MONORAIL ASSESSMENT REPORT
FOR THE
I-24 SOUTHEAST CORRIDOR

FINAL REPORT

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Tennessee Department of Transportation

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MONORAIL ASSESSMENT REPORT FOR THE I-24 SOUTHEAST CORRIDOR

OVERVIEW SUMMARY

1.0 INTRODUCTION AND PURPOSE

This report provides the results of a technology assessment of monorail systems, and explores the feasibility of a monorail system operating in the 33.7-mile long Interstate 24 (I-24) Southeast Corridor Regional Rapid/Urban Rail Transit Corridor (Southeast Corridor), as identified by the Nashville Area Metropolitan Planning Organization (MPO). The MPO's 2035 Regional Transportation Plan, adopted in December 2010, recommended rapid transit but did not identify a specific technology for the Southeast Corridor. This report was prepared as directed under Public Chapter 1009 (2014); its language is provided as follows, and its provisions and their coverage within this document are shown in Table OS.1.

> *SECTION 1. The department of transportation is directed to conduct a preliminary study to determine the feasibility of a monorail public transportation system along the Nashville Southeast Corridor that connects downtown Murfreesboro to downtown Nashville along Interstate 24. The study shall identify all public and private funding sources, including amounts, that can reasonably be anticipated and estimated costs and revenues. The department shall report its findings and any recommendations resulting from the study to the transportation and safety committee of the senate and the transportation committee of the house of representatives on or before February 1, 2015.*
>
> *SECTION 2. This act shall take effect upon becoming a law, the public welfare requiring it.*

The Southeast Corridor includes the region's largest employment destinations: downtown Nashville, the Vanderbilt-West End area adjacent to downtown Nashville, and the Murfreesboro area. Other destinations within the corridor include Nashville Airport, Dell, Interchange City, Starwood Amphitheater, the Nissan automobile plant, Treveca Nazarene University, Middle Tennessee State University, and the downtowns of LaVergne and Smyrna.

The intent of this monorail assessment is to assist the Tennessee Department of Transportation (TDOT) in answering the question of whether it is feasible to construct, operate, maintain, and finance a monorail system in the Southeast Corridor. It is important to note that this report is not an assessment of all possible public transit technologies nor does it provide an overview and comparison of premium transit technologies based on vehicle types, performance, stations, alignments, amenities and costs. It is not a sufficient document for the implementation of a monorail system, but it does provide an analysis of the conceptual feasibility of a monorail technology as a premium guideway transit service. It is also noted that transportation planning is a cooperative process designed to foster involvement by all users of the system, such as the business community, community groups, environmental organizations, the traveling public, freight operators, and the general public, through proactive public participation and technical coordination processes conducted by the Metropolitan Planning Organization with TDOT, local and regional jurisdictions, area transit operators, and other partners and stakeholders.

Table OS.1: Summary of Public Chapter 1009 (2014) Provisions

Public Chapter 1009 (2014) Provision	Location Where Provision Is Addressed in the Report	Comments
SECTION 1. The department of transportation is directed to conduct a preliminary study to determine the feasibility of a monorail public transportation system along the Nashville Southeast Corridor that connects downtown Murfreesboro to downtown Nashville along Interstate 24.	This study in its entirety constitutes the response to the direction to assess at a preliminary level the feasibility of a monorail service in the Southeast Corridor from downtown Nashville to Murfreesboro.	This feasibility study utilized a hypothetical alignment for premium transit service in the Southeast Corridor under exploratory analysis by the Nashville Area MPO so as to utilize its conceptual forecasts of premium transit ridership.
The study shall identify all public and private funding sources, including amounts that can reasonably be anticipated and estimated costs and revenues.	Section 11 of the report beginning on Page 56 provides discussion of various transit funding sources. Estimated costs (capital and operating/maintenance) for monorail are discussed in Section 10 beginning on Page 49.	Certain funding sources discussed in the report are not yet established, but are addressed to provide coverage of all potential sources.
The department shall report its findings and any recommendations resulting from the study to the transportation and safety committee of the senate and the transportation committee of the house of representatives on or before February 1, 2015.	The study findings are covered in Section 12 beginning on Page 65. The delivery schedule requirement has been satisfied.	No additional comment.
SECTION 2. This act shall take effect upon becoming a law, the public welfare requiring it.	Not applicable to this study.	No additional comment.

2.0 MONORAIL TECHNOLOGY OVERVIEW

The first generally recognized monorail was the Schwebebahn (“swaying railroad”) in Wuppertal, Germany. A single steel rail is suspended from an elevated structure along which a single rail runs. In this instance, the vehicle weight is both supported by the rail and guided by it. Modern versions of the Schwebebahn monorail look similar in that the monorail is suspended from above. However, instead of using a single rail for support and guidance, the single rail is replaced by a hollowed-out concrete or steel beam, and rubber tires are used instead of metal wheels. Although this is the most common configuration, numerous combinations of steel or concrete running surfaces and rubber tires or steel wheels—both singly and doubly flanged have been proposed.

