic survey zones (TSZ).
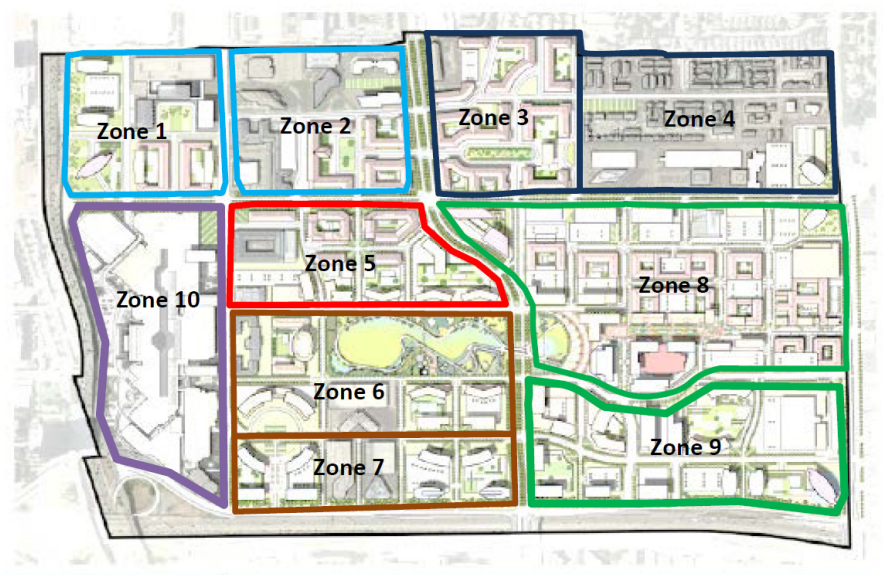
Figure 2: Dallas Midtown Zones

Figure 3: NCTCOG's Traffic Survey Zones (TSZ)

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Dallas Midtown Ridership Estimation Tool Validation Methodology
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Table 1: Study Zones within NCTCOG's TSZ

TSZ	Study Zones
6277	Zone 1, Zone 2
6279	Zone 3, Zone 4
6366	Zone 5
6367	Zone 6, Zone 7
6368	Zone 8, Zone 9
6363	Zone 10

Validation of *Ridership Estimation Tool Version 1.1* is explained below

Section 1: Instructions:

The instructions tab gives users general information about the *Ridership Estimation Tool Version 1.1.* This tab gives user information about the purpose, potential uses, cautionary notes, version, definition of acronyms, and contact information. This section is only for information purpose and doesn't require validation. Only quality and reasonableness checks were performed for this section.

Section 2: Land use Inputs:

The land use inputs tab includes the land use information that are used for the ridership estimation. *Institute of Transportation Engineer's (ITE) Trip Generation Manual 10th Edition* land use categories were used. This section has rates and regression equations, directional distribution percentage, ITE code, and land use units used in estimation tool. This section is used to input expected number of land use units. Since this section is input only section, no output are generated in this section, no validation is required for this section. Only quality and reasonableness checks were performed for this section.

Section 3: Multi-Modal Inputs:

Multi-modal inputs section has input related to different modes of transportation considered in this study. Inputs entered here are used to calculate the modal split between the modes of transportation. In this tool, mode split is performed between three modes: Walking, Automated Transportation System (ATS) and Personal Vehicle/Passenger Car. Multi-modal inputs related to speed, delay, and cost are also entered here to calculate the generalized cost associated with each mode. Since this section is input only section, no output are generated in this section, no validation is required for this section. Only quality and reasonableness checks were performed for this section.

Section 4: Trip Generation:

Trip generation for the planned Dallas Midtown was performed using the *ITE Trip Generation Manual 10th Edition*. Trip generation uses the rate and regression equation from the Trip Generation Manual to generate the number of trips. The rates and regression

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Dallas Midtown Ridership Estimation Tool Validation Methodology
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equations used in trip generation are validated as part of the Trip Generation Manual, they are considered validated for the ridership estimation tool. The number of trips produced by estimation tool are therefore be considered as valid and no additional validation is required for trip generation step. A reasonableness check of the generated number of trips was completed and the total number of trips generated were considered reasonable. Detail land use information with their respective rates and regression equation used in trip generation are included in **Appendix A.**

Section 5: Internal Trip Estimation:

The internal trips were categorized into two types: Intrazonal trips and Interzonal trips. The trips that were only internal to each zone were categorized as Intrazonal trips and the trips that were internal to the site but were external to each zone were categorized as Interzonal trips. The Intrazonal trips were estimated based on the percentages from *ITE Trip Generation Manual 10th Edition*. The Intrazonal trip capture percentages used are included in **Appendix B.** The validation of Intrazonal trip calculation was done by comparing the total Intrazonal trips calculated for each land use pair by Dallas Midtown *Ridership Estimation Tool Version 1.1* and NCHRP 684 Internal Trip Capture Estimation tool. NCHRP 684 Internal Trip Capture Estimation tool is also included in *ITE Trip Generation Manual 10th Edition* to calculate the internal trips for mixed-use development. Intrazonal trips validation results is shown in **Appendix C**. The Interzonal trips are calculated based on engineering judgment and characteristic of proposed Dallas Midtown mixed-use development to achieve a reasonable site capture percentage. No validation was done for Interzonal trips calculation at this point because they are based on engineering judgment and total site capture-to be calculate in the next step.

Section 6: Site Capture Estimation:

The total site capture of study area was estimated by summation of Intrazonal trips and Interzonal trips. The total site capture percentage of the study area is based upon the total site capture percentage of a similar mixed-use development as suggested by the *ITE Trip Generation Manual 10th edition* and engineering judgment. For our site capture estimation to be valid it should fall within the acceptable range of site capture of a similar development. We reviewed similar sites to the proposed Dallas Midtown like the Legacy Town Center located in the city of Plano, Texas, Mockingbird Station in Dallas, Texas and Atlantic Station Located in the city of Atlanta, Georgia, and discussed with NCTCOG to come up with the reasonable site capture estimation. The internal capture percentage for Dallas Midtown were primarily referenced from Legacy Town Center in Plano, Texas, Mockingbird Station in Dallas, Texas and Atlantic Station in Atlanta, Georgia, studies all of which are included in NCHRP 684. For Legacy Town Center the average AM internal capture was approximately 13%, for Atlantic Station it was approximately 15% and for Mockingbird Station it was 27%. For PM peak period average internal capture was higher for all three development approximately around 35%, 41%, and 37% respectively for Legacy Town Center, Atlantic Station, and Mockingbird Station. The total daily site capture for Dallas Midtown mixed use development was assumed to be 40%. The site capture in the ridership estimation tool is within the reasonable range when compared to these sites so the site capture percentage for Dallas midtown are considered valid. In addition to

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above comparison, total site capture trips from estimation tool were also compared with the trips from NCTCOG. The total daily site capture trips from estimation tool were approximately 41,499 and the total daily trips from TSZ within Dallas midtown from NCTCOG's model were 41,601. This reinforced the validation of assumed site capture percentage. Daily trips comparison between estimation tool and NCTCOG model is shown in **Appendix D**. **Figure 4** below is diagrammatic representation of site capture estimation.
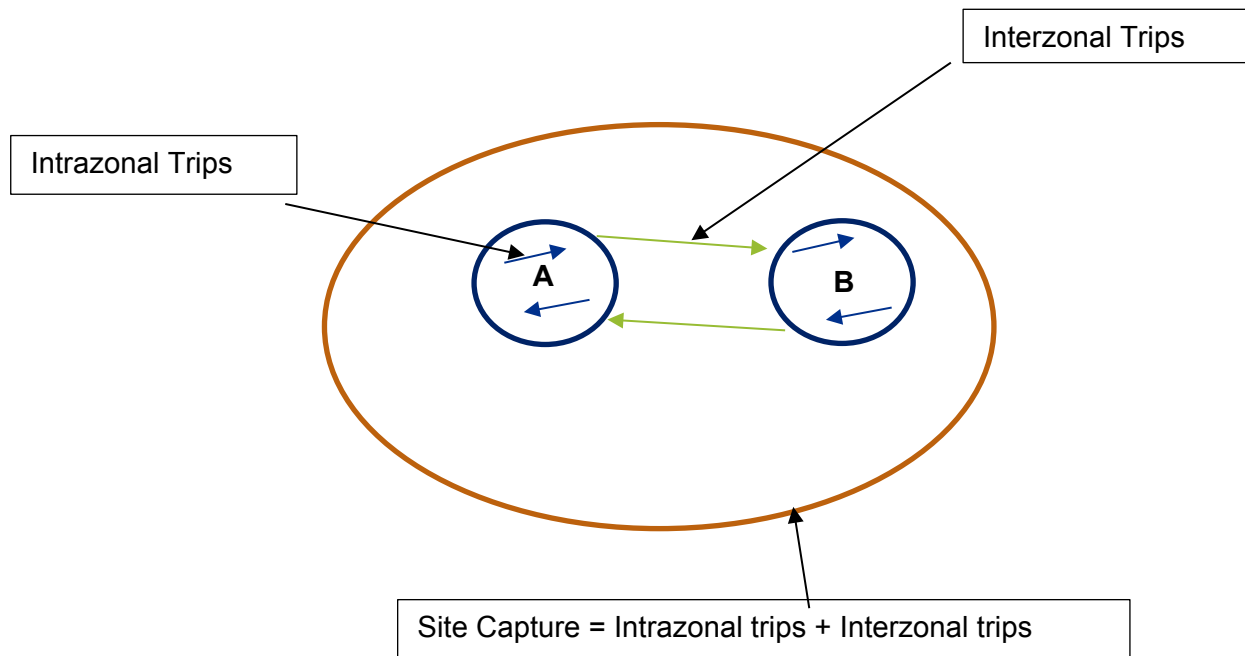
Figure 4: Site Capture Diagrammatic Representation

Section 7: Trip Distribution:

The trip distribution was performed using the gravity model like NCTCOG uses for trip distribution in the Dallas-Fort Worth Regional Travel Model. The Gamma function was used as a friction factor to create an impedance matrix for the gravity model and the parameters for the Gamma function were referenced from the NCHRP report 716. The parameter that were used in the gamma functions are included in **Appendix E.** Validation of trip distribution step was carried out by validation of parameters used and validation of trip distribution result. Since the parameters used in the calculation of the impedance matrix are from NCHRP 716, they are considered valid. The distribution of trips using gravity method is considered reliable and hence no validation is required for trips distributed by gravity model.

Section 8: Trip Distribution Results:

This section is to view the trip distribution results. It has total of 12 matrices, considering three-time periods (AM, PM, and Daily), three trip purposes (HBW, HNW, NHB) and total. Total is summation of all trip purposes. This section is only for information purpose and

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doesn't require validation. Only quality and reasonableness checks were performed for this section.

Section 9: Modal Split:

Modal split was performed between three modes: Walking, Automated Transportation System (ATS), and Passenger Car. Before performing trip distribution, vehicular trips were converted into personal trips using the vehicle occupancy factor of 1.25 for both AM and PM. These vehicle occupancy factor were referenced from Legacy Town Center, Plano Texas study included in NCHRP 684 and engineering judgment. These vehicle occupancy factor were applied only to the interzonal trips for assignment to the network. Validation of modal split was done by validation of variables used, parameter used, and modal split result. The variables used in calculation of generalized cost matrix for three modes of transportation were validated by checking their sensitivity. The variable sensitivity check was performed by forming different alternative combination of variables. The ridership estimation tool was run 29 times with different combination of variables and the results have been reviewed. The changes to the variables produced change in mode share percentage. The results from variable sensitivity checks are included in **Appendix F**. The only parameter used in the multinomial logit formula to perform modal split was calibration parameter Beta (β). This parameter was assumed to be 1 assuming equal possibility of riding three modes of transportation.

Section 10: Modal Split Results:

This section is to view mode split results from the modal split step. It has a total of nine matrices, considering three-time periods (AM, PM, and Daily) and three modes (Walking, ATS and Personal Vehicle). This section is only for information purpose and doesn't require validation. Only quality and reasonableness checks were performed for this section.

Section 11: Visual Output:

This section is to view result from *Ridership Estimation Tool Version 1.1* in visual format. Pie charts are used for visual representation of data for different time of day and trip purposes. This section is only for information purpose and doesn't require validation. Only quality and reasonableness checks were performed for this section.

Section 12: Trip Assignment:

Trip assignment was not performed in this tool. Trip assignment was performed for only the ATS trip matrix using TransCAD Traffic Assignment tool. The ATS network created in TransCAD was QA/QC to verify it is coded correctly for the proposed ATS. After the Trip assignment was run the results are spot checked to ensure the trips were accurately assigned to the network.

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Dallas Midtown Ridership Estimation Tool Validation Methodology
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APPENDIX A

TRIP GENERATION RATES AND EQUATIONS

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APPENDIX B

<u>INTERNAL CAPTURE PERCENTAGE</u>

Memorandum

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APPENDIX C

<u>INTRAZONAL TRIP COMPARISON</u>

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APPENDIX D

SITE CAPTURE COMPARISON

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APPENDIX E

<u>GAMMA FUNCTION PARAMETERS</u>

Memorandum

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APPENDIX F

<u>VARIABLE SENSITIVITY CHECK</u>

Appendix C
Current State of Autonomous Vehicle Technology White Paper
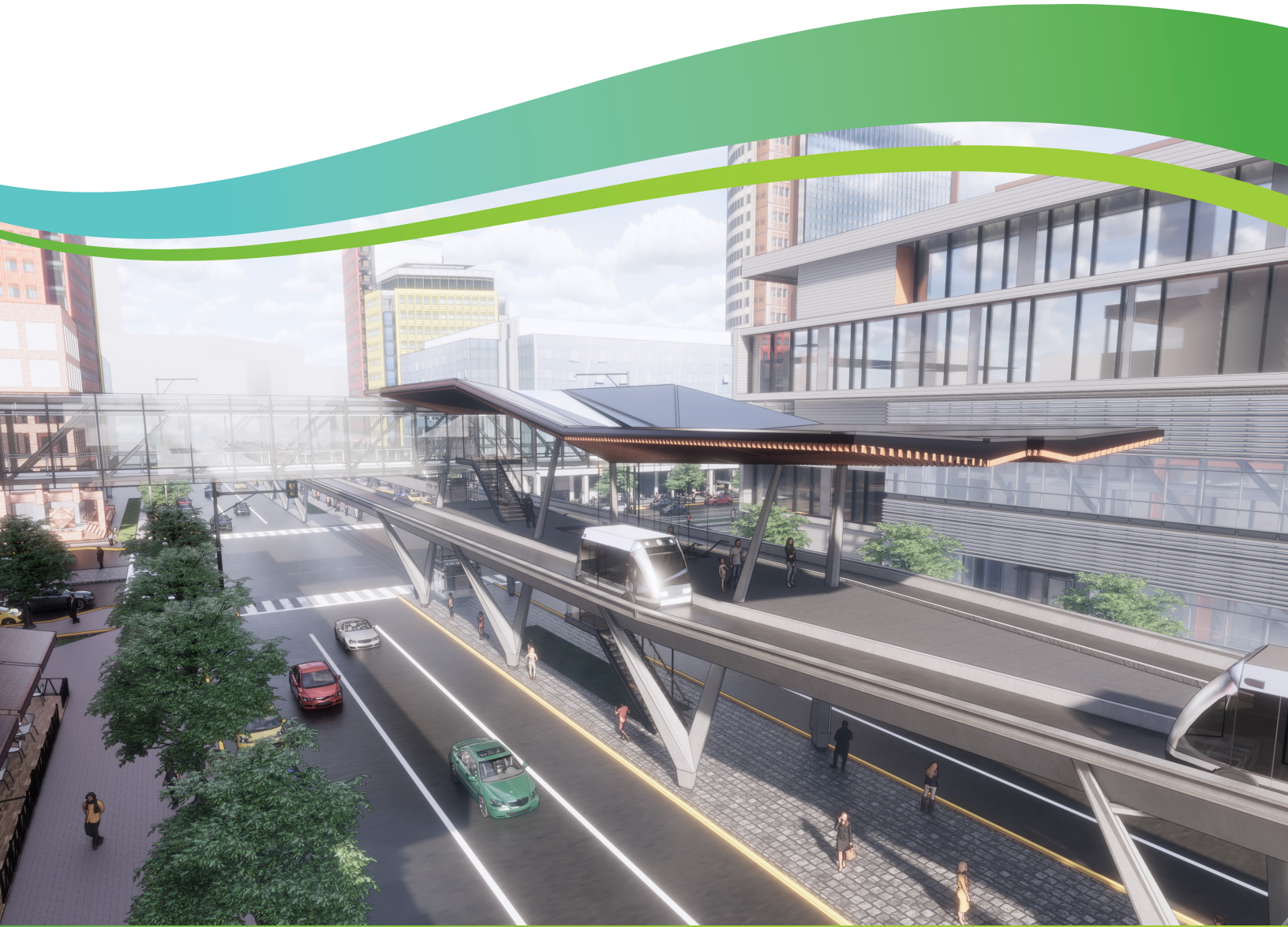
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Dallas Midtown Automated Transportation System Conceptual Engineering Study

Technology Scan White Paper

North Central Texas Council of Governments

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May 9, 2018
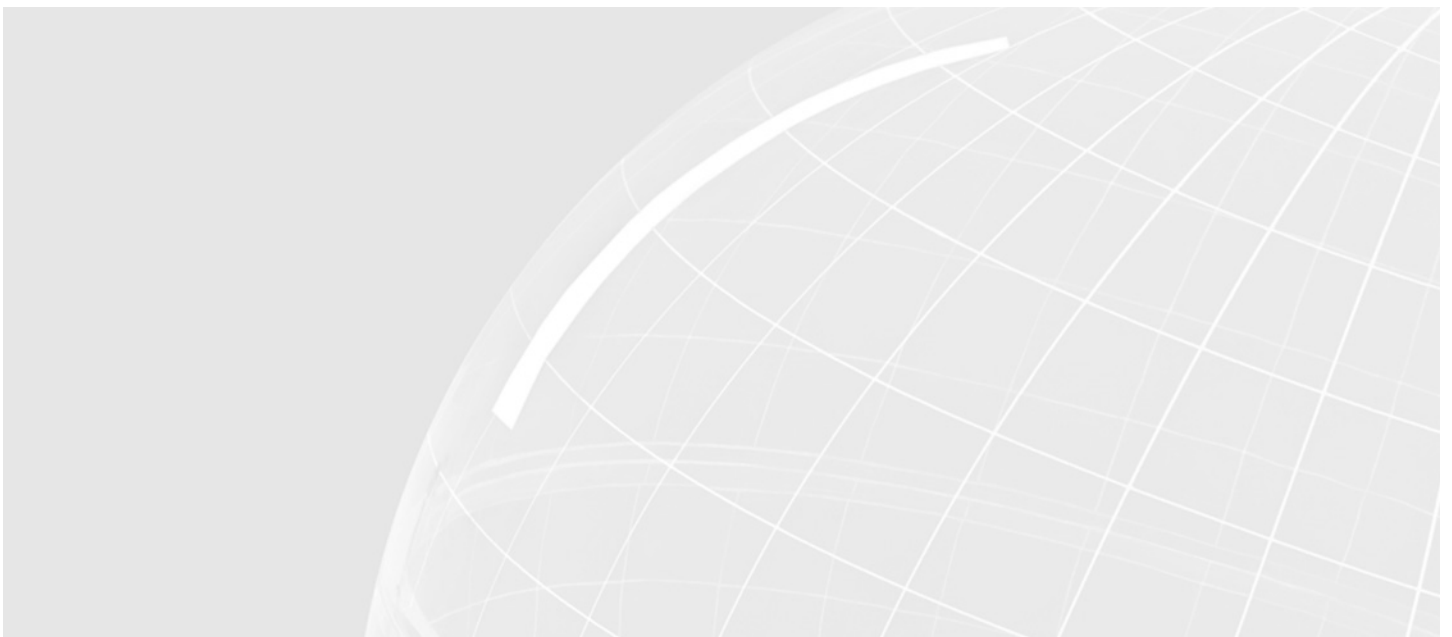
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Dallas Midtown Automated Transportation System Conceptual Engineering Study

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Revision:	0
Date:	May 9, 2018
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Project Manager:	Jeremy Wyndham
Author:	Brian Burkhard, Craig Elliott, Stacy Learn, Marcus Ashdown
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Jacobs Engineering Group Inc.
1999 Bryan Street, Suite 1200
Dallas, Texas 75201
United States
T +1.214.638.0145
F +1.214.638.0447
www.jacobs.com

Contents

1. Introduction

This Technology Scan White Paper is intended to provide a review of current industry usage of public transportation vehicle capabilities. In particular, this paper puts forth transportation planning's best practice in the context of automation. The purpose of this white paper is to inform and enlighten stakeholders of the Dallas Midtown area on considerations as they move forward on building the development. It is also intended to serve as a means of outreach to engage stakeholders in the alternatives conversations to follow.

The paper reviews technologies for Automated Vehicles and Fleets as well as more traditional Automated People Movers, Monorail, Cable Propelled Systems and Personal and Group Rapid Transit.

1.1   History of the Modern Automated People Mover

Some of the earliest modern-day Automated People Mover (APM) concepts were developed in the 1950s when General Motors investigated driverless vehicles on separate guideways. Later in that same decade, the New York City Transit Authority briefly demonstrated an automated people mover operation along 42nd Street between Times Square and Grand Central Station. About a decade later, Westinghouse Electric Corporation developed an APM technology called Skybus with federal funding provided by the U.S. Department of Housing and Urban Development. Skybus utilized transistor technology, rubber tires, and center guidebeam guidance. The system was called the South Park Demonstration Project for the Port Authority of Allegheny County (PAAC). It operated between 1965 and 1966, and while Pittsburgh's urban transportation experiment did not survive, Westinghouse further developed the Skybus technology and implemented a later version called the C-100 at Tampa International Airport 5 years later as the first airport APM.

Figure 1. PAAC Skybus Demonstration Project[1]

The construction of the Morgantown automated system in 1975 and the UMTA Downtown People Mover Program (DPM) highlights U.S. Government interest in PRT and APM systems in the 1960s-1970s as a less expensive alternative to other mass transit systems while promoting a more comprehensive approach to city planning. The development of the Morgantown PRT system in West Virginia was supported by President Nixon as a USDOT PRT Demonstration Project as well as by UMTA development grants and is still operating today.

The UMTA DPM encouraged cities to build APMs as downtown circulators as an alternative to more expensive mass transit systems. From 1976-1977 the UMTA selected Baltimore, Cleveland, Detroit, Houston, Indianapolis, Jacksonville, Los Angeles, Miami, Norfolk, St. Louis, and St. Paul for its DPM program. In the end, only Detroit, Jacksonville, and Miami constructed APMs, all of which are still running today.

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[1] Image: www.pghbridges.com

Figure 2. Transportation Sec. William Coleman, right, looks at plans for Downtown People Movers in five U.S. cities in 1976. (AP Photo/Harvey Georges)[2]

It was at this time, U.S. defense contractors diversified into transportation. Boeing supplied APM vehicles for the Morgantown (West Virginia University) automated system in 1975. LTV Aerospace Corporation (Vought) became an APM supplier with an extensive project at the Dallas/Fort Worth Airport (DFW), the 13-mile AIRTRANS system. This AIRTRANS technology served as the basis for the "Japanese Standard APM Technology" that several Japanese APM manufacturers licensed, including Kawasaki and Mitsubishi.

Although the U.S. government's investment during the 1960s and 1970s in new systems research and development was aimed at urban applications, APMs would go on to achieve greater success at airports throughout the world. Starting with Tampa in 1971 and continuing to the present day, APMs have been instrumental in overcoming the problem of the growing scale of airports in terms of their configuration and passenger volumes. Today, there are over 100 APMs operating in airport and urban environments.

Figure 3. Dallas/Fort Worth International Airport AIRTRANS[3]

Recently, urban APMs are undergoing a resurgence in the USA. Several new systems using cable technologies have been constructed in Las Vegas and Portland, Oregon. In addition, older APM systems are being refurbished and/or redesigned, such as Morgantown and Jacksonville. In Dallas-Fort Worth, new construction and connections to DART light rail in Las Colinas have increased ridership on its APM and have led to the construction of a new station, system refurbishment, and renewed interest in system expansion.

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[2] http://www.cdandrews.com/2014/08/downtown-people-movers-houstons-people.html
[3] Image: Lea+Elliott

2. Automated People Mover (APM)

Introduction to APMs

While classifying APMs by categories can be challenging and subject to debate as there can be overlap between technology concepts, this report will present APMs into these generally-accepted categories: APM, Monorail, Cable Systems, Personal Rapid Transit (PRT) and Group Rapid Transit (GRT).

Technologies that are within the APM category can be differentiated by the suspension and propulsion methods used. Most vehicles are supported by the guideway on which they travel. This includes most monorails that straddle the top of the guidebeam and all other guideway-supported vehicles that are supported by rubber tires, steel wheels, pressurized air or magnetic levitation. However, suspended monorail technology hangs under the guideway as the name implies. The means of propulsion can be divided between those that are self-propelled with on board electric motors, cable-propelled by a continuous cable along the guideway or guideway-propelled using Linear Induction Motors (LIMs). While there can be on-board attendants, APMs are distinguished by their ability to be operated fully automated without drivers. The examples presented herein of automatic operation requires an exclusive right of way. Examples of how guidance can be provided are by horizontally-mounted guide wheels that track side-mounted guide rails, guideway-mounted center guidebeam, the guidebeam itself, guideway-mounted center guide rail or traditional rails.

The primary application of these systems have been at major activity centers, such as airports and city centers, but there are also numerous urban transit APM systems. These vehicles are typically supported on rubber tires, but also use steel wheels on steel rails. They operate using automatic, driverless control permitting more cost-effective operations on short headways to minimize waiting time for passengers.

APMs feature level boarding and operate under strict ride comfort parameters, permitting most passengers to stand thereby increasing passenger carrying efficiency to moderately high levels. The vehicles typically have two sets of doors on each side that allow all passengers including the mobility impaired in wheel chairs to board. System designs are proprietary and are not interchangeable with other APM technologies.

The guideway of the APM system refers to the track or other running surface (including supporting structure) that supports, powers, contains, and physically guides APM vehicles designed to travel exclusively on it. APMs require a separate and exclusive guideway that can be elevated, at-grade (fenced or otherwise protected) or in tunnels. The guideway structure itself is part of the APM facilities that is often, but not always, provided by other suppliers.

Stations are located along the guideway to allow passenger access to the APM system. The station equipment typically includes automatic station platform edge doors and dynamic passenger information signs. The stations also have APM equipment rooms to house command, control, and communications equipment and other APM equipment. Boarding platforms can be side (on the outer sides of the guideway), center (in between the guideways), or triple (both outer sides and in between the guideways).

A description of the Bombardier, Mitsubishi and Schwager Davis APM technologies and sample installations are discussed in the following sections.

2.1   Bombardier INNOVIA APM 200/300

Website: https://www.bombardier.com/en/transportation/products-services/rail-vehicles/automated-people-movers.html

Bombardier Transportation, headquartered in Germany, is a division of Bombardier, Inc., a Canadian firm. They have implemented over 30 APMs around the world of varying models. The most recent version of their self-propelled, rubber-tired APM is the INNOVIA APM 200 and the INNOVIA APM 300. These two models are very similar. The INNOVIA APM 300 offers increased passenger capacity, higher top speed and an aluminum car body.

Figure 4. Bombardier INNOVIA APM 200, Dallas/Fort Worth Airport, TX, USA[4]

Both systems are guided by a center guidebeam, utilize on-board rotary electric motors and can operate as trains of up to 6 vehicles. Power is supplied via a "third rail" on the guideway and they operate fully automated without drivers.

Bombardier has three recent implementations of the INNOVIA APM 300 – one at the Munich Airport in Germany, one at the Dubai Airport in the UAE and one still underway at the King Abdulaziz International Airport in Jeddah, Saudi Arabia. The SkyLink APM at the Dallas-Fort Worth International Airport and the PHX Sky Train at the Phoenix International Airport currently utilize Bombardier INNOVIA APM 200 technology.

Vehicle specifications for the Bombardier INNOVIA 200/300 are shown on the next page.

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[4] Image: Lea+Elliott

Table 1. Bombardier INNOVIA APM 200/300 vehicle specifications.

Bombardier INNOVIA APM 200/300 vehicle specifications	Value
Vehicle length	39.2 – 41.8 ft.
Vehicle width	9.4 ft.
Vehicle height	11.1 ft.
Vehicle weight (unloaded)	31,967 – 34,172 lb.
Vehicle capacity (@ 4 passengers/m^2)	100 – 103
Maximum speed	37 – 50 mph

2.2   Mitsubishi Crystal Mover

Website: http://www.mhi.com/products/transport/automated_people_mover.html

Mitsubishi Heavy Industries, Ltd., headquartered in Japan, has implemented over a dozen self-propelled, rubber-tired APMs around the world of varying models. The most recent version of their self-propelled, rubber-tired APM is the Crystal Mover. The Crystal Mover is guided by side-mounted guide wheels running against guideway wall-mounted guide rails. It utilizes on board rotary electric motors and can operate in trains of 1- to 6-vehicles. Power is supplied via a "third rail" on the guideway and it operates fully automated without drivers. Miami International Airport North Terminal will use Mitsubishi Crystal Mover APM technology.

Figure 5. Mitsubishi Crystal Mover, Miami Airport, FL USA[5]

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[5] Image: Lea+Elliott

Table 2. Mitsubishi Crystal Mover vehicle specifications.

Mitsubishi Crystal Mover vehicle specifications	Value
Vehicle length	37.6 ft.
Vehicle width	8.9 ft.
Vehicle height	12.1 ft.
Vehicle weight (unloaded)	31,967 lb.
Vehicle capacity	105
Maximum speed	50 mph

2.3 Schwager Davis UniTrak

Website: https://www.schwagerdavis.com/divisions/transit/

Schwager Davis, Inc. (SDI) is a turnkey contractor in new system design, construction and installation including system alignment, utility relocation, foundations, elevated cast in place or precast super structures, station construction, electrical power feed, distribution and control system as well as the rolling stock.

SDI implemented a 1.4 mi. fully-automated, fully-elevated transit system for Indiana University Health (formerly Clarian Health Partners, Inc.) and the City of Indianapolis. The system has three stations connecting three hospital campuses. SDI has continued to operate and maintain this installation.

Figure 6. Schwager Davis UniTrak vehicle, IU Health, Indianapolis, IN USA[6]

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[6] Image: SDI

The UniTrak vehicle installed at IU Health is classified as a small APM but could also be implemented as GRT based on its car size. Each car of the 3-car train accommodates 8 seated and 19 standing passengers for a total capacity of 27 passengers per car. Each car is fully air-conditioned and has a single 4.9 ft. wide bi-parting door for station loading. The vehicles utilize rotary electric motors and run on rubber tires with horizontally mounted rubber guide wheels. While the trains at IU Health operate in 3-car consists, it is possible that SDI could configure the UniTrak vehicle in single or 2-car configurations.

SDI has identified itself as a transit supplier with the creativity and willingness to adapt its transit products to the project-specific needs of Owners. Vehicle specifications are shown in Table 3.

Table 3. Schwager Davis UniTrak car specifications.

Schwager Davis UniTrak car specifications	Value
Vehicle length	22 ft.
Vehicle width	7.9 ft.
Vehicle height	9.8 ft.
Vehicle weight (unloaded)	15,000 lb.
Vehicle capacity	27
Maximum speed	28 mph

3. Monorail

While monorail technology is typically considered a member of the APM technology category, for the purpose of this study it will be considered as its own category due to the unique nature that the guideway is utilized. Monorails can be considered a rail-based transportation system however the rail in this case is a concrete beam (or steel) which the monorail vehicle "straddles." Monorails are self-propelled with on board electric motors. While there can be on-board attendants, monorails are distinguished by their ability to be operated fully automated without drivers. Automatic operation requires an exclusive right of way. All other APM characteristics mentioned previously in Section 2 also apply to monorails including stations and guideways.

Monorails offer high speed, high capacity, fully automated transportation with a major feature being the minimal guideway requirement of only the beam(s) elevated on single piers above the roads or streets. The beams are precast off site using purpose designed forms that maintain the quality and the consistency of the shape and finish.

A description of the Bombardier and Hitachi monorail technologies and sample installations are discussed in the following sections.

3.1   Bombardier INNOVIA Monorail 200/300

Website: https://www.bombardier.com/en/transportation/products-services/rail-vehicles/automated-monorails.html

Bombardier Transportation, headquartered in Germany, is a division of Bombardier, Inc., a Canadian firm. They have implemented four monorails in the USA of varying models with two additional installations underway. The most recent version of their self-propelled, rubber-tired monorail is the INNOVIA Monorail 200 and the INNOVIA Monorail 300. These two models are very similar. However, the INNOVIA Monorail 300 offers walk through capability between cars. Both systems are supported and guided by a single concrete guidebeam, utilize on board rotary electric motors and can operate as trains of 2- to 8-cars. Power is supplied via a "third rail" on the guidebeam and they operate fully automated without drivers. Both systems can be paired with Bombardier's communication-based train control, CITYFLO 650.

Figure 7. Bombardier INNOVIA Monorail 200, Las Vegas, NV USA[7]

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[7] Image: Bombardier

Currently Bombardier has one INNOVIA Monorail 200 operating in Las Vegas. Bombardier also has two INNOVIA Monorail 300 projects underway – one at the King Abdullah Financial District in Riyadh, Kingdom of Saudi Arabia and the other in São Paulo, Brazil. Examples of a system implementation of the INNOVIA Monorail 300 are provided further below.

Table 4. Bombardier INNOVIA Monorail 300 car specifications.

Bombardier INNOVIA Monorail 300 car specifications	Value
Vehicle length	38.7 – 44 ft.
Vehicle width	10.3 ft.
Vehicle height	13.5 ft.
Vehicle weight (unloaded)	29,983 lb. per car (average)
Vehicle capacity (@ 4 passengers/m^2)	86-95 per car
Maximum speed	50 mph

3.2 Hitachi Monorail

Website: http://www.hitachi-rail.com/products/rolling_stock/monorail/index.html

Hitachi, Ltd., headquartered in Japan, has implemented a dozen self-propelled, rubber-tired monorails around the world of varying models (nine are still in operation). The models are categorized as Small, Standard and Large (the large model is not presented here as the scale of the system is inappropriate for this study). Car specifications of the Small and Standard models can be found in Table 5 below.

All systems are self-propelled and rubber-tired. These systems are supported and guided by a single concrete guidebeam, utilize on board rotary electric motors and can operate as trains of 2- to 6-cars. Power is supplied via a "third rail" on the guidebeam and they can be operated fully automated without drivers or manually-operated with drivers. Hitachi currently has no monorail systems operating in North America, but has several operating in Japan, South Korea, China, Malaysia, and UAE.

3.2.1 Hitachi Standard Monorail

The Hitachi Standard Monorail has been implemented as both fully-automated and manually-operated systems Hitachi has Standard Monorails operating in Tokyo, Okinawa, Dubai, and in South Korea.

Figure 8. Hitachi Palm Jumeirah Monorail, Dubai, UAE, Fully-automated without driver[8]

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[8] Image: Hitachi

3.2.2   Hitachi Small Monorail

The Hitachi Small Monorail has been implemented as a manually-operated system. This technology could also be implemented as a fully-automated driverless system. Hitachi claims that the Small Monorail capital cost is 50% less than a large-type monorail. Hitachi operates one of these systems in Singapore harbor.

Figure 9. Hitachi Sentosa Express Monorail, Sentosa, Singapore (Manually-operated with driver)

Table 5. Hitachi Standard and Small Monorail Car Specifications.

Car Specifications	Hitachi Standard Monorail	Hitachi Small Monorail
Vehicle length	48.2 ft.	24.9 - 32 ft.
Vehicle width	9.8 ft.	8.2 ft.
Vehicle height	16.7 ft.	15.3 ft.
Vehicle weight (unloaded)	52,600 – 55,000 lb. per car	28,200 - 37,800 lb.
Vehicle capacity	82 per car	43 - 49 per car
Maximum speed	37 mph	37.5 mph

4. Cable-Propelled Systems

While cable-propelled technology is also considered a member of the APM technology category, for the purpose of this study it will be considered as its own category due to the unique nature that the vehicles are propelled. Cable-propelled transit systems can be categorized in two groups: 1) guideway-based and 2) aerial-based. Guideway-based systems are supported by wheels (rubber or steel) on a dedicated guideway or rails. Aerial-based systems are supported by an overhead cable or cables. Both groups are propelled by gripping (either permanently or detachable) a moving cable traveling between stations. The vehicles are passive and propulsion is provided to the cable drive wheel(s) at the station(s).

For the guideway-based systems, all other APM characteristics mentioned previously in Section 2 also apply to cable-propelled systems including stations and guideways. For the aerial-based systems, there is no guideway structure as the cables are supported by towers. Stations are typically at the two end points but can be located at points in between.

While the guideway-based systems can be operated fully automated without drivers, the aerial-based systems typically have attendants at the stations. Automatic operation requires an exclusive right of way. Passenger capacity per cabin can range from 4 for gondolas up to 120 for aerial tramways. Vehicle speeds can range from 13-31 mph.

A description of the Doppelmayr and Leitner-Poma guideway-based and aerial-based cable technologies and sample installations are discussed in the following sections.

4.1 Doppelmayr Cable Car (DCC) Cable Liner Shuttle

Website: https://www.dcc.at/

DCC Doppelmayr Cable Car GmbH & Co, headquartered in Austria, is a subsidiary of the Doppelmayr/Garaventa Group. They have implemented nine cable-propelled systems around the world. The Cable Liner Shuttle is rubber-tired with horizontal guide wheels riding inside a steel guideway. The system is cable-propelled and can operate as trains of 1- to 8-vehicles. They operate fully automated without drivers.

DCC has two recent implementations of the Cable Liner Shuttle – one connecting the Oakland International Airport to the regional Bay Area Rapid Transit (BART) rail system and the other at the new Hamad International Airport in Doha, Qatar. Examples of system implementations of the Cable Liner Shuttle are provided further below.

Figure 10. Doppelmayr Cable Liner Shuttle, CityCenter, Las Vegas, NV USA[9]

Table 6. Doppelmayr Cable Car (DCC) Cable Liner Shuttle vehicle specifications.

Doppelmayr Cable Car (DCC) Cable Liner Shuttle vehicle specifications	Value
Vehicle length (1 car)	19.7 ft.
Vehicle width	9.8 ft.
Vehicle height	11.3 ft.
Vehicle weight (unloaded)	11,023 lb.
Vehicle capacity (1 car @ 4 passengers/m^2)	56
Maximum speed	31 mph

[9] Image: Lea+Elliott

4.2 Leitner-Poma Mini Metro

Website: http://en.minimetro.com/Home

Leitner-Poma of America is based in Grand Junction, Colorado. It is the North American subsidiary of French-based Poma, which is owned by the Italian company Leitner Technologies, part of the Leitner Group. They currently have approximately 20 cable-propelled systems and funiculars implemented around the world. The Mini Metro can be rubber-tired, steel-wheeled or air-levitated (Hovair®). The system is cable-propelled and can operate as trains of 1- to 4-vehicles. They operate fully automated without drivers. Leitner-Poma systems can currently be found in operation at airports in Minneapolis-St. Paul, Detroit, Zurich, and Cairo,

Figure 11. Leitner-Poma (formerly Poma Otis) Mini Metro utilizing steel wheels/steel rail guidance, Minneapolis-St. Paul Airport, MN USA[10]

Table 7. Leitner-Poma Mini Metro standard vehicle specifications.

Leitner-Poma Mini Metro vehicle specifications	Value
Vehicle length (1 car)	48.9 ft.
Vehicle width	9.4 ft.
Vehicle height	12.7 – 13.5 ft.
Vehicle weight (unloaded)	33,069 – 35,274 lb.
Vehicle capacity (1 car @ 4 passengers/m^2)	66 – 70
Maximum speed	27 mph

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[10] Image: Lea+Elliott

The Mini Metro system is also available in a smaller cab configuration. Leitner-Poma currently has one system, called Squaire Metro, operating at Frankfurt International Airport.

Figure 12. Leitner-Poma Mini Metro small vehicle on The Squaire metro, Frankfurt Airport, Germany[11]

Table 8. Leitner-Poma Mini Metro small vehicle specifications.

Leitner-Poma Mini Metro small vehicle specifications	Value
Vehicle length (1 car)	18.1 ft.
Vehicle width	6.9 ft.
Vehicle height	9.5 ft.
Vehicle weight (unloaded)	7,716 lb.
Vehicle capacity (1 car @ 4 passengers/m^2)	33
Maximum speed	16 mph

[11] Image: Leitner-Poma

5. Gondolas

Website; https://www.doppelmayr.com/en/products/
Website: http://leitner-poma.com/products/

In Gondola systems, cabins are propelled and supported by the same cable which is suspended from poles or towers. The cabins are small and typically carry 4-15 passengers per cabin. Gondola cabins can also be suspended by two or three closely-spaced cables. Cabins loop around the system. At the end stations, cabins are detached from the cable and are mechanically pulled around a semicircle. Rubber wheels accelerate and decelerate the cabins without stopping the cable drive. This reorientation at end stations does not interrupt the traveling operation of the other cabins.

One area of concern regarding Gondolas is that their aerial location and suspended cable alignment make them more susceptible to operational disruptions associated with high winds. However, this does not preclude using gondolas in areas of high winds, as many mountainous regions have gondola systems. Nevertheless, system design for gondolas, and other suspended cable-based systems, must take into consideration the environmental conditions of the location where it operates to ensure safe operation year-round against wind.

Doppelmayr/Garaventa and Leitner-Poma both offer Gondola systems. Examples of urban gondolas can be found throughout the world, including, Barcelona, Caracas (Venezuela), Hong Kong, La Paz (Bolivia), London, Medellin (Columbia), Singapore, and Tlemcen (Algeria). Disney recently announced a new gondola system as part of its new park expansion in Florida.

Figure 13. Doppelmayr/Garaventa gondola[12]

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[12] Image: Doppelmayr/Garaventa

Figure 14. Leitner-Poma gondola, Barcelona, Spain[13]

Table 9. Gondola system specifications

Gondola system specifications	Value
Vehicle capacity (1 cabin)	4 - 15
Average Grade	20 – 35%
Maximum speed	13 mph
Minimum horizontal curve radius	n/a

5.1   Aerial Tramways

Website: https://www.doppelmayr.com/en/products/
Website: http://leitner-poma.com/products/

The basic Aerial Tramway configuration has at least two cables, with one or more fixed cables providing support and guidance while the haul rope propels the vehicle. All cables are suspended by poles or towers. Aerial Tramways have cabins bigger than gondolas and provide a high capacity of passenger movement. In many cities, Aerial Tramways are part of the transit infrastructure. Vehicle capacities range between approximately 30 and 120 passengers per cabin.

Doppelmayr/Garaventa and Leitner-Poma both offer Aerial Tramway systems in two configurations, as a jig-back (reversible) system or as a single loop operation similar to gondola systems. In a jig-back system, the haul cable propels the vehicles up and down without any impact to other vehicles. In the second configuration, a set of carriers move in a single path of travel.

There are currently four operating Aerial Tramways operating in urban areas in the United States. The Roosevelt Island Aerial Tramway in New York City (opened in 1976), the Portland Aerial Tram (2007), the Palm Spring Aerial Tramway (1963), and the Mount Roberts Tramway in Juneau, Alaska (1996). Note that the latter two are considered more like tourist attractions, however they do operate within their respective urban areas.

[13] Image: Leitner-Poma

Figure 15: Portland Aerial Tram, Portland, Oregon, USA[14]

Figure 16. Leitner-Poma Aerial Tramway, Roosevelt Island, New York, NY USA[15]

Table 10. Aerial Tramway system specifications

Aerial Tramway system specifications	Value
Vehicle capacity (1 cabin)	30 - 120
Average Grade	25 – 50%
Maximum speed	13 – 27 mph
Minimum horizontal curve radius	n/a

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[14] Image: www.gobytram.com
[15] Image: Leitner-Poma

6. Personal Rapid Transit (PRT)

Personal Rapid Transit (PRT) is an automated transportation technology that uses small vehicles operating at very short headways providing non-stop, origin-to-destination travel to a selected destination. The non-stop, point-to-point routing is accomplished by using small, off-line stations connected by a network of guideway and sophisticated automated vehicle control hardware and software. The goal of PRT is to provide an experience equivalent to a private automobile or taxi.

Characteristics of PRT:

- PRT systems utilize small vehicles (two to six passengers) that are designed to operate directly between origin and destination stations in a network configuration.

- Some vehicles have limitations: height for entry and exit requiring riders to sit in the vehicles and the lack of capacity for larger groups traveling together.

- The PRT system including its stations and vehicles are designed to accommodate the mobility impaired, including those in a wheelchair.

- Speeds are expected to be in the 20 to 30 mph range and may vary depending on guideway configuration.

- PRT systems are powered by batteries, which are recharged while the vehicles are dwelling at the stations. Other PRT Systems use a third rail to receive electric power.

- PRT propulsion can also range from conventional electric rotary motors to Linear Induction Motors (LIM) for propulsion.

- Since PRTs are automated they require a separate and exclusive guideway that is usually elevated. However, like Automated People Movers (APMs), PRTs can be at-grade with fencing/barriers protecting their right of way or can be located in tunnels.

The use of PRT Systems is designed to be straightforward. By pushing a button on equipment either on the platform or on the vehicle (depending on PRT supplier), a passenger indicates to the control system his desired destination. The desired destination information is sent electronically to the control system, which instructs the vehicle to take the passenger to the desired location by means of the shortest non-stop route. In addition to providing vehicles with directional instructions, Central Control also controls empty vehicle management and ensures there is no interaction between vehicles.

The PRT system off-line stations require sufficiently long exit ramps and entry ramps leading to and from the main guideway to the vehicle berths. The preference is that the ramp's geometry will allow the vehicle to remain at guideway speed until it exits the main guideway so as to not affect main guideway flow. Station design and passenger flow management are critical to the success of a PRT system and various station configurations could be designed to allow for location and ridership requirements. Typically, stations are configured with in-line berths, parallel off-line berths or off-line with saw-tooth berths.

Some suppliers state system capacities of several thousand passengers per hour per lane based on vehicles operating on very close headways (approximately 2-3 seconds).

Currently, there are three suppliers who have systems in passenger service: Ultra Global at London Heathrow Airport, 2getthere in Masdar City, Abu Dhabi, UAE, and Vectus in Suncheon Bay, South Korea. A description of the Ultra Global, 2getthere, and Vectus PRT technologies and their initial installations are discussed in the following sections.

6.1   2getthere

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

2getthere, a Dutch company, is currently operating a 0.75 mi round trip PRT line in Masdar City in Abu Dhabi, UAE, with two stations connecting the Masdar Institute of Science and Technology (MIST) to a parking facility. This system is a pilot program for an expanded network, though the original extensive network plan has been scaled back.

This system utilizes an open passive guideway with all propulsion and switching functions accomplished on board the rubber-tired vehicle. Vehicles are guided by on-board maps and error correction is provided by magnets embedded at 13 ft. intervals along the guideway. The single lane guideway requires a minimum width of 5.9 ft. and needs no guideway edges or curbs. Vehicle mounted sensors detect obstructions and adjust braking and propulsion for collision avoidance. It seats four adults and two children in forward and rear seats facing the center of the car. The cars are fully air conditioned. Figure 17 below depicts the mainline curbless lanes of the Masdar system and a 2getthere vehicle. Vehicle specifications are shown in the Table 11.

Figure 17. Masdar City PRT vehicle exterior[16]

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[16] Image: Lea+Elliott

Table 11. 2getthere vehicle specifications.

2getthere vehicle specifications	Value
Vehicle length	12.8 ft.
Vehicle width	4.9 ft.
Vehicle height	6.6 ft.
Vehicle weight (unloaded)	3086 lb.
Vehicle capacity	4 adults + 2 children
Maximum speed	25 mph

6.2   Ultra Global

Website: http://www.ultraglobalprt.com/

Ultra Global, a United Kingdom (UK) company, has installed a starter system connecting a parking lot (with two stations) with a single station at Terminal 5 at London Heathrow Airport (LHR). Opened in 2011, this initial alignment is more linear or "line-haul" in its configuration than what is typically envisioned for PRT, but it could develop into more of a grid network under its planned expansion.

The T5 Car Park has two PRT stations, Station A and Station B, with station boarding areas in a "saw tooth" configuration and the interface where a passenger will select his/her destination.

The Ultra Global PRT system utilizes an open passive guideway with all propulsion and switching functions accomplished on board the rubber-tired vehicle. Optical sensors on board the vehicles sense the guideway edge curbs and provide feedback for vehicle steering and switching (lane changes). The single lane guideway is estimated to be 7.2 ft. at its widest point, which is at curves. The vehicle seats four adult passengers, two forward-facing and two rear-facing, all facing the center of the car. Vehicle specifications are shown in the table below.

It has been reported that Ultra Global has licensed its technology to Ultra Fairwood based in Singapore and has announced plans for a project in Ajman City in the United Arab Emirates (UAE).

Figure 18. Ultra Global pod on guideway, Heathrow Airport, London, UK[17]

Table 12. Ultra Global vehicle specifications.

Ultra Global vehicle specifications	Value
Vehicle length	12.1 ft.
Vehicle width	4.9 ft.
Vehicle height	5.9 ft.
Vehicle weight (unloaded)	1808 lb.
Vehicle capacity	4
Maximum speed	25 mph

6.3   Vectus

Website: http://www.vectusprt.com/EN/

The Vectus system is rail-running and guided and can be installed on a concrete or steel structure, or at-grade. The track is passive and all switching is done on board the vehicle with a mechanical switch. Guidance is provided through guide rails, and guide wheels ensure that the vehicles are mechanically "locked" on the guideway. Propulsion can be provided by the vehicle using rotary motors or guideway power using Linear Induction Motors (LIMs). The vehicle seats four adult passengers in forward and rear seats facing the center of the car. Multiple station configurations can be supported including in-line, series, or parallel off-line berths.

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[17] Image: Lea+Elliott

Vectus, a UK/South Korean company, constructed a 2.8 mi. PRT system at the Suncheon Bay coastal wetlands area in South Korea in April 2014.

Figure 19. Suncheon Bay PRT vehicle and guideway, Republic of Korea[18]

Table 13. Vectus vehicle specifications.

Vectus PRT vehicle specifications	Value
Vehicle length	12.1 ft.
Vehicle width	6.9 ft.
Vehicle height	8.2 ft.
Vehicle weight (unloaded)	3307 lb.
Vehicle capacity	6-8
Maximum speed	43 mph

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[18] Image: Vectus

7. Group Rapid Transit (GRT)

Group Rapid Transit (GRT) is similar to Personal Rapid Transit but with higher-occupancy vehicles and grouping of passengers with either the same destination or potentially different origin-destination pairs, depending on the GRT's control system and vehicle assignment algorithm. In this respect, GRT can be seen as a direct-service or "typical" horizontal elevator. Such systems may have fewer direct-to-destination trips than single-destination PRT but still have fewer average stops than conventional transit, acting more as an automated share taxi system than a private cab system. Such a system may have advantages over low-capacity PRT in some applications, such as where higher passenger density is required or advantageous. It is also conceivable for a GRT system to have a range of vehicle sizes to accommodate different passenger load requirements, for example at different times of day or on routes with less or more average traffic. Such a system may constitute an "optimal" surface transportation routing solution in terms of balancing trip time and convenience with resource efficiency.

GRT has principally been proposed as a corridor service, where it can potentially provide a travel time improvement over conventional rail or bus and can also interface with PRT systems. However, GRT's potential grouping of passengers makes it much less attractive in applications with lower passenger density or where few origin-destination pairs are shared among passengers.

All other PRT characteristics related to stations and guideways mentioned previously in Section 6 also apply to GRT.

7.1   West Virginia University Personal Rapid Transit

Website: https://transportation.wvu.edu/prt

The West Virginia University Personal Rapid Transit System in Morgantown, WV is an automated people mover system that provides non-stop origin to destination travel between the separated campuses of West Virginia University and the Central Business District. The system consists of a fleet of 71 electrically-powered, rubber-tired, passenger-carrying vehicles (8-seated and 13-standing), operating on a dedicated guideway network at close headways (minimum 15 seconds). Since 1975, the system has provided and continues to provide a safe, comfortable, low polluting reliable means of transportation. The system consists of 8.2 mi of guideway and five passenger stations. Although called a PRT, many feel that this system is better labeled Group Rapid Transit (GRT) because these vehicles can carry up to 21 passengers. This technology was originally supplied by Boeing and is not currently commercially available.

Figure 20. WVU PRT vehicle and station[19]

Table 14. Technical specifications of Morgantown PRT vehicle

Morgantown PRT vehicle specifications[20]	Value
Vehicle length	15.5 ft.
Vehicle width	6.7 ft.
Vehicle height	8.8 ft.
Vehicle weight (unloaded)	8750 lb.
Vehicle capacity	21 (8 seated)
Maximum speed	30 mph

7.2   Vectus

Website: http://www.vectusprt.com/EN/

Vectus has announced plans for a GRT vehicle which will be longer and taller yet will operate on the same guideway as the PRT vehicle. The larger vehicles are designed to accommodate standees as well as seated passengers. The door spacing of the larger vehicles matches the door spacing of two adjacent PRT vehicles stopped in a station. This feature allows the GRT vehicles to share the same station infrastructure with the PRT vehicles. It is anticipated that the Vectus PRT and GRT vehicles will be able to operate simultaneously on the same network.

The Vectus system is rail-running, rail-guided and can be installed on a concrete or steel structure, or at-grade. The track is passive and all switching is done on board the vehicle with a mechanical switch. Guidance is provided

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[19] Image: Lea+Elliott
[20] https://onlinelibrary.wiley.com/doi/pdf/10.1002/atr.5670250303

through guide rails, and guide wheels ensure that the vehicles are mechanically "locked" on the guideway. Propulsion can be provided by the vehicle using rotary motors or guideway power using Linear Induction Motors (LIMs). The larger Group Rapid Transit (GRT) vehicle is planned to accommodate seated and standing passengers, from 20 to 60 total, to be determined. A prototype vehicle for testing purposes is planned as part of Vectus' ongoing R&D program.

Figure 21. Vectus Group Rapid Transit (GRT) vehicle[21]

Table 65. Vectus GRT vehicle specifications.

Vectus GRT vehicle specifications	Value
Vehicle length	Not available
Vehicle width	6.9 ft.
Vehicle height	In development
Vehicle weight (unloaded)	In development
Vehicle capacity	20-60 (TBD)
Maximum speed	43 mph

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[21] Image: Vectus

8. Automated Vehicle Shuttle

Automated vehicles (AV) are vehicles used to move passengers or freight with a level of automation. They are classified into six different levels of automation, as defined by the Society of Automotive Engineers (SAE). The first three levels of automation (Levels 0-3) require a human driver to monitor the environment, while the last three levels (Levels 4-6) allow an automated system to perform driving tasks. This paper introduces existing Shared Automated Vehicles (SAV), which are level 4 and higher. These vehicles aim to transform transportation by significantly improving safety and mobility, improving the efficiency of rides on demand, reducing carbon footprints of cities, and solving the public transportation problem of the first and last mile connectivity.

Automated people movers are considered AV systems that are already in operation today, primarily for use in controlled, fixed-guideway systems as described in previous sections.[22] SAVs, such as AV shuttles and fleets, are being deployed for use in a less fixed, nonetheless still contained, environment (i.e., public roadways). AV shuttles are small, electric passenger buses that are equipped with SAE Level 5[23] (full automation) control. While all automated shuttle service pilots are in the initial testing phase, some pilots are offering rides to the public. These pilots are testing the feasibility of automated vehicle technology for public transit and user acceptance. EasyMile, NAVYA, and Local Motors are three major manufacturers of low-speed automated shuttles.

8.1   EasyMile

Website: http://www.easymile.com/

EasyMile, headquartered in France, is a joint venture between vehicle manufacturer Ligier Group and Robosoft, a high tech company specializing in robotics[24] and autonomous vehicle technology. The venture has provided its electric AV model "EZ10" for the CityMobil2 program, a multi-stakeholder project co-funded by the European Union (EU). The goal of the CityMobil2 project is to set up a pilot platform for automated road transport systems and study the technical, financial, cultural, and behavioral aspects of Shared Autonomous Vehicle (SAV) systems[25]. The objective of CityMobil2 is to deliver:

- An automated road transport service running for at least six months at five sites across Europe
- Guidelines to design and implement an automated transport system
- Improved understand of the interaction between automated vehicles and other road users
- A legal framework proposal for certifying automated road transport systems in Europe
- Showcases at numerous sites across Europe
- Technical specifications for interoperable automated road transport systems, including a communications architecture[26]

Outside of the CityMobil2 project, the EZ10 shuttle has been deployed in 20 countries across Asia-Pacific, Middle-East, North America, and Europe. In 2015, EasyMile and GoMentum station – a testing ground for connected and automated vehicles in Concord, California – announced their partnership to launch the first fleet of EZ10 vehicles in Northern California.[27] The shuttles arrived at GoMentum Station in September 2016, and the pilot demonstration project with the Contra Costa Transportation Authority marks the first time EasyMile shuttles will be utilized in the United States[28]. The EZ10 is the first fully self-driving vehicle to be approved for public roads trials in California[29].

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[22] https://www.itf-oecd.org/sites/default/files/docs/shared-automated-vehicles-business-models.pdf
[23] https://web.archive.org/web/20170903105244/https://www.sae.org/misc/pdfs/automated_driving.pdf
[24] http://gomentumstation.net/wp-content/uploads/2015/10/Press-Release-Easymile-Gomentum-Station-Announce-Exclusive-Agreement-October-5-2015-1.pdf
[25] http://www.citymobil2.eu/en/About-CityMobil2/Overview/
[26] http://www.citymobil2.eu/en/About-CityMobil2/Outputs-deliverables/
[27] http://gomentumstation.net/easymile-and-gomentum-station-announce-exclusive-agreement/
[28] http://www.ccta.net/about/download/GoMentum%20Station%20and%20BestMile%20Announce%20Partnership.pdf
[29] http://easymile.com

Figure 22. EasyMile's EZ10 driverless shuttle.[30]

Table 16. Technical specifications of EasyMile's EZ10

EasyMile's EZ10 driverless shuttle vehicle specifications[31]	Value
Vehicle length	12.9 ft.
Vehicle width	6.5 ft.
Vehicle height	9 ft.
Vehicle weight (loaded)	1270 lb.
Vehicle capacity	12 (6 seated)
Maximum speed	25 mph

8.2 NAVYA

8.2.1 AUTONOM SHUTTLE

Website: https://navya.tech/en/autonom-en/autonom-shuttle/

NAVYA, headquartered in France, developed AUTONOM SHUTTLE as a driverless, electric shuttle service. In 2016, NAVYA delivered two AUTONOM SHUTTLEs known as ARMA for use in a two-year demonstration

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[30] http://www.easymile.com/#Newsroom
[31] https://www.nctr.usf.edu/wp-content/uploads/2016/04/Evaluation-of-Automated-Vehicle-Technology-for-Transit-2016-Update-UPDATED-FINAL.pdf

launched in the city of Sion, Switzerland[32]. BestMile, a Swiss start-up, provides the software for fleet management, allowing the remote control of the vehicles and optimization of driverless vehicle fleets[33]. The two AUTONOM SHUTTLES provided shuttle service that was the first test of an autonomous passenger service, and is also free and open to the public. As of January 2018, NAVYA has 65 vehicles deployed worldwide, in cities and on private sites in Europe, the United States, Asia, and the Pacific. NAVYA's AUTONOM shuttle is shown in Figure 23. Table 17 presents the technical specifications of NAVYA's AUTONOM SHUTTLE.

Figure 23. NAVYA's AUTONOM SHUTTLE on demo.[34]

Table 77. Technical specifications of NAVYA's AUTONOM SHUTTLE.[35]

NAVYA's AUTONOM SHUTTLE vehicle specifications	Value
Vehicle length	15.6 ft.
Vehicle width	6.9 ft.
Vehicle height	8.7 ft.
Vehicle weight (unloaded)	5291 lb.
Vehicle capacity	15
Maximum speed	28 mph

In 2017, NAVYA brought the first AUTNOM SHUTTLE to the United States at the University of Michigan's (Mcity) Mobility Transformation Center (MTC) in Ann Arbor, Michigan. Mcity will study how passengers react, track ridership and usage patterns, and survey users to gauge rider acceptance[36]. This data will help improve the safety and operations of the vehicles.

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[32] https://navya.tech/en/carpostal-and-the-city-of-sion-extend-the-navya-shuttle-experimentation/
[33] https://bestmile.com/2015/09/30/bestmile-teams-up-with-navya/
[34] https://navya.tech/en/navya-presented-its-autonomous-shuttle-on-demo-at-the-apta-expo/
[35] http://navya.tech/en/shuttle-configurator/
[36] http://ns.umich.edu/new/multimedia/videos/24923-driverless-shuttle-service-coming-to-u-m-s-north-campus

8.2.2 AUTONOM CAB

Website: https://navya.tech/en/autonom-en/autonom-cab/

NAVYA launched AUTONOM CAB, the first autonomous taxi on the market, in Paris, France in November 2017. It was introduced to the United States at the Consumer Electronics Show (CES) in Las Vegas, Nevada in January 2018. Visitors tested the cab, which transported more than 1,500 people on the streets of Las Vegas.[37] AUTONOM CAB is available as a private or shared service and is used for on-demand trips. Similar to NAVYA's objective for AUTONOM SHUTTLE, it aims to use AUTONOM CAB to ease congestion in city centers, provide a solution to the demand for first and last mile service, optimize variable costs, and improve safety by providing a fluid mobility service.[38] NAVYA plans to begin service of AUTONOM CAB in the second quarter of 2018. Partnerships with transport specialists such as KEOLIS in Europe and the U.S. will enable NAVYA to have fleets of the autonomous vehicles operating in city centers. NAVYA's AUTONOM CAB is shown in Figure 24.

Figure 24. NAVYA'S AUTONOM CAB in the streets of Paris.[39]

To use AUTONOM CAB, the passenger uses the smartphone application called NAVYA APP to order the cab and open and close the vehicle's door. When inside the vehicle, the passenger can utilize the onboard touchscreen, allowing them to order tickets for a movie, select songs, and obtain tourist information, further enhancing the user experience. In addition to its fluid communication, AUTONOM CAB boasts its communicative design on the exterior with its colored light band that communicates with passengers, person who ordered the cab, and pedestrians. The technical specifications of the vehicle can be seen in Table 18.

Table 18. Technical Specifications of NAVYA's AUTONOM CAB.

NAVYA's AUTONOM CAB vehicle specifications	Value
Vehicle length	15.3 ft.
Vehicle width	6.4 ft.
Vehicle height	6.9 ft.
Vehicle weight (unloaded)	4409 lb.
Vehicle capacity	6
Maximum speed	55 mph

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[37] https://navya.tech/en/ces-2018-navya-presented-its-autonomous-shuttle-and-its-robo-taxi-in-the-streets-of-las-vegas/
[38] https://navya.tech/wp-content/uploads/2018/01/Brochure_CAB_GB_US.pdf
[39] https://navya.tech/en/rac-wa-to-trial-autonom-cab-in-perth/

8.3   Local Motors

Website: https://localmotors.com/meet-olli/

Local Motors, an American automobile manufacturing company, developed the world's first 3D printed transit vehicle – Olli, a self-driving shuttle. Local Motors design engineers are able to reduce tooling costs by 50% and reduce overall production time by 90%, all while keeping part production in-house using tools like the MakerBot Replicator+, a cloud-enabled desktop 3D printer[40]. Olli made its debut in National Harbor, Maryland (see Figure 25) in June 2016[41], where it traveled on local public roads within the boundaries of National Harbor in its trial run.

Figure 25. Local Motors' Olli on demo in National Harbor, Maryland. [42]

To use Olli, a rider will use the Modally mobile app to book a ride and set your destination, similar to other ride-sharing programs. Olli is equipped with IBM Watson Internet of Things (IoT) technology, which allows interaction with the vehicle. This advanced vehicle technology allows passengers to converse with Olli in such a way that creates more intuitive and interactive experiences due to the nature of its cognitive computing capability. Together, IBM and Local Motors have produced a vehicle that combines the capabilities of a chauffeur, a tour guide, and a technology expert to communicate with passengers using spoken conversational language[43]. In addition to casual conversation, Olli has the ability to update passengers for the duration of the ride, taking into account upcoming traffic, weather, or other potential issues that may affect the commute. Table 19 presents the technical specifications of Local Motors' Olli.

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[40] https://www.makerbot.com/local-motors-case-study/
[41] https://localmotors.com/meet-olli/
[42] https://localmotors.com/2017/06/01/local-motors-celebrates-national-autonomous-vehicle-day/
[43] https://www-01.ibm.com/common/ssi/cgi-bin/ssialias?htmlfid=WW112356USEN

Table 19. Technical specifications of Local Motors' Olli. [44]

Local Motors' Olli vehicle specifications	Value
Vehicle length	12.9 ft.
Vehicle width	6.7 ft.
Vehicle height	8.2 ft.
Vehicle weight (unloaded)	4056 lb.
Vehicle capacity	10
Maximum speed	25 mph

8.4   AV Shuttle Comparison

A comparison of the vehicles of the three main AV shuttle manufacturers – EasyMile, NAVYA, and Local Motors – can be found in Table 20.

Table 20. Comparison of the specifications of EasyMile's EZ10, NAVYA's AUTNOM SHUTTLE, NAVYA's AUTNOM CAB and Local Motors' Olli. [45]

Specification	EasyMile EZ10	NAVYA's AUTONOM SHUTTLE	NAVYA's AUTONOM CAB	Local Motors' Olli
Capacity	12	15	6	10
Cruising Speed	12 mph	15.5 mph	30 mph	12 mph
Maximum Speed	25mph	28 mph	55 mph	25 mph
Vehicle Weight	3900 lb.	5291 lb.	4409 lb.	4056 lb.
Fully Loaded Weight	6000 lb.	7606 lb.	5512 lb.	6261 lb.

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[44] https://localmotors.com/wp-content/uploads/2017/06/LM_Olli_SpecSheet-1-1.pdf
[45] http://en.sip-adus.jp/evt/workshop2017/file/evt_ws2017_s7_ElizabethMachek.pdf

9. Automated Vehicle Fleet

Similar to automated vehicle shuttles, automated vehicle fleets offer rides to the public but through a controlled fleet of passenger vehicles supplied with automated vehicle technology.

9.1　Waymo

Website: https://waymo.com/

Waymo, an American self-driving tech company, began as the Google self-driving car project in 2009 and became its own independent company in 2016.　Waymo's fully self-driving technology has driven over 5 million miles on real-world roads since 2009[46]. Waymo formed a partnership in 2016 with Fiat Chrysler Automobiles (FCA) to supply Chrysler Pacifica minivans for its public road testing.[47]

9.1.1　System Operations

Waymo's vehicles cross-reference their pre-built, detailed three-dimensional maps with real-time sensor data to precisely determine their location on the road, rather than relying on GPS[48]. The sensors and software continuously scan for objects up to 300 meters away in every direction of the vehicle. The software predicts future movements of dynamic objects based on trajectory and current speed, predicts numerous possible paths of other road users, and considers the potential impacts of changing road conditions (e.g., road blocks) on the behavior of other road users. This information allows the software to determine the exact trajectory, speed, lane, and steering maneuvers necessary to safely proceed ahead.

The vehicles are equipped with an SAE Level 4 automated driving system, which allows the vehicle to come to a safe stop in the event of a system failure. They gather information from their LiDAR, vision, GPS, radar, and audio detection systems to not only assess the current driving situation, but also think several steps ahead to make the best decision. Figure 26 shows the general components of Waymo's vehicles.
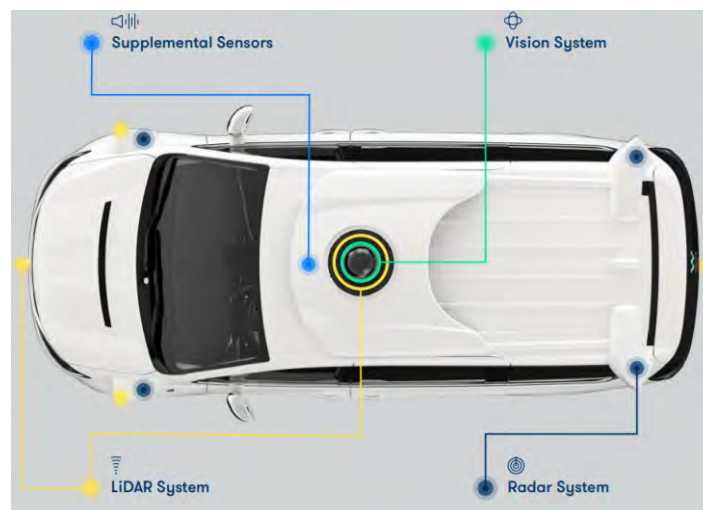
Figure 26. Individual components of Waymo's vehicles' software system[49]

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[46] https://waymo.com/safetyreport
[47] http://www.autonews.com/article/20180130/MOBILITY/180139999/waymo-fiat-chrysler-chrysler-pacifica-minivans
[48] https://storage.googleapis.com/sdc-prod/v1/safety-report/waymo-safety-report-2017.pdf
[49] http://safecarnews.com/waymo-releases-their-safety-report/

Waymo's vehicles are designed to:

- Drive in inclement weather
- Not operate outside of its approved operational design domain
- Detect sudden changes and come to a safe stop
- Comply with federal, state, and local laws within their geographic area of operations

At its level of automation, Waymo's technology is capable of performing a safe stop, known as a "minimal risk condition" or fallback, which may include situations when the self-driving system experiences a problem, when the vehicle is involved in a collision, or when environmental conditions change in a way that would affect safe driving within the operation design domain. The vehicle's system has the ability to automatically detect each of the scenarios, assess the surrounding environment and conditions, and determine an appropriate response for the safety of its passengers.

9.1.2   Testing

Waymo's self-driving technology is tested on the road, in closed areas, and in simulations. The three subsystems of the vehicles are rigorously tested: the base vehicle, in-house hardware, and self-driving software. The vehicle's hardware is tested to ensure that the vehicle operates safely in manual mode, self-driving mode with a test driver at the wheel, and fully self-driving mode without a person inside the vehicle. The individual components of the vehicle's software, which include perception, behavior prediction, and planner, are tested individually and as a whole. Each software update undergoes simulation testing, closed-course testing, and driving on public roadways. Simulation testing uses virtual scenarios of the most challenging, real-world situations that the vehicles have experienced. Then, this new software is tested on a private test track. Waymo has a private, 91-acre closed-course testing facility in California to conduct thousands of structured tests. Finally, once it has been confirmed that the updated software is working as intended, it is introduced to vehicles on public roads. Real-world testing provides a continuous feedback loop that allows for continuous refinement of the self-driving system.

In April 2017, Waymo launched an early rider program – a public trial of its self-driving vehicles – in Phoenix, Arizona. Each vehicle offering rides to passengers in the early rider program had a test driver to monitor the rides in its early testing stages. By November 2017, Waymo removed human drivers from test fleets, deploying fully self-driving vehicles on the streets.[50] FCA agreed to supply thousands of additional Chrysler Pacifica minivans in Waymo's effort to expand its operations and deployment, which will be available in late 2018. Waymo is also conducting public road tests in 25 cities in the U.S., including San Francisco, metro Detroit, and Atlanta. More recently, Waymo has announced its new partnership with Jaguar Land Rover. Together, they are working to engineer the world's first premium electric fully self-driving vehicle, the I-PACE, which will begin testing later this year.[51]

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[50] http://fortune.com/2018/03/13/waymo-driverless-minivans-phoenix/
[51] https://medium.com/waymo/meet-our-newest-self-driving-vehicle-the-all-electric-jaguar-i-pace-375cecc70eb8

Figure 27. Waymo's I-PACE vehicle[52]

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Table 21. Technical specifications of Waymo's I-PACE vehicle

Waymo's I-PACE vehicle specifications[53]	Value
Vehicle length	15.4 ft.
Vehicle width	6.2 ft.
Vehicle height	5.1 ft.
Vehicle weight (unloaded)	4784 lb.
Vehicle capacity	5
Maximum speed	124 mph

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[52] http://www.businessinsider.com/waymo-jaguar-all-electric-self-driving-cars-i-pace-2018-3
[53] https://www.jaguarusa.com/all-models/i-pace/specifications/index.html

9.2   Drive.ai

Website: https://www.drive.ai.com

Is an on-demand, self-driving car service company founded in 2015 by graduate students and others affiliated with Stanford's Artificial Intelligence Lab. This California-based company collaborates with public and private entities to develop geofenced Level 4 self-driving solutions to mobility problems. Drive.ai uses "deep-learning" to develop integrated software/hardware mobility solutions that are scalable and flexible to work seamlessly with various vehicle types and urban environments[54].
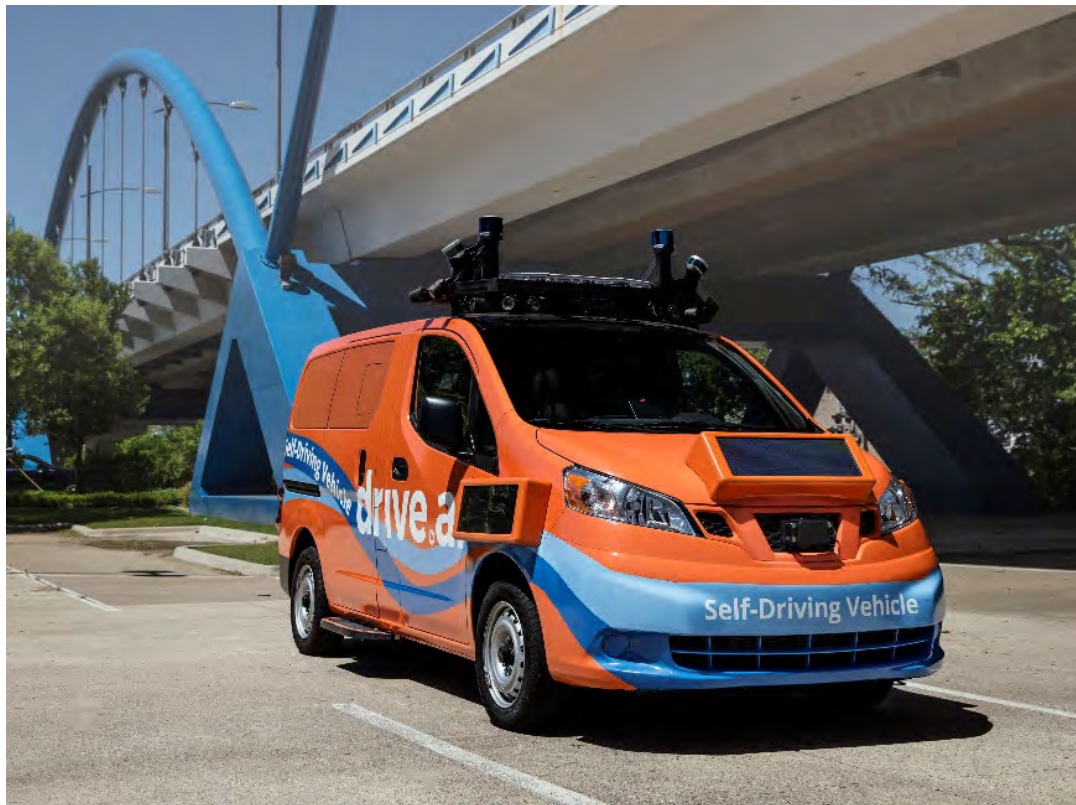
Figure 28: A Drive.ai Nissan NV200 van with sensors[55].

Drive.ai will start a six-month pilot program using four vehicles in Frisco, Texas starting in July, 2018. During trial period, Drive.ai will offer complimentary rides during daylight hours to employees, residents, and patrons in a geofenced area in Frisco's North Platinum Corridor. This will be the first time that the general public will have access to an on-demand, self-driving vehicle service in the US[56].

Users will request rides using Drive.ai's ride-hailing smartphone app at select pickup and drop-off locations (finalized in May-June of 2018[57]) within the geofenced area (see Figure 29). Drive.ai plans to expand its service to Frisco Station and perhaps elsewhere in and beyond the North Platinum Corridor at a future date[58]. The company also has plans to develop a similar service in the San Francisco Bay Area[59].

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[54] https://www.Drive.ai.com
[55] https://www.Drive.ai.com , https://www.bloomberg.com/news/articles/2018-05-07/drive-ai-will-offer-uber-like-service-with-autonomous-vans-this-summer
[56] https://www.Drive.ai.com , http://scipol.duke.edu/content/driverless-car-startup-driveai-launching-ride-hailing-service-texas
[57] https://www.theverge.com/2018/5/7/17321610/drive-ai-autonomous-ride-share-texas
[58] https://www.Drive.ai.com , https://www.techcrunch.com/2018/05/07/drive-ai-is-launching-an-autonomous-ride-hailing-network-in-texas
[59] https://www.techcrunch.com/2018/05/07/drive-ai-is-launching-an-autonomous-ride-hailing-network-in-texas

Figure 29: Initial Drive.ai service area in Frisco, Texas[60]

Table 22. Technical specifications of Drive.ai's Nissan NV200 Van

Drive.ai's Nissan NV200 Van specifications[61]	Value
Vehicle length	15.5 ft.
Vehicle width	5.6 ft.
Vehicle height	6.2 ft. *(excluding sensor apparatus)*
Vehicle weight (unloaded)	3263 lb.
Vehicle capacity	4 passengers and one operator/chaperone in self-driving version
Maximum speed	45 mph

[60] https://www.Drive.ai.com
[61] https://www.Drive.ai.com, https://www.nissanusa.com/NCV, https://www.nissanusa.com/vehicles/commercial/2017-nyc-taxi.html?dcp=psn.5870002305602118&gclid=CIDeuq6IzNsCFUSfgQod3OoKiA&gclsrc=ds&dclid=CN_Ewq6IzNsCFUK9Twodpm0MJw

10.   Future Technologies

Shared Autonomous Vehicles (SAVs) are still in their preliminary stages, gradually being introduced to the public. However, new technologies are continuously evolving, aiming to be fully autonomous. Toyota introduced its e-Palette concept vehicle, a level 5 automation, all-electric progressive vehicle that intends to meet individual and business needs, such as ride-sharing or delivery. Toyota plans to conduct feasibility testing of the e-Palette Concept in the early 2020s.[62] Similarly, Volkswagen's SEDRIC is a cross-brand ideas platform[63] that offers autonomous shared mobility services. The SEDRIC vehicle will begin testing on public roads in 2021.

Figure 30. e-Palette concept vehicle[62]

Figure 31. SEDRIC concept vehicle[64]

These concept vehicles are designed to highlight an integrated mobility concept for the future in road traffic,[65] while improving efficiency, convenience, sustainability and flexibility. Although these vehicles are currently exploratory, they can be considered as a mobility service platform, similar to the human-operated services of Lyft and Uber, paving the way for new opportunities to interface AVs with APM systems.

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[62] https://newsroom.toyota.co.jp/en/corporate/20546438.html
[63] http://fortune.com/2017/03/07/volkswagen-self-driving-car-sedric/
[64] https://www.volkswagen-media-services.com/delegate/convert/documents/10541/5578101/DB2017AU01348_small.jpg/f86bed91-6fdc-4745-bf31-584ed2c65cc6?type=fp
[65] https://www.volkswagenag.com/en/news/2017/03/Autonomous_driving.html

Appendix D

Shared-Use Parking Analysis Methodology
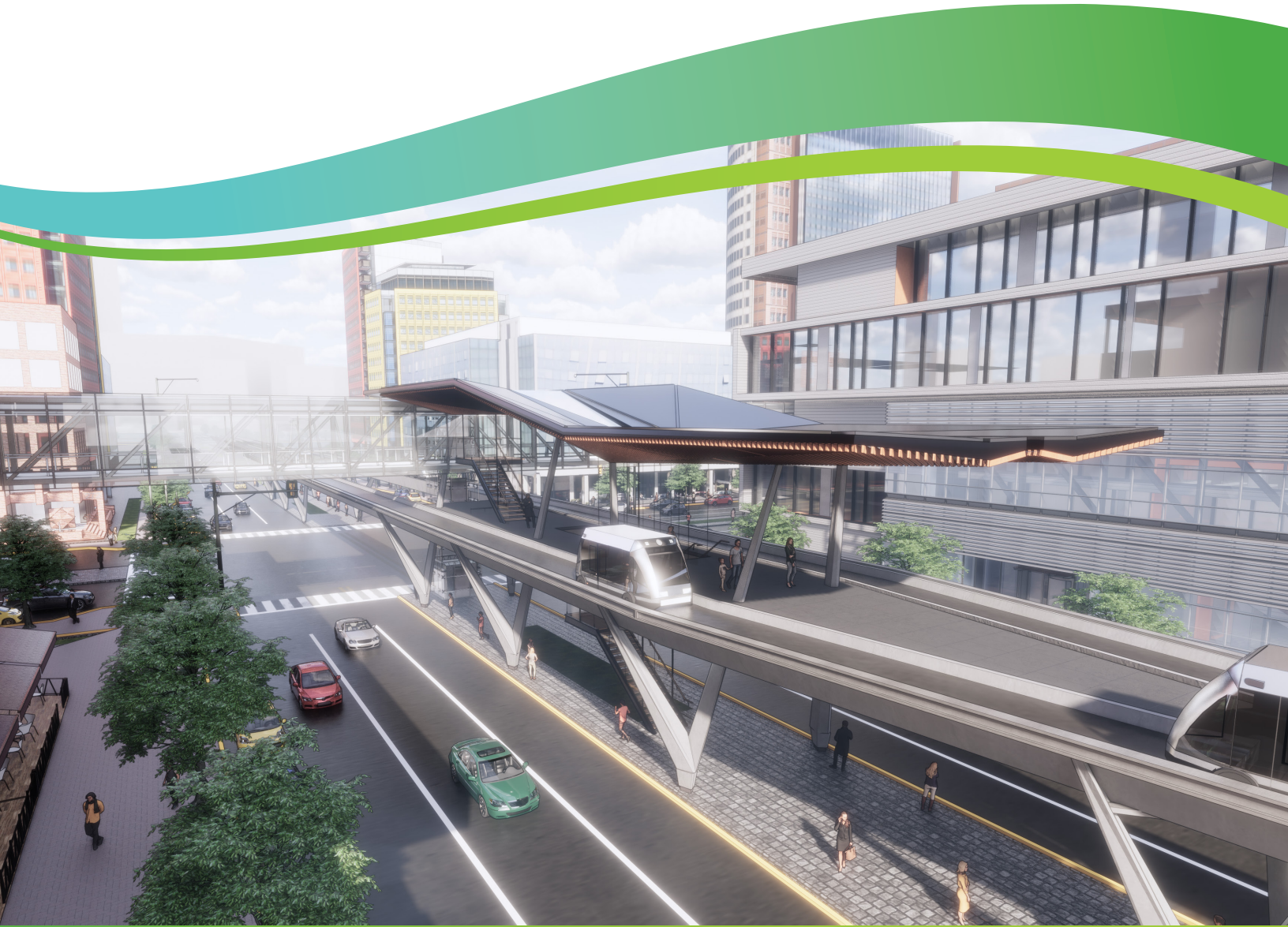
Date	August 19, 2019
To	North Central Texas Council of Governments (NCTCOG)
From	Casey Wagner PE, Mallory Baker, Jeff Weckstein PE
Subject	Dallas Midtown Parking Analysis

PROJECTED SHARED-USE PARKING DEMAND

Walker prepared a shared parking analysis, utilizing the Walker shared parking model for the Midtown area, to supplement the zone by zone models developed by Jacobs using the ULI shared parking model.

Shared parking analysis, in accordance with *Shared Parking* is the generally accepted methodology for determining the appropriate parking supply for a mixed-use development or for a developing district. Shared parking is the use of a parking space by vehicles generated by more than one land use. The ability to share parking spaces is the result of two conditions:

- Variations in the accumulation of vehicles by hour, by day or by season at the individual land uses.
- Relationships among the land uses that result in visiting multiple land uses on the same auto trip.

For example, restaurants have peak parking needs during the evening and weekends, while hotels and residential land uses have peak parking needs overnight.

Although the ULI methodology for shared parking analysis was developed in the early 1980s, the concept of shared parking was already well established: a fundamental principle of downtown planning from the earliest days of the automobile has always been to share parking resources rather than to have each use or building have its own parking. The resurgence of many central cities resulting from the addition of vibrant residential, retail, restaurant and entertainment developments continues to rely heavily on shared parking for economic viability. In addition, mixed-use projects in many different settings have benefited from shared parking. There are numerous benefits of shared parking to all parties to development, including the community at large, not the least of which is the environmental benefit of significantly reducing the square feet of parking (usually in surface lots) provided to serve the development.

As a result of this analysis, this appendix provides a projection of the peak parking demand for Dallas Midtown based on the projected peak hour of design day parking demand. This does not represent the maximum ever generated by the development. In Walker's experience, designing a parking system for the absolute peak busiest day of the year leads to overbuilding of parking spaces. Similarly, one does not build for an average day and have insufficient supply for the peak (if not multiple) hours on 50 percent of the days in a year. The peak in this analysis refers to the "design day" or "design hour," one that recurs frequently enough to justify providing spaces for that level of parking activity. The 85th percentile of peak-hour observations is generally recommended by *Shared Parking*, except for retail shopping, for which the 20th highest hour of the year is employed.

Walker constructed two shared parking models:

- Conventional model
  - Similar assumptions for drive ratio as the Jacobs parking analysis (92% for office workers, 87% for service workers).
  - Utilizes a different category for the Galleria (super regional shopping center versus generic retail).
  - Assumption of 1.5 reserved resident spaces per dwelling unit (1-space per 1-bedroom unit, 2-space per 2-bedroom unit, assumes 50% 1-bedroom and 50% 2-bedroom units)
  - Assumes 20% of proposed retail space is fast food/fast casual food.
- Recommended model
  - Lower drive ratios used under the assumption that the area's multi-modal vision is achieved through planning and implementation of a transportation and parking management authority (70% drive ratio for office workers, 50% drive ratio for service workers).
  - Assumption that 50% of residential spaces (0.75 spaces per unit) are reserved, with the remaining 50% unreserved and available to the shared parking pool.
  - Assumes 20% of proposed retail space is fast food/fast casual food.
  - Lower retail non-captive utilized for weekday daytime assuming integration of entire Midtown area into a cohesive plan is achieved.

Figure 4 shows the zone delineations provided by Jacobs.

Figure 4: Dallas Midtown Zones

Source: Jacobs, 2019
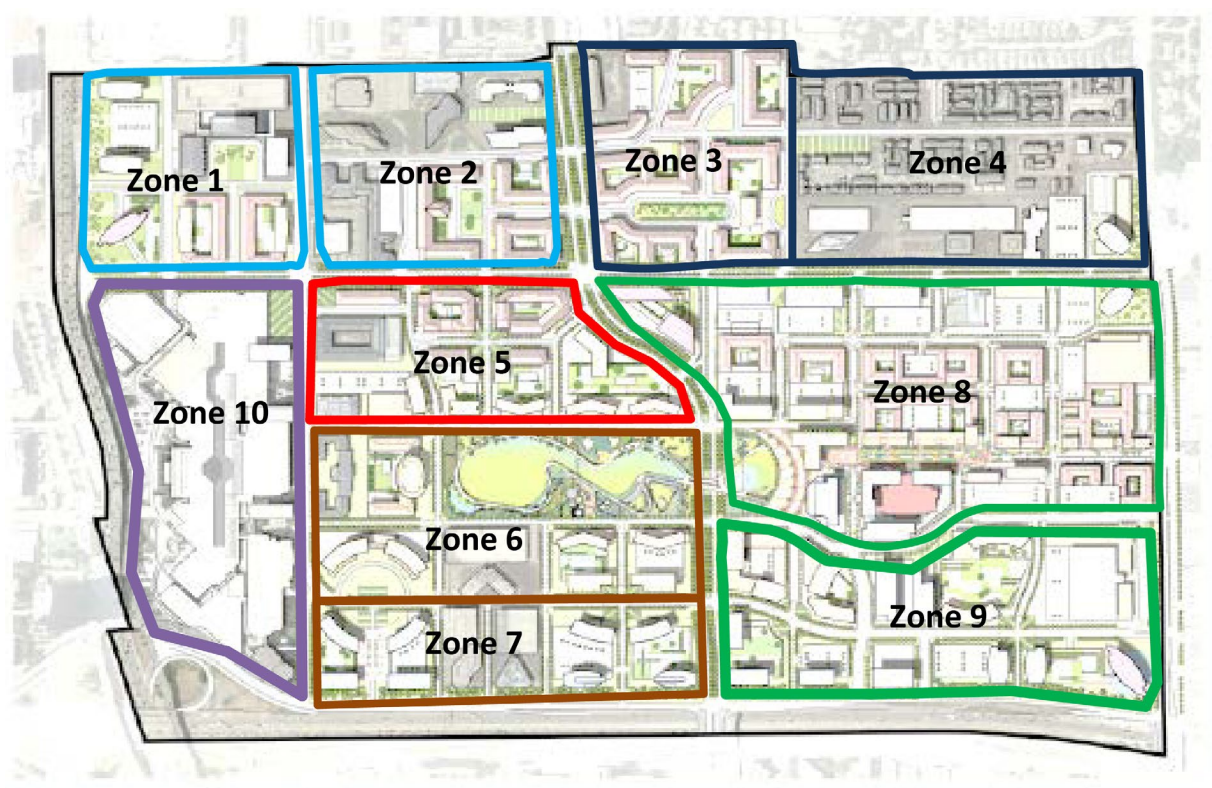
CONVENTIONAL MODEL OUTPUT:

Figure 5 shows the results of the conventional shared parking model for the Midtown area. The output shown in this analysis is for the weekday as the large amount of office uses planned in Midtown result in a weekday daytime peak. Given the scale of office development, the Midtown development could likely support additional night and weekend uses, including special events at the park, utilizing office parking facilities during non-peak times with shared parking agreements.

Figure 5: Midtown – Conventional Shared Parking Model Output (Weekday)

Land Use	Base Demand	Month Adjustment December	Peak Hour Adjustment 2:00 PM	Non Captive Daytime	Drive Ratio Daytime	Demand December 2:00 PM
Retail - Customer	3,045	100%	100%	50%	95%	1,446
Retail - Employee	735	100%	100%	98%	87%	624
Super Regional Shopping Center - Customer	6,080	100%	100%	50%	95%	2,888
Super Regional Shopping Center - Employee	1,520	100%	100%	98%	87%	1,290
Restaurant - Customer	3,302	100%	90%	0%	95%	0
Restaurant - Employee	583	100%	95%	98%	87%	470
Hotel - Guest	1,496	67%	60%	100%	66%	397
Hotel - Employee	374	100%	100%	98%	87%	318
Residential Guest	1,237	100%	20%	100%	95%	235
Residential Reserved	18,553	100%	100%	100%	100%	18,553
Residential Unreserved	0	100%	70%	100%	100%	0
Office - Guest	2,167	100%	100%	85%	100%	1,842
Office - Employee	28,176	100%	100%	99%	92%	25,738
Subtotal Customer/Guest	17,327					6,808
Subtotal Employee/Resident	31,388					28,440
Subtotal Reserved Resident	18,553					18,553
Total Parking Spaces Required	**67,268**					**53,801**

Base Ratio - refers to parking demand assuming a suburban site where 100% of customers/ employees drive to the site and assuming that all uses provide parking separately.

Month Adjustment – takes into account the seasonal peak of each land use.

Peak Hour Adjustment – takes into account the hourly usage pattern of each land use.

Non-Captive – accounts for users already parked on site for another use (for example a guest at a hotel with a car patronizing a restaurant in the immediate vicinity while remaining parked at the hotel).

Drive Ratio – refers to the percentage of customers/employees projected to drive to the use, and accounts for carpooling and alternative modes of transportation.

Source: Walker, 2019

Figure 6 shows the results of the conventional shared parking model by zone. Included in Figure 5 is an estimate of existing parking in each zone that will remain in place for the foreseeable future. The surplus/deficit line shows the additional parking supply that would be necessary to support the buildout of the conceptual plan for Midtown as provided in the Jacobs study, assuming shared parking principles and agreements are in effect.