The straddle monorail is by far the most common monorail type that has been put into operation. It is visually probably the most pleasing type and fits into urban environments better than suspended monorails which normally need to be taller to allow for the necessary vehicular clearance under the train. The straddle monorail is consists of a train running on a concrete or steel guideway. The train's load bearing tires run on top of the guideway beam while the guidance tires run along the two sides of the beam. Proposals for high speed straddle monorails that use the straddle principle use slightly different configurations but the principle is roughly the same.

Currently, the primary transit-grade straddle monorail systems are manufactured by Hitachi of Japan and Bombardier of Canada. All transit-grade straddle monorails are descendents of the monorails of the now defunct German company, ALWEG, which built the Seattle monorail for the 1962 world's fair. Hitachi bought the rights from Alweg to manufacture straddle monorail systems. Hitachi is by far the most successful monorail manufacturer having built several systems and having invested heavily in the development and adaptation of the straddle monorail technology.

The Canadian transportation giant, Bombardier, readapted the Walt Disney World Monorail for its transit monorail, which was built in Las Vegas and which has been proposed for other American cities. Bombardier has built monorail systems in Germany, England, Brazil, Saudi Arabia, and Australia.

3.0 KEY OPERATING CHARACTERISTICS

Monorail operates solely on exclusive right-of–way. In this respect monorail operates as a "rapid transit" system. Monorails cannot operate in mixed traffic as buses or trams do, because the guideway beams cannot be crossed by other vehicular or pedestrian traffic at ground level unlike rail tracks which can be imbedded into the street. However monorail guideways placed on aerials allow for unimpeded traffic flow below. Monorails are served by stations most commonly elevated, but also underground or a few feet above ground level. Although stations require considerably more investment than simple street level light rail platforms, stations do add to the public "visibility" of the transit system. A station can also provide other services, such as retail space that make public transportation a more pleasant and convenient method of travel.

3.1 Speed

Transit-grade monorails generally operate at maximum speeds of 40 to 55 mph, which is comparable to most applications of rail technology within urban areas. Average operating speeds of monorails are comparable to subways due to the fact that they are likewise grade separated and use similar station spacing distances. Speeds are generally in the range of 20 to 30 mph, very high for urban mass-transit.

3.2 Ride

Monorails' ride is superior to cars and buses and similar to that of wielded rail. Suspension is usually provided by air-springs. Forces exerted in curves are reduced by banking the guideway slightly in straddle-systems. Suspended monorails can sway several degrees in curves, reducing forces. Both straddle and suspended monorails provide passengers with the sensation of smooth flight, especially since passenger's visual cues support the sensation.

3.3 Switching

One of the most common misconceptions about monorails is that monorails do not, or cannot, employ switches. In reality, switching is extremely important to monorail operations. The Shonan suspended monorail in Japan employs switches at stations so that a single guideway between stations can be used for bi-directional operation. Even the Disney monorails which operate in a loop must have switches to move trains to and from the maintenance yard. There are a wide range of switches for different purposes. For example, the straddle-type Las Vegas monorail utilizes turnout, crossover and pivot switches in its operation. Due to the weight and size of concrete or steel beams, the switching is slower—roughly 15 seconds compared to 0.6 seconds for traditional rail. This increase in switching time would likely result in increased minimum headways over traditional rail if the switching is to be used regularly in line operation.

3.4 Safety and Evacuation

Monorails have been shown to be one of the very safe forms of transportation. Grade-separated operation generally rules out collisions with automobiles, trucks and pedestrians. Since nearly all monorails built since the original Schwebebahn have not used a single rail as the term "monorail" would imply, and have instead used concrete guideways, derailment is extremely unlikely. The straddle monorail, in particular, hugs the guideway in such a way to almost rule out such a possibility.

3.5 Evacuation

The fact that monorail is usually elevated poses some evacuation challenges. Suspended monorails usually have doors in the floor linked to stairs or a slide as on commercial aircraft. Japanese straddle monorail standards require fully articulated vehicles to allow longitudinal evacuation through the front and rear of the train onto a waiting train. The Malaysian system uses lateral evacuation to a waiting train on the guideway that supports trains in the other direction. Older American monorails use another train to push the stranded vehicle to the next station but when that is not possible, rescue via ladder from the ground is necessary. The Las Vegas monorail provides an emergency walkway between dual monorail beams which is more in line with most rapid transit systems.

3.6 Rubber Tired Traction and Guidance

With few exceptions, like the Schwebebahn, monorail systems use rubber tires for traction. Aside from the guideway, this is the main technological difference between monorail and traditional rail. While rubber traction on steel rails is found on at least one monorail system (Aerobus), most systems with rubber tires run on concrete surfaces. In this regard, most monorail vehicles run more like road vehicles than railway trains. To be sure, such rubber on concrete traction can be found on the Paris, Montreal and Sapporo Metros as well as on most Automated Guideway Transit (AGT) systems. There are both advantages and drawbacks to this method.

3.7 Energy Consumption

Energy consumption is somewhat higher with rubber tired traction. Rubber tires on concrete (as well as rubber tires on steel) have a greater rolling resistance and rotational inertia than steel on steel rail technology. Common rail operation tactics such as coasting can be much less utilized by monorails. Since energy consumption varies with the particular operating regime of a line, exact figures are not possible. However, an estimate of 25 to 30 percent greater energy consumption over rail technology is given.

3.8 Acceleration and Breaking

Rubber tired vehicles can achieve a much higher rate of acceleration and breaking than steel tired ones. For monorail systems, however, this is usually not a significant advantage since acceleration is limited much more by passenger comfort, especially by the passenger comfort of standing passengers. Also, high breaking rates are less necessary where exclusive right-of-way generally rules out collisions with street traffic, which happens to be the case for monorail.

3.9 Gradients

Theoretically, rubber tired traction can overcome gradients of more than 15% whereas rail technology cannot safely exceed 10%. In reality, steep gradients require very powerful motors and are uncomfortable for standing passengers. This means that rubber tired technologies do not have quite as strong an advantage over rail in this respect. In difficult alignments, however, monorail's climbing ability does stand out. An example of this is the Shonan suspended monorail in Japan, where 10 % gradients are found. And the authority responsible for designing Seattle's proposed system found that steeper gradients over water crossings would shorten bridges and thus lower bridge costs significantly.

3.10 Noise

Rubber tired systems are generally quieter in sharp curves than the best rail technology. When rail maintenance is lacking or postponed, as is far too often the case, the benefit of rubber tires can be appreciable. In addition, both straddle and SAFEGE-type monorail systems shield the tire noise unlike other rubber tired applications. Straddle monorails trains shield the tires since the train side stretches beneath the wheels to access the electric catenary, whereas SAFEGE-type monorails have the wheels shielded within the guideway. Rubber tired vehicles produce much less vibration than vehicles with steel tires. Furthermore, since rubber tired monorails produce basically no electromagnetic “pollution”, they can be run near hospitals and scientific institutes without concern.

In general, monorail technology is suited to urban transit applications. It compares favorably to traditional rail technology on the whole. While monorails do have several significant disadvantages that cannot be outright dismissed—like somewhat higher energy costs (for rubber-tired systems) and slower switching as compared with similar rail systems, it is rare that these considerations would amount to a “fatal-flaw”. In fact, these considerations should, more often than not, be minor in the general exercise of mass-transit planning. Indeed, it is in those very areas where monorail technology holds the advantage over steel-rail technology—most notably in its lower noise production and greater grade-climbing abilities—where monorail has the ability to make a fixed transit line feasible where it would not be otherwise.

4.0 GENERAL CONCERNS REGARDING MONORAIL TECHNOLOGIES

There are concerns usually expressed about monorail systems when undertaking a corridor study and attempting to identify the “ideal mode” for a specific corridor. Those concerns are noted below with a brief description of the nature of the concern followed by a response to the concern.

4.1 Proprietary Nature of Monorail Technology

Concern: It was believed that the specialized components needed for monorails would be hard to find or only available from a limited number of distributors. The operator of such a system would be tied to that supplier or manufacturer. Introducing new technology into the study area would require a new, specialized work force or additional training for existing workers. Maintenance shops already in place would possibly not be able to provide service to the new technology if it required different parts than the existing systems.

- Response: It appears Hitachi and other vendors proprietary system used in their monorail systems is limited, i.e., Hitachi’s track switching system. While this is a significant element of the total system, the fact that the remaining portions of the system are non-proprietary indicates that the availability of parts and support for the system may not be as great as feared.

4.2 Incompatibility with Existing Systems

- Concern: There were concerns about the idea of introducing another transit mode in a region - where other rail modes already exist.

- Response: While the introduction of a new technology to the regional transit network will require an investment in new systems, vehicles, and maintenance resources, similar investments would be required to expand any of the existing rail systems.

With regards to the compatibility of monorail technologies with existing stations: where a transit line is being extended, it does make more sense to extend the existing mode rather than introducing a second mode to the line. However, where a new transit service is being used to provide an intermodal link between two or more existing transit lines, the reduced guideway requirements of monorail technologies may make it easier to integrate a new service into the site design of existing stations.

4.3 Limited Capacity of Monorails

Concern: Monorails have much smaller capacity than what might be needed.

- Response: The systems reviewed have demonstrated passenger capacities of up to 49,000 passengers per hour per direction. Used in the appropriate corridors, a monorail system should be ample for the needs of ridership demand in most transit corridors.

4.4 Safety and Reliability

Concern: The safety and reliability of monorail systems has not been proven. A concern about monorail technology involved the ability of trains to execute a track switch when necessary. This raised questions about the safety of passengers in the event of an emergency and the reliability of the system in the event of a vehicle breakdown.

- Response: The National Fire Protection Association 130: *Standard for Fixed Guideway Transit and Passenger Rail Systems* code must be met in order to operate a rail system in the United States. Additionally, there are other standards that must be met in the United States.

- Existing monorail technologies may require additional research and development in order to adapt them to federal, state, and local safety requirements. The reliability of monorail services varies considerably among the technologies reviewed. The side straddle systems on the market today may require additional right-of-way for turn back loops in order to preserve service around disabled vehicles. As with other conventional rail services, the ability to preserve service will be dependent on the availability of crossovers and other system elements necessary to move around disabled vehicles.