Figure 6: Midtown - Conventional Shared Model Output by Zone (Weekday) and Projected Parking Needs

Distribution of Weekday Demand by Zone											
December											
2:00 PM	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Total
Retail - Customer	320	207	41	193	83	0	0	395	207	0	1,446
Retail - Employee	138	89	18	83	36	0	0	171	89	0	624
Super Regional Shopping Center - Customer	0	0	0	0	0	0	0	0	0	2,888	2,888
Super Regional Shopping Center - Employee	0	0	0	0	0	0	0	0	0	1,290	1,290
Restaurant - Customer	0	0	0	0	0	0	0	0	0	0	0
Restaurant - Employee	90	73	11	64	36	0	0	127	69	0	470
Hotel - Guest	0	0	0	0	0	136	0	0	146	115	397
Hotel - Employee	0	0	0	0	0	109	0	0	117	92	318
Residential Guest	6	22	42	21	65	30	7	33	9	0	235
Residential Reserved	433	1,725	3,300	1,695	5,130	2,379	516	2,625	750	0	18,553
Residential Unreserved	0	0	0	0	0	0	0	0	0	0	0
Office - Guest	382	122	0	92	0	59	337	85	510	255	1,842
Office - Employee	5,324	1,710	0	1,285	0	831	4,712	1,188	7,125	3,563	25,738
Subtotal Customer/Guest	708	351	83	306	148	225	344	513	872	3,258	6,808
Subtotal Employee/Resident	5,552	1,872	29	1,432	72	940	4,712	1,486	7,400	4,945	28,440
Subtotal Reserved Resident	433	1,725	3,300	1,695	5,130	2,379	516	2,625	750	0	18,553
Total Demand	6,693	3,948	3,412	3,433	5,350	3,544	5,572	4,624	9,022	8,203	53,801
Existing Supply to Remain (Estimate)	4,343	2,200	-	3,100	625	750	1,220	-	-	9,671	21,909
Surplus/(Deficit)	(2,350)	(1,748)	(3,412)	(333)	(4,725)	(2,794)	(4,352)	(4,624)	(9,022)	1,468	(31,892)

Source: Walker, 2019

Zone 10, which is the Galleria, is generally built out and has enough parking to support existing uses and planned changes to the Galleria. Zones 8/9, which involve complete redevelopment of the existing uses in them, would need to build new parking supplies. Other zones, with a mix of existing to remain and planned development fall in the middle and could benefit from increased utilization of existing parking assets with shared parking.

RECOMMENDED MODEL OUTPUT:

Figure 7 shows the results of the recommended shared parking model for the Midtown area. The output shown in this analysis is for the weekday as the large amount of office uses planned in Midtown result in a weekday daytime peak. Given the scale of office development, the Midtown development could likely support additional night and weekend uses, including special events at the park, utilizing office parking facilities during non-peak times with shared parking agreements.

Figure 7: Midtown – Recommended Shared Parking Model Output (Weekday)

Land Use	Base Demand	Month Adjustment December	Peak Hour Adjustment 2:00 PM	Non Captive Daytime	Drive Ratio Daytime	Demand December 2:00 PM
Retail - Customer	3,045	100%	100%	30%	85%	776
Retail - Employee	735	100%	100%	98%	50%	359
Super Regional Shopping Center - Customer	6,080	100%	100%	50%	85%	2,584
Super Regional Shopping Center - Employee	1,520	100%	100%	98%	50%	742
Restaurant - Customer	3,302	100%	90%	0%	85%	0
Restaurant - Employee	583	100%	95%	98%	50%	270
Hotel - Guest	1,496	67%	60%	100%	50%	301
Hotel - Employee	374	100%	100%	98%	50%	182
Residential Guest	1,237	100%	20%	100%	70%	173
Residential Reserved	9,277	100%	100%	100%	100%	9,277
Residential Unreserved	9,277	100%	70%	100%	100%	6,494
Office - Guest	2,167	100%	100%	75%	90%	1,463
Office - Employee	28,176	100%	100%	99%	70%	19,583
Subtotal Customer/Guest	17,327					5,297
Subtotal Employee/Resident	40,665					27,630
Subtotal Reserved Resident	9,277					9,277
Total Parking Spaces Required	**67,268**					**42,204**

Base Ratio - refers to parking demand assuming a suburban site where 100% of customers/ employees drive to the site and assuming that all uses provide parking separately.

Month Adjustment – takes into account the seasonal peak of each land use.

Peak Hour Adjustment – takes into account the hourly usage pattern of each land use.

Non-Captive – accounts for users already parked on site for another use (for example a guest at a hotel with a car patronizing a restaurant in the immediate vicinity while remaining parked at the hotel).

Drive Ratio – refers to the percentage of customers/employees projected to drive to the use, and accounts for carpooling and alternative modes of transportation.

Source: Walker, 2019

Compared to the conventional model, approximately 9,000+ fewer parking spaces are needed in the recommended model, an approximately 17% decrease.

Figure 8 shows the results of the recommended shared parking model by zone. Included in Figure 7 is an estimate of existing parking in each zone that will remain in place for the foreseeable future. The surplus/deficit line shows the additional parking supply that would be necessary to support the buildout of the conceptual plan for Midtown as provided in the Jacobs study, assuming shared parking principles and agreements are in effect.

Figure 8: Midtown – Recommended Shared Model Output by Zone (Weekday) and Projected Parking Needs

Distribution of Weekday Demand by Zone											
December											
2:00 PM	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Total
Retail - Customer	173	111	22	103	44	0	0	212	111	0	776
Retail - Employee	80	51	10	48	21	0	0	98	51	0	359
Super Regional Shopping Center - Customer	0	0	0	0	0	0	0	0	0	2,584	2,584
Super Regional Shopping Center - Employee	0	0	0	0	0	0	0	0	0	742	742
Restaurant - Customer	0	0	0	0	0	0	0	0	0	0	0
Restaurant - Employee	52	42	6	36	21	0	0	73	40	0	270
Hotel - Guest	0	0	0	0	0	103	0	0	111	87	301
Hotel - Employee	(1)	0	0	0	0	63	0	0	67	53	182
Residential Guest	4	16	31	16	48	22	5	24	7	0	173
Residential Reserved	215	863	1,650	848	2,565	1,190	258	1,313	375	0	9,277
Residential Unreserved	150	604	1,155	593	1,796	833	181	919	263	0	6,494
Office - Guest	302	97	0	73	0	47	268	68	405	203	1,463
Office - Employee	4,051	1,301	0	978	0	632	3,585	904	5,421	2,711	19,583
Subtotal Customer/Guest	479	224	53	192	92	172	273	304	634	2,874	5,297
Subtotal Employee/Resident	4,332	1,998	1,171	1,655	1,838	1,528	3,766	1,994	5,842	3,506	27,630
Subtotal Reserved Resident	215	863	1,650	848	2,565	1,190	258	1,313	375	0	9,277
Total Demand	5,026	3,085	2,874	2,695	4,495	2,890	4,297	3,611	6,851	6,380	42,204
Existing Supply to Remain (Estimate)	4,343	2,200	-	3,100	625	750	1,220	-	-	9,671	21,909
Surplus/(Deficit)	(683)	(885)	(2,874)	405	(3,870)	(2,140)	(3,077)	(3,611)	(6,851)	3,291	(20,295)

Source: Walker, 2019

Zone 10, which is the Galleria, is generally built out and would have a surplus of parking to share with the rest of Midtown in the recommended model. Given the proximity of two proposed ATS stops to the Galleria, this could be a source of parking for patrons looking to hop on the ATS to go to the park, who may then come back to the Galleria to dine or shop before departing. In the recommended model, Zone 4 also appears to have enough existing parking to remain to support the new development planned in the zone since the existing office building in Zone 4 would likely have excess capacity if recommended mode splits are achieved for office workers. Subject to shared parking agreements, the existing structure could provide parking for planned retail and multi-family and could be a hub for ATS parking given the proximity to an ATS stop.

While the shared parking model has been organized into the zones provided by Jacobs, it should be noted that the intent and structure of the shared parking model encourages the sharing of parking across zones as the zones may experience different periods of peak parking demand. For example, a zone dominated by office uses will experience peaks between 10:00 AM and 2:00 PM on weekdays, while zones with more retail, restaurant and entertainment uses will peak on weekends at lunchtime and dinnertime. An office-centric zone would utilize some of the parking in an entertainment-centric zone on weekdays, with the reverse occurring on weekends.

The per zone output is intended as a guide to help distribute parking assets throughout the study area so that most users experience a good level of service. Additionally, in the case of Dallas Midtown, the proposed ATS system affords additional flexibility in the location of the parking supply, as users can park near an ATS stop and utilize the system to get closer to their destination.

Appendix E

Dallas Midtown Vehicle Technology and Routing Preliminary Screening Memorandum
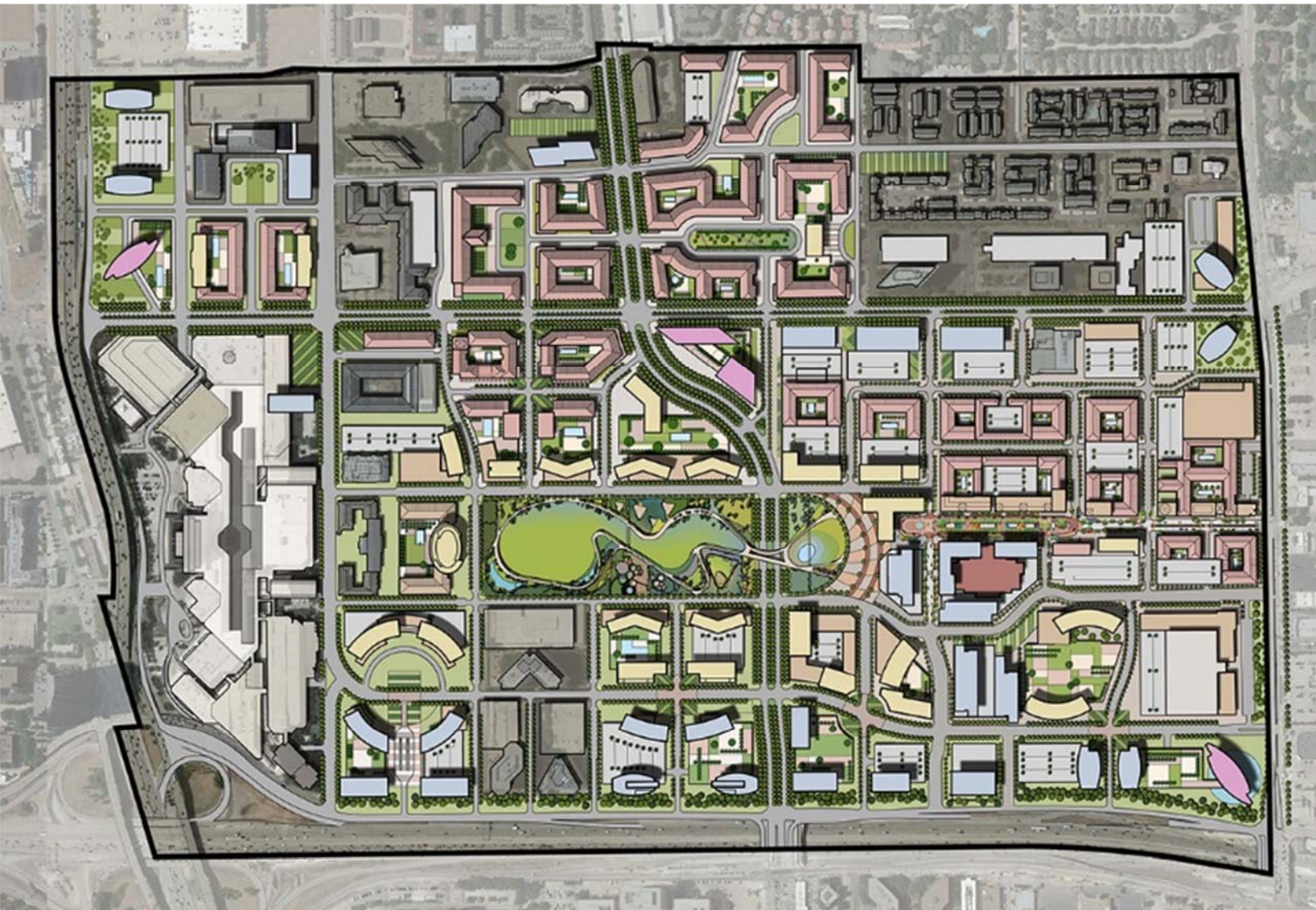
DALLAS MIDTOWN AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY
TECHNOLOGY ASSESSMENT

October 22, 2018

LEA ELLIOTT

TABLE OF CONTENTS

Executive Summary

The purpose of this Technology Assessment is to identify transit technology categories and assess their characteristics for applicability to improve mobility and provide access to local land uses in Dallas Midtown. In addition, along with connecting to other transit services, a Dallas Midtown Automated Transportation System (ATS) could enhance mobility in the area, improve regional connectivity, and support the North Central Texas Council of Government's (NCTCOG's) goal of providing a multimodal transportation network throughout the Dallas-Fort Worth region.

This Technology Assessment considers the following system characteristics in establishing the viability of specific technologies with regard to the application:

> *Performance*
> *Level of Service*
> *Urban Insertion Impact*
> *Cost*
> *Technical Maturity*

NCTCOG is interested in analyzing options pertaining to an ATS to provide access to local land uses and improve mobility in the Valley View – Galleria study area, known as Dallas Midtown. The study area is located in a unique location within the Dallas-Fort Worth Metroplex, as it is bordered by Southern Boulevard to the north, Preston Road to the east, and two of North Central Texas' most heavily traveled highways – IH 635 (LBJ) Freeway to the south and the Dallas North Tollway to the west, while encompassing the Galleria and former Valley View Mall developments (see Figure ES-1). This provides a premier location as a potential major employment center. A comprehensive vision for Midtown was established through a collaborative effort consisting of major land owners, developers, neighborhood groups, city staff, and technical experts. The vision reimagines the underperforming and obsolete Valley View Mall into a diverse, pedestrian and bicycle friendly, mixed-use development anchored around an 18-acre park where visitors are encouraged to park once and walk.

Figure ES-1 Dallas Midtown Area Map

Most of the technologies considered in this study operate on a fixed guideway which can be designed in varying operating configurations. The configuration of the guideway determines how the vehicles navigate it. Examples include single-lane shuttle, single-lane shuttle with bypass, dual-lane shuttle, dual-lane shuttle with bypass, single-lane loop, dual-lane loop, and pinched loop. Some technologies presented in this study do not require a fixed guideway and can operate in the same manner by utilizing a fixed route or they can navigate in a network configuration meaning they can travel anywhere in the system. The operating configuration also includes the vertical elevation, which falls under one of three categories: elevated, at-grade or underground.

Smart Vehicle / Dumb Guideway

A concept that has been proposed by NCTCOG is that of a "Smart Vehicle / Dumb Guideway." This concept has been made possible by developing technologies including improvements in batteries and guidance systems. The term refers to an automated transit system and its related guideway infrastructure that is different than the norm. Many automated transit systems have a dedicated, fixed guideway which contains numerous system components including, but not limited to, electric power rail, guide rail, train control equipment, communications cabling, electrical/mechanical switches, etc.

A Smart Vehicle / Dumb Guideway system would eliminate these components by utilizing on-board batteries, other guidance/navigation methods, radio communication and on-board switching. This has the potential to offer two benefits: 1.) potentially decrease the capital and O&M costs of the guideway infrastructure and 2.) allow the flexibility to permit shared use of the guideway for one or more system technologies initially or in the future. Several of the technologies presented in this report either already utilize this or are capable of utilizing this concept.

The following system characteristics are used to compare and evaluate technologies and will be used as evaluation criteria for the Technology Assessment. Each will be discussed in more detail in Section 4.

- Performance
  - Capacity (pphpd) / Ability to Meet Passenger Demand
  - Speed
  - Geometry / Configuration
  - Expandability
  - Operating Range
  - Failure Management / Availability

- Level of Service
  - Trip Times
  - Headways / Wait Times
  - Minimal Transfers
  - Safety

- Urban Insertion Impact
  - Acceptable Noise or Vibration Levels
  - Visually Acceptable Infrastructure
  - Impacts to Existing Infrastructure
  - Fixed Facilities Space Requirements
  - Constructability

- Cost
  - Capital Cost Comparison
  - O&M Cost Comparison

> Technology Maturity
>> o Service-Proven Technology
>> o Supply and Manufacturing Capability
>> o Operations & Maintenance Capability
>> o Commercial Considerations

Section 3 of this report reviews transit technologies that are potentially applicable to the project. While classifying transit technologies by categories can be challenging and subject to debate as there can be overlap between technology concepts, this report will present the technologies into these generally-accepted categories:

> Automated People Mover (APM)
> Monorail
> Cable-Propelled APM
> Gondolas / Aerial Tramways (G/AT)
> Personal Rapid Transit (PRT)
> Group Rapid Transit (GRT)
> Automated Vehicle Shuttles / Autonomous Vehicles (AV)
> Automated Vehicle Fleet (AF)

Several alignment options were developed for the various technology categories. However, for the Technology Assessment, one representative alignment was selected for the evaluation. Section 5 shows which alignment was considered for each technology during the evaluation. The entire collection of alignment options is located in Appendix 1.

A key part of the Dallas Midtown Automated Transportation System Conceptual Engineering Study has been the development of alternative alignments/routes that could interconnect with regional transit connections, for various automated transit technologies appropriate for the scale and needs of the Dallas Midtown development. As the needs for internal circulation and regional transit connections are significantly different, the primary focus has been for separate transit systems for the internal circulation component and the regional transit connections. However, the project team has also considered a combined regional connector/internal circulator that would utilize a common technology and shared guideway. Section 5.9 helps bring into focus several of the challenges that such a configuration would have including Ridership Differences, Synchronization Challenges, Impacts/Inefficiencies of ATS System, and Fixed Facilities Requirements and Wayfinding.

In Section 6, an evaluation matrix of the technologies presented was created to assess the ability of each technology to meet the criteria defined considering the alignments presented. Table ES-1 is a summary of the evaluation results presented in Section 6.

Table ES-1 Evaluation Matrix Summary

Evaluation Criteria	Automated People Mover (APM)	Monorail	Cable-Propelled APM	Gondolas	Aerial Tramways	Personal Rapid Transit (PRT)	Group Rapid Transit (GRT)	Automated Vehicle Shuttles / Autonomous Vehicles (AV)	Automated Vehicle Fleet (AF)
Performance	🟢	🟢	🔺	X	X	X	🔺	🔺	X
Level of Service	🟢	🟢	🟢	🔺	🟢	🟢	🟢	🔺	🟢
Urban Insertion Impact	🔺	🔺	🔺	🟢	🔺	🟢	🟢	🟢	🟢
Cost	🔺	🟥	🔺	🔺	🔺	🔺	🔺	🟢	🟢
Technology Maturity	🟢	🟢	🟢	🟢	🟢	🔺	🔺	🔺	🔺

🟢 - Candidate technology provides lower risk for evaluation criterion

🔺 - Candidate technology provides moderate risk for evaluation criterion

🟥 - Candidate technology provides higher risk for evaluation criterion

X - Candidate technology cannot meet evaluation criteria

The detailed Evaluation Matrix is shown in Section 6.1. Significant findings and differentiators identified in the Evaluation Matrix are discussed in Section 6.2.

From the general technology categories considered, the technology assessment has identified the applicable technology categories to be APM, Monorail, Cable-Propelled APM, Group Rapid Transit (GRT) and Automated Vehicle Shuttles / Autonomous Vehicles (AV). Representative suppliers of these technologies are as follows:

- ➢ Automated People Mover (APM)
  - o Aeromovel
  - o Bombardier INNOVIA APM 200/300
  - o IHI Niigata
  - o Mitsubishi Crystal Mover
  - o Schwager Davis (SDI) UniTrak
  - o Siemens Cityval
  - o Woojin K-AGT
- ➢ Monorail
  - o Bombardier INNOVIA Monorail 200/300
  - o Hitachi Standard
  - o Hitachi Small
  - o Scomi
- ➢ Cable-Propelled APM
  - o Doppelmayr Cable Car - Cable Liner Shuttle
  - o Leitner-Poma Mini Metro

- ➢ Group Rapid Transit (GRT)
  - o 2getthere
  - o Vectus
- ➢ Automated Vehicle Shuttle / Autonomous Vehicle (AV)
  - o Easy Mile EZ10
  - o Local Motors Olli
  - o NAVYA AUTONOM SHUTTLE (ARMA)

It is not recommended that a specific supplier be selected at this time based upon our evaluation, but rather, it is recommended that these technologies be carried forward into the Conceptual Design Analysis (Task 5).

Based upon input received during the Dallas Midtown Conceptual Design Analysis meeting held on September 7, 2018, the five applicable technology categories are consolidated into the following three technology groups for the Conceptual Design Analysis:

1. Automated People Mover/Monorail

2. Cable-Propelled APM

3. Group Rapid Transit/Automated Vehicle Shuttles

Technology Assessment

1.   Introduction

The purpose of this Technology Assessment is to identify transit technology categories and assess their characteristics for applicability to improve mobility and provide access to local land uses in Dallas Midtown. In addition, along with connecting to other transit services, a Dallas Midtown Automated Transportation System (ATS) could enhance mobility in the area, improve regional connectivity, and support the North Central Texas Council of Government's (NCTCOG's) goal of providing a multimodal transportation network throughout the Dallas-Fort Worth region.

This Technology Assessment considers the following system characteristics in establishing the viability of specific technologies with regard to the application:

- ➢ **Performance** and the adequacy or appropriateness of the capacity of the technology with regard to the current and potential future ridership requirements and the ability to meet the geometric constraints of the project site.
- ➢ **Level of Service** provided by the technology which contributes to the passenger experience.
- ➢ **Urban Insertion Impact** of the technology in terms of impacts to the existing or planned infrastructure and ability to utilize the existing available space.
- ➢ **Cost** of the technology in terms of high-level capital and operations and maintenance (O&M) cost comparisons.
- ➢ **Technical Maturity** of the technology in terms of whether it is service-proven, has sufficient manufacturing capability and other commercial considerations.

2.   Project Background and Requirements

2.1   Project Study Area

NCTCOG is interested in analyzing options pertaining to an ATS to provide access to local land uses and improve mobility in the Valley View – Galleria study area, known as Dallas Midtown. The study area is located in a unique location within the Dallas-Fort Worth Metroplex, as it is bordered by Southern Boulevard to the north, Preston Road to the east, and two of North Central Texas' most heavily traveled highways – IH 635 (LBJ) Freeway to the south and the Dallas North Tollway to the west, while encompassing the Galleria and former Valley View Mall developments (see Figure 2.1-1). This provides a premier location as a potential major employment center. A comprehensive vision for Midtown was established through a collaborative effort consisting of major land owners, developers, neighborhood groups, city staff, and technical experts. The vision reimagines the underperforming and obsolete Valley View Mall into a diverse, pedestrian and bicycle friendly, mixed-use development anchored around an 18-acre park where visitors are encouraged to park once and walk.
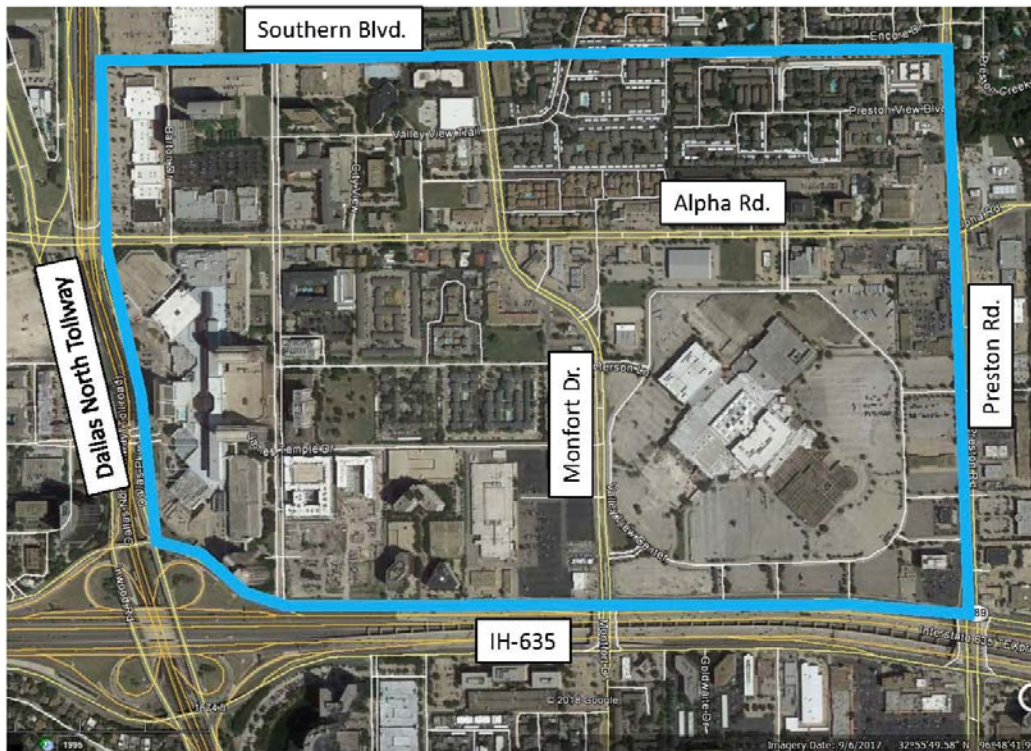
Figure 2.1-1 Dallas Midtown Area Map

2.2   System Alignment/Configuration

Most of the technologies considered in this study operate on a fixed guideway which can be designed in varying operating configurations. The configuration of the guideway determines how the vehicles navigate it. Examples include single-lane shuttle, single-lane shuttle with bypass, dual-lane shuttle, dual-lane shuttle with bypass, single-lane loop, dual-lane loop, and pinched loop. Figure 2.2-1 illustrates the different types of operating configurations. Some technologies presented in this study do not require a fixed guideway and can operate in the same manner by utilizing a fixed route or they can navigate in a network configuration meaning they can travel anywhere in the system (Figure 2.2-2). The operating configuration also includes the vertical elevation, which falls under one of three categories: elevated, at-grade or underground.
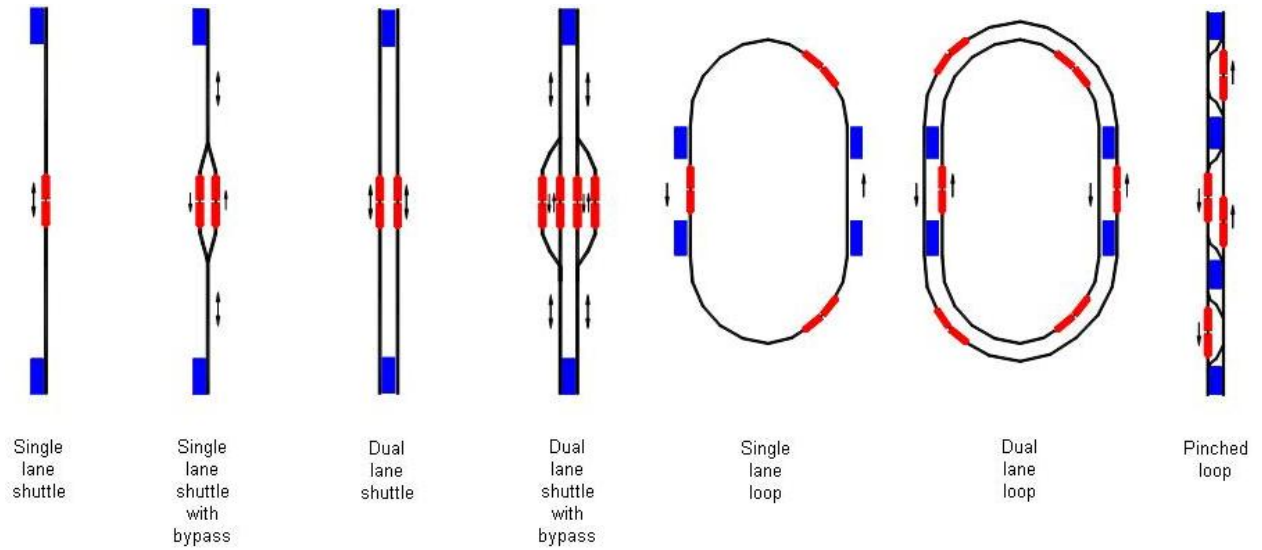
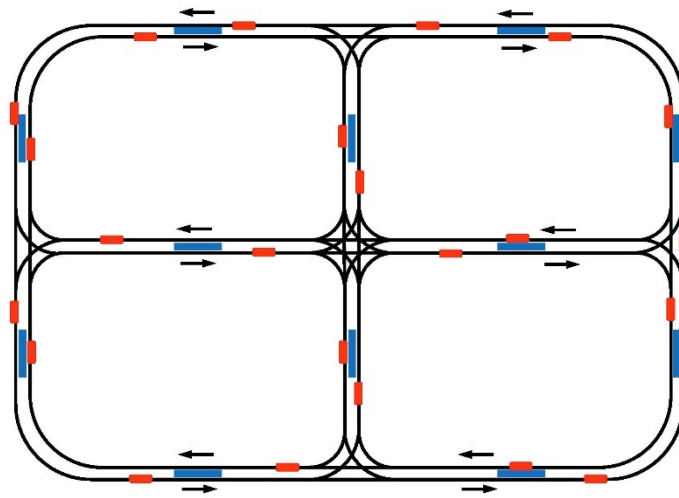**Figure 2.2-1 Types of Operating Configurations**

Figure 2.2-2 Example of a Network Configuration

<u>Smart Vehicle / Dumb Guideway</u>

A concept that has been proposed by NCTCOG is that of a "Smart Vehicle / Dumb Guideway." This concept has been made possible by developing technologies including improvements in batteries and guidance systems. The term refers to an automated transit system and its related guideway infrastructure that is different than the norm. Many automated transit systems have a dedicated, fixed guideway which contains numerous system components including, but not limited to, electric power rail, guide rail, train control equipment, communications cabling, electrical/mechanical switches, etc.

A Smart Vehicle / Dumb Guideway system would eliminate these components by utilizing on-board batteries, other guidance/navigation methods, radio communication and on-board switching. This has the potential to offer two benefits: 1.) potentially decrease the capital and O&M costs of the guideway infrastructure and 2.) allow the flexibility to permit shared use of the guideway for one or more system technologies initially or in the future. Several of the technologies presented in this report either already utilize this or are capable of utilizing this concept.

2.3   System Characteristics

The following system characteristics are used to compare and evaluate technologies and will be used as evaluation criteria for the Technology Assessment. Each will be discussed in more detail in Section 4.

- ➢ Performance
    - o Capacity (pphpd) / Ability to Meet Passenger Demand
    - o Speed
    - o Geometry / Configuration
    - o Expandability
    - o Operating Range
    - o Failure Management / Availability

- ➢ Level of Service
    - o Trip Times
    - o Headways / Wait Times
    - o Minimal Transfers
    - o Safety

- ➢ Urban Insertion Impact
    - o Acceptable Noise or Vibration Levels
    - o Visually Acceptable Infrastructure
    - o Impacts to Existing Infrastructure
    - o Fixed Facilities Space Requirements
    - o Constructability

- ➢ Cost
    - o Capital Cost Comparison
    - o O&M Cost Comparison

- ➢ Technology Maturity
    - o Service-Proven Technology
    - o Supply and Manufacturing Capability
    - o Operations & Maintenance Capability
    - o Commercial Considerations

3. Technology Identification and Representative Technology Suppliers

This report reviews transit technologies that are potentially applicable to the project. While classifying transit technologies by categories can be challenging and subject to debate as there can be overlap between technology concepts, this report will present the technologies into these generally-accepted categories:

- Automated People Mover (APM)
- Monorail
- Cable-Propelled APM
- Gondolas / Aerial Tramways (G/AT)
- Personal Rapid Transit (PRT)
- Group Rapid Transit (GRT)
- Automated Vehicle Shuttles / Autonomous Vehicles (AV)
- Automated Vehicle Fleet (AF)

3.1 Automated People Mover (APM)

Technologies that are within the APM category can be differentiated by the suspension and propulsion methods used. Most vehicles are supported by the guideway on which they travel using rubber tires, steel wheels, pressurized air or magnetic levitation. The means of propulsion can be divided between those that are self-propelled with on-board electric motors, cable-propelled by a continuous cable along the guideway, guideway-propelled using Linear Induction Motors (LIMs) or pneumatically-propelled using pressurized air in the guideway.

APMs are distinguished by their ability to be operated fully automated without drivers. Automatic operation requires an exclusive right of way. Examples of how guidance can be provided are by horizontally-mounted guide wheels that track side-mounted guide rails, guideway-mounted center guidebeam, the guidebeam itself, guideway-mounted center guide rail or traditional rails. Non-mechanical guidance is also in development by many of the APM suppliers. The guideway of the APM system refers to the track or other running surface (including supporting structure) that supports, powers, contains, and physically guides APM vehicles designed to travel exclusively on it. APMs require a separate and exclusive guideway that can be elevated, at-grade (fenced or otherwise protected) or in tunnels. Electric power is supplied via a "third rail" on the guideway at 480 or 600 VAC; or 600, 750, or 1500 VDC. Headways can be as low as 90 seconds but are typically between two and five minutes.

The primary application of APMs has been at major activity centers, such as airports and city centers, but there are also numerous urban transit APM systems. Automatic, driverless control permits more cost-effective operations on short headways to minimize waiting time for passengers. APMs feature level boarding and operate under strict ride comfort parameters, permitting most passengers to stand, thereby increasing passenger carrying efficiency to moderately high levels. The vehicles typically have two door sets on each side that allow all passengers, including the mobility impaired in wheelchairs, to board. System designs are proprietary and are not interchangeable with other APM technologies, except in rare instances discussed later in this section.

3.1.1   Aeromovel

Website: http://www.aeromovel.com/

The Aeromovel A-100 (1-car vehicle) is a pneumatically-propelled transit system propelled by air pressure. A "sail" attached beneath the passive vehicle through a slot in the guideway moves through the hollow void in the guideway. Power Propulsion Units (PPUs) spaced along the guideway generate air thrust to move the sail and the vehicle with positive and negative pressure. This is accomplished at a relatively low PSI. The vehicles are supported and guided by steel wheels on steel rails on a dedicated guideway. Train consists range from 1-4 cars and can be separate vehicles coupled together or semi-permanently coupled with a walk-through design. This technology is provided by just one supplier. An example of a commercially available pneumatically-propelled APM is shown below.

Table 3.1.1-1 Aeromovel A-100/A-200 Vehicle Specifications

Aeromovel A-100/A-200 vehicle specifications	Value
Vehicle length	A-100: 43.45 ft. A-200 (walk-through): 81.04 ft.
Vehicle width	8.64 ft.
Vehicle height	10.92 ft.
Vehicle weight (unloaded)	A-100: 20,357 lb. A-200 (walk-through): 35,274 lb.
Vehicle capacity (@ 4pax/m^2 or 2.7 sf/pax)	A-100: 97 A-200: 183
Vehicle door opening (clear width)	6.07 ft.
Maximum speed	50 mph (design), 37.3 mph (typical)
Minimum horizontal curve radius	65.2 ft. (88.6 ft. at switch)

Figure 3.1.1-1 Aeromovel A-100, Porto Alegre Airport, Porto Alegre, Brazil (Image: Aeromovel)

Figure 3.1.1-2 Aeromovel A-200 (walk-through), Porto Alegre Airport, Porto Alegre, Brazil (Image: Aeromovel)

Figure 3.1.1-3 Aeromovel A-200 (walk-through) vehicle interior, Porto Alegre Airport, Porto Alegre, Brazil (Image: Aeromovel)

3.1.2   Bombardier

Website: https://www.bombardier.com/en/transportation/products-services/rail-vehicles/automated-people-movers.html

Bombardier Transportation, headquartered in Germany, is a division of Bombardier, Inc., a Canadian firm. They have implemented over 30 APMs around the world of varying models. The most recent version of their self-propelled, rubber-tired APM is the INNOVIA APM 200 and the INNOVIA APM 300. These two models are very similar. The INNOVIA APM 300 offers increased passenger capacity, higher top speed and an aluminum car body.

Both systems are guided by a center guidebeam, utilize on-board rotary electric motors and can operate as trains of 1- to 6-vehicles. Power is supplied via a "third rail" on the guideway and they operate fully automated without drivers. Both systems can be paired with Bombardier's communication-based train control, CITYFLO 650.

Bombardier has three implementations of the INNOVIA APM 200 at the Dallas/Fort Worth Airport and the Phoenix Airport in the USA and London Heathrow Airport in the UK. There are two recent implementations of the INNOVIA APM 300 at the Munich Airport in Germany and the Dubai Airport in the UAE and one underway at the King Abdulaziz International Airport in Jeddah, Saudi Arabia. Examples of system implementations of the INNOVIA APM 200/300 are provided below.

Table 3.1.2-1 Bombardier INNOVIA APM 200/300 Vehicle Specifications

Bombardier INNOVIA APM 200/300 vehicle specifications	Value
Vehicle length	39.2 – 41.8 ft.
Vehicle width	9.4 ft.
Vehicle height	11.1 ft.
Vehicle weight (unloaded)	31,967 – 34,172 lb.
Vehicle capacity (@ 4pax/m^2 or 2.7 sf/pax)	100 – 103
Vehicle door opening (clear width)	6.2 – 6.5 ft.
Maximum speed	37 – 50 mph
Minimum horizontal curve radius	72.2 ft.

Figure 3.1.2-1 Bombardier INNOVIA APM 200, Dallas/Fort Worth Airport, TX, USA (Image: DFW Airport)
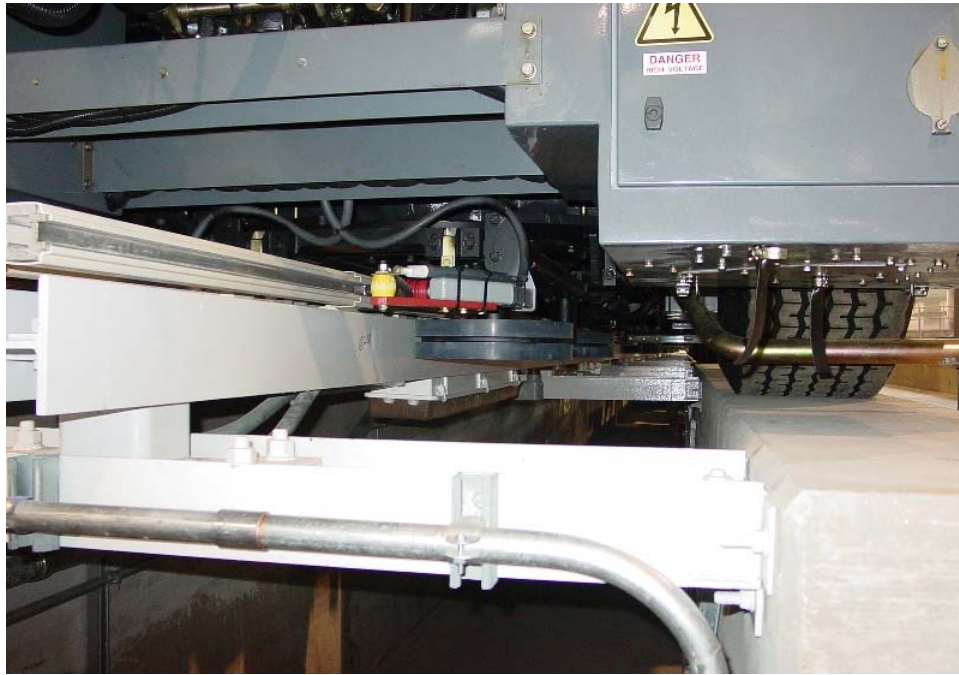

Figure 3.1.2-2 Bombardier INNOVIA APM 200, Phoenix Airport, AZ, USA (Image: City of Phoenix)

Figure 3.1.1-3 Bombardier INNOVIA APM 300, Munich Airport, Germany (Image: Bombardier)

Figure 3.1.2-4 Bombardier INNOVIA APM 200 vehicle interior, Dallas/Fort Worth Airport, USA

**Figure 3.1.2-5 Bombardier INNOVIA APM 200 guidance system, Dallas/Fort Worth Airport, TX, USA
(Image: Lea+Elliott)**

3.1.3   IHI Niigata

Website: https://www.ihi.co.jp/en/products/infrastructure_offshore/transportation_systems/

http://www.niigata-transys.com/en/products.html

Ishikawajima-Harima Heavy industries Co., Ltd. (IHI), headquartered in Japan, acquired the Niigata Engineering Co. Ltd. In 2003 and established the Niigata Transys Co., Ltd. (NTS). They have implemented over a dozen self-propelled, rubber-tired APMs either completed or under contract. The most recent version of their self-propelled, rubber-tired APM is the iMax. The iMax is guided by side-mounted guide wheels running against guideway wall-mounted guide rails. It utilizes on-board rotary electric motors. Power is supplied via a "third rail" on the guideway and it operates fully automated without drivers.

IHI Niigata has implemented airport APM systems in Kansai, Japan; Taipei, Taiwan; and Hong Kong. This technology is based on the Japanese Standard technology and therefore, in certain applications, can co-exist in fleets with other similar models (e.g. Mitsubishi Crystal Mover and Woojin K-AGT). Sometimes these mixed fleets can couple together while other times they must operate as separate trains on the same system. Examples of system implementations of the IHI Niigata APM system are provided below.

Table 3.1.3-1 IHI Niigata APM Vehicle Specifications

IHI Niigata APM vehicle specifications	Value
Vehicle length	39.4 ft.
Vehicle width	9.4 ft.
Vehicle height	12.1 ft.
Vehicle weight (unloaded)	32,630 lb.
Vehicle capacity (@ 4pax/m^2 or 2.7 sf/pax)	~102
Vehicle door opening (clear width)	6.9 ft.
Maximum speed	43 mph
Minimum horizontal curve radius	98.4 ft.

Figure 3.1.3-1 IHI Niigata vehicle, Hong Kong Airport, HK

Figure 3.1.3-2 IHI Niigata iMax vehicle on test track (Image: IHI Niigata)

Figure 3.1.3-3 IHI Niigata vehicle interior (Image: IHI Niigata)

3.1.4 Mitsubishi Heavy Industries (MHI)

Website: http://www.mhi.com/products/transport/automated_people_mover.html

Mitsubishi Heavy Industries, Ltd., headquartered in Japan, has implemented over a dozen self-propelled, rubber-tired APMs around the world of varying models. The most recent version of their self-propelled, rubber-tired APM is the Crystal Mover. The Crystal Mover is guided by side-mounted guide wheels running against guideway wall-mounted guide rails. It utilizes on-board rotary electric motors and can operate in trains of 1- to 6-vehicles. Power is supplied via a "third rail" on the guideway and it operates fully automated without drivers.

Mitsubishi has recent implementations of the Crystal Mover at the Tampa, Orlando and Dubai airports. This technology is based on the Japanese Standard technology and therefore, in certain applications, can co-exist in fleets with other similar models (e.g. IHI Niigata and Woojin K-AGT). Sometimes these mixed fleets can couple together while other times they must operate as separate trains on the same system. Examples of system implementations of the Crystal Mover are provided below.

Table 3.1.4-1 Mitsubishi Crystal Mover Vehicle Specifications

Mitsubishi Crystal Mover vehicle specifications	Value
Vehicle length	37.6 ft.
Vehicle width	8.9 ft.
Vehicle height	12.1 ft.
Vehicle weight (unloaded)	31,967 lb.
Vehicle capacity	105
Vehicle door opening (clear width)	6 ft.
Maximum speed	50 mph
Minimum horizontal curve radius	98.4 ft.

Figure 3.1.4-1 Mitsubishi Crystal Mover, Atlanta Airport, GA USA (Image: Lea+Elliott)

Figure 3.1.4-2 Mitsubishi Crystal Mover, Miami Airport, FL USA (Image: Lea+Elliott)

Figure 3.1.4-3 Mitsubishi Crystal Mover, Washington Dulles Airport, VA USA (Image: Lea+Elliott)

Figure 3.1.4-4 Mitsubishi Crystal Mover vehicle interior, Atlanta Airport, GA, USA (Image: Lea+Elliott)

Figure 3.1.4-5 Mitsubishi Crystal Mover vehicle interior with urban seating application, Singapore (Image: Mitsubishi)

Figure 3.1.4-6 Mitsubishi Crystal Mover guidance system, Atlanta Airport, GA USA (Image: Lea+Elliott)

3.1.5   Schwager Davis Inc. (SDI)

Website: https://www.schwagerdavis.com/divisions/transit/

A general contractor and technology supplier with over two decades of experience, SDI is a turnkey contractor in new system design, construction and installation including system alignment, utility relocation, foundations, elevated cast in place or precast super structures, station construction, electrical power feed, distribution and control system as well as the rolling stock.

SDI implemented a 1.4 mi. fully-automated, fully-elevated transit system for Indiana University Health (formerly Clarian Health Partners, Inc.) and the City of Indianapolis. The UniTrak vehicle installed at IU Health is classified as a small APM. Each car of the 3-car train accommodates 8 seated and 19 standing passengers for a total capacity of 27 passengers per car. Each car is fully air-conditioned and has a single 4.9 ft. wide bi-parting door for station loading. The vehicles utilize rotary electric motors and run on rubber tires with horizontally mounted rubber guide wheels. The trains operate in 3-car consists.

SDI has identified itself as a transit supplier with the creativity and willingness to adapt its transit products to the project-specific needs of Owners. Vehicle specifications are shown in the table below.

Table 3.1.5-1 Schwager Davis UniTrak Car Specifications

Schwager Davis UniTrak car specifications	Value
Vehicle length	22 ft.
Vehicle width	7.9 ft.
Vehicle height	9.8 ft.
Vehicle weight (unloaded)	15,000 lb.
Vehicle capacity	27 per car
Vehicle door opening (clear width)	4.9 ft.
Maximum speed	28 mph
Minimum horizontal curve radius	100 ft.

Figure 3.1.5-1 Schwager Davis UniTrak, IU Health, Indianapolis, IN USA (Image: SDI)

Figure 3.1.5-2 Schwager Davis UniTrak vehicle at IU Health, USA (Image: SDI)

Figure 3.1.5-3 Schwager Davis UniTrak vehicle interior (Image: SDI)

Figure 3.1.5-4 Schwager Davis UniTrak guidance system (Image: SDI)

3.1.6   Siemens

Website: https://www.siemens.com/global/en/home/products/mobility/rail-solutions/rolling-stock/val-systems.html

Siemens AG, headquartered in Germany, has implemented numerous self-propelled, rubber-tired APMs around the world of varying models. The most recent version of their self-propelled, rubber-tired APM is the Neoval. The Neoval is available in two models – Airval and Cityval. The Airval is configured for airport applications with floor to ceiling windows and less seating. The Cityval is configured for urban applications with half height windows and more seating. Neoval is guided by center-mounted, "vee"-shaped guide wheels gripping a single, flush guiderail in the guideway. This guidance system was developed in conjunction with Lohr Industrie, a French firm, who has deployed it successfully on their Translohr guided trams. Neoval utilizes on-board rotary electric motors and can operate in trains of 1- to 6-vehicles. Power is supplied via a "third rail" on the guideway and it operates fully automated without drivers.

Examples of a test track implementation of the Neoval are provided below. Siemens has reported that it is implementing the first Cityval system in Rennes, France which is scheduled to open in 2018 and an Airval system at the Frankfurt Airport which is scheduled to open in 2023.

Table 3.1.6-1 Siemens Neoval Vehicle Specifications

Siemens Neoval vehicle specifications	Value
Vehicle length	36.7 ft.
Vehicle width	9.2 ft.
Vehicle height	11.8 ft.
Vehicle weight (unloaded)	35,274 lb.
Vehicle capacity (@ 4 pax/m^2 or 2.7 sf/pax)	~103 (est.)
Vehicle door opening (clear width)	6.4 ft.
Maximum speed	50 mph
Minimum horizontal curve radius	98.4 ft.