In addition to the regulatory safety requirements of a system, there are two other practical issues which need to be taken into consideration:

- Evacuation Procedures: Both the vehicle and the guideway must allow passengers to exit the system in the case of emergency. This is an especially important point with automated systems since there may not be transit personnel on board a vehicle during the time of an accident.

- Operating Recovery Plans: In case of a disruption of service, it is crucial for a system to have mechanisms and procedures in place which would allow regular service vehicles to bypass the affected section of the system.

5.0 MONORAIL IN THE SOUTHEAST CORRIDOR

This study reviewed prior transit planning in this corridor, examined alignment and station locations, considered recent transit ridership forecasting, and developed capital and O&M cost estimates for the monorail technology in this corridor.

5.1 Prior Planning and Corridor Growth

As a frame of reference, it is useful to summarize prior transportation planning relevant to the Southeast Corridor running generally along I-24. This planning has been led by the Nashville Area Metropolitan Planning Organization (MPO).

The **Nashville Southeast Corridor High-Performance Transit Alternatives Study (August 2007)** was conducted by the MPO to address the future transportation needs of this growing corridor. The study considered initially a broad range of transit technologies, including: bus rapid transit – light, bus rapid transit, light rail transit, heavy rail/subway transit, monorail, commuter rail and high speed rail. The study steering committee screened alignment and technology combinations to a reduced set of options which included commuter rail, light rail transit and bus rapid transit. After final screening, the Locally Preferred Alternative selected for the corridor was a combination of phased bus service enhancements, including development of express bus and skip stop bus services on I-24 and Murfreesboro Road (US 41) and extended local bus service on Murfreesboro Road.

The **Nashville Area MPO 2035 Regional Transportation Plan (December 2010)** contained an expanded vision for public transportation in the greater Nashville region. This plan is the result of a cooperative process designed to foster involvement by all stakeholders, such as the business community, community groups, environmental organizations, the traveling public, freight operators, and the general public, through a proactive public participation process conducted by the Metropolitan Planning Organizations, TDOT, and the area transit operators. The plan identified a range of potential transit technologies and service configurations, but did not include the monorail technology. The long-range vision for transit incorporated commuter rail, rapid transit (either BRT or LRT), and express bus, in addition to standard fixed route bus service and supporting transit circulator services. For the Southeast Corridor, the plan called for in the short-term to develop express coach service from Murfreesboro to downtown Nashville using the I-24 High Occupancy vehicle (HOV) lanes, in the mid-term for enhanced and bus rapid transit service as delineated in the prior 2007 study, and in the long-term for further upgrading of bus services, and the reevaluation of the corridor within 5-10 years for possible fixed-guideway transit investments.

The **Regional Transit Vision** was an integral component of the 2035 transportation plan. It included supporting documentation and a stylized depiction of future transit services across the region. The vision was not intended to depict exact alignments and station locations, but rather convey a sense of the transit coverage and hierarchy of transit services that conceivably could serve the Nashville region of the future. For the long-range vision of the Southeast Corridor, the map identified a Bus Rapid Transit – Lite line extending from downtown southeasterly to the Hickory Hollow district, and a Rapid Transit Line (either LRT or BRT) extending from downtown to Murfreesboro.

The ongoing **Southeast Area Transportation and Land Use Study** is developing a preferred vision for growth and development in the area paralleling I-24 between I-40 and I-65 in Davidson and Rutherford Counties. The study initially focused on land use trends and alternative land use scenarios, arriving at a consensus for an alternative land use configuration that would be more supportive of transit. The study is now engaged in examining premium transit service alternatives, continuing to look at rapid transit service – either light rail transit or bus rapid transit service in the corridor. Preliminary transit ridership forecasts to the year 2040 for Southeast Corridor transit service, including rapid transit service along a hypothetical alignment and a 13-station configuration traversing from downtown Nashville to Murfreesboro along Murfreesboro Pike, Bell Road, and I-24 have been developed.

The Nashville Area MPO service area, including Davidson, Maury, Robertson, Rutherford, Sumner, Williamson, and Wilson Counties, has a population of nearly 1.6 million, per the US Bureau of the Census 2013 estimate. Population in Davidson and Rutherford Counties along the Southeast Corridor was estimated by US Bureau of the Census as 939,631 persons in 2013, and is forecast to grow to 1,163,312 persons by 2035, according to the 2035 Regional Transportation Plan, and continuing a trend of continued growth over recent decades. The MPO is in the process of updating regional demographic forecasts as part of developing the 2035 Regional Transportation Plan, adopted in December 2010, to the year 2040.

Finally, it is noted that there have been high-level corridor studies of an Atlanta-to-Chattanooga high speed rail service (HSR), with a potential connection to Nashville along the I-24 corridor. HSR technology has not been and should not be considered for commuter-type service within the Southeast Corridor. HSR is intended for long-distance, intercity travel, and the proximity of stations within a suburban commuter corridor would defeat the intended benefit of high speed travel, as well as the economic and societal benefit expected from an HSR project.