Figure 3.1.6-1 Siemens Airval on test track (Image: Siemens)

Figure 3.1.6-2 Siemens Airval on exhibit (Image: Laurent Charlier)

Figure 3.1.6-3 Siemens Airval vehicle interior on exhibit (Image: Laurent Charlier)

Figure 3.1.6-4 Siemens Airval guidance system on exhibit (Image: Laurent Charlier)

3.1.7   Woojin Industrial Systems Co., Ltd.

Website: http://wjis.co.kr/eng/

http://www.wjisamerica.com/

Woojin Industrial Systems Co., Ltd., headquartered in the Republic of Korea, has implemented two self-propelled, rubber-tired APMs in Korea, one in Indonesia and another two systems have been announced. Their self-propelled, rubber-tired APM is called the K-AGT (Korean Automated Guideway Transit). The K-AGT is available in two models – Standard and Advanced. The Standard system is intended for urban settings while the Advanced system is for airport settings. The K-AGT is guided by side-mounted guide wheels running against guideway wall-mounted guide rails. It utilizes on-board rotary electric motors and can operate in trains of 1- to 6-vehicles. Power is supplied via a "third rail" on the guideway and it operates fully automated without drivers.

Woojin has implemented an expansion of the APM system at Incheon Airport in the Republic of Korea and a new system at the Jakarta Airport in Indonesia. This technology is based on the Japanese Standard technology and therefore, in certain applications, can co-exist in fleets with other similar models (e.g. IHI Niigata and Mitsubishi Crystal Mover). Sometimes these mixed fleets can couple together while other times they must operate as separate trains on the same system. Examples of system implementations of the K-AGT are provided below.

Table 3.1.7-1 Woojin K-AGT Vehicle Specifications

Woojin K-AGT vehicle specifications	Value
Vehicle length	36.7 ft.
Vehicle width	8.8 ft.
Vehicle height	12.2 ft.
Vehicle weight (unloaded)	35,000 lb.
Vehicle capacity (@ 4 pax/m^2 or 2.7 sf/pax)	87
Vehicle door opening (clear width)	~6 ft.
Maximum speed	50 mph
Minimum horizontal curve radius	98.4 ft.

Figure 3.1.7-1 Woojin Advanced K-AGT on exhibit at INNOTRANS (Image: INNOTRANS)

Figure 3.1.7-2 Woojin Advanced K-AGT, Jakarta Airport, Indonesia (Image: Jakarta Post)

Figure 3.1.7-3 Woojin Standard K-AGT, Busan, Republic of Korea (Image: Wikipedia)

3.2   Monorail

While monorail technology is considered a member of the APM technology category, for the purpose of this study it will initially be considered as its own category due to the unique nature of the guideway that is utilized. Monorails can be considered a rail-based transportation system however the rail in this case is a concrete or steel beam which the monorail vehicle "straddles." Monorails that straddle the top of the guidebeam are typically supported by rubber tires. However, suspended monorail technology hangs under the guideway as the name implies. Monorails are self-propelled with on-board electric motors. All other APM characteristics mentioned in Section 3.1 also apply to monorails including stations and guideways.

Monorails offer high speed, high capacity, fully automated transportation with a major feature being the minimal guideway requirement of only the beam(s) elevated on single piers above the roads or streets. The beams are precast offsite using purpose designed forms that maintain the quality and the consistency of the shape and finish.

A description of the Bombardier, Hitachi and Scomi monorail technologies and sample installations are discussed in the following sections. Those monorails that are noted as manually-operated could be offered as fully automated.

3.2.1 Bombardier

Website: https://www.bombardier.com/en/transportation/products-services/rail-vehicles/automated-monorails.html

Bombardier Transportation, headquartered in Germany, is a division of Bombardier, Inc., a Canadian firm. They have implemented four monorails in the USA of varying models with two additional installations underway. The most recent version of their self-propelled, rubber-tired monorail is the INNOVIA Monorail 200 and the INNOVIA Monorail 300. These two models are very similar. However, the INNOVIA Monorail 300 offers walk through capability between cars.

Both systems are supported and guided by a single concrete guidebeam, utilize on-board rotary electric motors and can operate as trains of 2- to 8-cars. Power is supplied via a "third rail" on the guidebeam and they operate fully automated without drivers. Both systems can be paired with Bombardier's communication-based train control, CITYFLO 650.

Currently Bombardier has one INNOVIA Monorail 200 operating in Las Vegas. Bombardier has two implementations of the INNOVIA Monorail 300 underway – one at the King Abdullah Financial District in Riyadh, Kingdom of Saudi Arabia and the other in São Paulo, Brazil (Phase 1 opened in 2014). Examples of a system implementation of the INNOVIA Monorail 200 are provided below.

Table 3.2.1-1 Bombardier INNOVIA Monorail 300 car specifications

Bombardier INNOVIA Monorail 300 car specifications	Value
Vehicle length	38.7 – 44 ft.
Vehicle width	10.3 ft.
Vehicle height	13.5 ft.
Vehicle weight (unloaded)	29,983 lb. per car (average)
Vehicle capacity (@ 4 pax/m^2 or 2.7 sf/pax)	86-95 per car
Vehicle door opening (clear width)	5.2 ft.
Vehicle range	Unlimited (guideway has continuous power rail)
Maximum speed	50 mph
Minimum horizontal curve radius	150.9 ft.

Figure 3.2.1-1 Bombardier INNOVIA Monorail 200, Las Vegas, NV USA (Image: Bombardier)

Figure 3.2.1-2 Bombardier INNOVIA Monorail 300, Sao Paulo, Brazil (Image: Bombardier)

Figure 3.2.1-3 Bombardier INNOVIA Monorail 300 vehicle interior (Image: Bombardier)
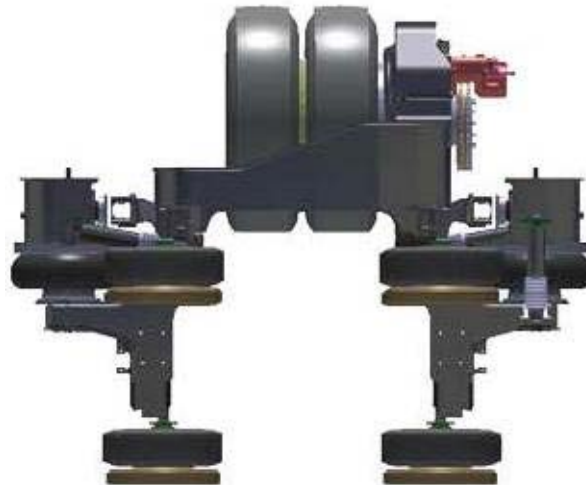
Figure 3.2.1-4 Bombardier INNOVIA Monorail 300 guidance system (Image: Bombardier)

3.2.2   Hitachi

Website: http://www.hitachi-rail.com/products/rolling_stock/monorail/index.html

Hitachi, Ltd., headquartered in Japan, has implemented a dozen self-propelled, rubber-tired monorails around the world of varying models (nine are still in operation). The models are categorized as Small, Standard and Large (the large model is not presented here as the scale of the system is inappropriate for this study). Car specifications of the Small and Standard models can be found in Table 5 below.

All systems are self-propelled and rubber-tired.   These systems are supported and guided by a single concrete guidebeam, utilize on-board rotary electric motors and can operate as trains of 2- to 6-cars. Power is supplied via a "third rail" on the guidebeam and they can be operated fully automated without drivers or manually-operated with drivers. Hitachi currently has no monorail systems operating in North America, but has several operating in Japan, South Korea, China, Malaysia, and UAE.

3.2.2.1   Hitachi Standard Monorail

The Hitachi Standard Monorail is the medium-sized monorail in the Hitachi monorail product line and has been implemented as both fully-automated and manually-operated. Hitachi has Standard Monorails operating in Tokyo, Okinawa, Dubai, and in South Korea. Examples of system implementations of the Hitachi Standard Monorail are provided below.

Table 3.2.2.1-1 Hitachi Standard Monorail car specifications

Hitachi Standard Monorail car specifications	Value
Vehicle length	48.2 ft.
Vehicle width	9.8 ft.
Vehicle height	16.7 ft.
Vehicle weight (unloaded)	52,600 – 55,000 lb. per car
Vehicle capacity	82 per car
Vehicle door opening (clear width)	3.6 ft.
Vehicle range	Unlimited (guideway has continuous power rail)
Maximum speed	37 mph
Minimum horizontal curve radius	229.7 ft.

Figure 3.2.2.1-1 Hitachi Palm Jumeirah Monorail, Dubai, UAE, Fully-automated without driver (Image: Hitachi)

Figure 3.2.2.1-2 Hitachi Okinawa Monorail, Naha, Japan (Manually-operated with driver)

Figure 3.2.2.1-3 Hitachi Okinawa Monorail vehicle interior (Image: Hitachi / The Monorail Society)

Figure 3.2.2.1-4 Hitachi Standard Monorail guidance system (Image: Hitachi / The Monorail Society)

3.2.2.2   Hitachi Small Monorail

The Hitachi Small Monorail has been implemented as a manually-operated system. This technology could also be implemented as a fully-automated driverless system. Hitachi claims that the Small Monorail capital cost is 50% less than a large-type monorail. Hitachi operates one of these systems in Singapore harbor. An example of this system implementation of the Hitachi Small Monorail is provided below.

Table 3.2.2.2-1 Hitachi Small Monorail car specifications

Hitachi Small Monorail car specifications	Value
Vehicle length	24.9 - 32 ft.
Vehicle width	8.2 ft.
Vehicle height	15.3 ft.
Vehicle weight (unloaded)	28,200 - 37,800 lb.
Vehicle capacity	43 - 49 per car
Vehicle door opening (clear width)	4.6 ft.
Vehicle range	Unlimited (guideway has continuous power rail)
Maximum speed	37.5 mph
Minimum horizontal curve radius	147.6 ft.

Figure 3.2.2.2-1 Hitachi Sentosa Express Monorail, Sentosa, Singapore (Manually-operated with driver)

Figure 3.2.2.2-2 Hitachi Sentosa Express Monorail, Sentosa, Singapore (Manually-operated with driver)

Figure 3.2.2.2-3 Hitachi Sentosa Express vehicle interior, Sentosa, Singapore (Manually-operated with driver)

3.2.3   Scomi

Website: http://www.scomiengineering.com.my/

Scomi Rail Bhd, headquartered in Malaysia, is a division of Scomi Group Bhd. Their self-propelled, rubber-tired monorail is the SUTRA (Scomi Urban Transit Rail Application). The system is supported and guided by a single concrete guidebeam, utilizes on-board rotary electric motors and can operate as trains of 2- or 4-cars. Power is supplied via a "third rail" on the guidebeam and they are manually-operated with a driver. Scomi claims that automatic train operation equipment can be installed.

Scomi has two implementations of the SUTRA – one in Kuala Lumpur, Malaysia and the other in Mumbai, India – and another implementation underway in São Paulo, Brazil. An example of a system implementation of the Scomi SUTRA Monorail is provided below.

Table 3.2.3-1 Scomi SUTRA Monorail car specifications

Scomi SUTRA Monorail car specifications	Value
Vehicle length	35.6 – 38.9 ft.
Vehicle width	10.1 ft.
Vehicle height	15.5 ft.
Vehicle weight (unloaded)	33,069 lb. per car (average)
Vehicle capacity (@ 4 pax/m^2 or 2.7 sf/pax)	79-90 per car
Vehicle door opening (clear width)	3.3 ft.
Vehicle range	Unlimited (guideway has continuous power rail)
Maximum speed	50 mph
Minimum horizontal curve radius	164 ft.

Figure 3.2.3-1 Scomi SUTRA Mumbai Monorail, India, Manually-operated with driver (Image: Scomi)

Figure 3.2.3-2 Scomi SUTRA Mumbai Monorail, India, Manually-operated with driver (Image: Scomi)

Figure 3.2.3-3 Scomi SUTRA Monorail vehicle interior, Manually-operated with driver (Image: Scomi/NST)

Figure 3.2.3-4 Scomi SUTRA Monorail guidance system (Image: Scomi)

3.3 Cable-Propelled APM

While cable-propelled APMs are also considered a member of the APM technology category, for the purpose of this study it will be considered as its own category due to their unique propulsion.

Guideway-based cable-propelled APMs are supported by wheels (rubber or steel) or pressurized air on a dedicated guideway. The vehicles are propelled by gripping (either permanently or detachable) a moving cable traveling between stations. The vehicles are passive, and propulsion is provided by the cable drive wheel(s). They can be operated fully automated without drivers. Automatic operation requires an exclusive right of way. All other APM characteristics mentioned previously in Section 3.1 also apply to cable-propelled systems including stations and guideways.

A description of the Doppelmayr and Leitner-Poma guideway-based and aerial-based cable technologies and sample installations are discussed in the following sections.

3.3.1 Doppelmayr Cable Car (DCC)

Website: https://www.dcc.at/

DCC Doppelmayr Cable Car GmbH & Co, headquartered in Austria, is a subsidiary of the Doppelmayr/Garaventa Group. They have implemented ten APMs around the world with a new implementation announced at London's Luton Airport. The Cable Liner Shuttle is rubber-tired with horizontal guide wheels riding inside a steel guideway. The system is cable-propelled and can operate as trains of 1- to 8-vehicles. They operate fully automated without drivers.

DCC has two recent implementations of the Cable Liner Shuttle – one connecting the Oakland International Airport to the regional Bay Area Rapid Transit (BART) rail system and the other at the new Hamad International Airport in Doha, Qatar. Examples of system implementations of the Cable Liner Shuttle are provided below.

Table 3.3.1-1 Doppelmayr Cable Car (DCC) Cable Liner Shuttle Vehicle Specifications

Doppelmayr Cable Car (DCC) Cable Liner Shuttle vehicle specifications	Value
Vehicle length (1 car)	19.7 ft.
Vehicle width	9.8 ft.
Vehicle height	11.3 ft.
Vehicle weight (unloaded)	11,023 lb.
Vehicle capacity (1 car @ 4pax/m^2 or 2.7 sf/pax)	56
Vehicle door opening (clear width)	7.5 ft.
Maximum speed	31 mph
Minimum horizontal curve radius	164 ft.

Figure 3.3.1-1 Doppelmayr Cable Liner Shuttle, CityCenter, Las Vegas, NV USA (Image: Lea+Elliott)

Figure 3.3.1-2 Doppelmayr Cable Liner Shuttle, BART TO OAK, Oakland, CA USA (Image: Lea+Elliott)

Figure 3.3.1-3 Doppelmayr Cable Liner Shuttle vehicle interior, BART TO OAK, Oakland, CA USA (Image: Lea+Elliott)
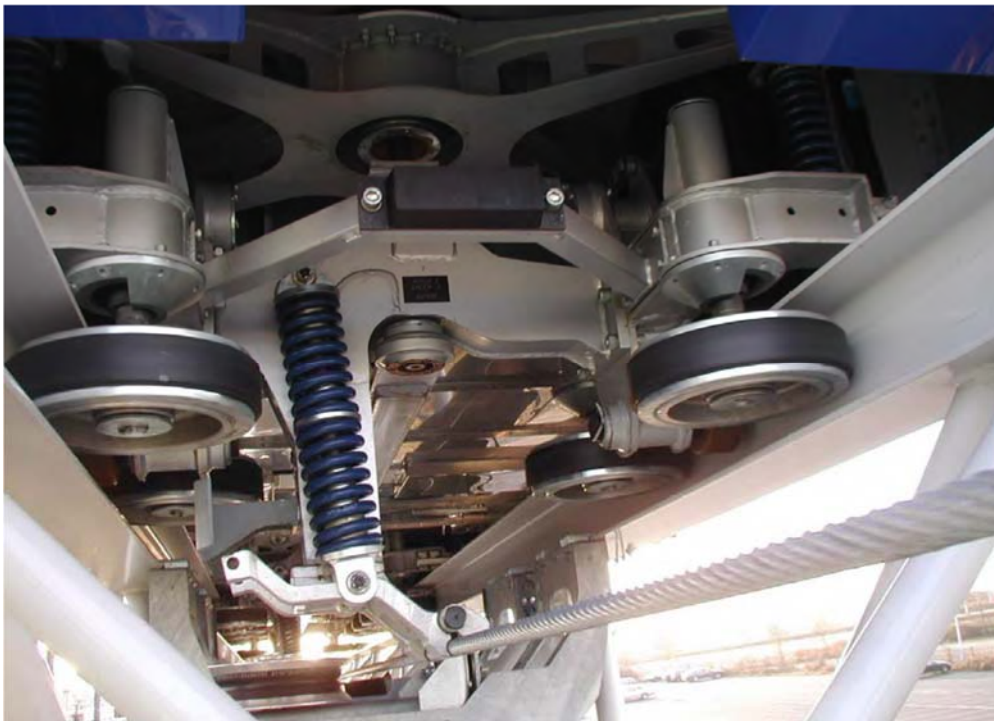
Figure 3.3.1-4 Doppelmayr Cable Liner Shuttle guidance system (Image: Doppelmayr)

3.3.2   Leitner-Poma

Website: http://en.minimetro.com/Home

Leitner-Poma of America is based in Grand Junction, Colorado. It is the North American subsidiary of French-based Poma, which is owned by the Italian company Leitner Technologies, part of the Leitner Group. They currently have approximately 20 APMs and funiculars implemented around the world. The MiniMetro can be rubber-tired, steel-wheeled or air-levitated (Hovair®). The system is cable-propelled and can operate as trains of 1- to 4-vehicles. They operate fully automated without drivers.

Leitner-Poma systems can currently be found in operation at airports in Minneapolis-St. Paul, Detroit, Zurich, and Cairo. Leitner-Poma has recent implementations at the airports in Pisa, Italy and Miami, Florida. Examples of system implementations of the MiniMetro are provided further below.

Table 3.3.2-1 Leitner-Poma MiniMetro vehicle specifications

Leitner-Poma MiniMetro vehicle specifications	Value
Vehicle length (1 car)	48.9 ft.
Vehicle width	9.4 ft.
Vehicle height	12.7 – 13.5 ft.
Vehicle weight (unloaded)	33,069 – 35,274 lb.
Vehicle capacity (1 car @ 4pax/m^2 or 2.7 sf/pax)	66 – 70 (large MiniMetro car)
Vehicle door opening (clear width)	4.9 ft.
Maximum speed	27 mph
Minimum horizontal curve radius	164 ft.

Figure 3.3.2-1 Leitner-Poma (formerly Poma Otis) MiniMetro utilizing steel wheels/steel rail guidance, Minneapolis-St. Paul Airport, MN USA (Image: Lea+Elliott)

Figure 3.3.2-2 Leitner-Poma MiniMetro utilizing Hovair® air levitation suspension, Cairo Airport, Egypt (Image: Leitner-Poma)

Figure 3.3.2-3 Leitner-Poma MiniMetro vehicle interior (Image: Leitner-Poma)

The MiniMetro system is also available in a smaller cab configuration shown below.

Figure 3.3.2-4 Leitner-Poma MiniMetro small vehicle in Perugia, Italy (Image: Leitner-Poma)

Figure 3.3.2-5 Leitner-Poma MiniMetro small vehicle on The Squaire metro, Frankfurt Airport, Germany (Image: Leitner-Poma)

3.4   Gondola / Aerial Tramway

Aerial-based cable-propelled transit systems are supported by an overhead cable or cables and are propelled by gripping (either permanently or detachable) a moving cable traveling between stations. The vehicles are passive, and propulsion is provided to the cable drive wheel(s) at the station(s).

Aerial-based systems typically have attendants at the stations. Passenger capacity per cabin can range from 4 for gondolas up to 120 for aerial tramways.

3.4.1   Gondola

Gondolas can have fixed grips (sometimes called pulsed gondolas), where the cabins are grouped together in closely-spaced groups, requiring that the entire ropeway slow down for passengers to be able to disembark at a station). Because of this, their capacity is rather limited, they lack operational flexibility, and make intermediate stations impractical. For purposes of this report, we will limit our discussion to detachable-grip gondolas.

Detachable-grip gondolas can vary in terms of the ropeway configuration for propulsion and support. One of the most common gondola types for urban applications would be a configuration where one cable is used for both support and propulsion (sometimes referred to as monocable detachable gondola). If one cable is used for support and a separate cable is used for propulsion, this type of gondola is sometimes referred to as a bicable detachable gondola. The most technologically advanced gondola system is where the cabin is supported by 2 cables and propelled by one separate cable (sometimes referred to as a tricable detachable gondola systems.

The cabins are small and carry 4-15 passengers per cabin. Gondola cabins can also be suspended by two or three closely spaced cables. Cabins loop around the system. At the end stations, cabins are detached from the cable and are mechanically pulled around a semicircle. Rubber wheels accelerate and decelerate the cabins without stopping the cable drive. This operation does not interrupt the operation of the other cabins.

One consideration regarding Gondolas is that their aerial location and suspended cable alignment make them more susceptible to operational disruptions associated with high winds. However, this does not preclude using gondolas in areas of high winds, as many mountainous regions have gondola systems. Nevertheless, system design for gondolas, and other suspended cable-based systems, must take into consideration the environmental conditions of the location where it operates to ensure safe operation year-round against wind. Tricable detachable gondolas are better suited to operations in higher wind conditions than monocable and bicable detachable gondolas.

Examples of urban gondolas can be found throughout the world, including, Barcelona, Caracas (Venezuela), Hong Kong, La Paz (Bolivia), London, Medellin (Columbia), Singapore, and Tlemcen (Algeria). Disney recently announced a new gondola system as part of its new park expansion in Florida.

Doppelmayr/Garaventa (parent company of DCC) and Leitner-Poma have installed numerous Gondola systems around the world mainly at ski resorts and amusement parks.

Website: https://www.doppelmayr.com/en/products/

Website: http://leitner-poma.com/products/

Examples of Gondola implementations are provided below.

Table 3.4.1-1 Gondola system specifications

Gondola system specifications	Value
Vehicle capacity (1 cabin)	4 - 15
Average Grade	20 – 35%
Maximum speed	13 mph
Minimum horizontal curve radius	n/a

Figure 3.4.1-1 Doppelmayr/Garaventa gondola (Image: Doppelmayr/Garaventa)

Figure 3.4.1-2 Doppelmayr/Garaventa gondola station (Image: Doppelmayr/Garaventa)

Figure 3.4.1-3 Leitner-Poma gondola, Barcelona, Spain (Image: Leitner-Poma)

Figure 3.4.1-4 Leitner-Poma gondola station, Manizales, Colombia (Image: Leitner-Poma)

3.4.2 Aerial Tramway

The basic Aerial Tramway configuration has at least two cables, with one or more fixed cables providing support and guidance while the haul rope propels the vehicle. All cables are suspended by poles or towers. Aerial Tramways have cabins bigger than gondolas and provide a high capacity of passenger movement. In some cities, Aerial Tramways are part of the transit infrastructure. Vehicle capacities range between approximately 30 and 120 passengers per cabin.

Aerial Tramways can operate with two configurations, as a jig-back (reversible) system or as a single loop operation similar to gondola systems. In a jig-back system, the haul cable propels the vehicles up and down without any impact to other vehicles. In the second configuration, a set of carriers move in a single path of travel.

Examples of Aerial Tramways currently operating in urban areas in the United States include the Roosevelt Island Aerial Tramway in New York City (opened in 1976), the Portland Aerial Tram (2007), the Palm Spring Aerial Tramway (1963), and the Mount Roberts Tramway in Juneau, Alaska (1996). Note that the latter two are considered tourist attractions, however they do operate within their respective urban areas. Other examples of Aerial Tramway implementations are provided below.

Doppelmayr/Garaventa (parent company of DCC) and Leitner-Poma have installed numerous Aerial Tramway systems around the world mainly at ski resorts and amusement parks.

Website: https://www.doppelmayr.com/en/products/

Website: http://leitner-poma.com/products/

Table 3.4.2-1 Aerial Tramway system specifications

Aerial Tramway system specifications	Value
Vehicle capacity (1 cabin)	30 - 120
Average Grade	25 – 50%
Maximum speed	13 – 27 mph
Minimum horizontal curve radius	n/a

Figure 3.4.2-1 Doppelmayr/Garaventa Aerial Tramway, Jackson Hole, WY USA (Image: Doppelmayr/Garaventa)

Figure 3.4.2-2 Doppelmayr/Garaventa Aerial Tramway (Image: Doppelmayr/Garaventa)

Figure 3.4.2-3 Leitner-Poma Aerial Tramway, Bozen, Italy (Image: Leitner-Poma)

**Figure 3.4.2-4 Leitner-Poma Aerial Tramway, Roosevelt Island, New York, NY USA
(Image: Leitner-Poma)**

Figure 3.4.2-5 Leitner-Poma Aerial Tramway station, Bozen, Italy (Image: Leitner-Poma)

3.5   Personal Rapid Transit (PRT)

Personal Rapid Transit (PRT) is an automated transportation technology that uses small vehicles operating at very short headways providing non-stop, origin-to-destination travel to a selected destination. The non-stop, point-to-point routing is accomplished by using off-line stations connected by a network of guideway and sophisticated automated vehicle control hardware and software. The goal of PRT is to provide an experience equivalent to a private automobile or taxi.

Characteristics of PRT:

> ➢ PRT systems utilize small vehicles (two to six passengers) that are designed to operate directly between origin and destination stations in a network configuration.
> ➢ Some vehicles have limitations: height for entry and exit requiring riders to sit in the vehicles and the lack of capacity for larger groups traveling together.
> ➢ The PRT system including its stations and vehicles are designed to accommodate the mobility impaired, including those in a wheelchair.
> ➢ Speeds can be in the 20 to 30 mph range and may vary depending on guideway configuration.
> ➢ Some PRT systems are powered by batteries, which are recharged while the vehicles are dwelling at the stations. Other PRT Systems use a third rail to receive electric power.
> ➢ PRT propulsion can also range from conventional electric rotary motors to Linear Induction Motors (LIM) for propulsion.
> ➢ Since PRTs are automated they require a separate and exclusive guideway that is usually elevated. However, like Automated People Movers (APMs), PRTs can be at-grade with fencing/barriers protecting their right of way or they can be located in tunnels.

The use of PRT Systems is designed to be straightforward. By pushing a button on equipment either on the platform or on the vehicle (depending on PRT supplier), a passenger indicates to the control system his desired destination. The desired destination information is sent electronically to the control system, which instructs the vehicle to take the passenger to the desired location by means of the shortest non-stop route. In addition to providing vehicles with directional instructions, Central Control also controls empty vehicle management and ensures there is no interaction between vehicles.

The PRT system off-line stations require sufficiently long exit ramps and entry ramps leading to and from the main guideway to the vehicle berths. The preference is that the ramp's geometry will allow the vehicle to remain at guideway speed until it exits the main guideway so as to not affect main guideway flow. Station design and passenger flow management are critical to the success of a PRT system and various station configurations could be designed to allow for location and ridership requirements. Typically, stations are configured with in-line berths, parallel off-line berths or off-line with saw-tooth berths (see Figure 3.5-1).

Some suppliers state system capacities of several thousand passengers per hour per lane based on vehicles operating on very close headways (approximately 2-3 seconds). However, the safest minimum headway in accordance with ASCE Standards and instantaneous stop or "Brick Wall" safe stopping distance criteria is approximately 12 seconds

Currently, there are three suppliers who have systems in passenger service: 2getthere in Masdar City, Abu Dhabi, UAE, Ultra Global at London Heathrow Airport and Vectus in Suncheon Bay, South Korea. A description of the 2getthere, Ultra Global and Vectus PRT technologies and their initial installations are discussed in the following sections.
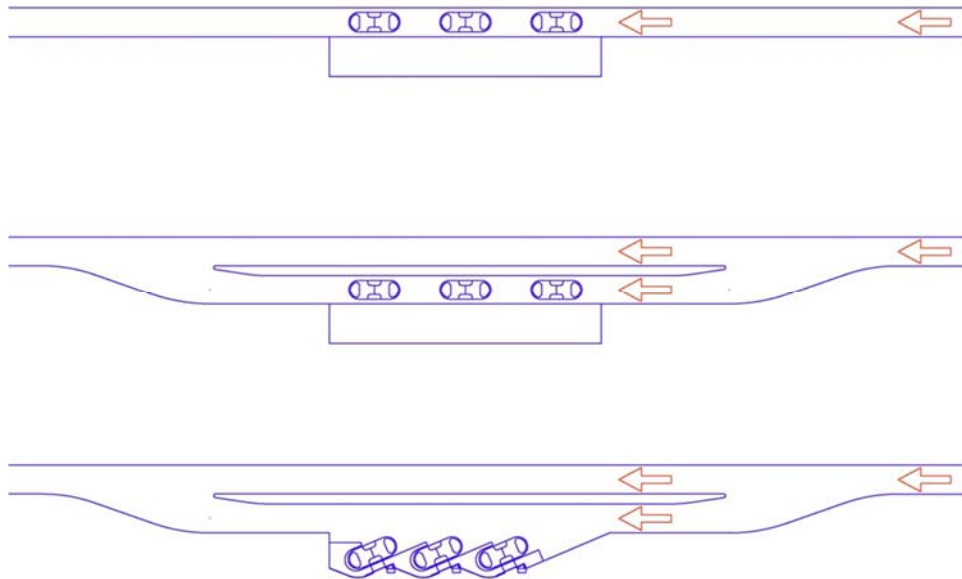
Figure 3.5-1 Typical PRT Station Configurations: in-line (top), parallel off-line (middle) or off-line with saw-tooth berths (bottom) Image: Lea+Elliott

3.5.1   2getthere

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

2getthere, a Dutch company, is currently operating a 0.75 mi round trip PRT line in Masdar City in Abu Dhabi, UAE, with two stations connecting the Masdar Institute of Science and Technology (MIST) to a parking facility. This system is a pilot program for an expanded network, though the original extensive network plan has been scaled back.

This system utilizes an open passive guideway with all propulsion and switching functions accomplished on-board the rubber-tired vehicle. Vehicles are guided by on-board maps and error correction is provided by magnets embedded at 13 ft. intervals along the guideway. The single lane guideway requires a minimum width of 5.9 ft. and needs no guideway edges or curbs. Vehicle mounted sensors detect obstructions and adjust braking and propulsion for collision avoidance. It seats four adults and two children in forward and rear seats facing the center of the car. The cars are fully air conditioned. Figure 3.5.1-1 below depicts the curb-less lanes of the Masdar system and a 2getthere vehicle. Vehicle specifications are shown in the table below.

Table 3.5.1-1 2getthere vehicle specifications

2getthere vehicle specifications	Value
Vehicle length	12.8 ft.
Vehicle width	4.9 ft.
Vehicle height	6.6 ft.
Vehicle weight (unloaded)	3086 lb.
Vehicle capacity	4 adults + 2 children
Vehicle door opening (clear width)	2.9 ft.
Maximum speed	25 mph
Minimum horizontal curve radius	18 ft.

Figure 3.5.1-1 2getther vehicle, Masdar City, Abu Dhabi, UAE (Image: Lea+Elliott)

Figure 3.5.1-2 2getthere vehicle interior, Masdar City, Abu Dhabi, UAE (Image: Lea+Elliott)

Figure 3.5.1-3 Masdar City PRT station berths (Image: Lea+Elliott)

3.5.2 Ultra Global

Website: http://www.ultraglobalprt.com/

Ultra Global, a United Kingdom (UK) company, has installed a starter system connecting a parking lot (with two stations) with a single station at Terminal 5 at London Heathrow Airport (LHR). Opened in 2011, this initial alignment is more linear or "line-haul" in its configuration than what is typically envisioned for PRT. A planned expansion into a grid network is currently on hold. The T5 Car Park has two stations, Station A and Station B, with station boarding areas in a "saw tooth" configuration and each with an interface where a passenger will select his/her destination.

The Ultra Global PRT system utilizes an open passive guideway with all propulsion and switching functions accomplished on-board the rubber-tired vehicle. Optical sensors on-board the vehicles sense the guideway edge curbs and provide feedback for vehicle steering and switching (lane changes). The single lane guideway is estimated to be 7.2 ft. at its widest point, which is at curves. The vehicle seats four adult passengers, two forward-facing and two rear-facing, all facing the center of the car. Vehicle specifications are shown in the table below.

It has been reported that Ultra Global has licensed its technology to Ultra Fairwood based in Singapore and has announced plans for a project in Ajman City in the United Arab Emirates (UAE).

Table 3.5.2-1 Ultra Global vehicle specifications

Ultra Global vehicle specifications	Value
Vehicle length	12.1 ft.
Vehicle width	4.9 ft.
Vehicle height	5.9 ft.
Vehicle weight (unloaded)	1808 lb.
Vehicle capacity	4
Vehicle door opening (clear width)	2.9 ft.
Maximum speed	25 mph
Minimum horizontal curve radius	16.4 ft.

Figure 3.5.2-1 Ultra Global pod, London Heathrow Airport, London, UK (Image: Lea+Elliott)

Figure 3.5.2-2 Ultra Global pod interior (Image: Lea+Elliott)

Figure 3.5.2-3 Ultra Global pods in LHR T5 station berths (Image: Lea+Elliott)

3.5.3   Vectus

Website: http://www.vectusprt.com/EN/

Vectus, a UK / South Korean company, constructed a 2.8 mi. PRT system at the Suncheon Bay coastal wetlands area in South Korea in April 2014 and has had a test track in Sweden in operation since 2007.

The Vectus system is rail-running and guided and can be installed on a concrete or steel structure, or at-grade. The track is passive, and all switching is done on-board the vehicle with a mechanical switch. Guidance is provided through guide rails, and guide wheels ensure that the vehicles are mechanically "locked" on the guideway. Propulsion can be provided by the vehicle using rotary motors or guideway power using Linear Induction Motors (LIMs). The vehicle seats four adult passengers in forward and rear seats facing the center of the car. Multiple station configurations can be supported including in-line, series, or parallel off-line berths.

Table 3.5.3-1 Vectus vehicle specifications

Vectus PRT vehicle specifications	Value
Vehicle length	12.1 ft.
Vehicle width	6.9 ft.
Vehicle height	8.2 ft.
Vehicle weight (unloaded)	3307 lb.
Vehicle capacity	6-8
Vehicle door opening (clear width)	2.9 ft.
Maximum speed	43 mph
Minimum horizontal curve radius	16.4 ft.

Figure 3.5.3-1 Vectus vehicle, Suncheon Bay, Republic of Korea (Image: Vectus)

Figure 3.5.3-2 Vectus vehicle interior, Suncheon Bay, Republic of Korea (Image: Vectus)

Figure 3.5.3-3 Suncheon Bay in-line station berths (Image: Vectus)

3.6   Group Rapid Transit (GRT)

Group Rapid Transit (GRT) is similar to Personal Rapid Transit but with higher-occupancy vehicles and grouping of passengers with either the same destination or potentially different origin-destination pairs, depending on the GRT's control system and vehicle assignment algorithm. Such systems may have fewer direct-to-destination trips than single-destination PRT but still have fewer average stops than conventional transit, acting more as an automated shared taxi system than a private cab system. Such a system may have advantages over low-capacity PRT in some applications, such as where higher passenger density is required or advantageous. It is also conceivable for a GRT system to have a range of vehicle sizes to accommodate different passenger load requirements, for example at different times of day or on routes with less or more average traffic.

GRT has principally been proposed as a corridor service, where it can potentially provide a travel time improvement over conventional rail or bus and can also interface with PRT systems. However, GRT's potential grouping of passengers makes it much less attractive in applications with lower passenger density or where few origin-destination pairs are shared among passengers. All other PRT characteristics related to stations and guideways mentioned previously in Section 3.5 also apply to GRT.

A notable mention in this section is the West Virginia University Personal Rapid Transit System in Morgantown, WV. It is an automated people mover system that provides non-stop origin to destination travel between the separated campuses of West Virginia University and the Central Business District. The system consists of a fleet of 71 electrically-powered, rubber-tired, passenger-carrying vehicles (8-seated and 13-standing), operating on a dedicated guideway network at close headways (minimum 15 seconds).

Since 1975, the system has provided and continues to provide a safe, comfortable, low polluting reliable means of transportation. The system consists of 8.2 mi of guideway and five passenger stations. Although called a PRT, many feel that this system is better labeled Group Rapid Transit (GRT) because these vehicles can carry up to 21 passengers.   This technology was originally supplied by Boeing and is not currently commercially available.

Figure 3.6-1 West Virginia University PRT Vehicle, Morgantown, WV, USA

Website: https://transportation.wvu.edu/prt

Several of the PRT suppliers have GRT vehicles in development including 2getthere and Vectus. Examples of GRTs are shown below.

3.6.1   2getthere

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

2getthere has been operating its 2nd generation ParkShuttle GRT system at the Rivium business park in Rotterdam, Netherlands since 1999 and has been working on its 3rd generation ParkShuttle. It has announced projects in Dubai, Singapore and Brussels. The Brussels system will be a phased implementation where it is planned to ultimately operate autonomously in mixed traffic on existing roadways.

Table 3.6.1-1 2getthere GRT vehicle specifications

2getthere GRT vehicle specifications	Value
Vehicle length	19.7 ft.
Vehicle width	6.9 ft.
Vehicle height	9 ft.
Vehicle weight (unloaded)	8,818 lb.
Vehicle capacity	22-28
Vehicle door opening (clear width)	Not available
Maximum speed	25 mph
Minimum horizontal curve radius	36.1 ft.

Figure 3.6.1-1 2getthere ParkShuttle GRT vehicle, Rivium, Rotterdam, Netherlands

(Image: 2getthere)

Figure 3.6.1-2 2getthere 3rd generation ParkShuttle GRT vehicle rendering (Image: 2getthere)

3.6.2   Vectus

Website: http://www.vectusprt.com/EN/

Vectus previously stated they have plans for a GRT vehicle which will be longer and taller yet will operate on the same guideway as the PRT vehicle. The larger vehicles are designed to accommodate standees as well as seated passengers. The door spacing of the larger vehicles matches the door spacing of two adjacent PRT vehicles stopped in a station. This feature allows the GRT vehicles to share the same station infrastructure with the PRT vehicles. It is anticipated that the Vectus PRT and GRT vehicles will be able to operate simultaneously on the same network.

The Vectus system is rail-running and guided and can be installed on a concrete or steel structure, or at-grade. The track is passive, and all switching is done on-board the vehicle with a mechanical switch. Guidance is provided through guide rails, and guide wheels ensure that the vehicles are mechanically "locked" on the guideway. Propulsion can be provided by the vehicle using rotary motors or guideway power using Linear Induction Motors (LIMs). The larger Group Rapid Transit (GRT) vehicle is planned to accommodate seated and standing passengers, from 20 to 60 total, to be determined. A prototype vehicle for testing purposes was planned as part of Vectus' ongoing R&D program.

Table 3.6.2-1 Vectus GRT vehicle specifications

Vectus GRT vehicle specifications	Value
Vehicle length	Not available
Vehicle width	6.9 ft.
Vehicle height	In development
Vehicle weight (unloaded)	In development
Vehicle capacity	20-60 (TBD)
Vehicle door opening (clear width)	2.9 ft.
Maximum speed	43 mph
Minimum horizontal curve radius	16.4 ft. (65.6 ft. recommended)

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Figure 3.6.2-1 Vectus GRT vehicle rendering (Image: Vectus)

3.7   Automated Vehicle Shuttle / Autonomous Vehicle (AV)

An Automated Vehicle Shuttle or Autonomous Vehicle (AV) is a vehicle technology that is capable of sensing its environment and navigating without human input. Unlike other forms of automated technology, this is achieved without a fixed guideway which can reduce infrastructure costs. AVs combine a variety of technologies to perceive their surroundings including radar, lidar, GPS, odometry, mapping and cameras. Advanced control systems interpret the information received to identify appropriate navigation paths as well as obstacles.

AVs are used to move passengers or freight with a level of automation. They are classified into six different levels of automation, as defined by the Society of Automotive Engineers (SAE). The first three levels of automation (Levels 0-2) require a human driver to monitor the environment, while the last three levels (Levels 3-5) allow an automated system to perform driving tasks. This report introduces existing Shared Automated Vehicles (SAV), which are level 4 and higher and are small (typically 8-15 passengers), battery-powered, electric vehicles. These vehicles aim to transform transportation by significantly improving safety and mobility, improving the efficiency of rides on demand, reducing carbon footprints of cities, and solving the public transportation problem of the first and last mile connectivity.

Automated People Movers are considered AV systems that are already in operation today, primarily for use in controlled, fixed-guideway systems as described in previous sections. SAVs, such as AV shuttles and fleets, are being deployed for use in a less fixed, nonetheless still contained, environment (i.e., public roadways). AV shuttles are equipped with SAE Level 5 (full automation) control. While all automated shuttle service pilot demonstration programs are in the initial testing phase, some are offering rides to the public. These pilot programs are testing the feasibility of automated vehicle technology for public transit and user acceptance. EasyMile, NAVYA, and Local Motors are three major manufacturers of low-speed (12-15 mph) automated shuttles.

3.7.1   EasyMile

Website: http://www.easymile.com/

EasyMile, headquartered in France, is a joint venture between vehicle manufacturer Ligier Group and Robosoft, a high-tech company specializing in robotics and autonomous vehicle technology. The venture has provided its electric AV model "EZ10" for the CityMobil2 program, a multi-stakeholder project co-funded by the European Union (EU). The goal of the CityMobil2 project is to set up a pilot platform for automated road transport systems and study the technical, financial, cultural, and behavioral aspects of Shared Autonomous Vehicle (SAV) systems. The objective of CityMobil2 is to deliver:

- An automated road transport service running for at least six months at five sites across Europe

- Guidelines to design and implement an automated transport system

- Improved understand of the interaction between automated vehicles and other road users

- A legal framework proposal for certifying automated road transport systems in Europe

- Showcases at numerous sites across Europe

- Technical specifications for interoperable automated road transport systems, including a communications architecture

Outside of the CityMobil2 project, the EZ10 shuttle has been deployed in 20 countries across Asia-Pacific, Middle-East, North America, and Europe. In 2015, EasyMile and GoMentum Station – a testing ground for connected and automated vehicles in Concord, California – announced their partnership to launch the first fleet of EZ10 vehicles in Northern California. The shuttles arrived at GoMentum Station in September 2016, and the pilot demonstration project with the Contra Costa Transportation Authority marks the first time EasyMile shuttles have been utilized in the United States. The EZ10 is the first fully self-driving vehicle to be approved for public roads trials in California.

Table 3.7.1-1 EasyMile AV vehicle specifications

EasyMile AV vehicle specifications	Value
Vehicle length	12.9 ft.
Vehicle width	6.5 ft.
Vehicle height	9 ft.
Vehicle weight (loaded)	1270 lb.
Vehicle capacity	12 (6 seated)
Maximum speed	25 mph

Figure 3.7.1-1 Easy Mile EZ10 vehicle (Image: EasyMile)

Figure 3.7.1-2 Easy Mile EZ10 vehicle, Arlington, TX USA (Image: Lea+Elliott)

3.7.2   Local Motors

Website: https://localmotors.com/meet-olli/

Local Motors, an American automobile manufacturing company, developed the world's first 3D printed transit vehicle – Olli, a self-driving shuttle. Local Motors design engineers are able to reduce tooling costs by 50% and reduce overall production time by 90%, all while keeping part production in-house using tools like the MakerBot Replicator+, a cloud-enabled desktop 3D printer. Olli made its debut in National Harbor, Maryland in June 2016, where it traveled on local public roads within the boundaries of National Harbor in its trial run (Figure 3.7.2-1).

To use Olli, a rider will use the Modally mobile app to book a ride and set your destination, similar to other ride-sharing programs. Olli is equipped with IBM Watson Internet of Things (IoT) technology, which allows interaction with the vehicle. This advanced vehicle technology allows passengers to converse with Olli in such a way that creates more intuitive and interactive experiences due to the nature of its cognitive computing capability. Together, IBM and Local Motors have produced a vehicle that combines the capabilities of a chauffeur, a tour guide, and a technology expert to communicate with passengers using spoken conversational language. In addition to casual conversation, Olli has the ability to update passengers for the duration of the ride, considering upcoming traffic, weather, or other potential issues that may affect the commute.

Table 3.7.2-1 Local Motors AV vehicle specifications

Local Motors AV vehicle specifications	Value
Vehicle length	12.9 ft.
Vehicle width	6.7 ft.
Vehicle height	8.2 ft.
Vehicle weight (unloaded)	4056 lb.
Vehicle capacity	10
Maximum speed	25 mph

Figure 3.7.2-1 Local Motors Olli on demo in National Harbor, Maryland (Image: Local Motors)

Figure 3.7.2-2 Local Motors Olli vehicle (Image: Local Motors, CNN)

3.7.3   NAVYA

NAVYA is a French company that specializes in the design and construction of autonomous and electric vehicles. NAVYA assists cities and private sites around the world in improving their transportation.

3.7.3.1   AUTONOM SHUTTLE (ARMA)

Website: https://navya.tech/en/autonom-en/autonom-shuttle/

NAVYA developed the AUTONOM SHUTTLE as a driverless, electric shuttle service. In 2016, NAVYA delivered two AUTONOM SHUTTLES, known as ARMA, for use in a two-year demonstration launched in the city of Sion, Switzerland. BestMile, a Swiss start-up, provides the software for fleet management, allowing the remote control of the vehicles and optimization of driverless vehicle fleets. The two AUTONOM SHUTTLES provided shuttle service that was the first test of an autonomous passenger service and is also free and open to the public. As of January 2018, NAVYA has 65 vehicles deployed worldwide in cities and on private sites in Europe, the United States, Asia, and the Pacific.

In 2017, NAVYA brought the first AUTONOM SHUTTLE to the United States at the University of Michigan's (Mcity) Mobility Transformation Center (MTC) in Ann Arbor, Michigan. Mcity will study how passengers react, track ridership and usage patterns, and survey users to gauge rider acceptance. This data will help improve the safety and operations of the vehicles. In November 2017, Las Vegas launched an autonomous bus route along a 0.6-mile route along Fremont Street using a NAVYA AV. While there is an on-board attendant who can stop or guide the shuttle in case of an emergency and an automobile that follows behind as a buffer to prevent rear ends, this makes Las Vegas the first to deploy AVs on public streets in mixed traffic.

Table 3.7.3.1-1 NAVYA AUTONOM SHUTTLE vehicle specifications

NAVYA AUTONOM SHUTTLE vehicle specifications	Value
Vehicle length	15.6 ft.
Vehicle width	6.9 ft.
Vehicle height	8.7 ft.
Vehicle weight (unloaded)	5291 lb.
Vehicle capacity	15
Maximum speed	28 mph

Figure 3.7.3.1-1 NAVYA AUTONOM SHUTTLE on demo at APTA EXPO (Image: NAVYA)

Figure 3.7.3.1-2 NAVYA AUTONOM SHUTTLE vehicle, Passenger Terminal EXPO, Cologne, Germany (Image: Lea+Elliott)

3.7.3.2   AUTONOM CAB

Website: https://navya.tech/en/autonom-en/autonom-cab/

NAVYA launched AUTONOM CAB, the first autonomous taxi on the market, in Paris, France in November 2017. It was introduced to the United States at the Consumer Electronics Show (CES) in Las Vegas, Nevada in January 2018. Visitors tested the cab, which transported more than 1,500 people on the streets of Las Vegas. AUTONOM CAB is available as a private or shared service and is used for on-demand trips. Similar to NAVYA's objective for AUTONOM SHUTTLE, it aims to use AUTONOM CAB to ease congestion in city centers, provide a solution to the demand for first and last mile service, optimize variable costs, and improve safety by providing a fluid mobility service. Partnerships with transport specialists such as KEOLIS in Europe and the U.S. will enable NAVYA to have fleets of the autonomous vehicles operating in city centers.

 To use AUTONOM CAB, the passenger uses the smartphone application called NAVYA APP to order the cab and open and close the vehicle's door. When inside the vehicle, the passenger can utilize the onboard touchscreen, allowing them to order tickets for a movie, select songs, and obtain tourist information, further enhancing the user experience. In addition to its fluid communication, AUTONOM CAB boasts its communicative design on the exterior with its colored light band that communicates with passengers, person who ordered the cab, and pedestrians.

Table 3.7.3.2-1 NAVYA AUTONOM CAB vehicle specifications

NAVYA AUTONOM CAB vehicle specifications	Value
Vehicle length	15.3 ft.
Vehicle width	6.4 ft.
Vehicle height	6.9 ft.
Vehicle weight (unloaded)	4409 lb.
Vehicle capacity	6
Maximum speed	55 mph

Figure 3.7.3.2-1 NAVYA AUTONOM CAB in the streets of Paris (Image: NAVYA)

3.8   Automated Vehicle Fleet (AF)

Similar to automated vehicle shuttles, automated vehicle fleets offer rides to the public but through a controlled fleet of passenger vehicles supplied with automated vehicle technology.

3.8.1   Waymo

Website: https://waymo.com/

Waymo, an American self-driving tech company, began as the Google self-driving car project in 2009 and became its own independent company in 2016. Waymo's fully self-driving technology has driven over 8 million miles on real-world roads since 2009. Waymo formed a partnership in 2016 with Fiat Chrysler Automobiles (FCA) to supply Chrysler Pacifica minivans for its public road testing.

3.8.1.1 System Operations

Waymo's vehicles cross-reference their pre-built, detailed three-dimensional maps with real-time sensor data to precisely determine their location on the road, rather than relying on GPS. The sensors and software continuously scan for objects up to 300 meters away in every direction of the vehicle. The software predicts future movements of dynamic objects based on trajectory and current speed, predicts numerous possible paths of other road users, and considers the potential impacts of changing road conditions (e.g., road blocks) on the behavior of other road users. This information allows the software to determine the exact trajectory, speed, lane, and steering maneuvers necessary to safely proceed ahead.

The vehicles are equipped with an SAE Level 4 automated driving system, which allows the vehicle to come to a safe stop in the event of a system failure. They gather information from their LiDAR, vision, GPS, radar, and audio detection systems to not only assess the current driving situation, but also think several steps ahead to make the best decision. Figure 3.8.1.1-1 shows the general components of Waymo's vehicles.
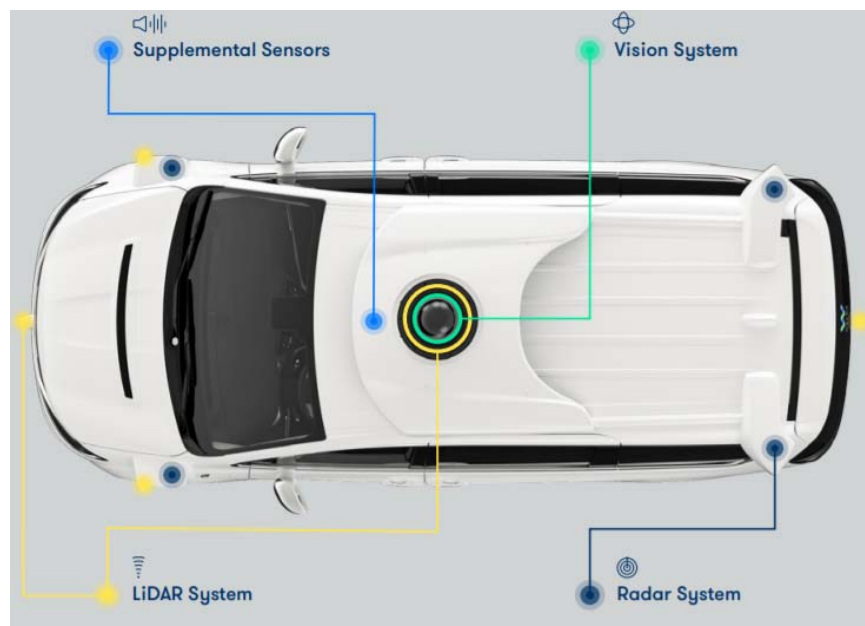
Figure 3.8.1.1-1 Individual components of Waymo's vehicles' software system

(Image: googleapis.com)

Waymo's vehicles are designed to:

- Drive in inclement weather

- Not operate outside of its approved operational design domain

- Detect sudden changes and come to a safe stop

- Comply with federal, state, and local laws within their geographic area of operations

At its level of automation, Waymo's technology is capable of performing a safe stop, known as a "minimal risk condition" or fallback, which may include situations when the self-driving system experiences a problem, when the vehicle is involved in a collision, or when environmental conditions change in a way that would affect safe driving within the operation design domain. The vehicle's system has the ability to automatically detect each of the scenarios, assess the surrounding environment and conditions, and determine an appropriate response for the safety of its passengers.

3.8.1.2 Testing

Waymo's self-driving technology is tested on the road, in closed areas, and in simulations. The three subsystems of the vehicles are rigorously tested: the base vehicle, in-house hardware, and self-driving software. The vehicle's hardware is tested to ensure that the vehicle operates safely in manual mode, self-driving mode with a test driver at the wheel, and fully self-driving mode without a person inside the vehicle. The individual components of the vehicle's software, which include perception, behavior prediction, and planner, are tested individually and as a whole. Each software update undergoes simulation testing, closed-

course testing, and driving on public roadways. Simulation testing uses virtual scenarios of the most challenging, real-world situations that the vehicles have experienced. Then, this new software is tested on a private test track. Waymo has a private, 91-acre closed-course testing facility in California to conduct thousands of structured tests. Finally, once it has been confirmed that the updated software is working as intended, it is introduced to vehicles on public roads. Real-world testing provides a continuous feedback loop that allows for continuous refinement of the self-driving system.

In April 2017, Waymo launched an early rider program – a public trial of its self-driving vehicles – in Phoenix, Arizona. Each vehicle offering rides to passengers in the early rider program had a test driver to monitor the rides in its early testing stages. By November 2017, Waymo removed human drivers from test fleets, deploying fully self-driving vehicles on the streets. FCA agreed to supply thousands of additional Chrysler Pacifica minivans in Waymo's effort to expand its operations and deployment, which will be available in late 2018. Waymo is also conducting public road tests in 25 cities in the U.S., including San Francisco, metro Detroit, and Atlanta. More recently, Waymo announced its new partnership with Jaguar Land Rover. Together, they are working to engineer the world's first premium, electric, fully self-driving vehicle using the Jaguar I-PACE. Waymo has ordered 20,000 I-Pace vehicles. The first three arrived in the San Francisco Bay Area and will begin testing later this year.

Table 3.8.1.2-1 Waymo I-PACE vehicle specifications

Waymo I-PACE vehicle specifications	Value
Vehicle length	15.4 ft.
Vehicle width	6.2 ft.
Vehicle height	5.1 ft.
Vehicle weight (unloaded)	4784 lb.
Vehicle capacity	5
Maximum speed	124 mph

Figure 3.8.1.2-1 Waymo's I-PACE vehicle (Image: businessinsider.com)

3.8.2 Drive.ai

Website: https://www.drive.ai/

Drive.ai is an on-demand, self-driving car service company founded in 2015 by graduate students and others affiliated with Stanford's Artificial Intelligence Lab. This California-based company collaborates with public and private entities to develop geofenced Level 4 self-driving solutions to mobility problems. Drive.ai uses "deep-learning" to develop integrated software/hardware mobility solutions that are scalable and flexible to work seamlessly with various vehicle types and urban environments.

Drive.ai started a six-month pilot program using four vehicles in Frisco, Texas in July 2018. During the trial period, Drive.ai will offer complimentary rides during daylight hours to employees, residents, and patrons in a geofenced area in Frisco's North Platinum Corridor. This will be the first time that the general public will have access to an on-demand, self-driving vehicle service in the U.S.

Users will request rides using Drive.ai's ride-hailing smartphone app at select pickup and drop-off locations (finalized in May-June of 2018) within the geofenced area (see Figure 29). Drive.ai plans to expand its service to Frisco Station and perhaps elsewhere in and beyond the North Platinum Corridor at a future date. The company also has plans to develop a similar service in the San Francisco Bay Area.

Table 3.8.2-1 Drive.ai Nissan NV200 Van vehicle specifications

Drive.ai Nissan NV200 Van vehicle specifications	Value
Vehicle length	15.5 ft.
Vehicle width	5.6 ft.
Vehicle height	6.2 ft. (excluding sensor apparatus)
Vehicle weight (unloaded)	3263 lb.
Vehicle capacity	4 passengers and one operator/chaperone in self-driving version
Maximum speed	45 mph

Figure 3.8.2-1 Drive.ai Nissan NV200 van with sensors, Arlington, Texas (Image: Lea+Elliott, Inc.)
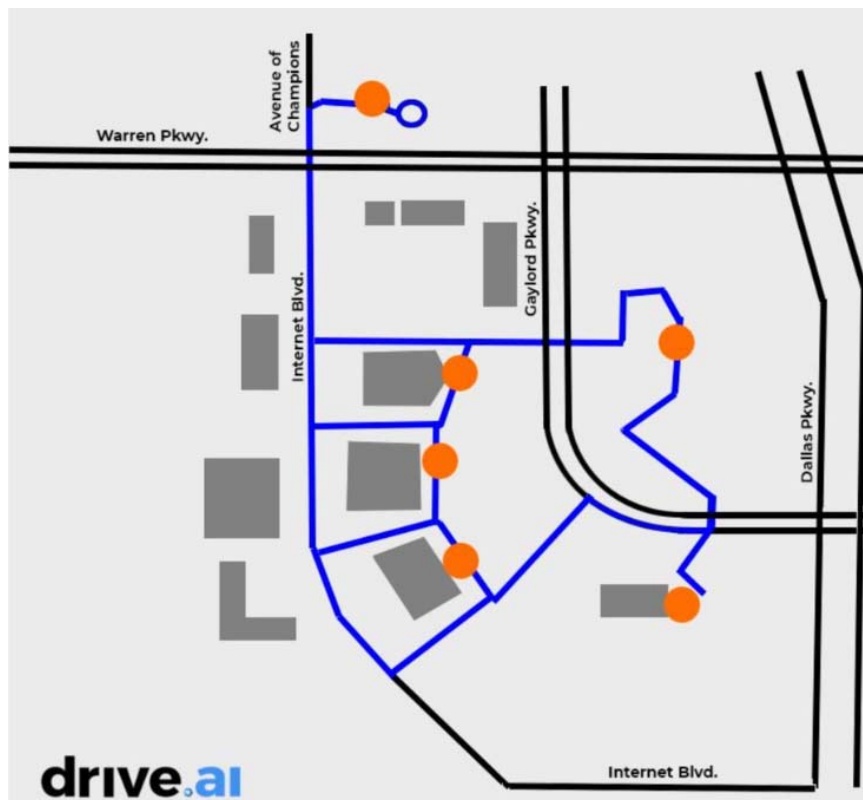
Figure 3.8.2-2 Initial Drive.ai service area in Frisco, Texas (Image: Drive.ai)

4.   Evaluation Criteria and Requirements

This section provides more detail and definitions of the system characteristics that were introduced in Section 2.3. These characteristics will be used as evaluation criteria when performing a system Technology Assessment. Technologies are typically evaluated based on these groups of factors:

- ➢ Performance
- ➢ Level of Service
- ➢ Urban Insertion Impact
- ➢ Cost Efficiency
- ➢ Technology Maturity

4.1   Performance

Each performance factor is explained in the following sections.

4.1.1   Capacity (pphpd) / Ability to Meet Passenger Demand

Capacity is the ability for a transit system to convey a prescribed number of passengers in a given direction for a specific period of time. The general unit used is passengers per hour per direction (pphpd). For a positive score, the system technology shall have sufficient capacity to satisfy or exceed the estimated peak hour ridership demand in passengers per hour per direction (pphpd). Another requirement is that the technology should have the flexibility to meet a range of capacities over a daily operating schedule and over the life of the system. This includes providing cost-effective service for peak, non-peak, night, and special event ridership. This is achieved by the Operations Control Center operator and the control system changing the fleet size in an efficient manner so that vehicles are removed from areas where ridership requirement is reduced, while at the same time a fleet can be built up and dispersed effectively.

4.1.2   Speed

The technology must be able to operate at a reasonable speed to generate satisfactory trip times while still providing a high level of passenger comfort. The technology's cruise speed, the system's station spacing, and degree of exclusivity of the guideway/track influence actual system speed. For this project, an operating speed of 25 – 35 mph is appropriate, but higher or lower speeds may be possible based on factors such as guideway geometry, the distances between stations and the degree of guideway segregation.

4.1.3   Geometry / Configuration

System technologies must be able to comply with spatial constraints and to operate over the alignment envisioned without undue disruption to current and planned adjacent infrastructure development. The alignment geometry is considered when identifying technologies that may be unable to operate within the system criteria. These requirements consider a technology's performance capabilities and constraints with regard to the currently proposed geometry of the baseline alignment(s). For horizontal alignment, this is measured by the minimum curve radius that a technology can reasonably negotiate while maintaining appropriate levels of passenger comfort and by clearance limits with respect to adjacent facilities. For the vertical alignment, the maximum grade and minimum vertical curve radius constraints of a technology are considered with respect to the proposed vertical alignment(s). Examples of limitations that a technology

can impose include structure height, the space requirements of stations, and the workability of various sites for locating a maintenance and storage facility or depot.

4.1.4   Expandability

This criterion includes the ease with which the system can be expanded cost effectively, either by extending the guideway or by increasing passenger-carrying capacity (typically achieved by increasing the operating fleet size). Depending on the degree of changes and the pre-planning for increase in the number of stations and ridership demand, expansion should be possible without significant disruption to the operating system.

4.1.5   Operating Range

This criterion considers the operating range of a vehicle in regular passenger-carrying service. For technologies with a continuous power rail, the range is considered to be unlimited. For battery-powered vehicles, operating range can be measured in elapsed time or distance. The operating range must be greater than the time or distance between charging opportunities and any required charging times must not interfere with the need to have sufficient fleet to satisfy the passenger-carrying requirements. Along with the traditional power demands of propulsion, communications and lighting, air conditioning is vital and is considered during an evaluation.

4.1.6   Failure Management / Availability

For automated transportation systems, failure management involves at least two nearly inseparable considerations. First, there is diagnosing and removing the cause of the service interruption that is necessitating the failure management (recovery) action. Second, while removing the cause is "in progress" the service provider must attempt to provide the most effective alternative or supplementary passenger service that conditions permit.

Each technology shall have a very high level of reliability and resulting Availability (measured in the percentage of time the full system is operating as specified) to provide the service levels required to attract ridership. At the same time, features such as allowing the establishment of run-around and by-pass modes of operation shall be considered.

4.2   Level of Service

The Level of Service (LOS) provided by the system depends on planning and design considerations, including: ride quality, passenger trip times, walk distances, ease-of-use, frequency of service and passenger wait times. The system should provide the optimum level of service in terms of minimizing passenger trip times and providing the best ride quality possible. Level of Service factors are used to measure the passenger's experience.

4.2.1   Trip Times

The system must carry passengers between stations in a reliable, competitive time, including both wait times (if applicable) and travel times. Wait times are affected by sustainable, reliable headways. Trip times and trip time reliability (the system's ability to travel between stations in a reliable amount of time, unaffected by outside influences) are both important in attracting and serving passengers. Passenger trip times are a function of the wait time in a station (frequency between vehicles) and the travel time on the system. Travel

times are primarily determined by vehicle speeds, station spacing, station dwell requirements and guideway alignment.

4.2.2 Headways / Wait Time

Passengers have come to expect a high frequency of service and low wait time when using airport transit systems. During some hours of the day, the headways will likely be driven by level of service goals rather than capacity requirements.

The technology should have the ability to operate at short headways (time between vehicles) to provide short wait times and high capacity. The headway is the elapsed time between successive vehicles traveling on the same guideway in the same direction.

4.2.3 Minimal Transfers

The technology should be able to operate in a fashion as to minimize the number of transfers that a passenger must make to arrive at their destination. Minimal transfers attract ridership, reduce travel times, provide better wayfinding and improve the passenger LOS. Minimizing transfers is most typically related to a technologies ability to navigate the optimum alignment which best serves the passenger demand.

4.2.4 Safety

The system must meet key codes and standards and safety and security requirements of the applicable regulating agencies. Further, its operations should inherently be safe, and the design of the system should accommodate safety concerns in a cost-effective manner.

The technologies must have the ability to evacuate vehicles at any point along the guideway in the case of an emergency or mechanical failure. Typically, egress is provided by means of a continuous emergency walkway along the guideway which passengers can use to walk to the nearest safe exit. Since technologies without a continuous guideway power rail do not pose an electrical hazard to evacuating passengers, the guideway itself can function as an emergency walkway provided the vehicles have an emergency exit door on the end(s) of the vehicle.

4.3   Urban Insertion Impact

The insertion of a new system into the existing environment will be considered to identify technologies that do not require unacceptable changes to the existing infrastructure. The system should be compatible with the existing infrastructure and not adversely affect existing structures or induce objectionable noise or other emissions.

4.3.1 Acceptable Noise or Vibration Levels

The technology should not create unacceptable noise or vibration levels in the surrounding areas, especially in residential neighborhoods. For an at-grade or elevated system, noise standards of automated people mover systems are typically specified to not exceed 67-74 dBA for exterior noise and 74-79 dBA for interior noise for various defined conditions, such as stopped in a station, and speeds up to 30 mph. Structure-borne noise/vibration shall be imperceptible at or in surrounding buildings.

4.3.2 Visually Acceptable Infrastructure

The technology must be in keeping with, consider and compliment the urban setting, along rights of way, and into specific developments. The technology should be aesthetically pleasing, avoid unacceptable physical and visual impacts in vehicle and guideway designs, station appearances, and the maintenance facility presence.

4.3.3 Impacts to Existing Infrastructure

The technology should bring together the aesthetic and architectural themes throughout the entire alignment and not create any unacceptable impacts in any of the areas. Such other impacts could potentially include roads, surface parking, parks, waterways and utilities.

4.3.4 Fixed Facilities Space Requirements

Minimizing the space requirements of a technology's fixed facilities may help to decrease the capital cost. Stations, guideways, Maintenance & Storage Facility and other structures that are large may be difficult to negotiate the alignment and increase the challenge of acquiring the necessary real estate for that facility.

4.3.5 Contructability

The term "constructability" defines the ease and efficiency with which structures can be built. The more constructible a structure is, the more economical it will be.

4.4 Cost

The initial cost to implement a technology and the cost to operate and maintain that technology on an annual basis are key criteria for Owners in the selection of a technology. These criteria are discussed, and comparisons made.

4.4.1 Capital Cost Comparison

The capital cost of the initial system must be within an acceptable level and any expansion must be at a reasonable cost. The capital cost of the alternative alignments will vary with elevated/at grade guideway, specific site conditions, system length, use of alternative structures, fleet size, and many other variables. In lieu of project-specific capital cost estimates of the final alignment alternative, representative cost comparisons relative to each technology will be used.

4.4.2 Operations and Maintenance (O&M) Cost Comparison

This criterion evaluates the approximate range of annual cost to operate and maintain a technology. O&M cost varies based on the location and specific operating and maintenance plans for each alternative system. A representative cost comparison relative to each technology type will be used.

4.5 Technology Maturity

The technology must be developed to a state that it can be implemented with minimum technological, budget, and schedule risks. In selecting a technology for a new or replacement system, it is important to assess the developmental and implementation risk associated with the technology. Risk can be determined by examining such factors as the years of proven service in similar transit applications, the number of systems currently in operation, the reliability and safety records of the operational systems and the experience of the technology supplier.

4.5.1   Service-Proven Technology

For a technology to be considered service-proven, it must demonstrate operational service for a specified length of time at a specified Availability. These values are project and Owner specific. On occasion, a new technology can be deemed service proven if the individual components of that technology are service proven. Examples may include bogies, doors, dynamic signage, motors and switches.

4.5.2   Supply and Manufacturing Capability

This criterion evaluates the Supplier's capability to manufacture and supply the system if awarded the contract. Manufacturing a fleet of vehicles and meeting project deadlines could prove challenging for some suppliers and/or subcontractors who do not have ample production facilities and organization. This would also involve interrelated features such as managerial and engineering organization, testing facilities, etc.

4.5.3   Operations & Maintenance Capability

Many Suppliers are awarded contracts to operate and maintain the system they supply after implementation. Often these contracts are for five years with an option to renew. This criterion evaluates a Supplier's ability to operate and maintain the system and meet the Availability requirements specified.

4.5.4   Commercial Considerations

Commercial Considerations encompasses the business-related qualities of a technology supplier as demonstrated on previous transit projects and general understanding. A major transit project requires substantial capital and personnel resources. This includes the ability to secure bonds and insurance, as well as engineering, manufacturing, field organization and a parts, replacement and repair organization.

5.   ALIGNMENTS FOR TECHNOLOGY ASSESSMENT

Several alignment options were developed for the various technology categories.   However, for the Technology Assessment, one representative alignment was selected for the evaluation.   The following sections show which alignment was considered for each technology during the evaluation.   The entire collection of alignment options is located in Appendix 1.

5.1   Automated People Mover (APM)
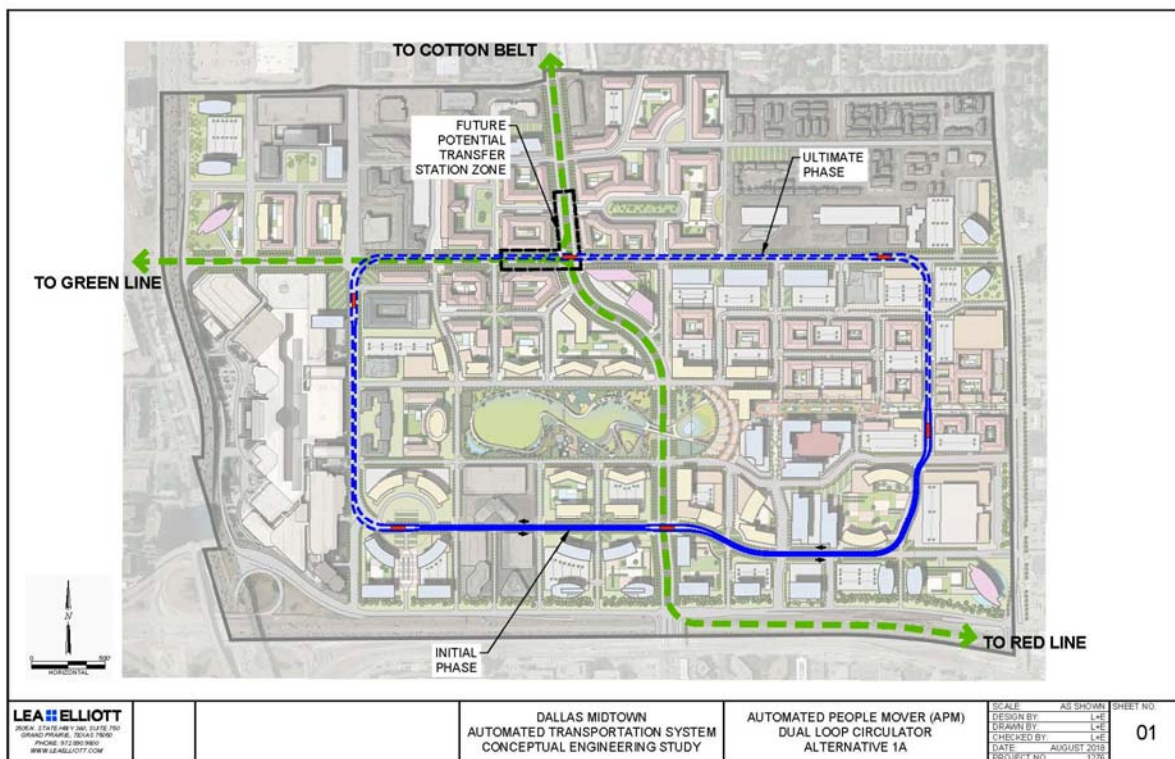
5.2   Monorail
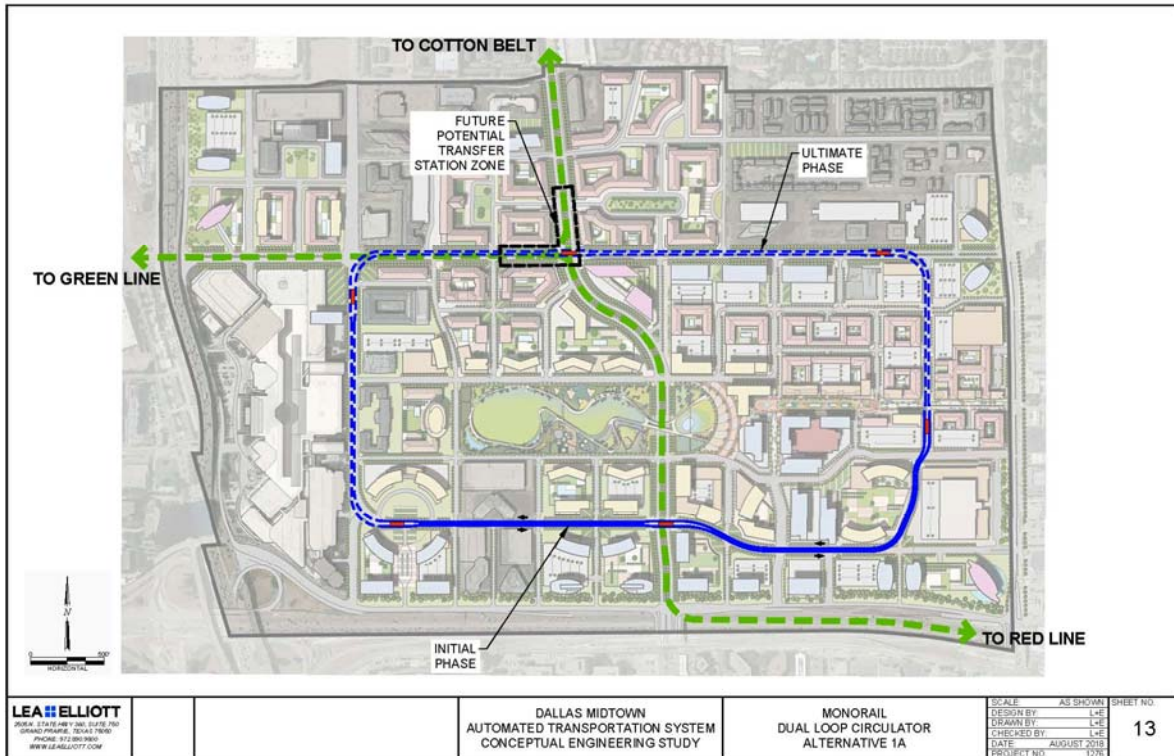
5.3 Cable-Propelled APM
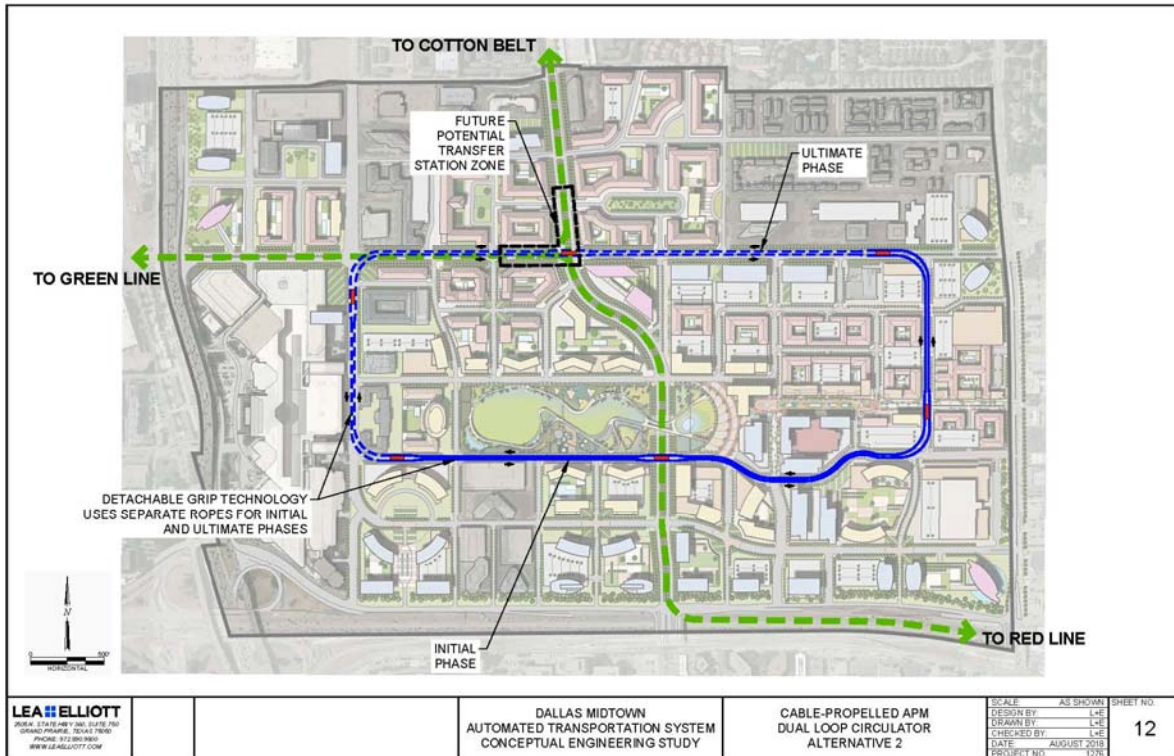
5.4 Gondola / Aerial Tramway
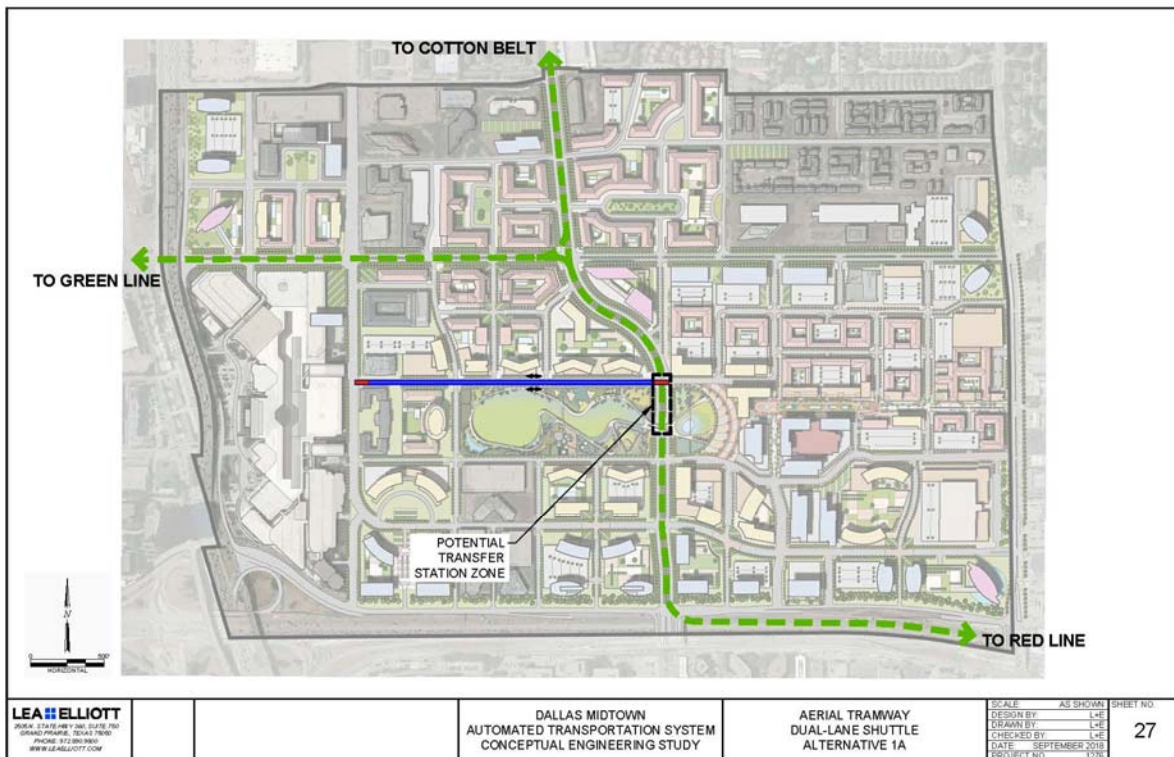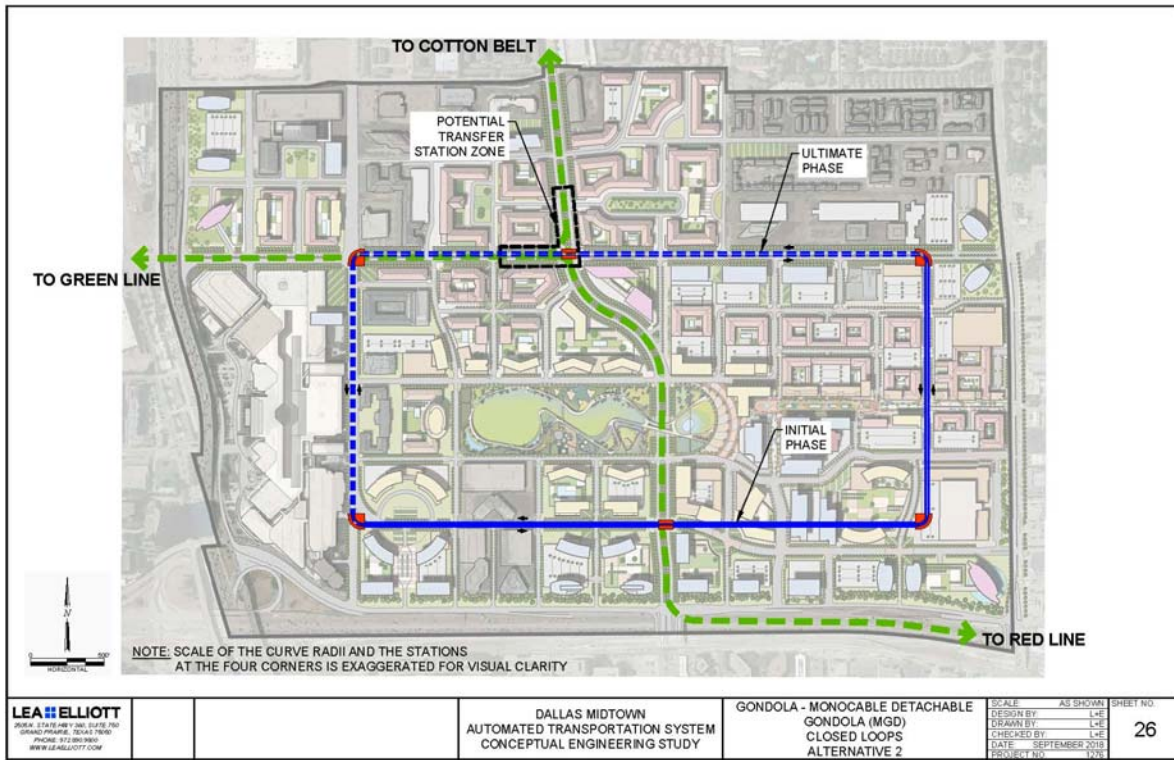
5.5 Personal Rapid Transit (PRT)
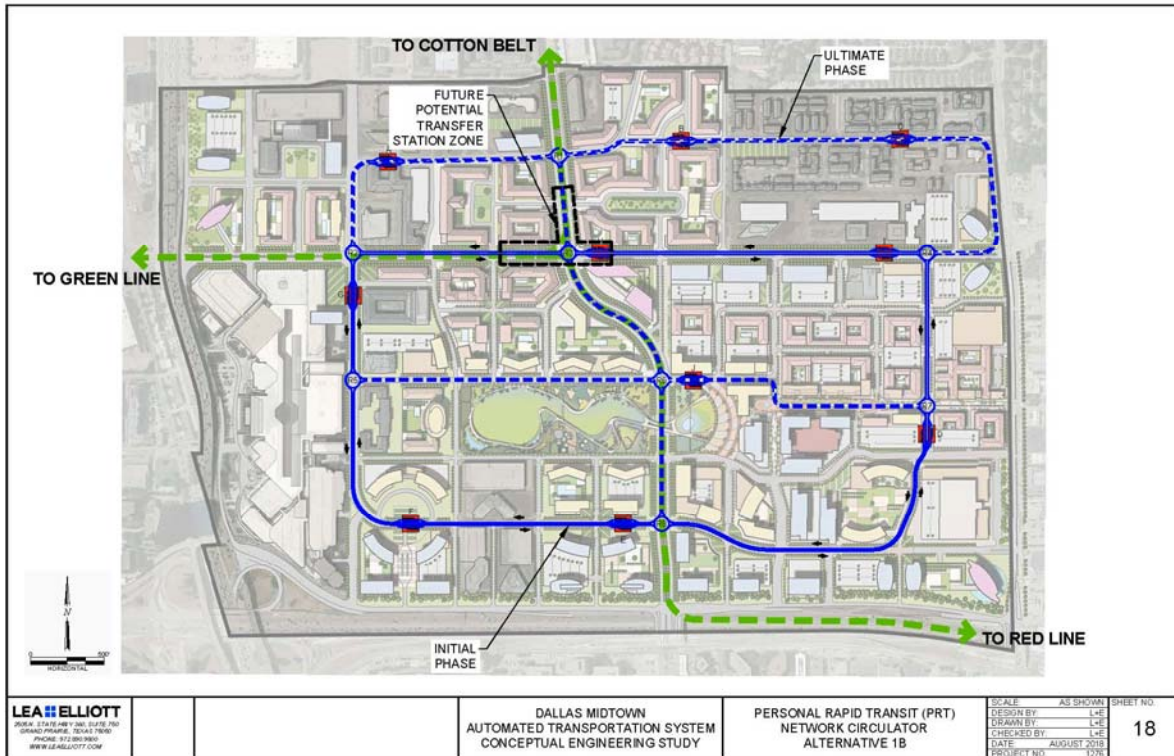
5.6   Group Rapid Transit (GRT)

LEA ELLIOTT
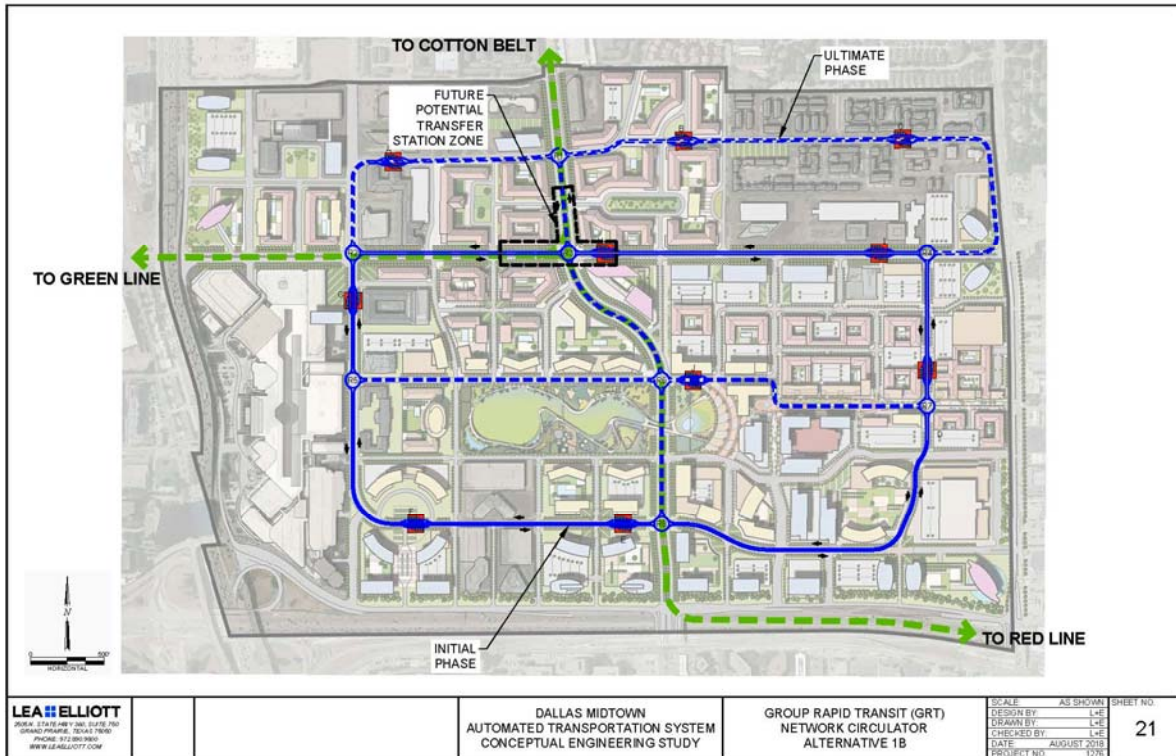
5.7 Automated Vehicle Shuttle / Autonomous Vehicle (AV)
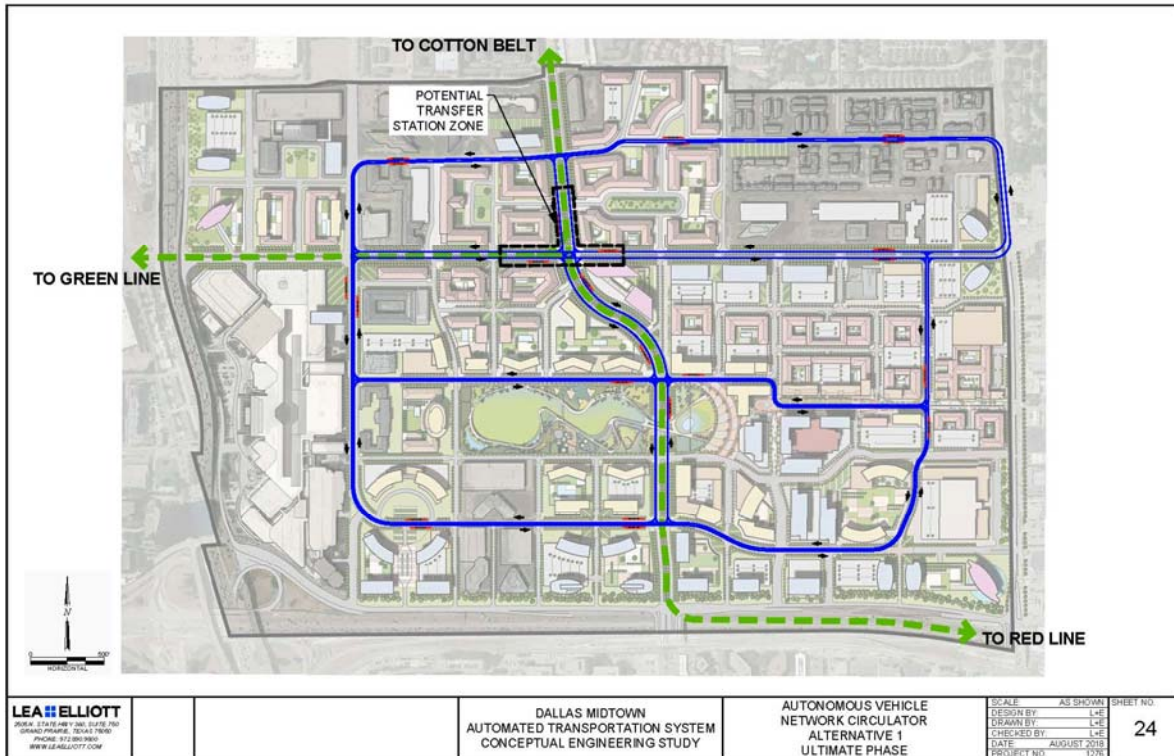
5.8 Automated Vehicle Fleet (AF)
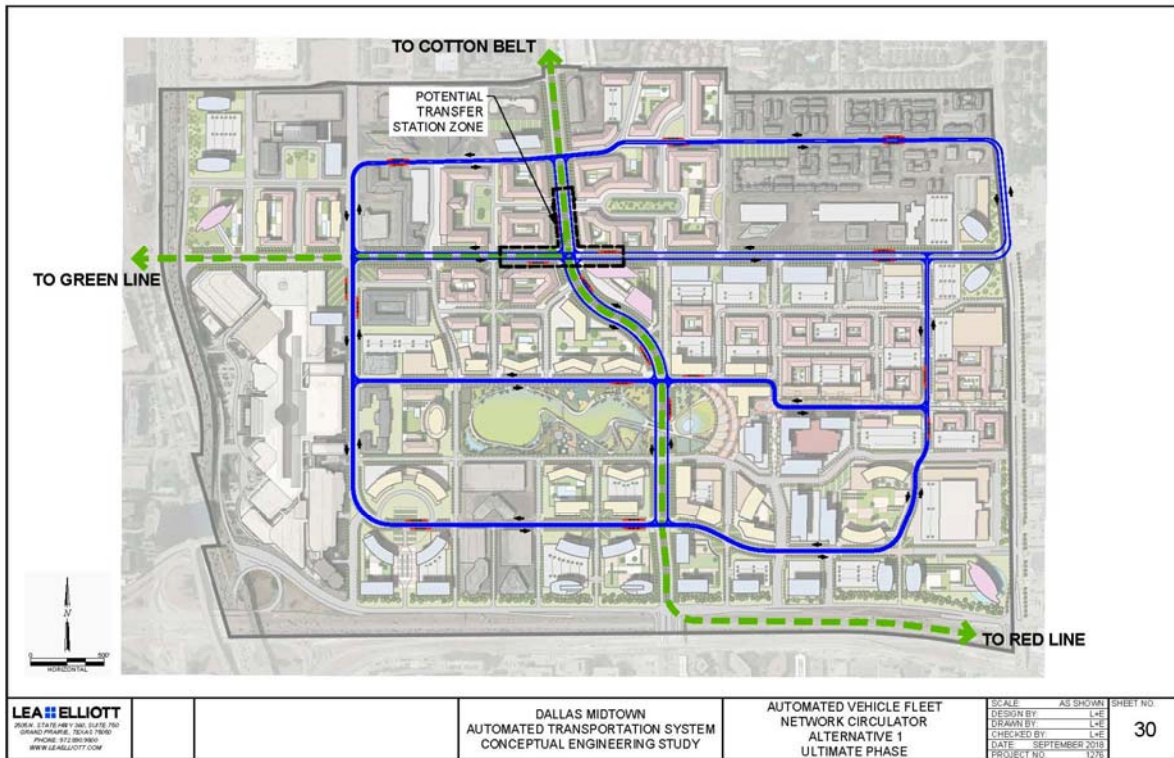
5.9   Combined Regional Connector / Internal Circulator