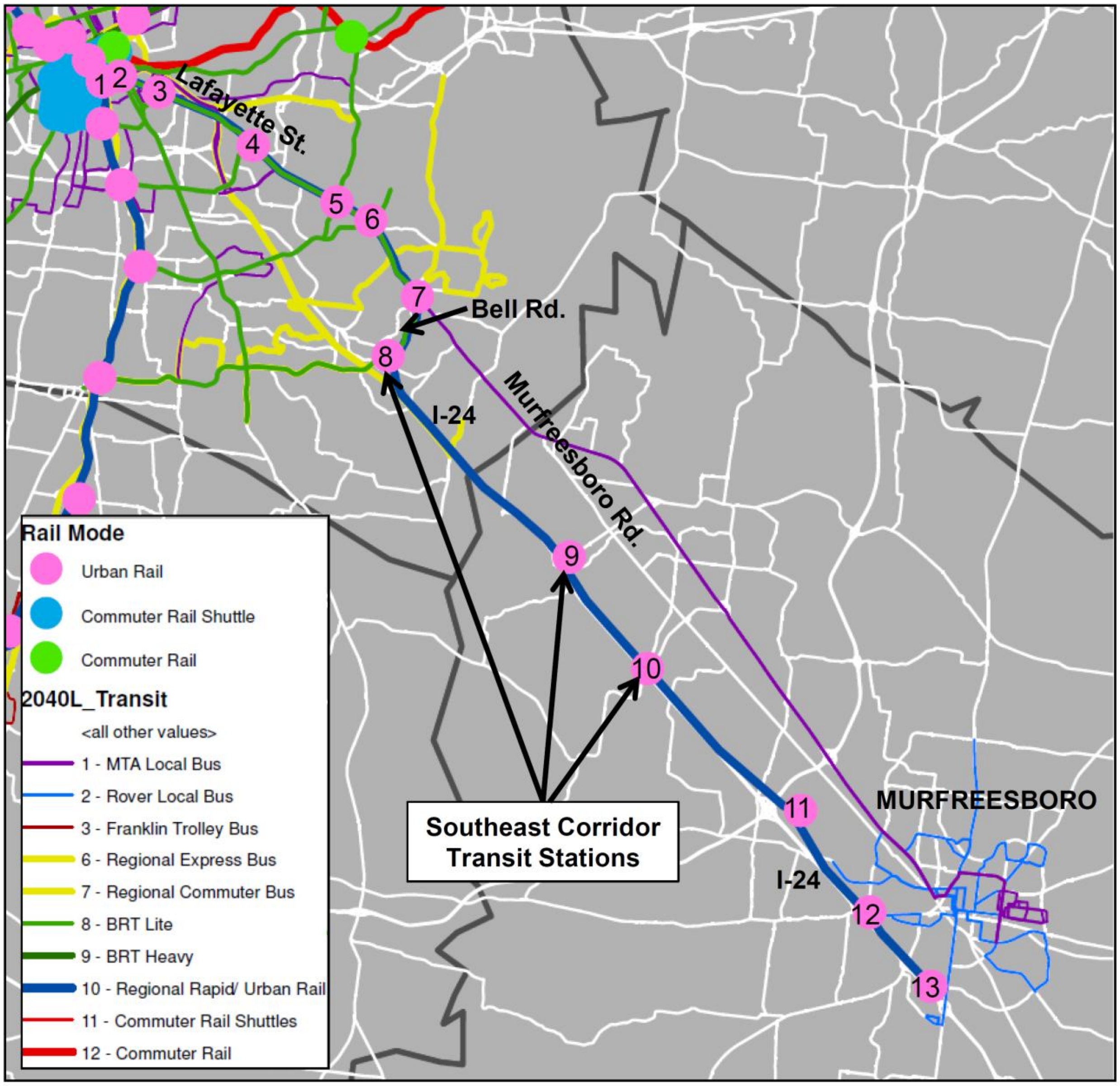
5.2 Alignment Considerations

The prior 2007 Southeast Corridor transit study considered three final options, each coupled with a unique transit technology (along with a lower cost Transportation Systems Management phased bus service alternative). Those options were commuter rail on the CSX rail line, bus rapid transit along I-24, and bus rapid transit along Murfreesboro Road. The ongoing Southeast Area Transportation and Land Use Study is initially investigating a hypothetical Rapid Transit Service that extends southeasterly from downtown Nashville along Lafayette Street and Murfreesboro Road to Bell Road, where the path turns south along Bell Road and Mountain View Road to I-24, and thence southeasterly along I-24 to Murfreesboro. In this study, Rapid Transit Service being studied would be either bus rapid transit or light rail transit. In its travel demand modeling work thus far for the current corridor study, the MPO has coded this premium transit service corridor as “urban rail/light rail transit”.

It is also noted that the MPO has not addressed at this time the configuration of light rail transit that would be utilized to insert the service into the arterial street segments of the hypothetical alignment. That is to say, it is not yet been analyzed if portions of the light rail transit alignment would be at-grade or elevated, in the median of the street or to the side, in mixed traffic flow or segregated from vehicular traffic. These are considerations of some importance as they can affect station configuration, extent of street reconstruction, need for right-of-way, utility impacts (both underground and overhead), and ultimately the capital cost of the facility.

The hypothetical Southeast Corridor alignment and hypothetical station locations in the MPO travel demand modeling work are shown in Figure OS.1. This configuration of hypothetical alignment and station locations is assumed for the monorail technology scenario examined in this study for consistency with current MPO transit corridor planning, including initial transit ridership forecasting.