A key part of the Dallas Midtown Automated Transportation System Conceptual Engineering Study has been the development of alternative alignments/routes that could interconnect with regional transit connections, for various automated transit technologies appropriate for the scale and needs of the Dallas Midtown development. As the needs for internal circulation and regional transit connections are significantly different, the primary focus has been for separate transit systems for the internal circulation component and the regional transit connections. However, the project team has also considered a combined regional connector/internal circulator that would utilize a common technology and shared guideway. Figure 5.9-1 illustrates the configuration of the alignment and Figure 5.9-2 illustrates the separate routes that would operate along this alignment configuration.
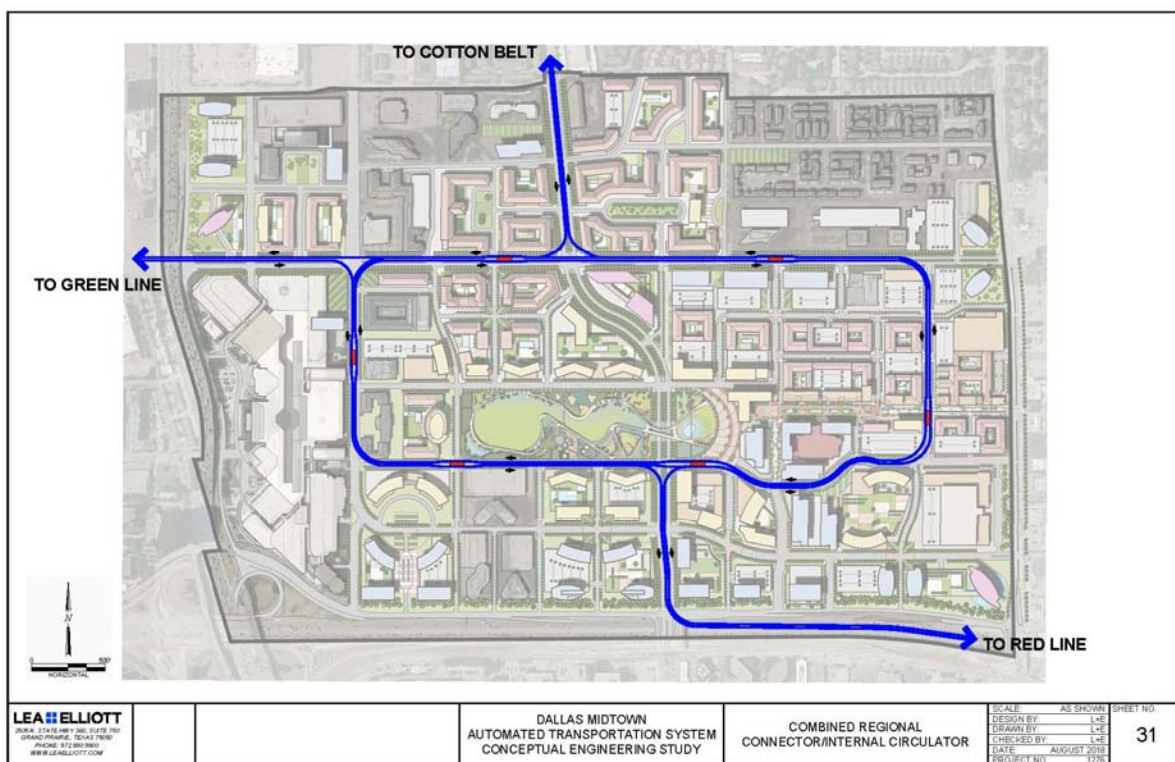
Figure 5.9-1 Combined Regional Connector / Internal Circulator Alignment Configuration
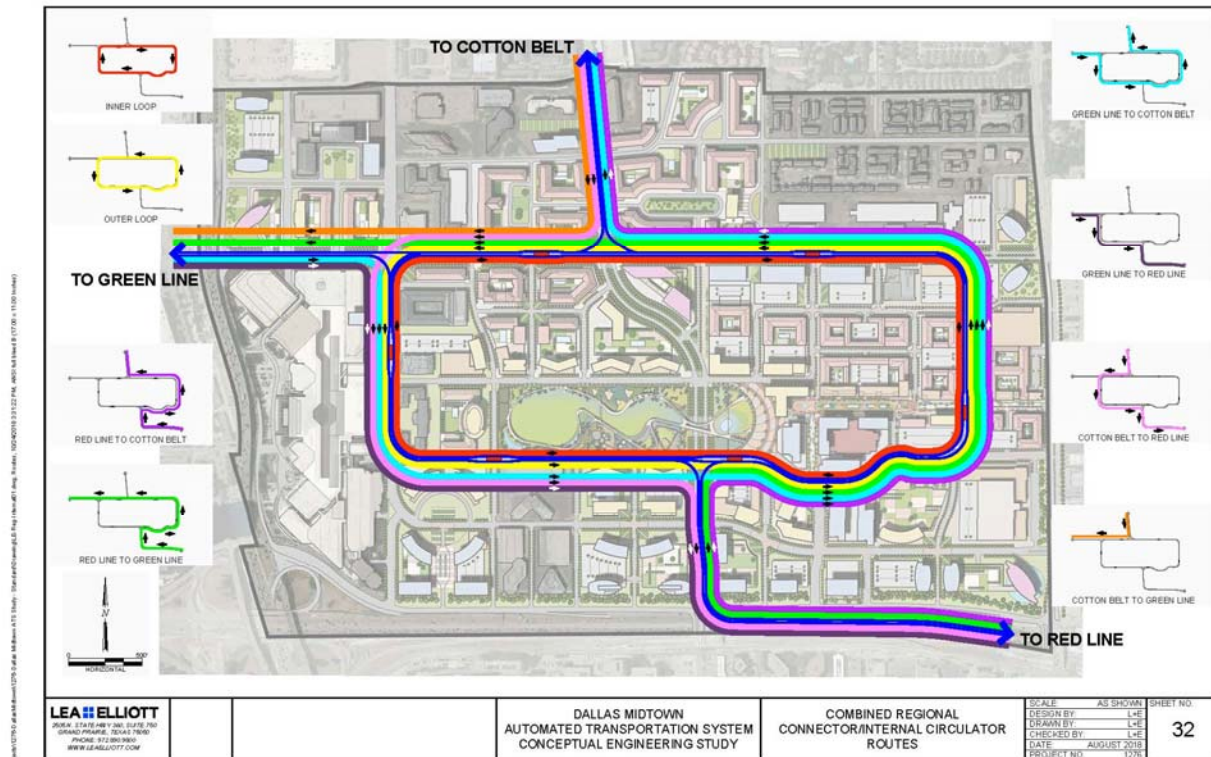
Figure 5.9-2 Combined Regional Connector / Internal Circulator Operational Routes

Figure 5.9-2 helps bring into focus several of the challenges that such a configuration would have.

Ridership Differences

The preliminary ridership for the internal circulation component indicates a peak hour link load of approximately 600 passengers per hour per direction (pphpd), whereas the peak hour link load for the regional connection component is 3,126 pphpd.

Synchronization Challenges

The outer loop route (in yellow) would have to be synchronized with three other regional connection routes in every segment, and the specific three routes vary within each segment of the internal circulation loops. It is extremely unlikely that all these routes would "naturally" synchronize and would likely require artificially induced operations such as slowing routes down or even holding vehicles longer than necessary at stations in order to achieve synchronization. If we were to assume an effective headway (of any trains from any of the four routes) of five minutes along the outer loop alignment, because it would involve four separate routes, each route would, at best, operate at 20-minute headways. Since each inbound and outbound regional connection route involves two separate routes, then they would need to alternate with each other and operate at an effective headway of 10 minutes between successive trains.

Impacts/Inefficiencies of ATS System and Fixed Facilities Requirements

Consider the inbound regional connection from the Red Line, with a ridership of 3,126 pphpd and effective headways of 10 minutes between successive trains. With 10-minute headways, the trains would have to carry 3,126 pphpd within 6 trains, which equates to 521 passengers per train. If an APM were used, it would require 6-car trains with an approximate length of 250 feet. The stations would need to be about 275 - 300 feet long to accommodate the required vertical circulation elements beyond the train length itself. This would mean that all the stations along the regional connection from the Red Line and all the stations within the outer loop alignment would need to be designed to accommodate 6-car trains and be about 275 – 300 feet long. The scale of these stations would be overwhelming for the scale of the development. Yet the internal circulation needs would only need to accommodate 600 pphpd, which could easily be met with 1-car trains with an approximate length of 40 feet and a total station length of about 55 - 65 feet, if the internal circulation is met with an automated transit system that is operationally separate from the regional connections.

Wayfinding

Another significant challenge is the complexity of wayfinding for users of a combined regional connector/internal circulator. Passengers waiting on the outer loop alignment platforms would need to get on the correct trains, having a choice of 4 different routes operating along the outer loop alignment. Passengers waiting on the regional connection platforms (away from the Midtown development) would also have a choice to make, depending upon their destination. From a level-of-service point of view, wayfinding would be very confusing to many and would likely result with some people taking the wrong train, which could have significant consequences for passengers leaving Midtown to transfer at the connection with the regional transit lines.

For the above reasons, it is not recommended that a combined regional connector/internal circulator be carried forward for further consideration.

6. Technology Assessment

6.1 Evaluation of Technology Categories

An evaluation matrix of the technologies presented in Section 3 was created to assess the ability of each technology to meet the criteria defined in Section 4 considering the alignments presented in Section 5. Table 6.1-1 shows the evaluation results using symbols.

Table 6.1-1 Evaluation Matrix

	Evaluation Criteria	Automated People Mover (APM)	Monorail	Cable-Propelled APM	Gondolas	Aerial Tramways	Personal Rapid Transit (PRT)	Group Rapid Transit (GRT)	Automated Vehicle Shuttles / Autonomous Vehicles (AV)	Automated Vehicle Fleet (AF)
Performance	Capacity (pphpd) / Ability to Meet Passenger Demand	●	●	●	■	●	X	●	▲	X
	Speed	●	●	●	▲	●	●	●	▲	●
	Geometry / Configuration	▲	▲	▲	■	■	●	●	●	●
	Expandability	▲	▲	■	X	X	▲	▲	●	●
	Operating Range	●	●	●	●	●	▲	▲	▲	▲
	Failure Management / Availability	●	●	▲	■	■	▲	▲	▲	▲
Level of Service	Trip Times	●	●	●	▲	●	●	●	▲	●
	Headways / Wait Time	●	●	●	●	●	●	●	●	●
	Minimal Transfers	●	●	●	●	●	●	●	●	●
	Safety	●	●	●	■	▲	●	●	▲	▲
Urban Insertion Impact	Acceptable Noise or Vibration Levels	●	●	●	●	●	●	●	●	●
	Visually Acceptable Infrastructure	▲	●	●	▲	■	●	●	●	●
	Impacts to Existing Infrastructure	▲	▲	▲	●	▲	●	●	▲	●
	Fixed Facilities Space Requirements	▲	▲	▲	●	▲	●	●	●	●
	Constructability	▲	▲	▲	▲	▲	▲	▲	●	●
Cost	Capital Cost Comparison	▲	■	▲	▲	▲	●	●	●	●
	O&M Cost Comparison	▲	■	▲	▲	▲	▲	▲	●	●
Technology Maturity	Service-Proven Technology	●	●	●	●	●	●	▲	■	■
	Supply and Manufacturing Capability	●	●	●	●	●	▲	▲	▲	▲
	Operations & Maintenance Capability	●	●	●	●	●	▲	▲	▲	▲
	Commercial Considerations	●	●	●	●	●	●	●	▲	●

● - Candidate technology provides lower risk for evaluation criterion

▲ - Candidate technology provides moderate risk for evaluation criterion

■ - Candidate technology provides higher risk for evaluation criterion

X - Candidate technology cannot meet evaluation criteria

6.2   Assessment Findings

Significant findings and differentiators identified in Table 6.1-1 are discussed below.   Abbreviations are summarized here:

APM = Automated People Mover

Cable = Cable-Propelled APMs

G/AT = Gondolas / Aerial Tramways

PRT = Personal Rapid Transit

GRT = Group Rapid Transit

AV = Automated Vehicle Shuttles / Autonomous Vehicles

AF = Automated Vehicle Fleet

Performance (reference Section 4.1)

The Performance criteria evaluates the ability of a technology to accomplish the basic functions and purpose of a transit system – to safely and reliably transport all passengers in comfort and to minimize service interruptions and trip delays.

Capacity (pphpd) / Ability to Meet Passenger Demand - Gondolas present a higher risk due to their small cabs. In addition, due to their even smaller cabs, PRT and AF cannot meet the requirements, which is considered to be a fatal flaw.

Speed - All technologies score well to reasonably well.

Geometry / Configuration - G/AT scores low due to the challenge of easily turning corners without substantial infrastructure (towers, stations, etc.). APM and Monorail score lower for the large infrastructure requirements.

Expandability – AV/AF score well due to their lack of guideway. APM, Monorail, Cable, PRT and GRT score lower due to their need for additional guideway for expansion. Cable scored slightly lower than the rest due to the need for an additional and/or new haul rope. G/AT cannot be readily expanded except by adding a new system so fail to meet this criterion.

Operating Range – Most technologies have a continuous power source and, therefore, score well. The battery-powered technologies score lower.

Failure Management / Availability – APM and Monorail score well as they deploy Maintenance and Recovery Vehicles (MRV) to recover disabled vehicles and initiate run-around modes using crossovers to maintain diminished operations. PRT, GRT, AV and AF have a less defined failure management plan with the latter two utilizing traditional auto recovery methods. G/AT score lowest due to the difficulty of emergency evacuation. Often the cabs are too high off the ground for rescue crews to reach.

Level of Service (reference Section 4.2)

The criteria of Level of Service (LOS), as applied for this evaluation, are to provide an indication of the convenience, experience and transit service provided to a passenger while using a transit technology.

Trip Times - All technologies score well to reasonably well. Gondolas score slightly lower due to the boarding process. AVs score lower due to their low speed.

Headways / Wait Time - All technologies score well and provide a good LOS with short headways and low average wait times.

Minimal Transfers - All technologies score well and require only one transfer.

Safety – The AV and AF technologies are assumed to operate predominantly at-grade and will likely interact with vehicular and pedestrian traffic in places. All other candidate technologies are assumed to operate within the confines of separated right of way, which prevent potential interaction with roadway and pedestrian traffic. These latter technologies better meet the goals of this key criterion in that the exclusivity of the right-of-way separates transit riders and transit vehicles from traffic accidents as well as protecting vulnerable pedestrians and vehicles from transit vehicles.

Evacuating passengers from Gondolas and Aerial Tramways presents more of a challenge as these technologies do not have emergency walkways and are frequently too high to reach from the ground. Some systems provide an emergency access cable and emergency recovery vehicle. In evacuation of large aerial tramways, one vehicle can be used as a recovery vehicle with a platform bridge between the two cabins.

APM, Monorail, Cable, PRT and GRT score high as they operate in a dedicated, restricted Right-Of-Way (ROW). AV/AF score lower as they run at-grade and can operate in mixed traffic in close proximity to pedestrians. G/AT scores lowest due to the difficulty of emergency evacuation and their susceptibility to high winds.

Urban Insertion Impact (reference Section 4.3)

The criteria of Insertion Impact evaluate how well a supplier's technology can be adapted to the Dallas Midtown environment without requiring unacceptable changes to the existing infrastructure. The system should be compatible with the existing infrastructure and not adversely affect existing structures or induce objectionable noise or other emissions. These criteria focus on spatial impacts.

Acceptable Noise or Vibration Levels - All technologies score well. It is noted that the Aeromovel technology runs on steel wheels, but the additional noise generated seems to be at reasonable levels.

Visually Acceptable Infrastructure – Monorail, Cable, PRT and GRT score high due to their less obtrusive guideway designs. AV and AF score high as they do not require a guideway. G/AF scores lowest due to the need for large towers or columns. APM scores lower due to their large guideway infrastructure.

Impacts to Existing Infrastructure – APM, Monorail, Cable and AT score lower due to larger minimum curve radii which could impact alignments and existing structures. All other technologies score well.

Fixed Facilities Space Requirements – APM, Monorail and Cable score lower due to the need for larger Maintenance and Storage Facilities (MSF). AT scores lower due to the need for large towers.

Cost (reference Section 4.4)

Two types of cost comparisons were considered in these criteria: Capital Cost Comparison and Operations and Maintenance (O&M) Cost Comparison.

Capital Cost Comparison - In general, Monorail is projected to have higher capital costs than the other technologies. APM, Cable and G/AT fall in the middle range with PRT, GRT, AV and AF expected to have the lowest capital cost.

O&M Cost Comparison – PRT, GRT, AV and AF score highest as they utilize many off-the-shelf parts and have smaller vehicles. AV and AF also do not require a guideway infrastructure including power rail and switches. Some PRT and GRT technologies utilize a passive guideway. APM and Cable have historically offered cost advantages over Monorail. In addition, Cable systems have less to maintain on the vehicles as most of the maintenance is on the drive machine, tensioner and bull wheel.

The ranges for all technologies overlap and costs at this stage in the project should not be a differentiating factor in proceeding with any of the viable technologies. The Capital Cost and the O&M Cost at this point should only be used as another level of comparison as part of the overall assessment. Market conditions, competition among suppliers and other factors will affect the cost during the procurement of a system.

Technology Maturity (reference Section 4.5)

The Technology Maturity criteria are used to indicate the level of capability and performance that technology suppliers have demonstrated in delivering and operating transit systems of similar scale and complexity to the Dallas Midtown project.

Service-Proven Technology – APM, Monorail, Cable, G/AT and PRT are considered service-proven as they all have systems that have been running for years. Siemens might present a moderate risk primarily because the Siemens Airval and Cityval are a design evolution from earlier generation vehicles and utilize a new guidance system, but a fully implemented Airval or Cityval has not yet been operational in revenue service. GRT, AV and AF score lowest as they are in development and/or demonstration phases.

Supply and Manufacturing Capability - APM, Monorail, Cable, G/AT score well as these technologies are owned by large corporations with proven track records of providing large transit systems in critical locations. PRT, GRT, AV and AF score lower as they have not implemented large systems.

Operations & Maintenance Capability – Generally, the suppliers score the same here as above and are forecast to have similar O&M capabilities. Because the Siemens Airval and Cityval are a design evolution from earlier generation vehicles and utilize a new guidance system, but a fully implemented Airval or Cityval has not yet been operational in revenue service, they have not yet demonstrated their operations and maintenance capability for these new designs, and for that reason, the Siemens technologies present a moderate risk for these evaluation criteria.

Commercial Considerations - Commercial Considerations involves the ability to acquire bonds, insurance, and the financial capacity for a large project as well as the resources to design, manufacture, assemble, install, test, and deployment of engineering, maintenance, field, parts replacement and repair organizations. APM, Monorail, Cable, G/AT PRT, GRT and AF and their parent organizations have the ability to accomplish these tasks and are expected to devote adequate resources and expertise to fulfilling both commercial and technical requirements. AV scores lower as, although they have large, well-known investor corporations, they are young firms with many years ahead left to prove their stability.

7.   Conclusions

This report includes a presentation of the various technologies to be considered for the Dallas Midtown Study. The technologies that have been considered are:

- Automated People Mover (APM)
- Monorail
- Cable-Propelled APM
- Gondolas / Aerial Tramways
- Personal Rapid Transit (PRT)
- Group Rapid Transit (GRT)
- Automated Vehicle Shuttles / Autonomous Vehicles
- Automated Vehicle Fleet

Characteristics of these technologies have been described, along with examples of evaluation criteria.

From the general technology categories considered, the technology assessment has identified the applicable technology categories to be APM, Monorail, Cable-Propelled APM, Group Rapid Transit (GRT) and Automated Vehicle Shuttles / Autonomous Vehicles (AV). Representative suppliers of these technologies are as follows:

- Automated People Mover (APM)
    - Aeromovel
    - Bombardier INNOVIA APM 200/300
    - IHI Niigata
    - Mitsubishi Crystal Mover
    - Schwager Davis (SDI) UniTrak
    - Siemens Cityval
    - Woojin K-AGT
- Monorail
    - Bombardier INNOVIA Monorail 200/300
    - Hitachi Standard
    - Hitachi Small
    - Scomi
- Cable-Propelled APM
    - Doppelmayr Cable Car - Cable Liner Shuttle
    - Leitner-Poma Mini Metro
- Group Rapid Transit (GRT)
    - 2getthere
    - Vectus
- Automated Vehicle Shuttle / Autonomous Vehicle (AV)
    - Easy Mile EZ10
    - Local Motors Olli
    - NAVYA AUTONOM SHUTTLE (ARMA)

It is not recommended that a specific supplier be selected at this time based upon our evaluation, but rather, it is recommended that these technologies be carried forward into the Conceptual Design Analysis (Task 5).

Based upon input received during the Dallas Midtown Conceptual Design Analysis meeting held on September 7, 2018, the five applicable technology categories are consolidated into the following three technology groups for the Conceptual Design Analysis:

1. Automated People Mover/Monorail

2. Cable-Propelled APM

3. Group Rapid Transit/Automated Vehicle Shuttles

8. Appendices

Appendix 1: Alignments for Technology Assessment

TO COTTON BELT

FUTURE
POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

TO RED LINE

INITIAL
PHASE

N

0   500'
HORIZONTAL

LEA ELLIOTT

2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
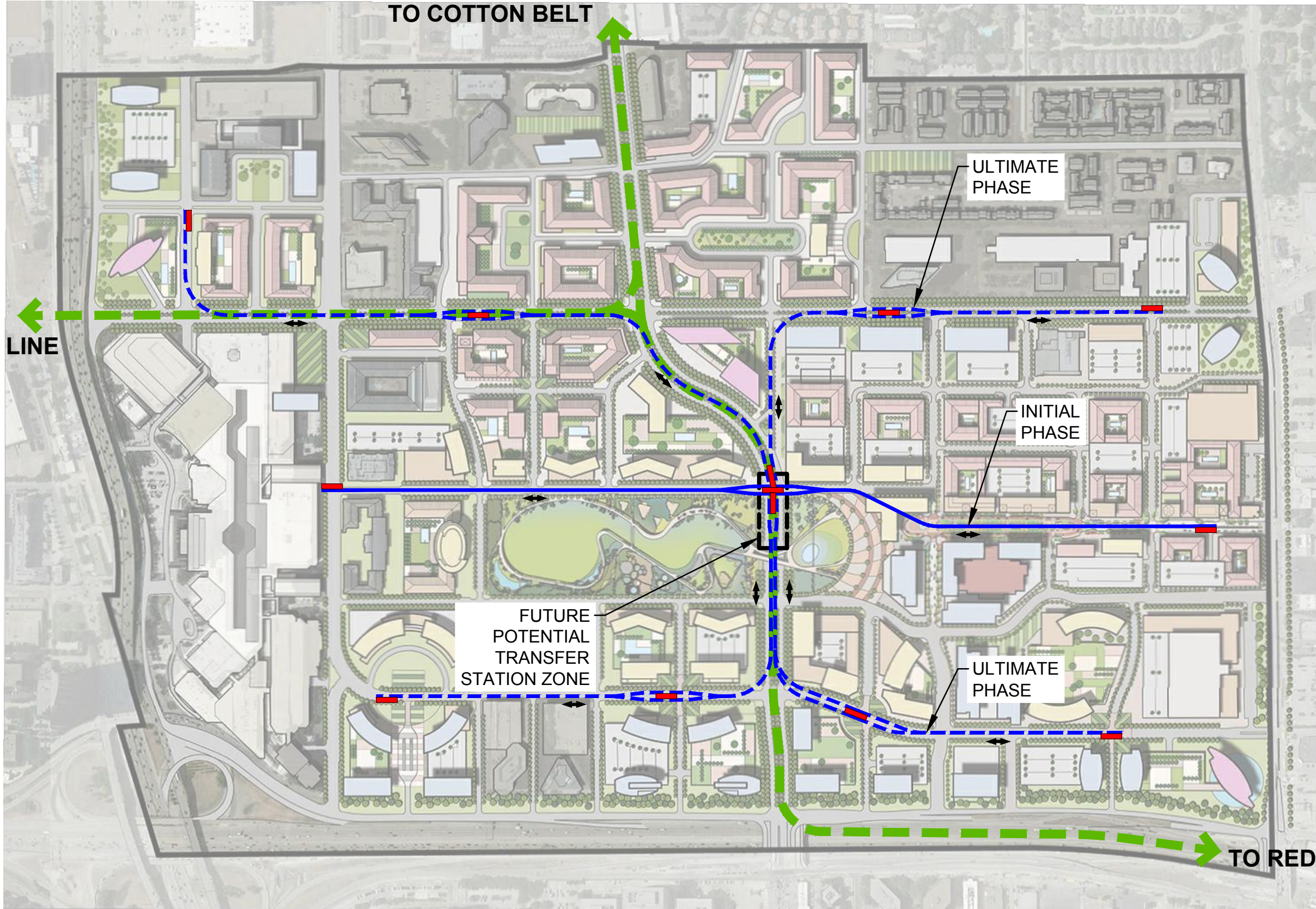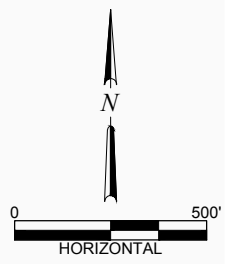AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
ALTERNATIVE 1A

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	01
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

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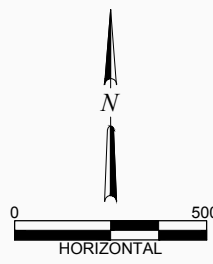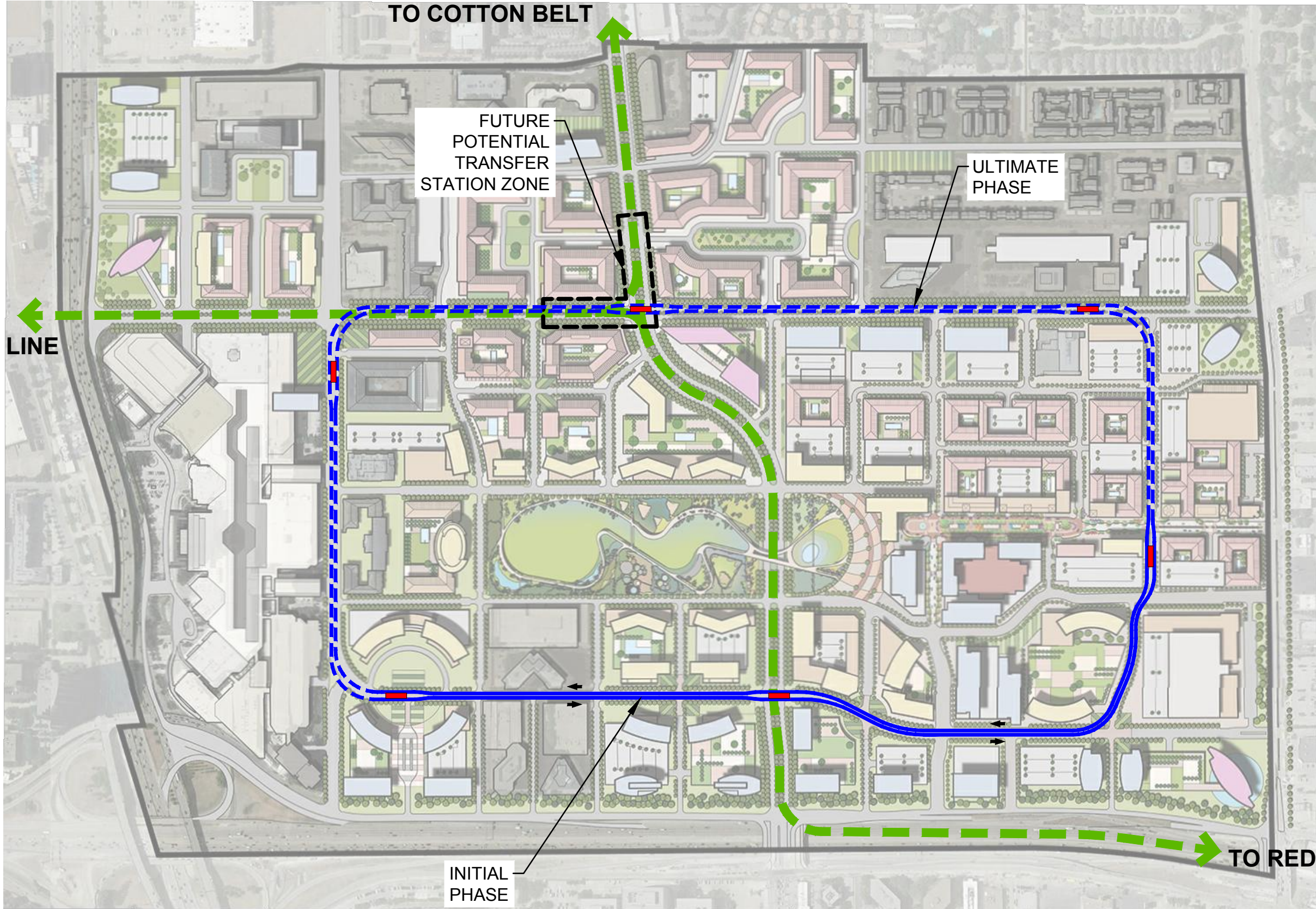
TO COTTON BELT

FUTURE
POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

TO RED LINE

INITIAL
PHASE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

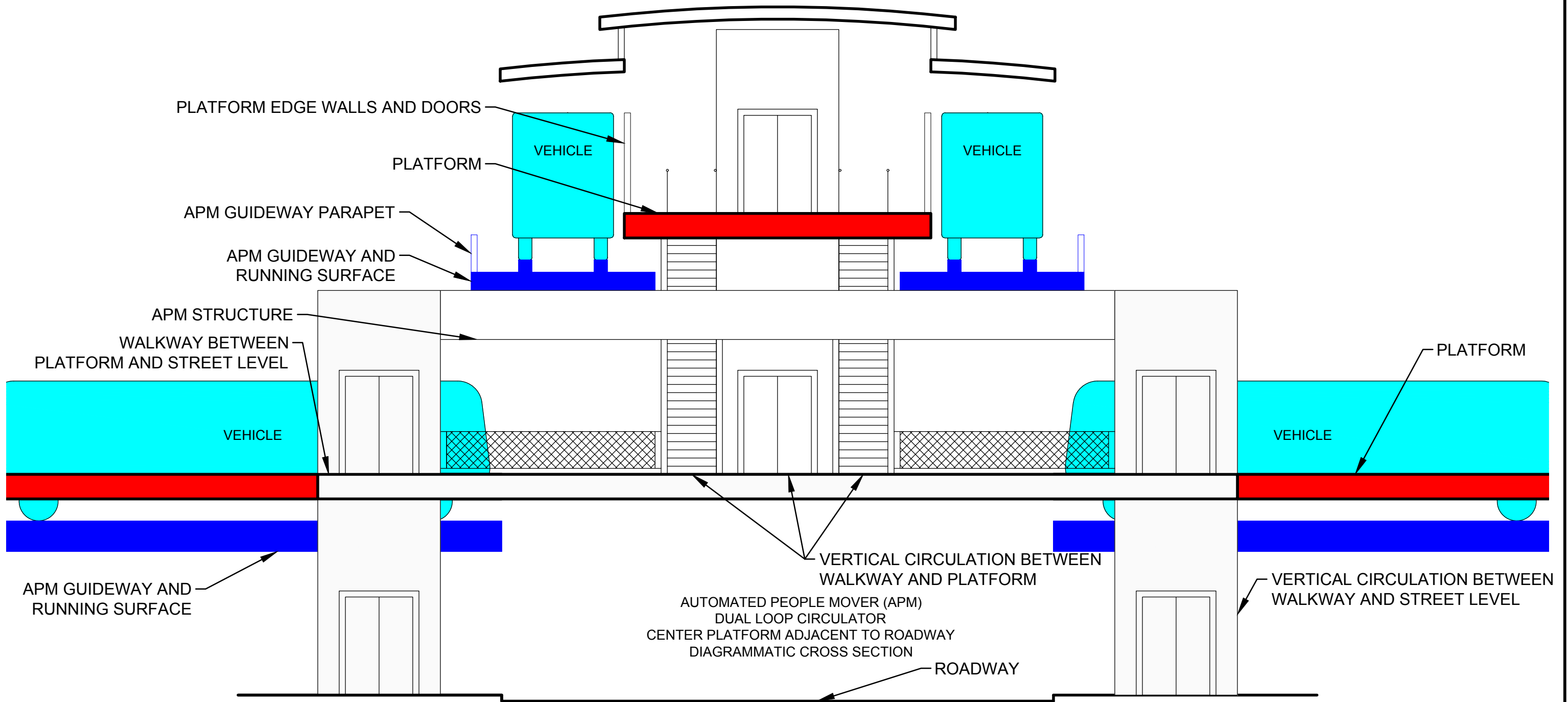DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
ALTERNATIVE 1B

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**02**
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

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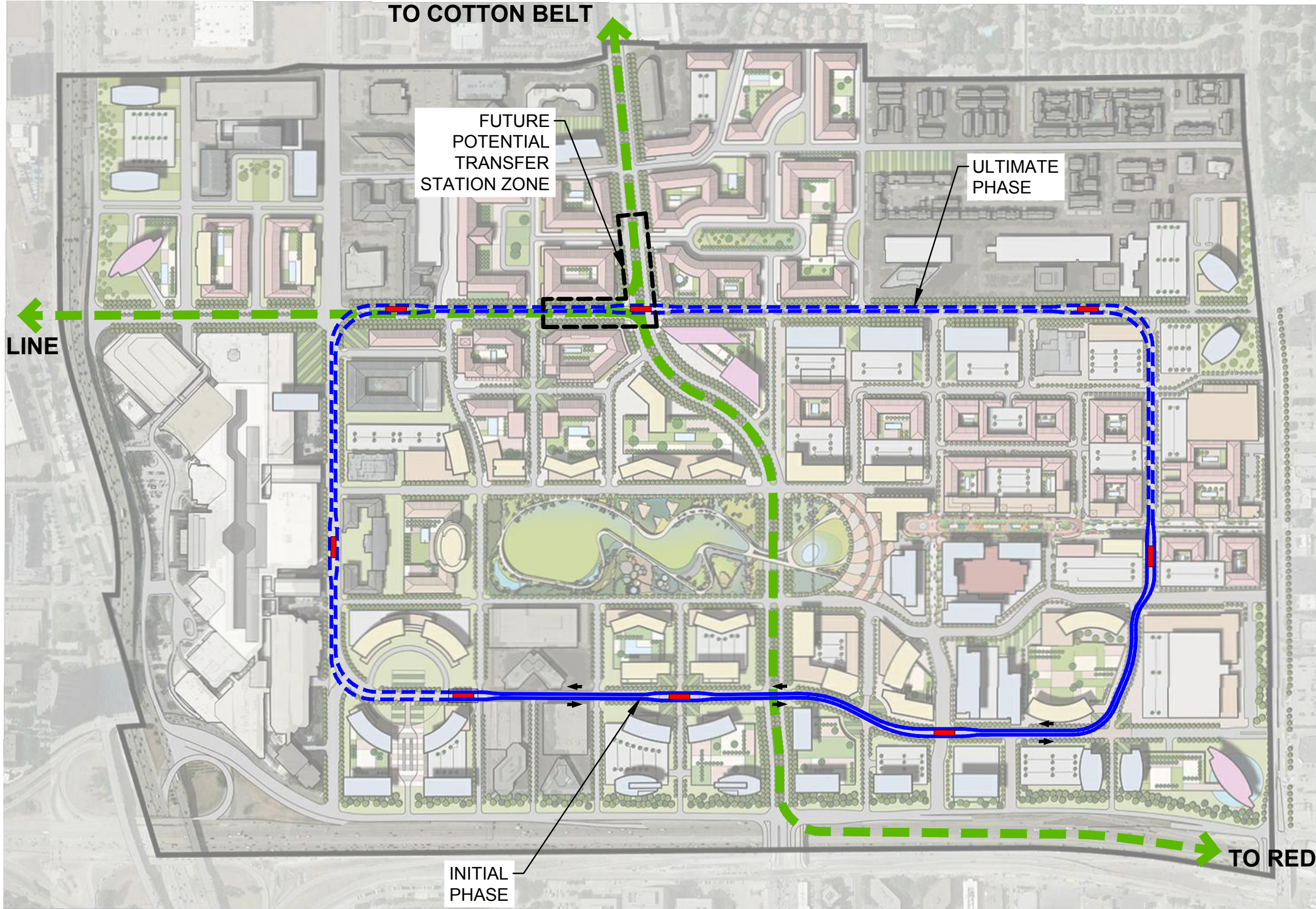
TO COTTON BELT

FUTURE
POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

TO RED LINE

INITIAL
PHASE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

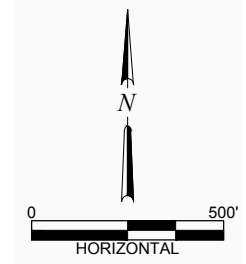DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
ALTERNATIVE 2A

SCALE:	AS SHOWN	SHEET NO.
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CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

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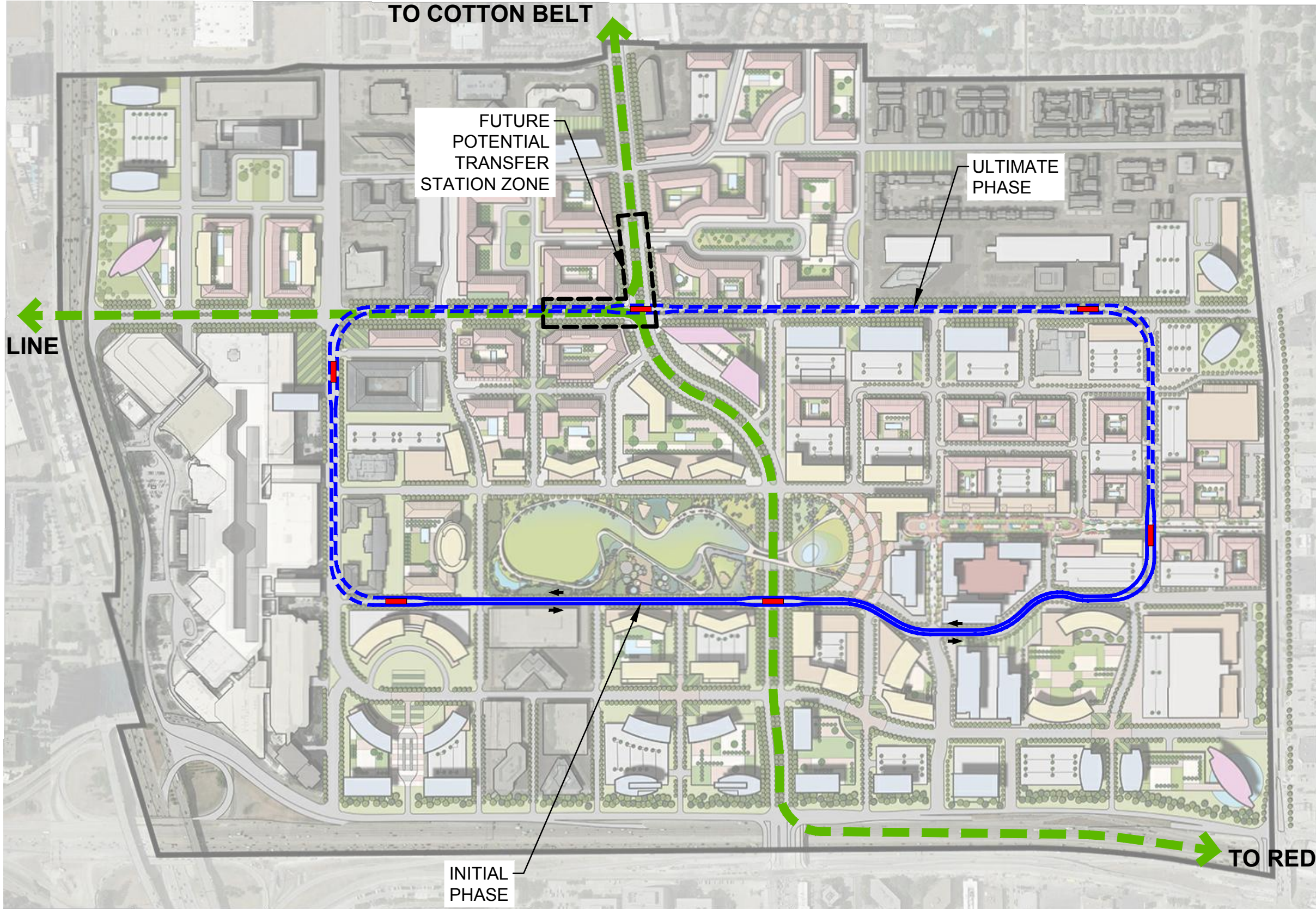
TO COTTON BELT

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

TO GREEN LINE

TO RED LINE

INITIAL PHASE

N

0   500'
HORIZONTAL

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-DualLoop02b-initial.dwg, B-Size, 10/24/2018 3:26:43 PM, ANSI full bleed B (17.00 x 11.00 Inches)

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2505 N. STATE HWY 360, SUITE 750
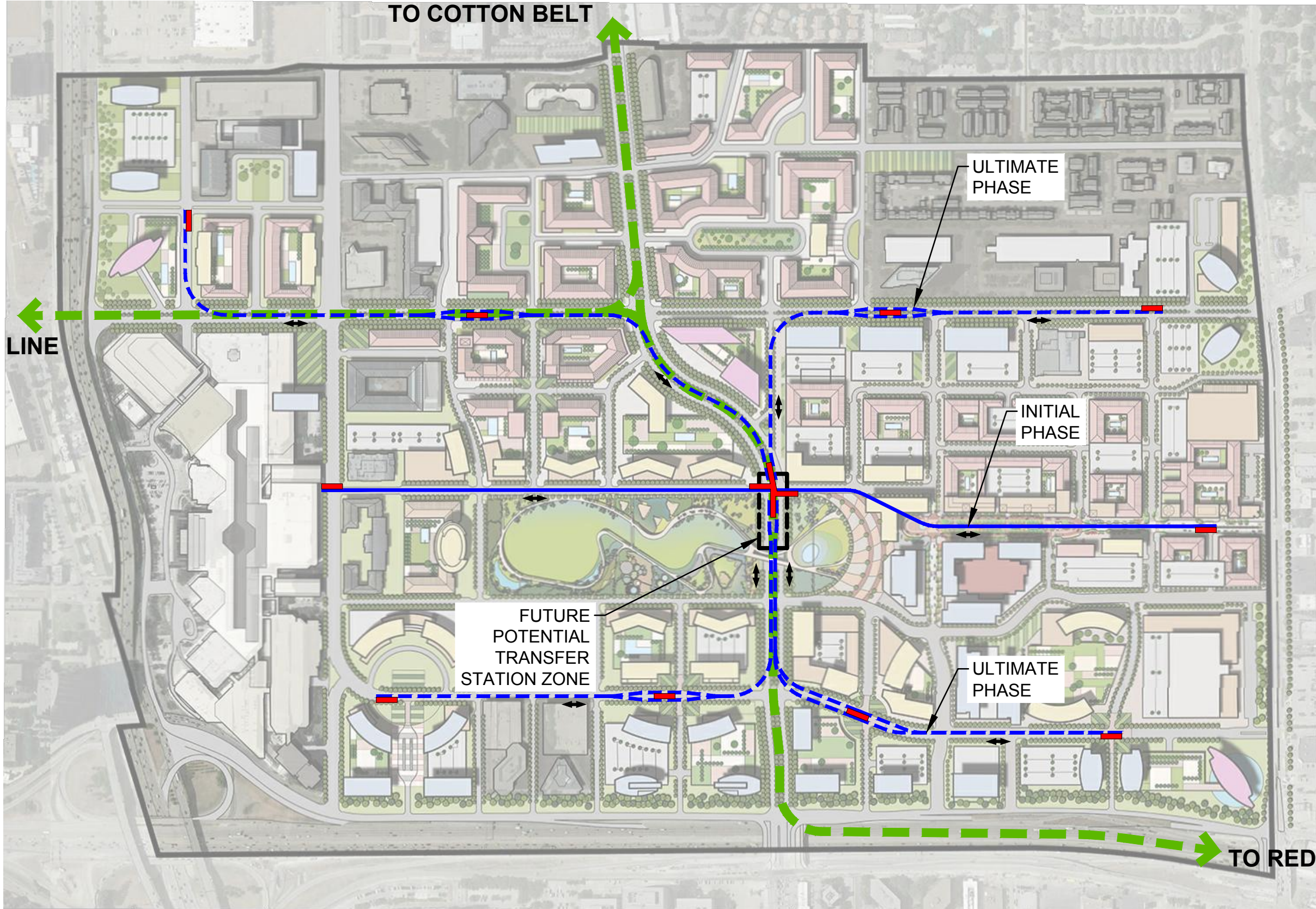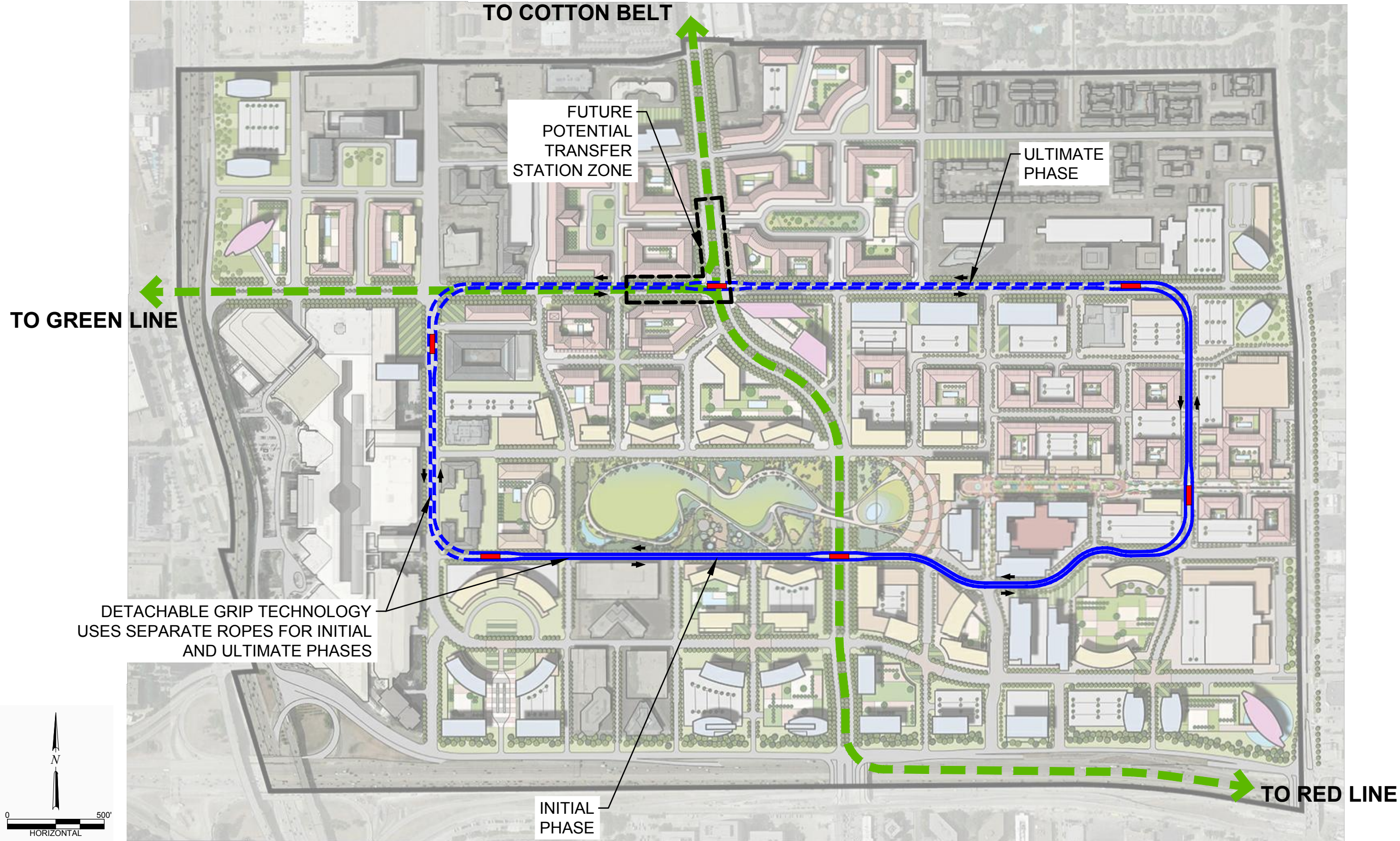GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
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DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
ALTERNATIVE 2B

SCALE:	AS SHOWN	SHEET NO.
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DATE:	AUGUST 2018	
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PLATFORM EDGE WALLS AND DOORS

VEHICLE

VEHICLE

PLATFORM

APM GUIDEWAY PARAPET

APM GUIDEWAY AND
RUNNING SURFACE

APM STRUCTURE

WALKWAY BETWEEN
PLATFORM AND STREET LEVEL

VERTICAL CIRCULATION BETWEEN
WALKWAY AND PLATFORM

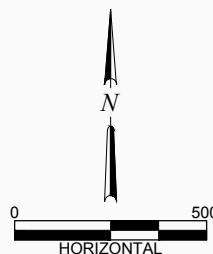VERTICAL CIRCULATION BETWEEN
WALKWAY AND STREET LEVEL

ROADWAY
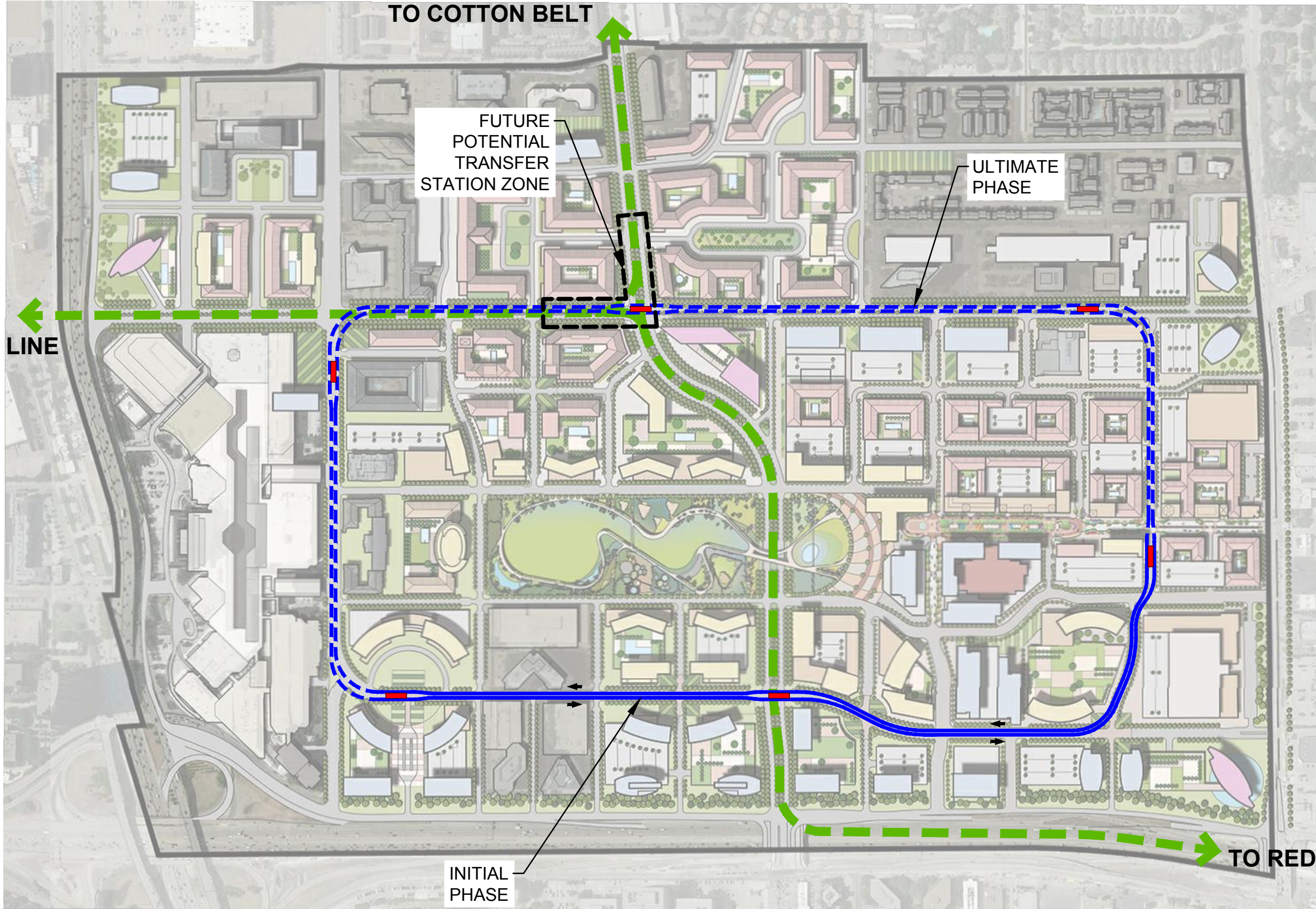
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GRAND PRAIRIE, TEXAS 75050
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DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
CENTER PLATFORM OVER ROADWAY
DIAGRAMMATIC CROSS SECTION

SCALE:	NOT TO SCALE	SHEET NO.
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CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

PLATFORM EDGE WALLS AND DOORS

WALKWAY BETWEEN PLATFORM AND STREET LEVEL

PLATFORM

APM GUIDEWAY AND RUNNING SURFACE

APM STRUCTURE

VERTICAL CIRCULATION BETWEEN WALKWAY AND STREET LEVEL

ROADWAY

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
SIDE PLATFORMS OVER ROADWAY
DIAGRAMMATIC CROSS SECTION

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CHECKED BY:	L+E	
DATE:	AUGUST 2018	
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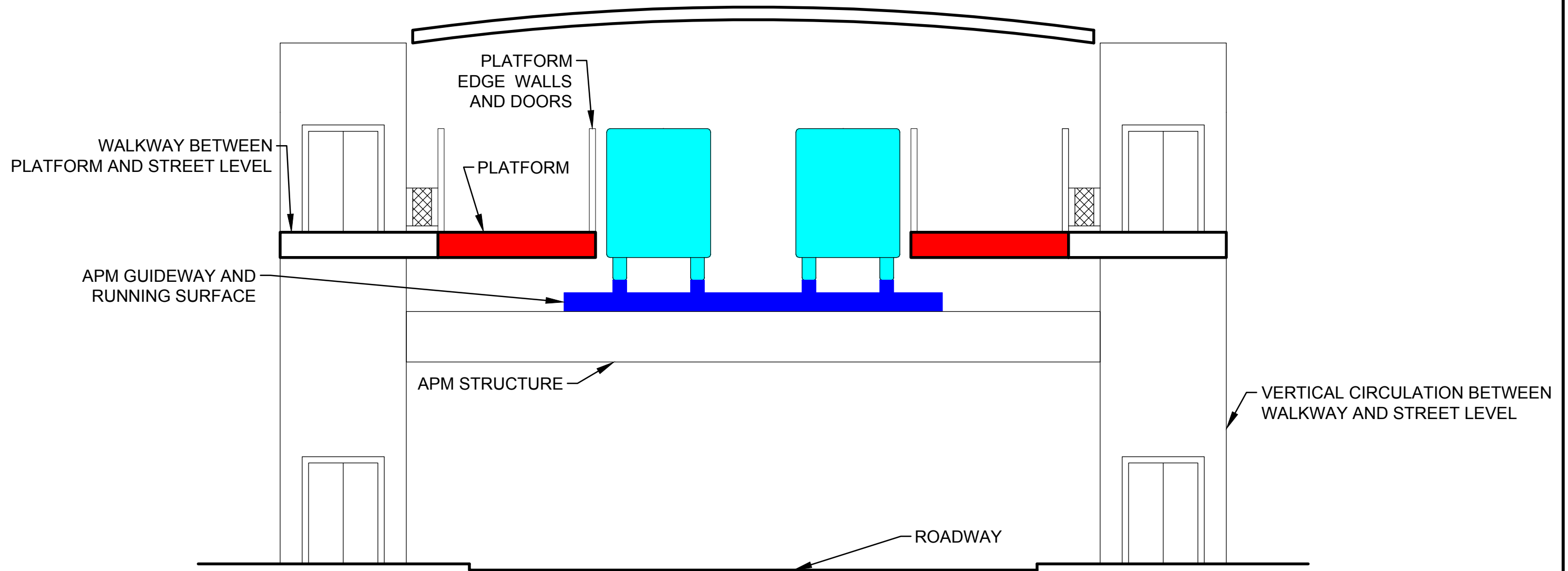
FREESTANDING STATION STRUCTURE OR
INTEGRATED INTO BUILDING OR PARKING GARAGE

PLATFORM EDGE WALLS AND DOORS

VEHICLE

VEHICLE

PLATFORM

APM GUIDEWAY PARAPET

APM GUIDEWAY AND
RUNNING SURFACE

APM STRUCTURE

VERTICAL CIRCULATION BETWEEN
PLATFORM AND STREET LEVEL

ROADWAY

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GRAND PRAIRIE, TEXAS 75050
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| DALLAS MIDTOWN AUTOMATED TRANSPORTATION SYSTEM CONCEPTUAL ENGINEERING STUDY | AUTOMATED PEOPLE MOVER (APM) DUAL LOOP CIRCULATOR CENTER PLATFORM ADJACENT TO ROADWAY DIAGRAMMATIC CROSS SECTION |

SCALE: NOT TO SCALE	SHEET NO.
DESIGN BY: L+E	
DRAWN BY: L+E	07
CHECKED BY: L+E	
DATE: AUGUST 2018	
PROJECT NO. 1276	

TO COTTON BELT

TO GREEN LINE

TO RED LINE

ULTIMATE PHASE

INITIAL PHASE

FUTURE POTENTIAL TRANSFER STATION ZONE
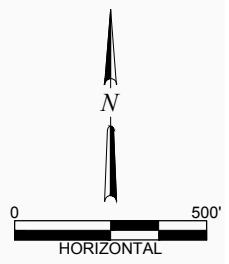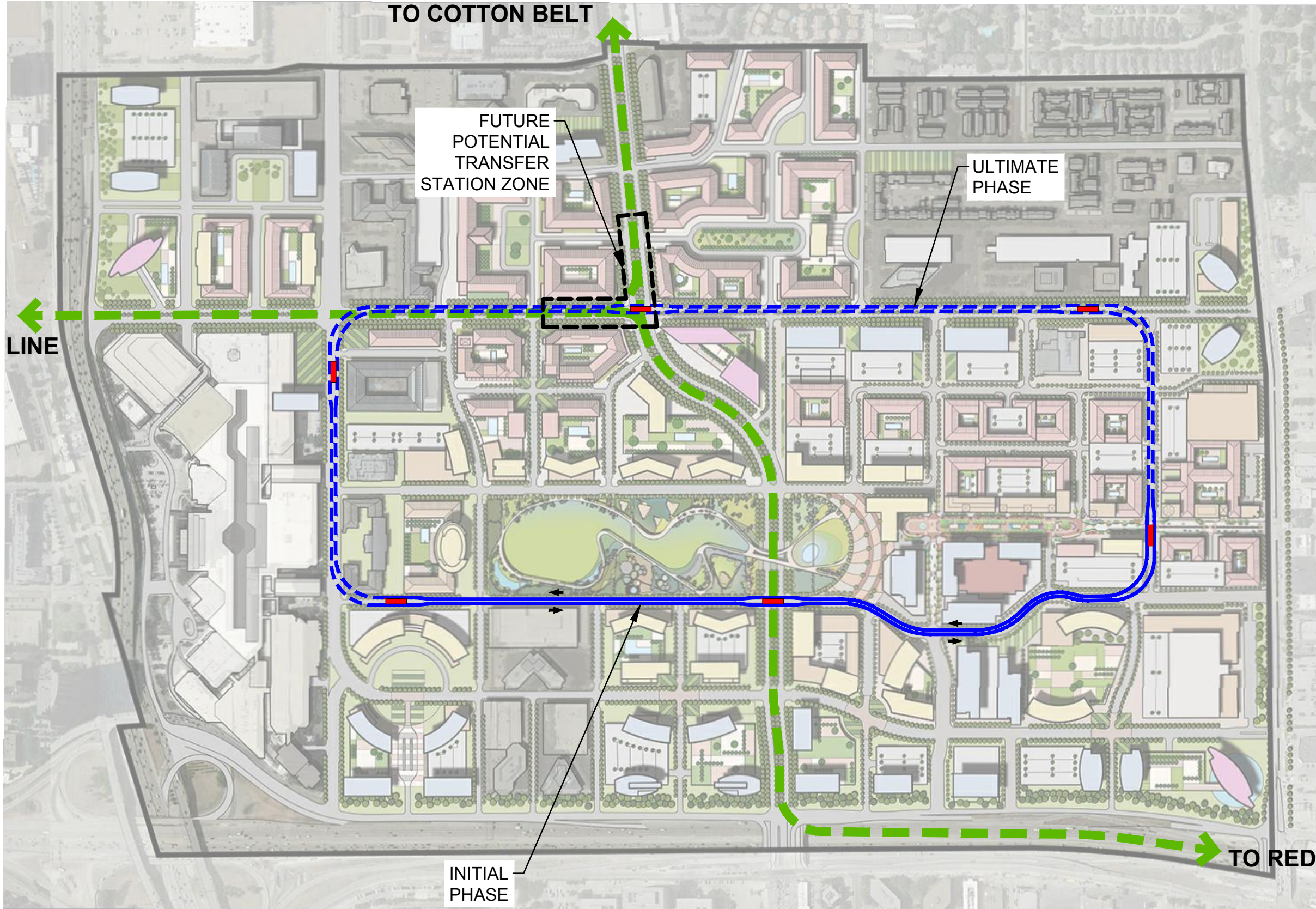
ULTIMATE PHASE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
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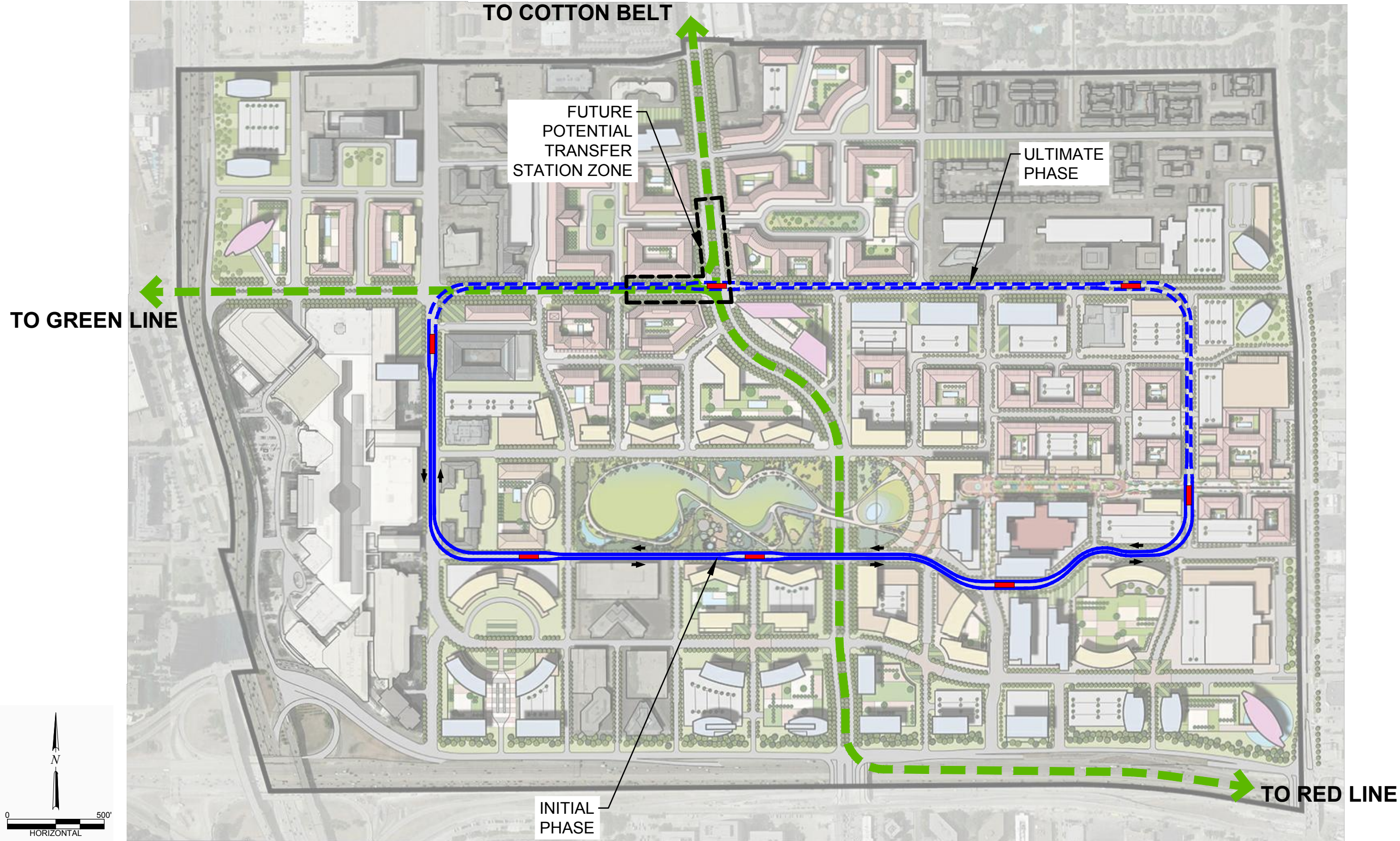DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

CABLE PROPELLED APM
RADIAL CIRCULATOR
ALTERNATIVE 1A

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**08**
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

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TO COTTON BELT

TO GREEN LINE

TO RED LINE

ULTIMATE PHASE

INITIAL PHASE

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

N

0   500'
HORIZONTAL

LEA + ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
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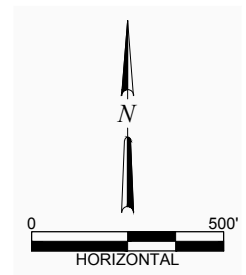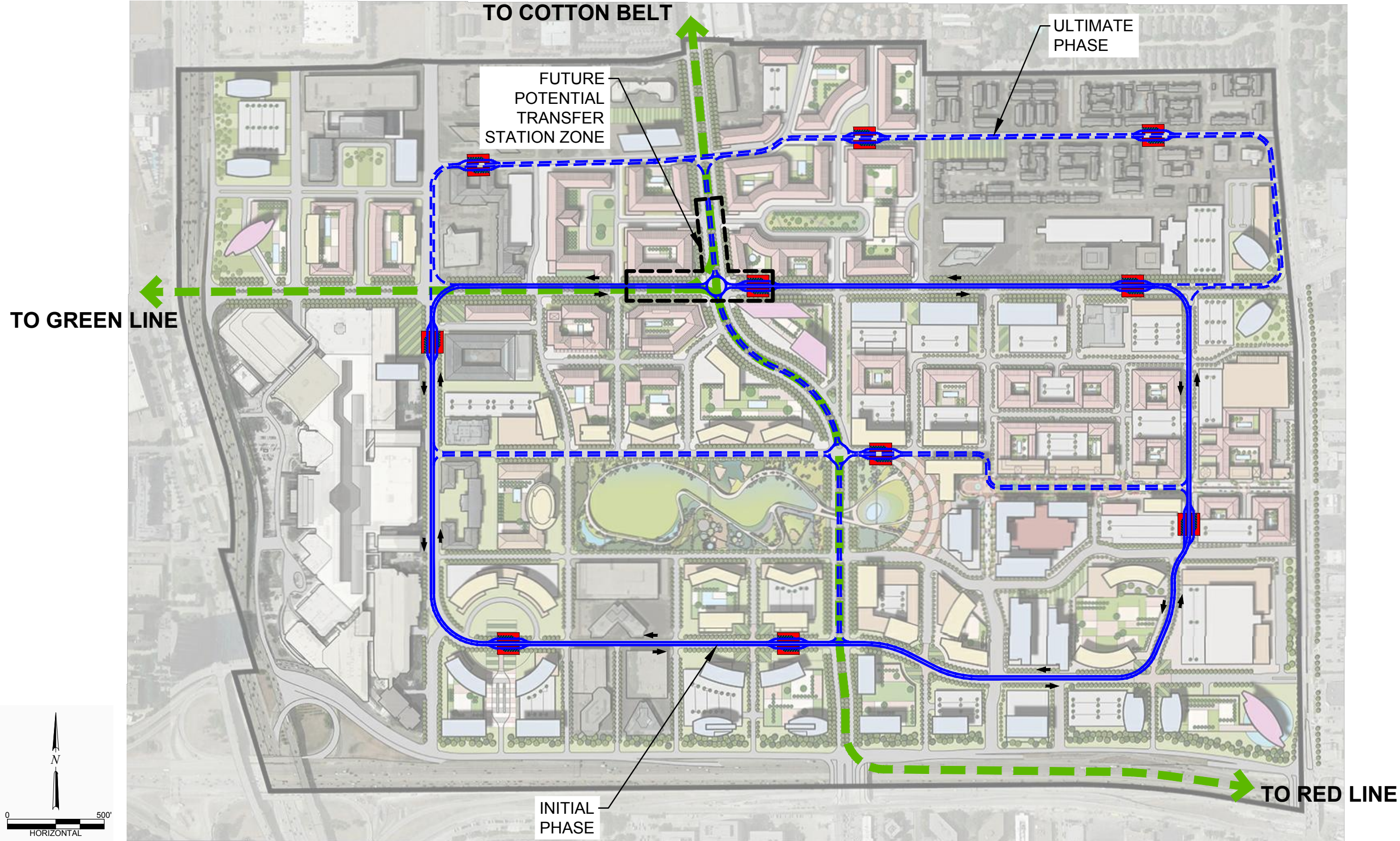DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

CABLE PROPELLED APM
RADIAL CIRCULATOR
ALTERNATIVE 1B

SCALE:	AS SHOWN
DESIGN BY:	L+E
DRAWN BY:	L+E
CHECKED BY:	L+E
DATE:	AUGUST 2018
PROJECT NO.	1276

SHEET NO.

09

PLATFORM EDGE WALLS AND DOORS

PLATFORM

APM GUIDEWAY PARAPET

APM GUIDEWAY AND
RUNNING SURFACE

APM STRUCTURE

WALKWAY BETWEEN
PLATFORM AND STREET LEVEL

VEHICLE

VEHICLE

VEHICLE

VEHICLE

PLATFORM

PLATFORM

APM GUIDEWAY AND
RUNNING SURFACE

VERTICAL CIRCULATION BETWEEN
WALKWAY AND PLATFORM

VERTICAL CIRCULATION BETWEEN
WALKWAY AND STREET LEVEL

AUTOMATED PEOPLE MOVER (APM)
DUAL LOOP CIRCULATOR
CENTER PLATFORM ADJACENT TO ROADWAY
DIAGRAMMATIC CROSS SECTION

ROADWAY

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

CABLE PROPELLED APM
RADIAL CIRCULATOR
ALTERNATIVE 1B
CENTER PLATFORM OVER ROADWAY
DIAGRAMMATIC CROSS SECTION

SCALE:	NOT TO SCALE	SHEET NO.
DESIGN BY:	L+E	
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DATE:	AUGUST 2018	
PROJECT NO.	1276	

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TO COTTON BELT

TO GREEN LINE

TO RED LINE

ULTIMATE PHASE

INITIAL PHASE

ULTIMATE PHASE

FUTURE POTENTIAL TRANSFER STATION ZONE

N

0   500'
HORIZONTAL

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2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
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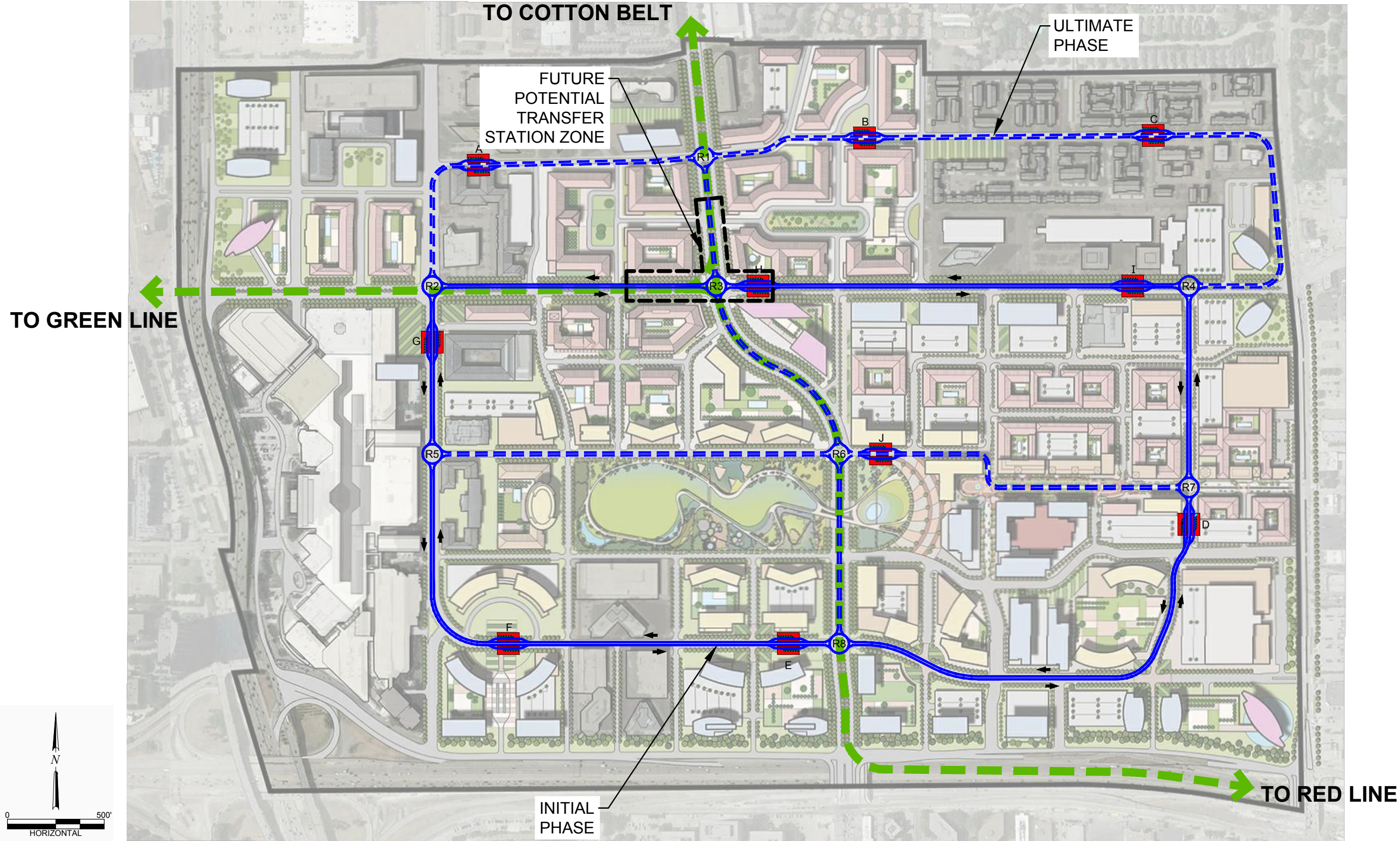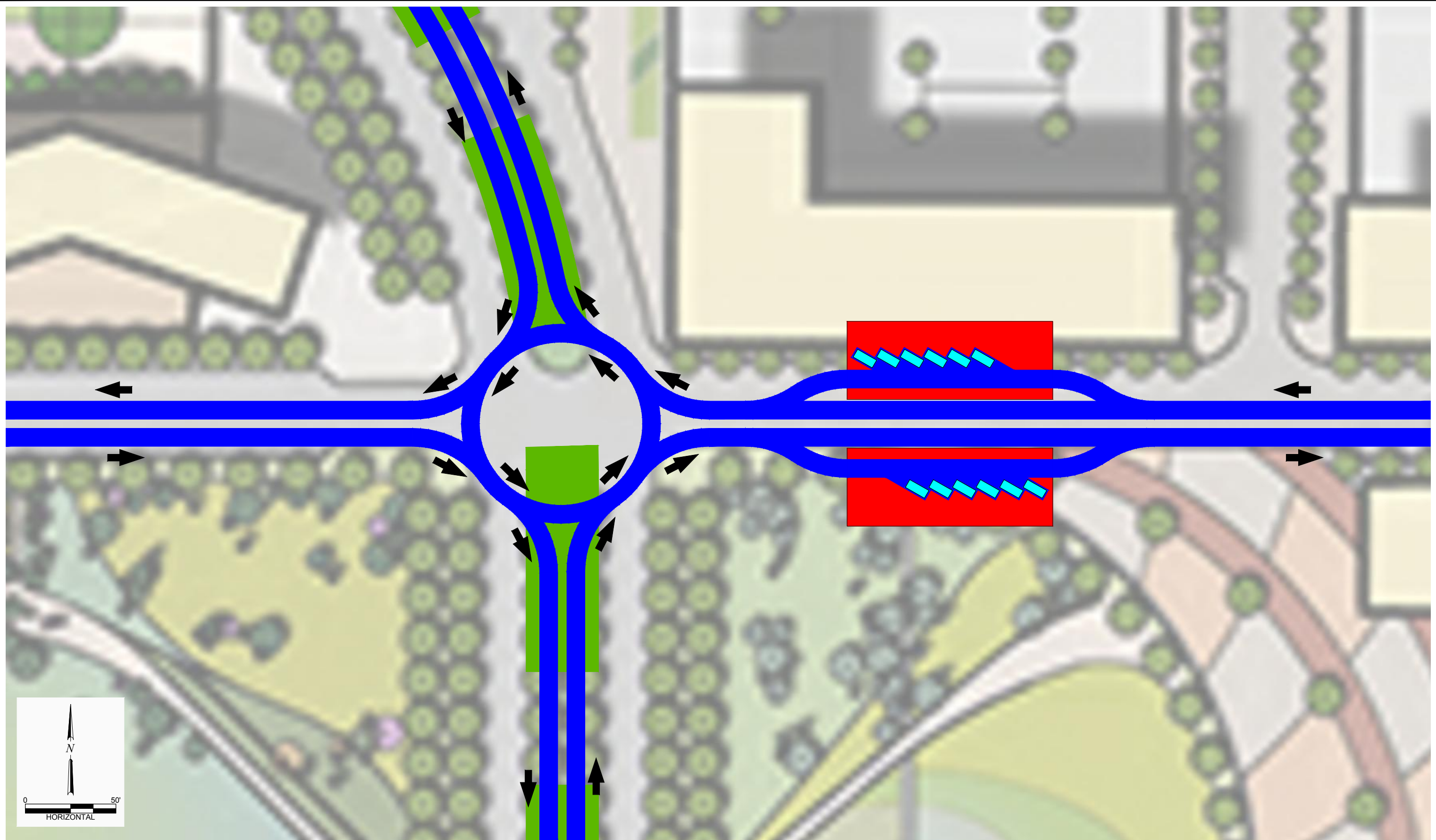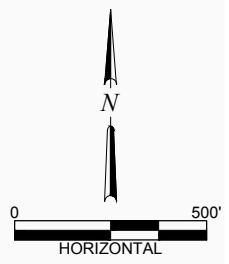DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

CABLE PROPELLED APM
RADIAL CIRCULATOR
ALTERNATIVE 1C

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
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DATE:	AUGUST 2018	
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TO COTTON BELT

FUTURE
POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

DETACHABLE GRIP TECHNOLOGY
USES SEPARATE ROPES FOR INITIAL
AND ULTIMATE PHASES

INITIAL
PHASE

TO RED LINE

N

0   500'
HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

CABLE-PROPELLED APM
DUAL LOOP CIRCULATOR
ALTERNATIVE 2

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	12
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

TO COTTON BELT

TO GREEN LINE

TO RED LINE

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

INITIAL PHASE

N

0   500'

HORIZONTAL
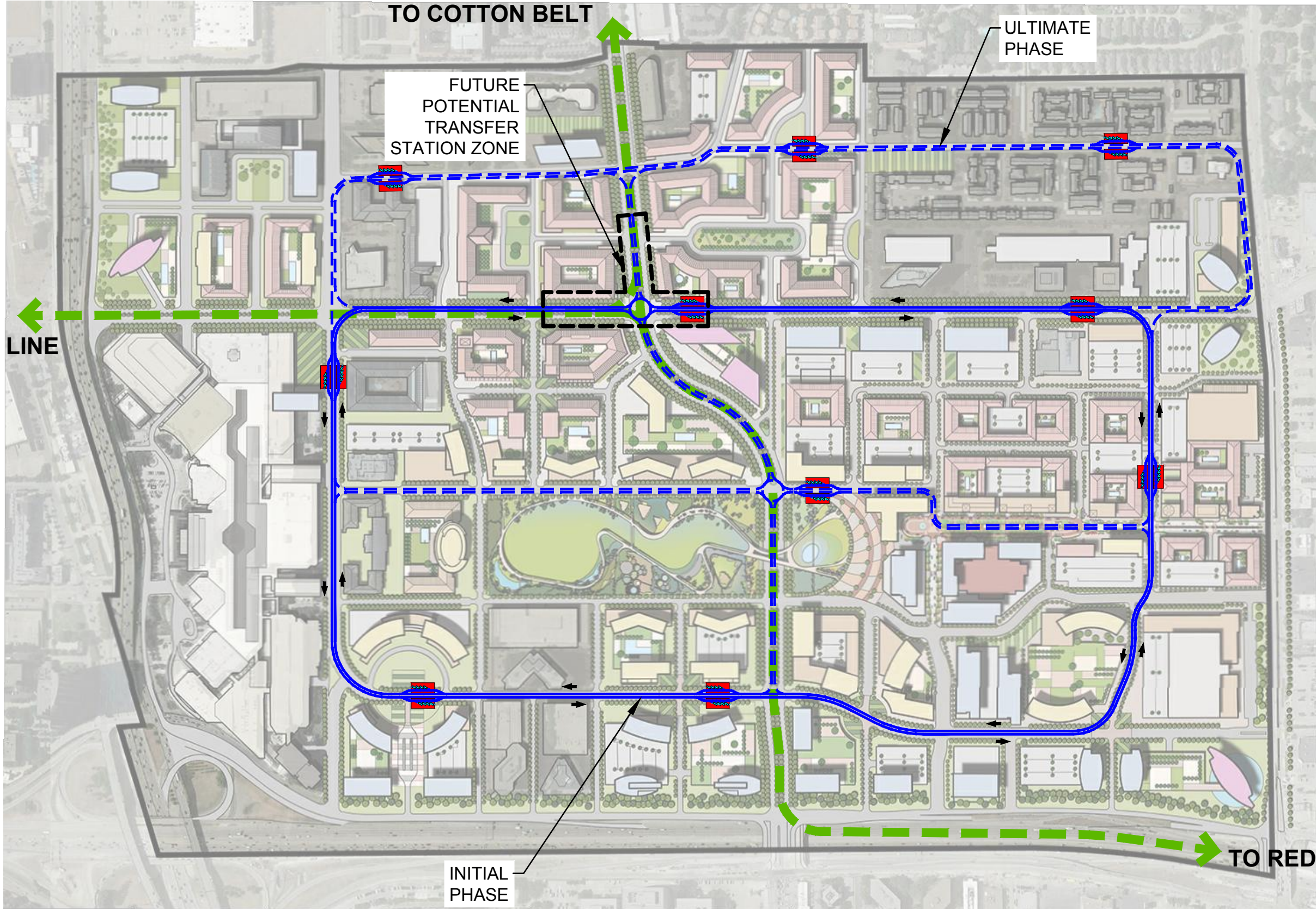
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2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
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DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

MONORAIL
DUAL LOOP CIRCULATOR
ALTERNATIVE 1A

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	13
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

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TO COTTON BELT

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

TO GREEN LINE

TO RED LINE

INITIAL PHASE

N

0   500'
HORIZONTAL

C:\projects\1276-Dallas Midtown ATS Study - Standard Drawing\LE-Monorail-DualLoop01b-Initial.dwg, B-Size, 10/24/2018 3:28:23 PM, ANSI full bleed B (17.00 x 11.00 Inches)

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2505 N. STATE HWY 360, SUITE 750
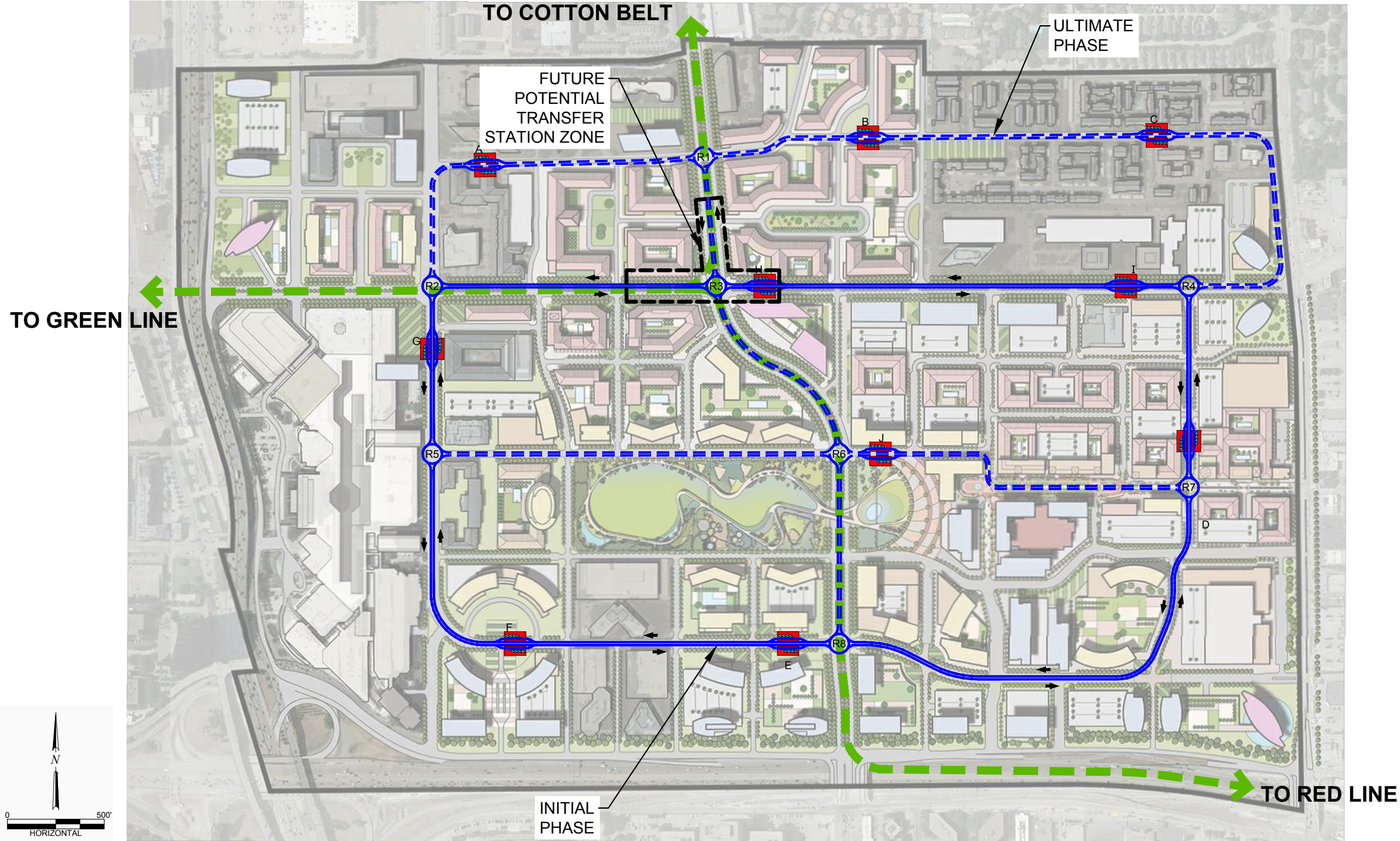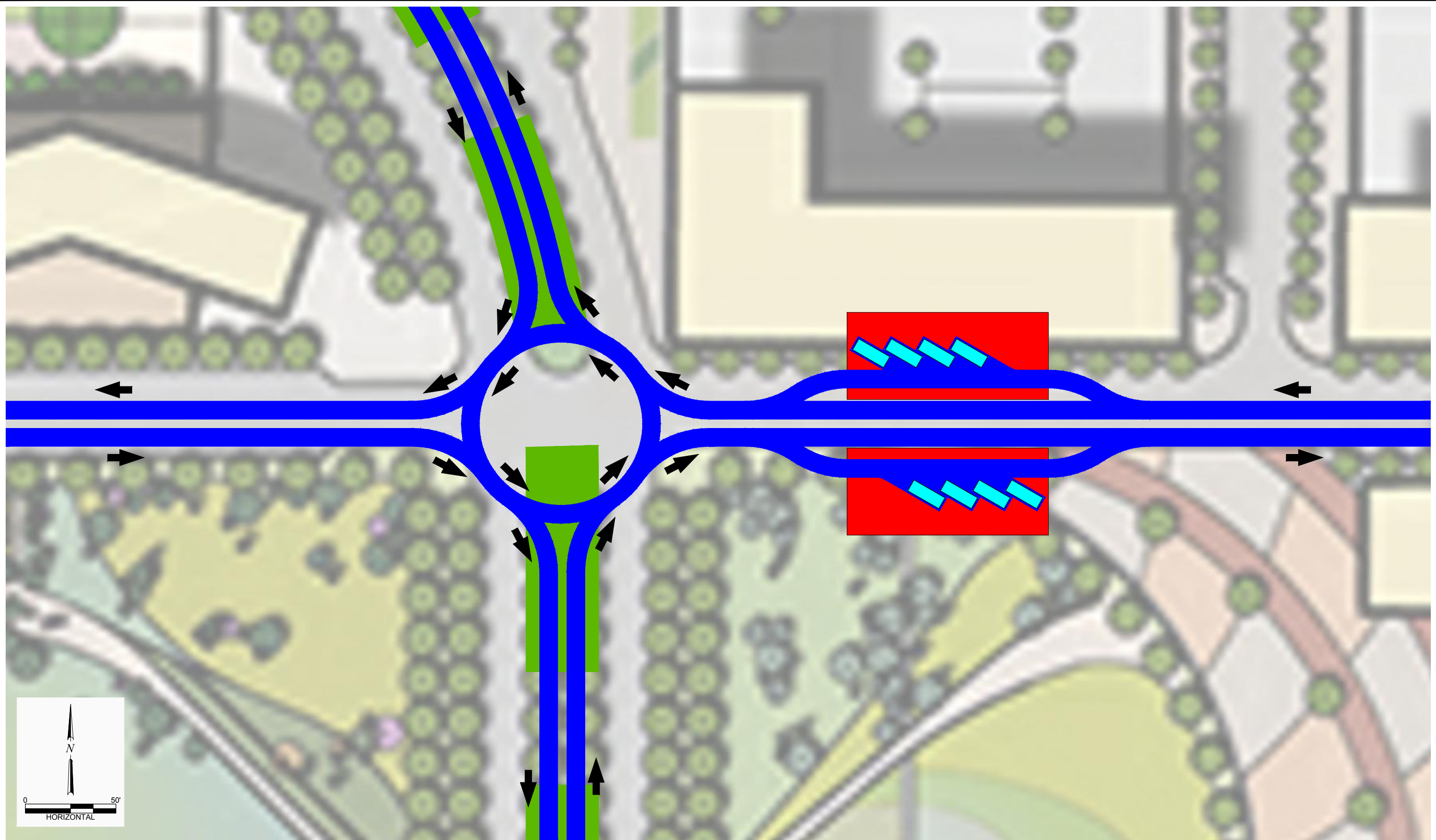GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY
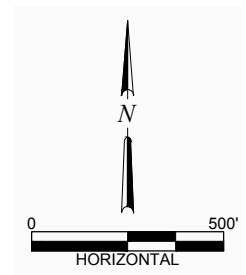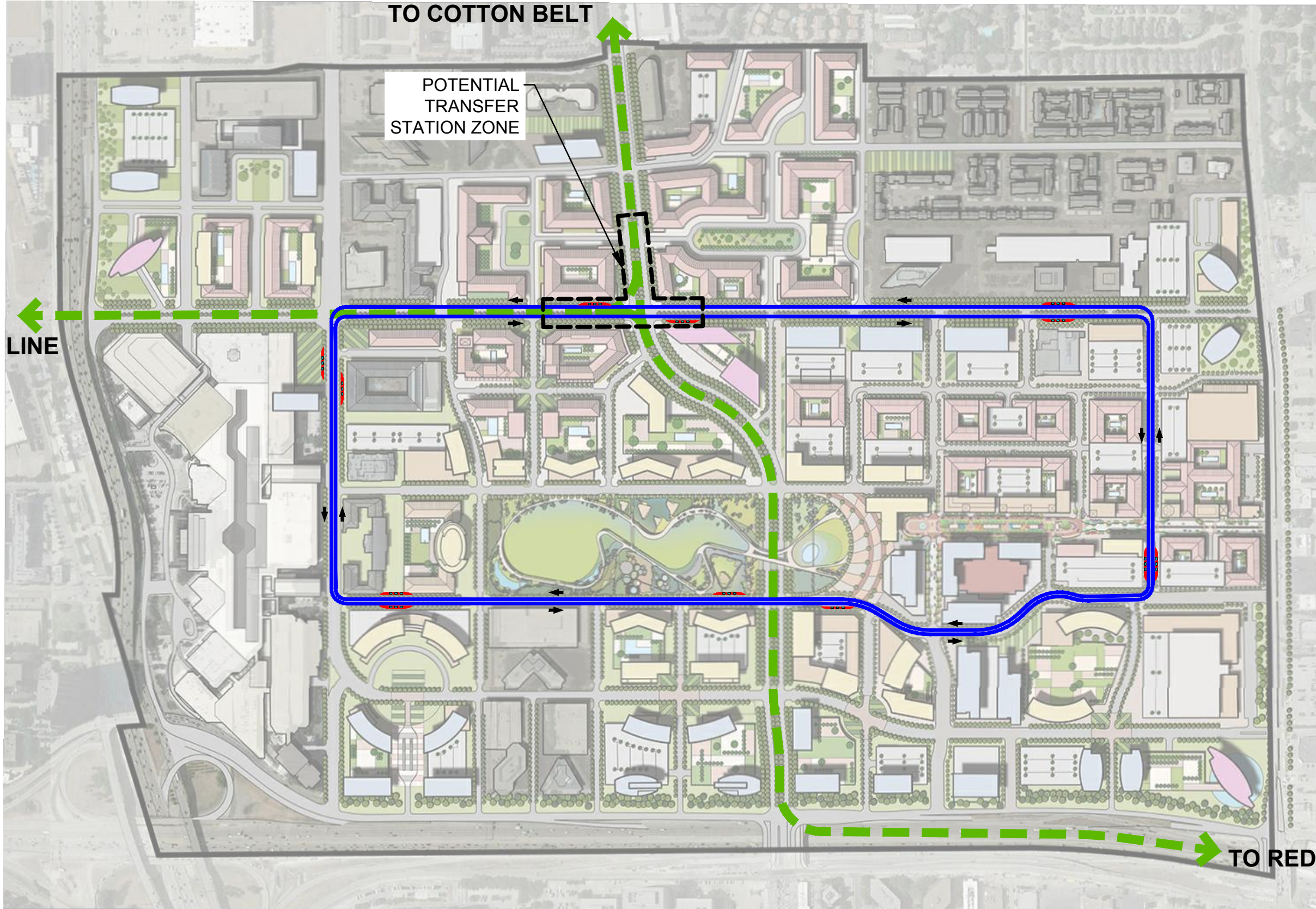
MONORAIL
DUAL LOOP CIRCULATOR
ALTERNATIVE 1B

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	14
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

TO COTTON BELT

FUTURE
POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

TO RED LINE

INITIAL
PHASE

N

0   500'

HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

MONORAIL
DUAL LOOP CIRCULATOR
ALTERNATIVE 2A

SCALE:	AS SHOWN
DESIGN BY:	L+E
DRAWN BY:	L+E
CHECKED BY:	L+E
DATE:	AUGUST 2018
PROJECT NO.	1276

SHEET NO.