Figure OS.1: Potential Southeast Corridor Premium Transit Alignment and Stations



It is assumed the monorail alignment would be located within the median of the surface streets between downtown Nashville and I-24, elevated on support columns. Along I-24, the monorail would run along the eastern edge of the I-24 right-of-way, with its profile elevated over roadways which cross I-24 and at station locations, and the profile following the topography along the freeway in an at-grade configuration.

Mention had been made of the monorail technology being applied to the I-24 corridor in an elevated configuration within the median of that roadway. It is noted that from I-40 southward to Rock Springs

Road just south of the Sam Ridley Parkway, a distance of 14.6 miles, the median of I-24 is approximately 21 feet wide with a separating barrier. Options for placement the monorail in the I-24 median were explored but not adopted as they are more costly with maintenance of traffic issues, and create station locations that are not adjacent to transit supportive land uses or park-and-ride facilities. Conceivably, monorail could be installed in the median of I-24 either in an elevated configuration, or at-grade in the median area of the freeway.

It is assumed that monorail stations will be elevated with center platform configurations. The monorail system requires a continuous separation from other crossing movements, whether vehicular or pedestrian. Transit users cannot cross the monorail guideway at-grade, so grade separation between the monorail and transit users is necessary. This need is generally better accommodated with the monorail elevated as that is a general condition for this technology. A center platform configuration allows for a single set of vertical circulation elements - stairways, elevators, and possibly escalators – to serve both directional guideways.

For stations within the street median, it is likely that the directional roadways would need to be flared approximately 15-25 feet further apart toward the outside of the roadway to create sufficient room in the median for supporting columns as well as vertical and horizontal pedestrian circulation. From this median station location, users would pass to the outside edge of the roadway by way of crosswalks at signalized intersections. Connecting buses would utilize bus bays on the side of the roadway at the station locations. This configuration could require right-of-way acquisition along the roadway in the station vicinity.

Along the I-24 right-of-way, since the alignment would be elevated over crossing roads and the five hypothetical stations would be located at crossing roads, these stations would also be elevated. However, it is expected that they would not be located within street medians but rather in freestanding sites with kiss-and-ride spaces as well as bus bays for other interconnecting transit services. Some stations would also have relatively large park-and-ride lots.

There are two particular locations along the potential monorail alignment that require further attention: (1) The crossing of I-40 near downtown, and (2) The underpass of Murfreesboro road at the Nashville International Airport runway and taxiway, which is approximately 1,000 feet long. Along the proposed alignment at I-40, options are to pass under the roadways within Lafayette Street, flyover the elevated I-40 mainline roadway with a very high structure, or shift the alignment slightly west and cross I-40 where it is closer to ground level. The latter option makes the most sense for monorail. To do so, the monorail could turn westerly from Lafayette Street and run along the south edge of the I-40 freeway, and then cross I-40 in the vicinity of 5th Avenue South or 6th Avenue South, returning to Ash Street and continuing to the end station on Fogg Street.

Approaching the airport runway underpass, the monorail guideway would be elevated in the median of Murfreesboro Road. However, between McGavock Pike to the north of the runway and Dell Parkway to the south, the monorail guideways would need to profile to existing grade and follow the roadway profile under the runway. The existing roadway under the runway consists of two 3-lane roadways 36 feet in width, a median of 12 feet which includes two narrow shoulders and the central support column of the underpass, and two outer unpaved shoulders of 10 feet in width.

The monorail guideways could be configured near the median on either side of the middle column, shifting the roadway lanes outward, or could be positioned in the outer shoulder areas, and likewise adjusting the roadway travel lanes. The latter option is deemed preferable. Roadway travel lanes would either need to be restriped for very narrow lanes, or one travel lane in each direction would be given over to the monorail guideways. As the roadway in this area has six through traffic lanes passing through traffic signals which reduce the throughput, four traffic lanes through the tunnel operating in free flow condition would provide sufficient capacity. It is noted that there may be issues with underground utilities, drainage and subsurface foundation systems for the underpass that could affect the viability of this proposal. All associated issues with this configuration of the monorail through the existing airport runway underpass would need to be examined and approved by TDOT, the Federal Highway Administration, the Federal Aviation Administration, the Nashville International Airport and others.

The use of Tennessee DOT highway right-of-way for public transportation is guided by provisions in the Code of Federal Regulations (23 CFR, Chapter 1, Part 810) entitled Mass Transit and Special Use Highway Projects. This guidance indicates that such use may be possible, provided that the use does not restrict future needed highway improvements nor impair highway safety. For the purposes of this analysis, it is noted that the alignment geometry of the hypothetical Rapid Transit Service being examined by the MPO follows US 41 and I-24 corridors, and it is assumed for this assessment that such use of public highway right-of-way for mass transit projects can be achieved.

5.3 Projected Ridership

The current MPO Southeast Area Transportation and Land Use Study has initiated examination of potential premium transit services in the Southeast Corridor. The estimates of transit ridership in 2040 for the Southeast Corridor are tentatively based on hypothetical transit service alignments and hypothetical station locations selected based on perceived ridership potential to test initial results and are expected to lead to various further refinements as the transit alternatives analysis process continues. At this point in time, only the initial transit ridership forecasts are available; for the Southeast Corridor Rapid Transit Service concept, the MPO has tested only the “urban rail/light rail transit" technology thus far. In addition to Rapid Transit Service in the corridor, the study is also examining several other transit service elements, including:

- BRT Lite service from downtown Nashville to the Hickory Hollow district,
- Route 15 standard bus service to be continued,
- Route 96 Express bus service, and
- Route 96 Community Circulator bus service.

Because monorail transit service parameters for Rapid Transit Service in the Southeast Corridor can be considered similar for the purposes of this analysis, it is therefore assumed that ridership on a monorail technology in this corridor would be very similar. To clarify, monorail can match the Rapid Transit Service option in terms of service frequency and schedule, station locations, corridor capacity, available park-and-ride facilities, and vehicle operating speed, such that it is equally attractive to prospective transit users in terms of the mode choice decision (auto vs. premium transit). It is also assumed that fares between Rapid Transit Service and monorail would also be comparable.

The initial results from the current MPO study for projected 2040 ridership show that the premium transit service in the Southeast Corridor in the form of the Rapid Transit Service (to date modeled as urban rail/light rail transit) attracts approximately 7,100 daily boardings in 2040 under the trend land use scenario, and 9,400 daily boardings, or about 32% higher, under the alternative land use scenario that was tested. It is noted that in the ridership forecasting, the MPO incorporated park-and-ride lots at several locations to support the drive access mode to transit stations. These ridership estimates were used to determine monorail service requirements. It is also noted that the total forecast transit ridership in the corridor is approximately 16,000 daily boardings when the other transit service components are considered. The MPO considers this value an upper end potential volume for the corridor, on the basis that the ridership for the other corridor services would be absorbed into the rapid transit option.

5.4 Capital Costs

Capital cost estimates were developed for a monorail system in a configuration within the Southeast Corridor parameters as described previously. It is noted that this estimate was developed at the conceptual level of project definition where many aspects of inserting a monorail facility into the Southeast Corridor have not yet been developed in much detail. The estimating process uses the Federal Transit Administration (FTA) Standard Cost Categories (SCC) worksheet tables which include 10 general cost categories, each with two or more cost line items. Allocated cost contingencies were added to each individual cost line item; these contingencies were set at 20% except for utilities which was 30% and right-of-way which was 50%. A standard general unallocated contingency of 15% was added to all cost category subtotals. It is noted that these costs are conceptual in nature as the monorail technology concept has not been articulated in any significant detail at this stage of discussion. Each of the SCC elements are described below along with pertinent assumptions:

A conceptual level cost estimate was prepared for a monorail system in the Southeast Corridor, and summarized for project budget purposes. Unit costs used to develop the estimates were based upon recently completed transit systems and modified as required for the monorail transit investments envisioned for the Southwest Corridor. Source information was derived from recent available comparable project cost estimates. The cost estimate was developed using 2014 base year costs and escalated to 2020 (presumed opening year) at a rate of 3.0 % per year based on recent construction cost trends. The FTA SCC spreadsheet includes an inflation worksheet that addresses this calculation step.

Unit costs for specific project components were drawn from data available to the consultant for project estimates for other similar recent projects. Certain costs associated specifically with monorail are not commonly available, and reasonable unit costs were identified by the consultant based on research and in-house estimates.

The estimated capital costs are approximately $1.63 billion ($47.0 million/mile) in 2014, and approximately $2.06 ($60.6 million/mile) in 2020.

5.5 Operations and Maintenance Costs

There is limited data for the operations and maintenance costs for monorail systems in North America. Information secured from selected manufacturers suggests that the operations and maintenance costs for monorail are similar to those for light rail transit (LRT). The annual operations and maintenance cost is a function of the proposed service plan for monorail operations previously summarized for this corridor in terms of the hours of operation, the service frequencies during the day, and the vehicle service requirements based on the scheduled operating speed.

The MPO corridor travel demand modeling for the Urban Rail option in this corridor as LRT was coded in the model with an overall operating speed of 44 mph. This speed is assumed to be the scheduled operating speed which needs to take into account the optimum technology operating speed adjusted for deceleration and acceleration time losses as well as dwell time losses at transit stations, as well as adjustments for horizontal curves and vertical curves which may affect operating speed. Typically achievable scheduled operating speeds for guideway transit in an urban and suburban environment given station spacing distances and common alignment curvatures is in the 30-35 mph range. The northern third of this hypothetical corridor alignment and station location layout is in the realm of prototypical corridor layouts, but the southernmost two-thirds of this corridor is a relatively straight alignment with widely separated station locations which are more widely spaced.

Based on this corridor characterization, the northern one-third of the corridor should operate near a 30 mph scheduled speed with its more closely spaced stations. To satisfy the overall scheduled operating speed of 45 mph, the southern two-thirds of the corridor would need to operate at a scheduled speed of 52.2 mph. This would require an average operating speed of 57.4 mph allowing for station stopping delays. For the purposes of this analysis, an overall corridor schedule operating speed of 38 mph was assumed.