15

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TO COTTON BELT

FUTURE
POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

TO RED LINE

INITIAL
PHASE

N

0   500'
HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

MONORAIL
DUAL LOOP CIRCULATOR
ALTERNATIVE 2B

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	16
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

TO COTTON BELT

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

TO GREEN LINE

TO RED LINE

INITIAL PHASE

N

0   500'
HORIZONTAL

C:\projects\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-PRT01a-Initial.dwg, B-Size, 10/24/2018 3:28:53 PM, ANSI full bleed B (17.00 x 11.00 Inches)

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2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

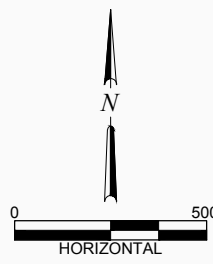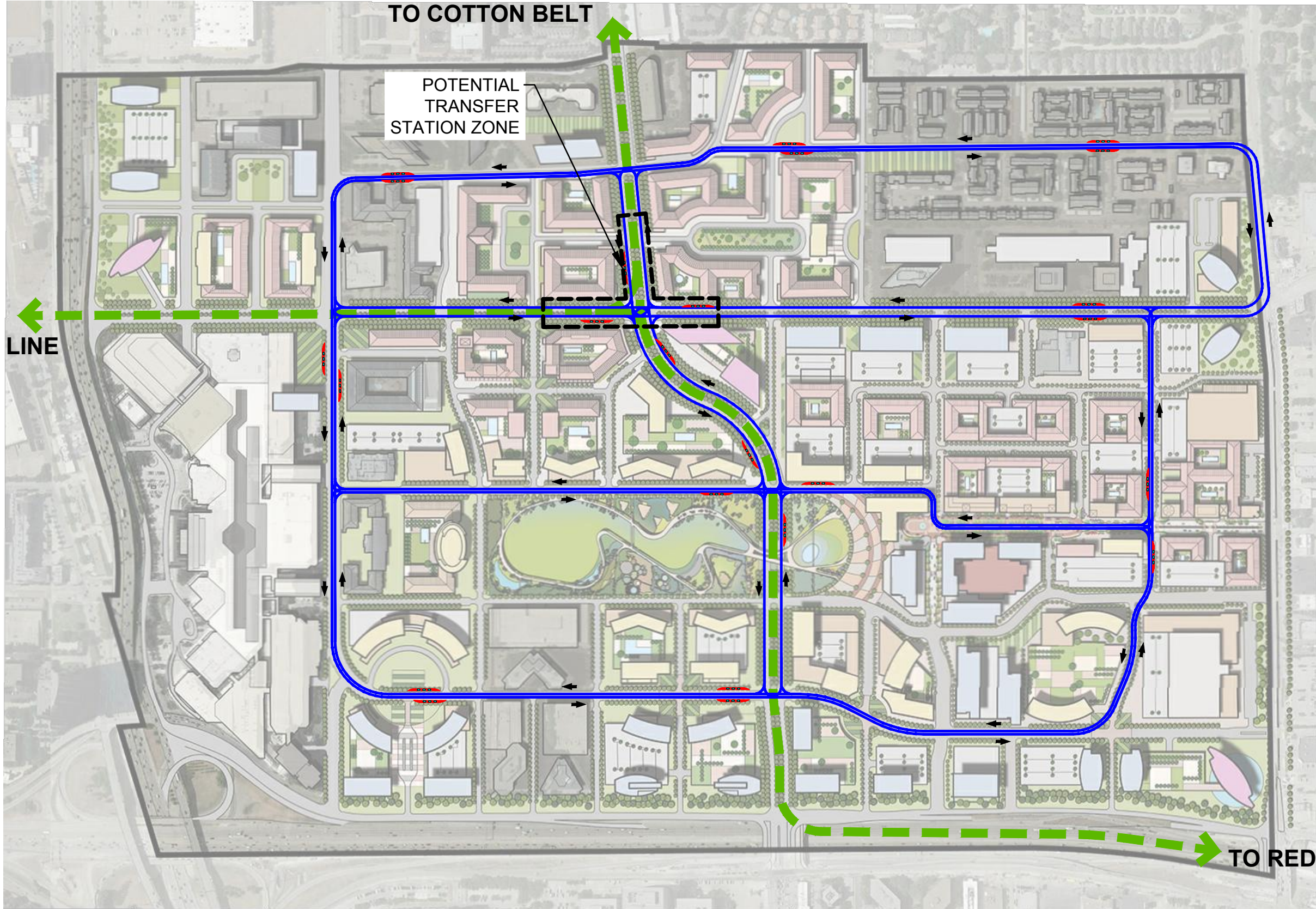DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

PERSONAL RAPID TRANSIT (PRT)
NETWORK CIRCULATOR
ALTERNATIVE 1A

SCALE: AS SHOWN
DESIGN BY: L+E
DRAWN BY: L+E
CHECKED BY: L+E
DATE: AUGUST 2018
PROJECT NO.   1276

SHEET NO.
17

TO COTTON BELT

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

TO GREEN LINE

INITIAL PHASE

TO RED LINE

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

PERSONAL RAPID TRANSIT (PRT)
NETWORK CIRCULATOR
ALTERNATIVE 1B

SCALE: AS SHOWN
DESIGN BY: L+E
DRAWN BY: L+E
CHECKED BY: L+E
DATE: AUGUST 2018
PROJECT NO. 1276

SHEET NO.

18

N

0   50'
HORIZONTAL

LEA ELLIOTT

2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
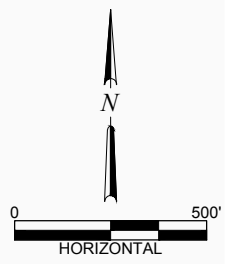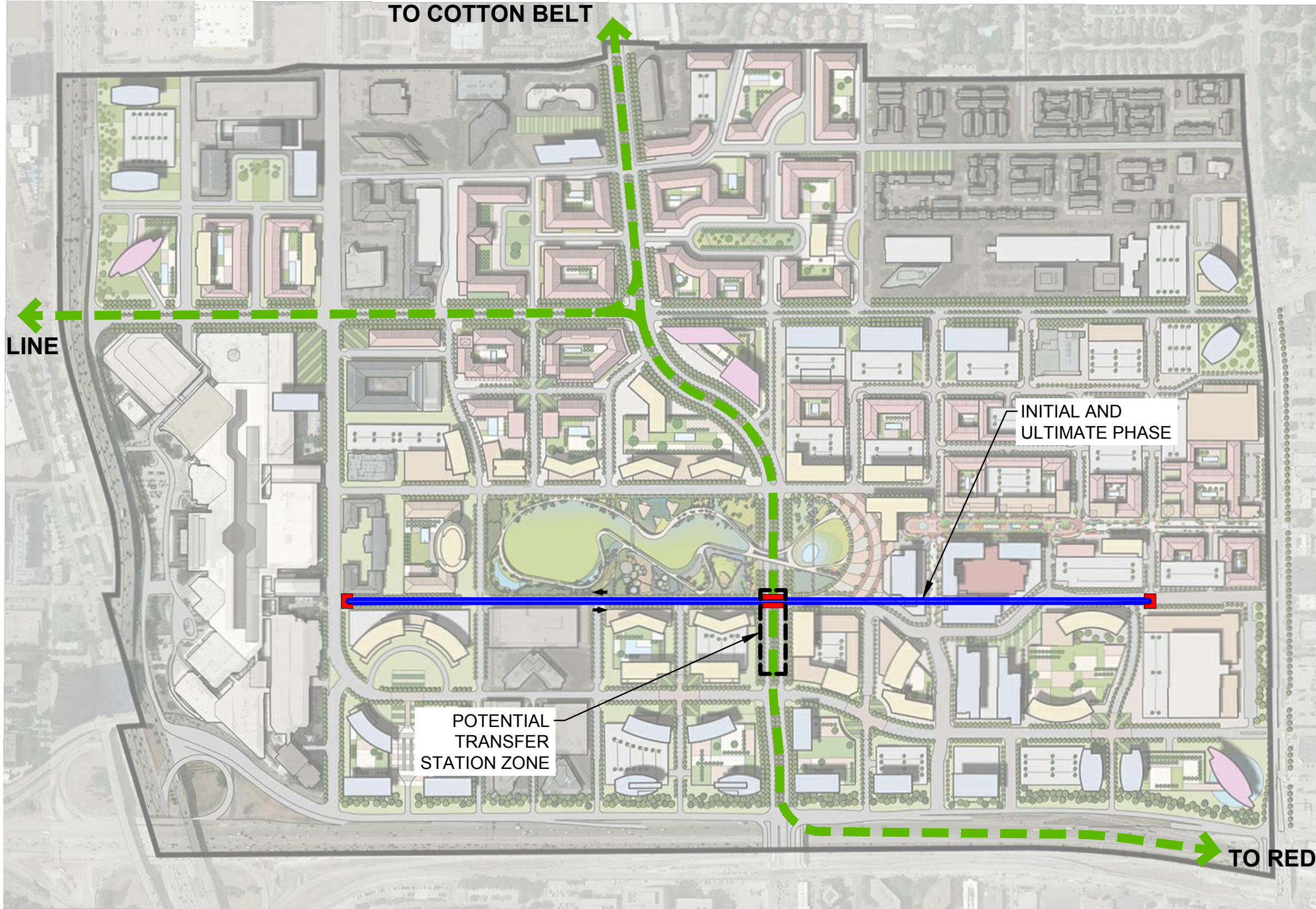AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

PERSONAL RAPID TRANSIT (PRT)
NETWORK CIRCULATOR
TYPICAL ROUNDABOUT AND STATIONS

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**19**
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

TO COTTON BELT

ULTIMATE PHASE

FUTURE POTENTIAL TRANSFER STATION ZONE

TO GREEN LINE

TO RED LINE

INITIAL PHASE

N

0   500'

HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
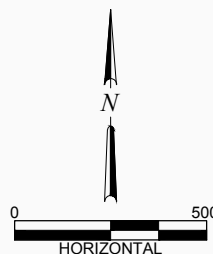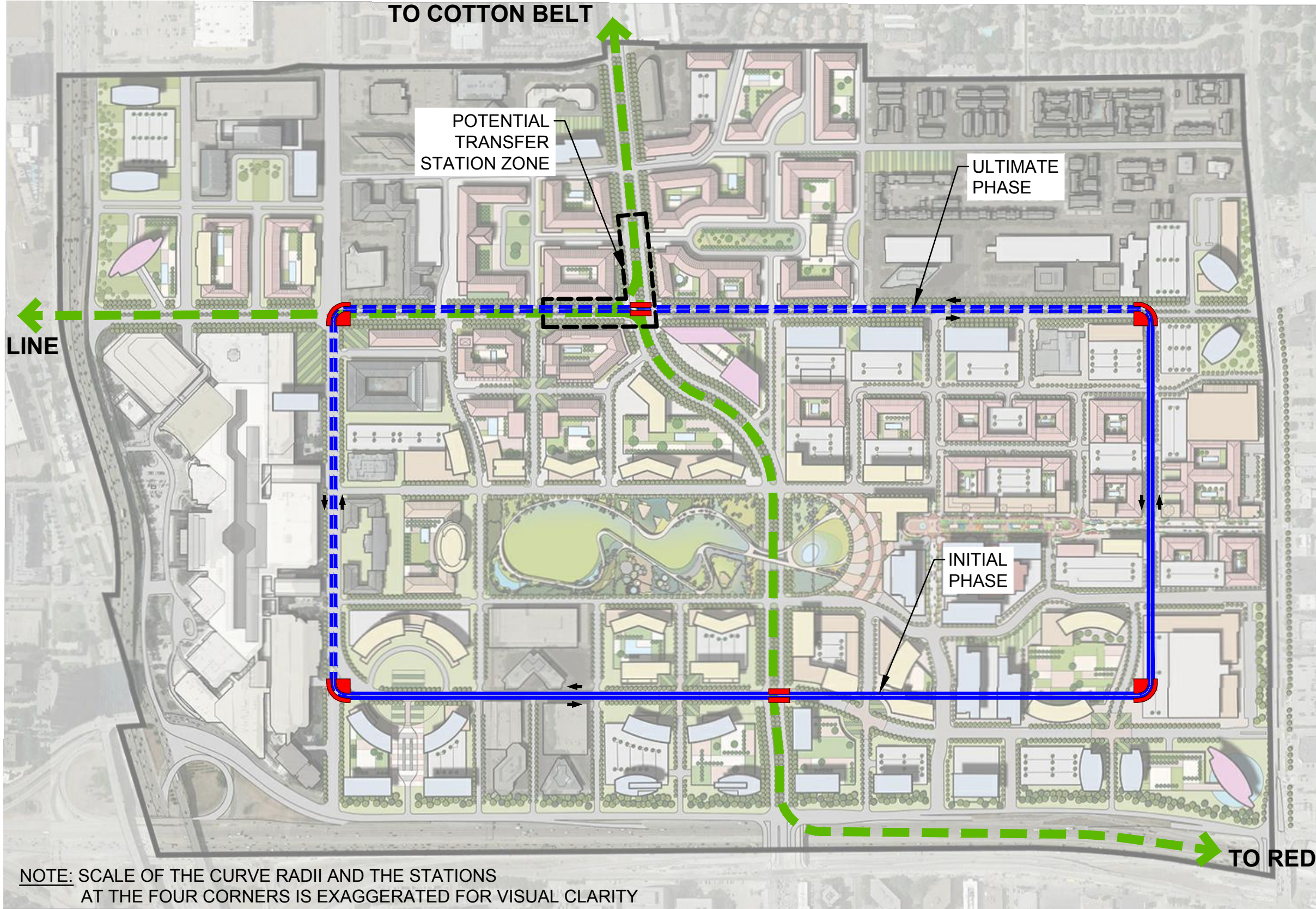GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

GROUP RAPID TRANSIT (GRT)
NETWORK CIRCULATOR
ALTERNATIVE 1A

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	20
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-GRT01-Initial.dwg, B-Size, 10/24/2018 3:29:23 PM, ANSI full bleed B (17.00 x 11.00 Inches)

TO COTTON BELT

FUTURE POTENTIAL TRANSFER STATION ZONE

ULTIMATE PHASE

TO GREEN LINE

TO RED LINE

INITIAL PHASE

N

0 500'
HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

GROUP RAPID TRANSIT (GRT)
NETWORK CIRCULATOR
ALTERNATIVE 1B

SCALE:	AS SHOWN
DESIGN BY:	L+E
DRAWN BY:	L+E
CHECKED BY:	L+E
DATE:	AUGUST 2018
PROJECT NO.	1276

SHEET NO.

21

LEA ELLIOTT

2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
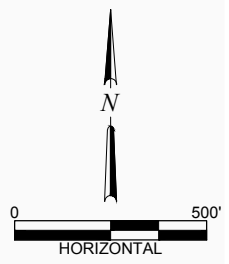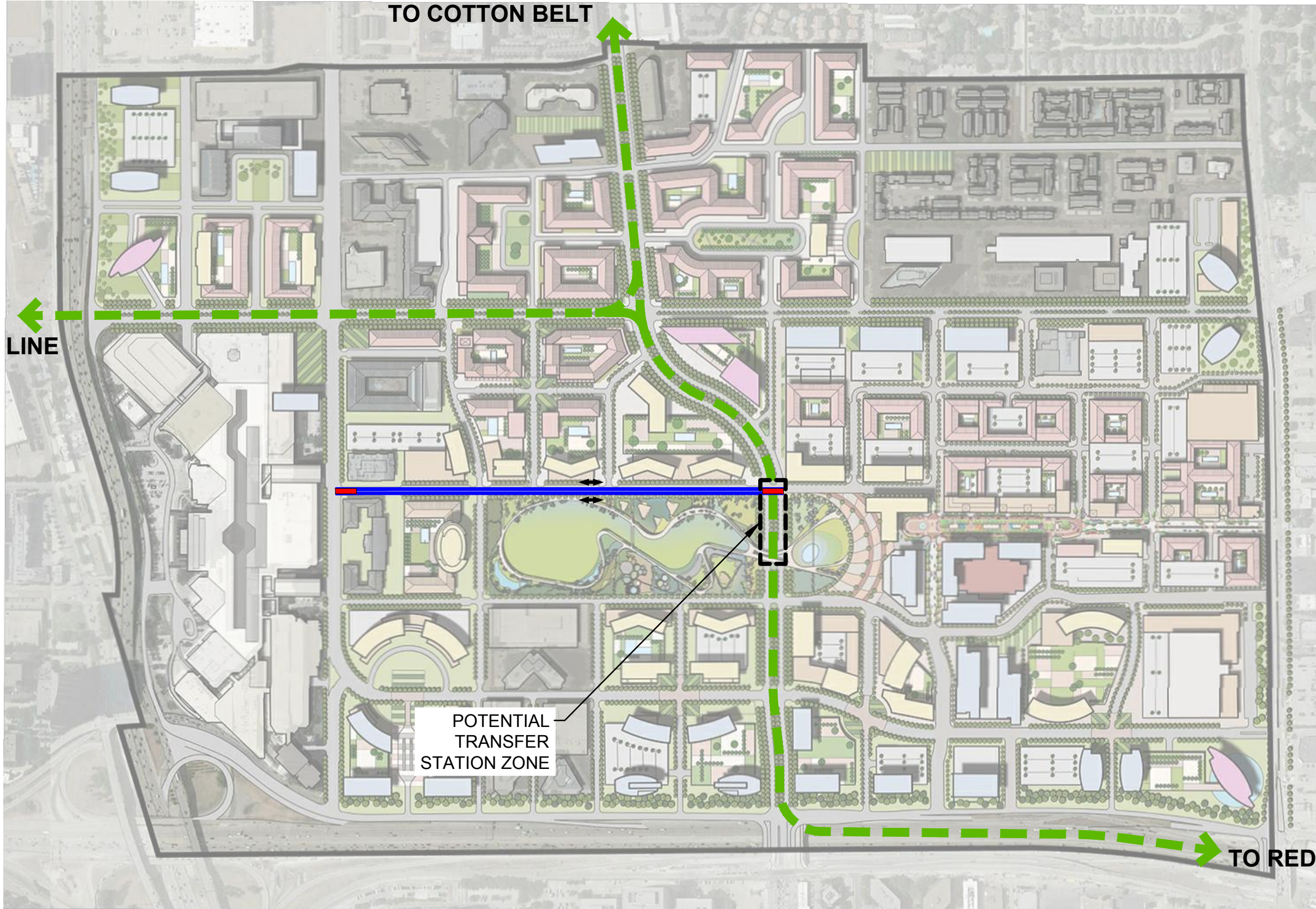AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

GROUP RAPID TRANSIT (GRT)
NETWORK CIRCULATOR
TYPICAL ROUNDABOUT AND STATIONS

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**22**
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

HORIZONTAL

0   50'

N

TO COTTON BELT

POTENTIAL
TRANSFER
STATION ZONE

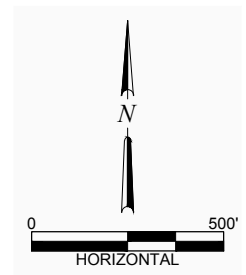TO GREEN LINE

TO RED LINE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTONOMOUS VEHICLE
DUAL LOOP CIRCULATOR
ALTERNATIVE 1
INITIAL PHASE
(FIXED ROUTE STOPPING AT ALL STOPS)

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**23**
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-Autonomous-Initial.dwg, B-Size, 10/24/2018 3:29:53 PM, ANSI full bleed B (17.00 x 11.00 inches)

TO COTTON BELT

POTENTIAL
TRANSFER
STATION ZONE

TO GREEN LINE

TO RED LINE

N

0   500'
HORIZONTAL

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-Autonomous.dwg, B-Size, 10/24/2018 3:30:03 PM, ANSI full bleed B (17.00 x 11.00 inches)
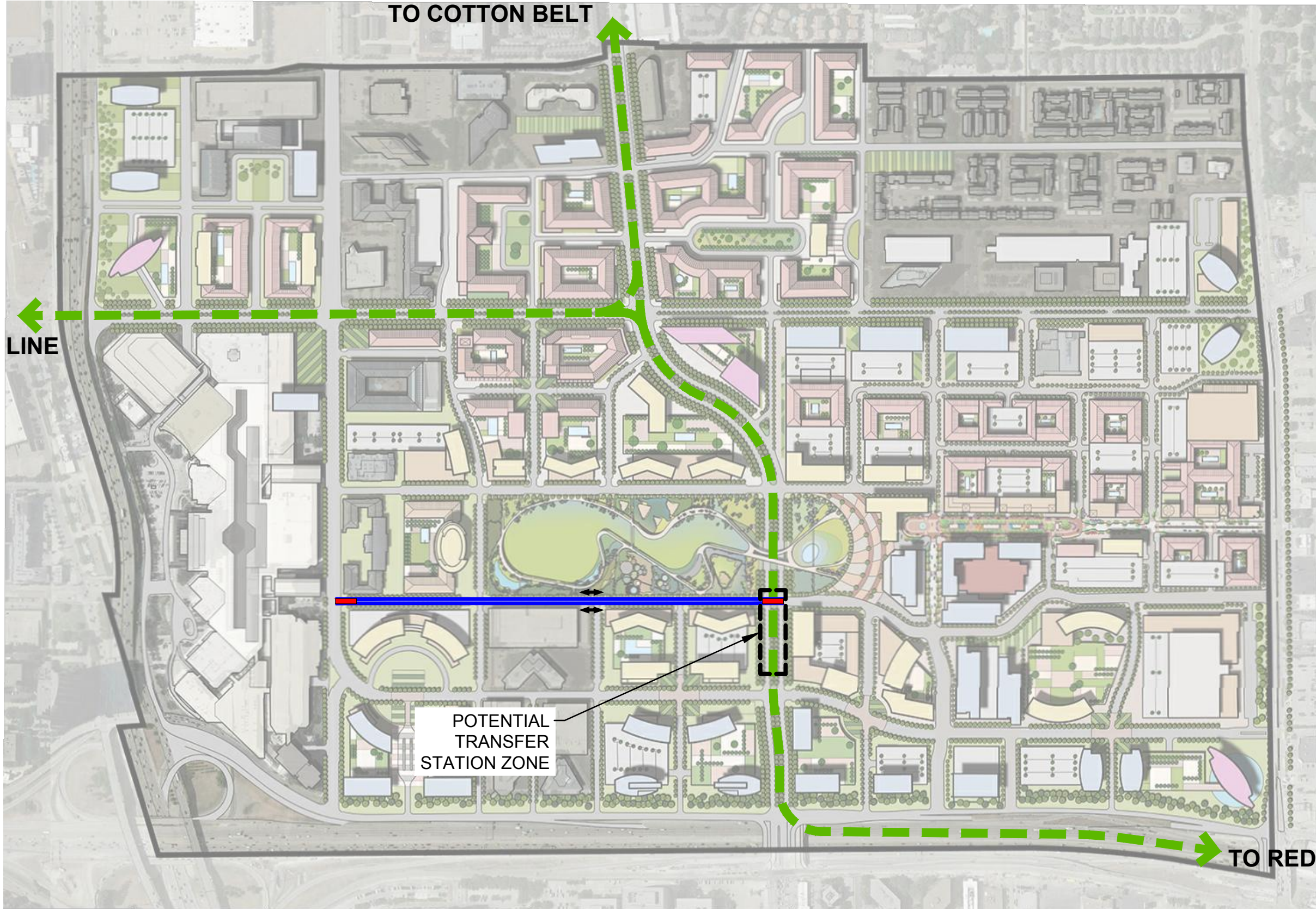
LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
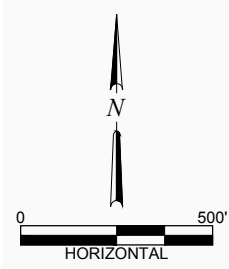GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTONOMOUS VEHICLE
NETWORK CIRCULATOR
ALTERNATIVE 1
ULTIMATE PHASE

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	24
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

TO COTTON BELT

TO GREEN LINE

INITIAL AND ULTIMATE PHASE

POTENTIAL TRANSFER STATION ZONE

TO RED LINE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

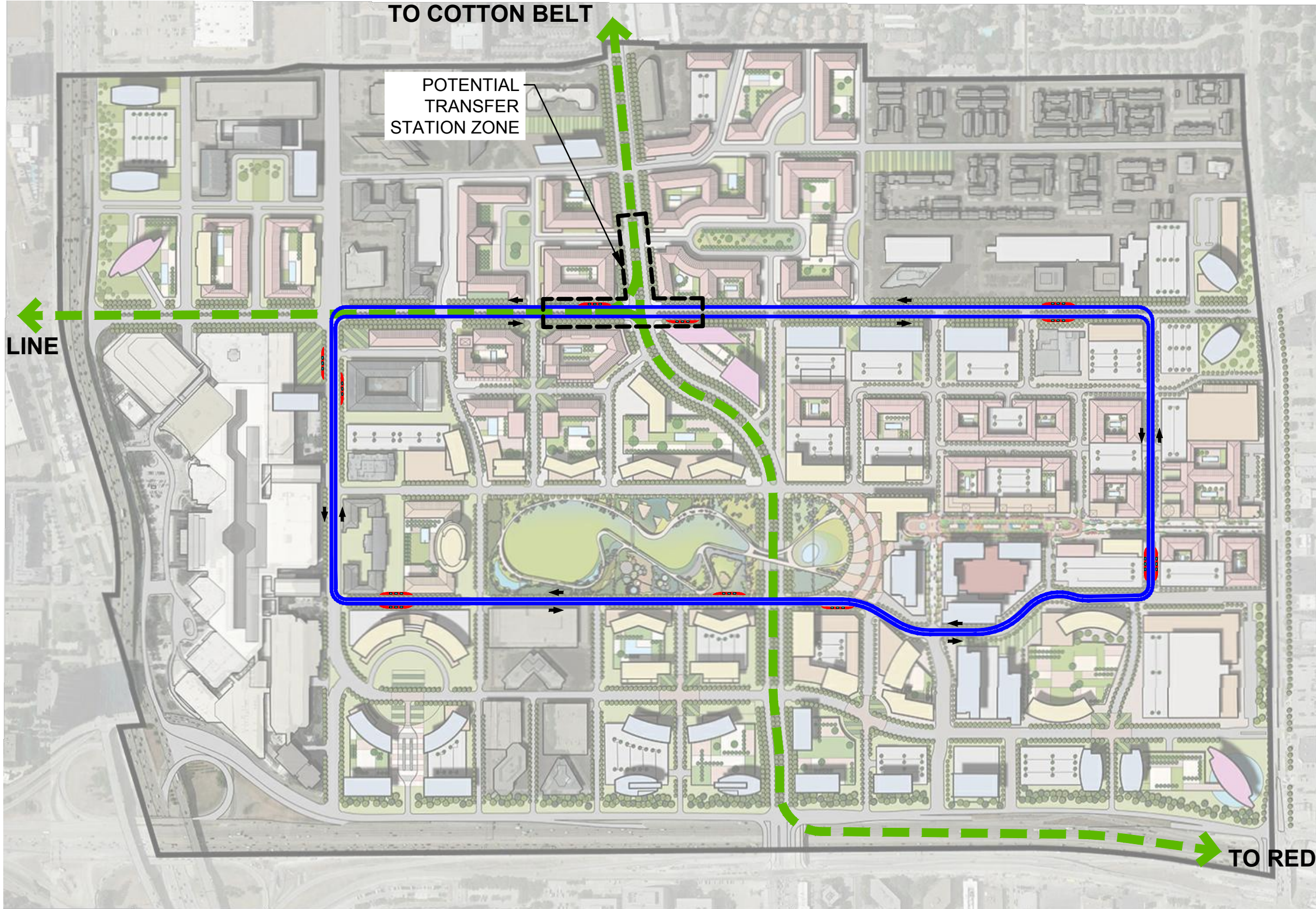DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

GONDOLA - MONOCABLE DETACHABLE
GONDOLA (MGD)
CLOSED LOOP(S)
ALTERNATIVE 1

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**25**
CHECKED BY:	L+E	
DATE:	SEPTEMBER 2018	
PROJECT NO.	1276	

TO COTTON BELT

POTENTIAL
TRANSFER
STATION ZONE

ULTIMATE
PHASE

TO GREEN LINE

INITIAL
PHASE

TO RED LINE

N

0   500'
HORIZONTAL

NOTE: SCALE OF THE CURVE RADII AND THE STATIONS
AT THE FOUR CORNERS IS EXAGGERATED FOR VISUAL CLARITY

C:\projects\1276-DallasMidtown ATS Study - Standard\Drawing\LE-Gondola02.dwg, B-Size, 10/24/2018 3:30:23 PM, ANSI full bleed B (17.00 x 11.00 Inches)

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
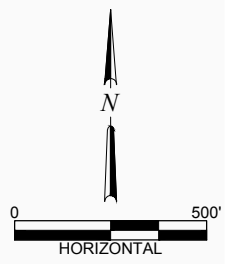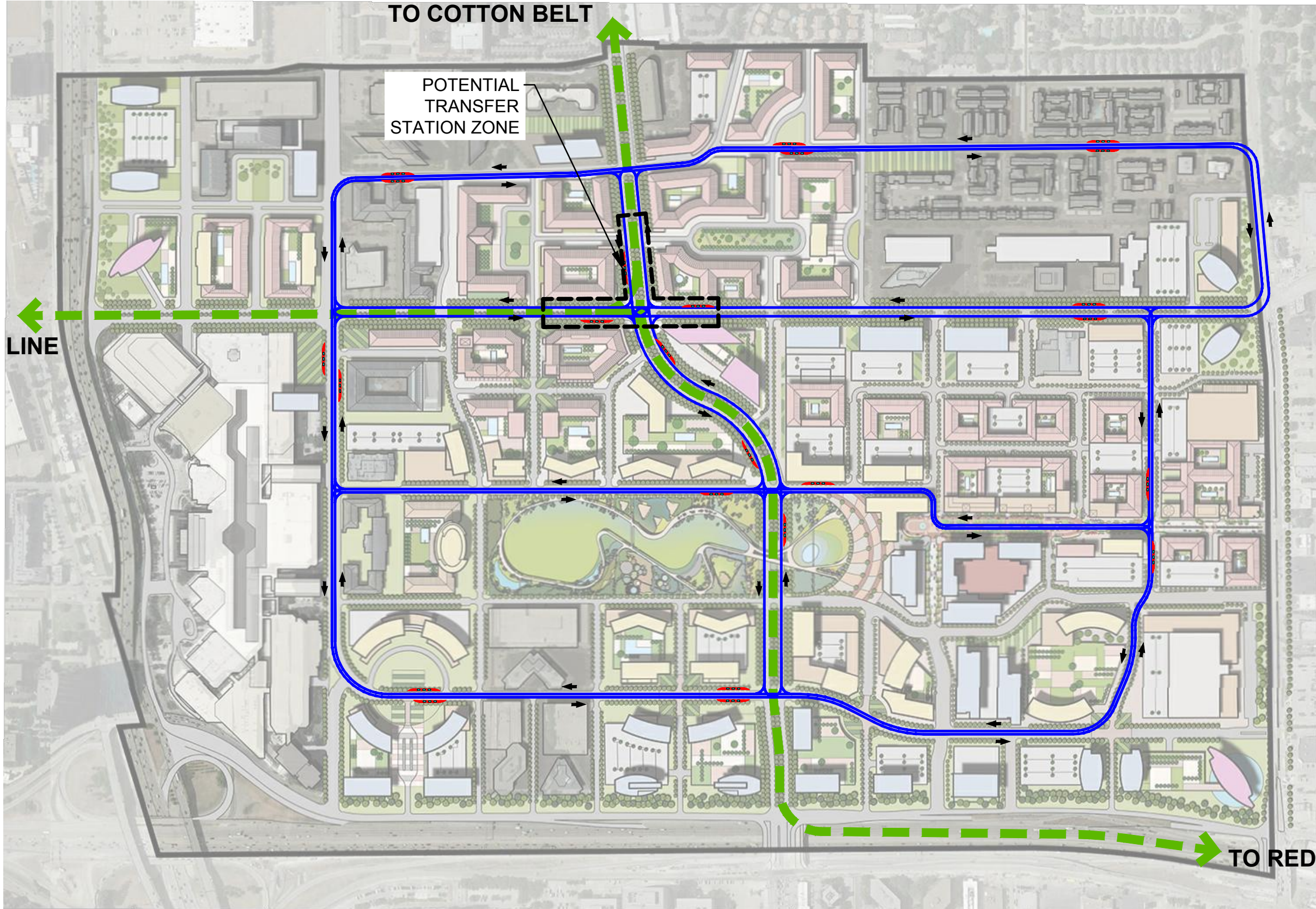PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

GONDOLA - MONOCABLE DETACHABLE
GONDOLA (MGD)
CLOSED LOOPS
ALTERNATIVE 2

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	26
CHECKED BY:	L+E	
DATE:	SEPTEMBER 2018	
PROJECT NO.	1276	

TO COTTON BELT

TO GREEN LINE

TO RED LINE

POTENTIAL
TRANSFER
STATION ZONE

N

0   500'
HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AERIAL TRAMWAY
DUAL-LANE SHUTTLE
ALTERNATIVE 1A

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	27
CHECKED BY:	L+E	
DATE:	SEPTEMBER 2018	
PROJECT NO.	1276	

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-AerialTram01.dwg, B-Size, 10/24/2018 3:30:33 PM, ANSI full bleed B (17.00 x 11.00 Inches)

TO COTTON BELT

TO GREEN LINE

TO RED LINE

POTENTIAL
TRANSFER
STATION ZONE

N

0   500'
HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AERIAL TRAMWAY
DUAL-LANE SHUTTLE
ALTERNATIVE 1B

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	28
CHECKED BY:	L+E	
DATE:	SEPTEMBER 2018	
PROJECT NO.	1276	

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TO COTTON BELT

POTENTIAL TRANSFER STATION ZONE

TO GREEN LINE

TO RED LINE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

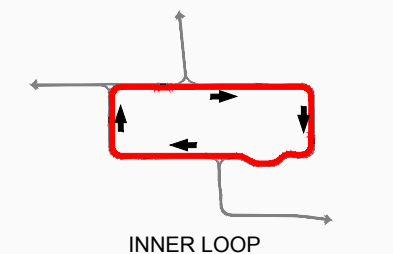DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY
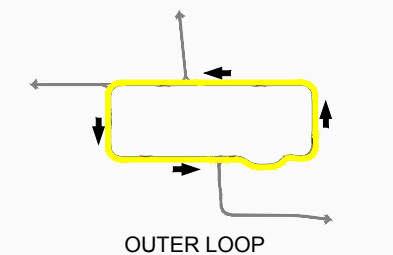
AUTOMATED VEHICLE FLEET
DUAL LOOP CIRCULATOR
ALTERNATIVE 1
INITIAL PHASE
(FIXED ROUTE STOPPING AT ALL STOPS)

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	29
CHECKED BY:	L+E	
DATE:	SEPTEMBER 2018	
PROJECT NO.	1276	

TO COTTON BELT

POTENTIAL TRANSFER STATION ZONE

TO GREEN LINE

TO RED LINE

N

0   500'
HORIZONTAL

LEA ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

AUTOMATED VEHICLE FLEET
NETWORK CIRCULATOR
ALTERNATIVE 1
ULTIMATE PHASE

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	30
CHECKED BY:	L+E	
DATE:	SEPTEMBER 2018	
PROJECT NO.	1276	

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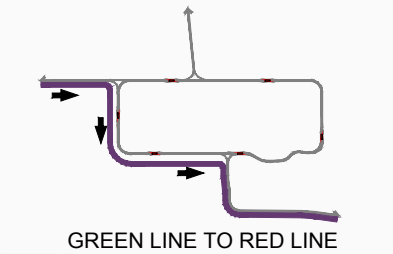
TO COTTON BELT

TO GREEN LINE

TO RED LINE

N

0   500'

HORIZONTAL

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

COMBINED REGIONAL
CONNECTOR/INTERNAL CIRCULATOR

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	31
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-Reg-Internal01.dwg, B-Size, 10/24/2018 3:31:14 PM, ANSI full bleed B (17.00 x 11.00 Inches)

TO COTTON BELT

TO GREEN LINE

TO RED LINE

INNER LOOP

OUTER LOOP
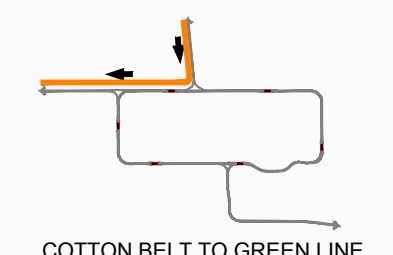
RED LINE TO COTTON BELT

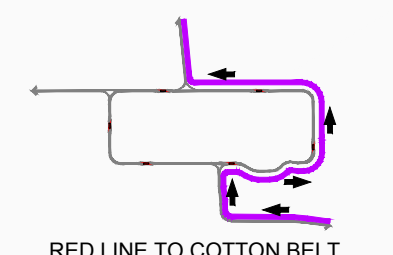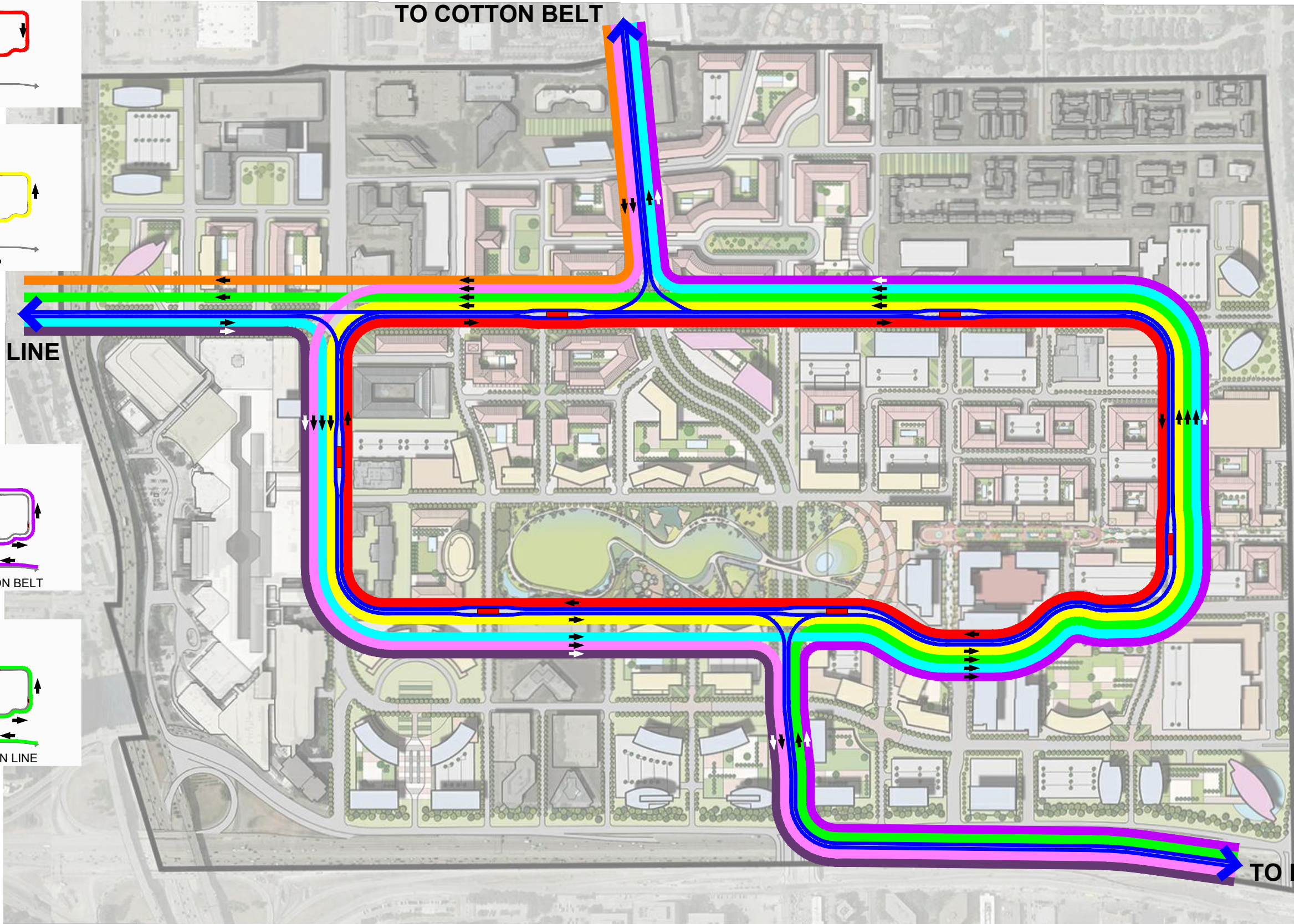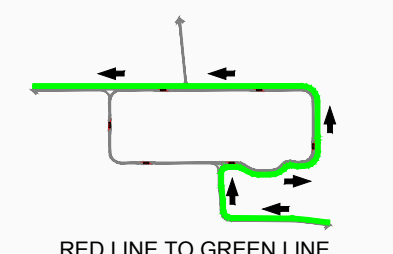RED LINE TO GREEN LINE

GREEN LINE TO COTTON BELT
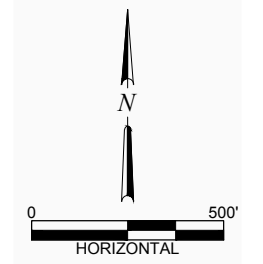
GREEN LINE TO RED LINE
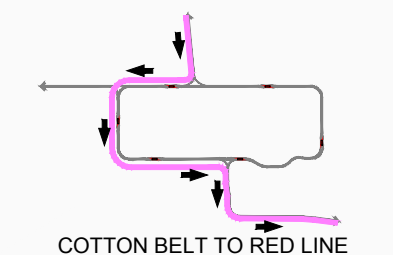
COTTON BELT TO RED LINE

COTTON BELT TO GREEN LINE

N

0   500'
HORIZONTAL

LEA+ELLIOTT
2505 N. STATE HWY 360, SUITE 750
GRAND PRAIRIE, TEXAS 75050
PHONE: 972.890.9800
WWW.LEAELLIOTT.COM

DALLAS MIDTOWN
AUTOMATED TRANSPORTATION SYSTEM
CONCEPTUAL ENGINEERING STUDY

COMBINED REGIONAL
CONNECTOR/INTERNAL CIRCULATOR
ROUTES

SCALE:	AS SHOWN	SHEET NO.
DESIGN BY:	L+E	
DRAWN BY:	L+E	**32**
CHECKED BY:	L+E	
DATE:	AUGUST 2018	
PROJECT NO.	1276	

C:\projects\1276-DallasMidtown\1276-Dallas Midtown ATS Study - Standard\Drawing\LE-Reg-Internal01.dwg, Routes, 10/24/2018 3:31:22 PM, ANSI full bleed B (17.00 x 11.00 Inches)