This value was applied to the calculated revenue hours of service and adjusted to an annual basis, for an estimated annual operating and maintenance cost of $17.22 million per year in 2014 dollars.

6.0 FINANCING THE PROJECT

Project finance refers to specially designed techniques and tools that supplement traditional transit financing methods, improving governments' ability to deliver transportation projects. Project finance typically entails borrowing money, either through bonds, loans or other financing mechanisms. Borrowing money for project implementation helps accelerate implementation of needed infrastructure.

Project finance has evolved at the Federal level as a product of dialogue between policy and administrative officials at United States Department of Transportation (USDOT) and partners at the state and local levels. Most of the programs and tools have been enabled by legislative changes to the U.S. Code, Title 23. As transportation finance needs evolve, new tools and programs are likely to add to the field of project finance.

Federal Transit Administration's (FTA) New Starts competitive grant program is the primary source of federal funding for fixed guideway transit construction projects, like the Southeast Corridor project. Individual projects from throughout the country compete against each other for limited funding. With Congress focusing on reducing federal government spending, federal funds for New Starts projects could be reduced. As a result, fewer projects may receive federal matching funds, and the level of federal matching funds will be less than the 50%.

Assuming the federal funds are approved for the Southeast Corridor project (whether it is a LRT or monorail project) the federal contribution for the Southeast Corridor would be in the range of $1.03 billion (2020 year of expenditure cost) and the remainder of $1.03 billion would fall to State, regional, local and other funding sources.

While motor fuel taxes have been the primary revenue source at both the state and federal level for transportation, the buying power of this revenue source has eroded significantly with inflation and will continue to as fuel efficiency standards increase. Other traditional transportation revenues, such as the titling tax or registration fees, have declined or stagnated in recent years due to the recession. In response to increasing demands for new projects and maintenance of aging systems, and declining availability of state and federal funds, state and local governments across the country are considering a variety of alternative strategies to finance transit project development. Transportation financing strategies that involve public-private partnerships (P3) continue to receive significant attention.

Four broad transportation revenue generation strategies the State could pursue to help finance the Southeast Corridor project are P3/availability payments, Transportation Infrastructure Finance and Innovation Act loan, value capture, and local option revenues. It is important to keep in mind, however, that these strategies are neither exhaustive nor mutually exclusive. Also, it is understood some of these financing techniques may require State legislative action to implement them.

Local and regional financial support is critically important to support transit state of good repair projects, new major transit infrastructure projects and on-going transit O&M costs. There is an ongoing effort in the Middle-Tennessee region, as noted by the MPO, to pursue local dedicated revenue sources for major transit projects in this and other regionally significant corridors. Typical revenue sources include the following: (1) traditional tax- and fee-based funding sources; (2) common business, activity, and related funding sources; (3) revenue streams from projects; (4) new “user” or “market-based” funding sources; (5) financing mechanisms; and (6) fare policy and strategy.

In summary, while Tennessee has relied on traditional transportation revenue sources in the past, new revenue sources and more innovative transportation financing strategies may be required to expand Tennessee’s transit infrastructure. This section of the report identified several transportation financing mechanism strategies that could be implemented to help the State as well as regional and local governmental entities realize their transit goals.

7.0 FINDINGS AND RECOMMENDATIONS

Based on the analyses conducted in this assessment, the following findings are offered:

- Monorail technologies are capable of providing operating speeds and passenger capacities comparable to those of other modes of premium transit. They have a demonstrated history of reliable operations.

- There are a number of monorail manufacturers, some of which have established a business presence in the United States, with a proven history of operations to minimize some of the risks associated with introducing a new technology to the regional transportation network. In areas where at-grade transit technologies or aerial heavy rail transit may pose serious physical impacts to a corridor, the lower impacts of monorail systems may offset some of the costs of building such systems.

- The side-straddle systems under development pose a service reliability issue as they are unable to maneuver around disabled or stopped trains by “switching tracks” as rail and straddle-system monorails do. However, if this issue can be resolved, side-straddle monorails may offer savings in costs and impacts, since they are able to fit two guideways on a single narrow structure.

- Although there is uncertainty about the reliability of the monorail technologies still under development, the existing systems have demonstrated a sufficient record of reliability and effectiveness. Because of this, monorail technologies may be considered as a technology alternatives for new transit alignments in the Southeast Corridor.

- The MPO’s 2035 Regional Transportation Plan, adopted in December 2010, recommended rapid transit but did not identify a specific technology for the Southeast Corridor. The 2007 MPO study (Nashville Southeast Corridor High-Performance Transit Alternatives Study) discounted the monorail technology for various reasons, including: its aerial structural system and aerial stations are expensive on a per mile basis compared to at-grade transit service, its track record in providing urban/suburban transit service has not been demonstrated, and monorail is not applicable for express service when compared to proven bus and commuter rail modes. These reasons are legitimate in terms of the project context, namely that there is very limited application of monorail to the daily commuter environment of suburban corridors in North America. There are optimistic citations by some monorail developers as to the cost economy of their technology, but these often do not include full project cost components and the associated soft costs of projects. Cost comparisons are often apples-to-oranges situations, causing confusion as to actual facts. Cost/mile of light rail transit, has in fact grown significantly over recent years based on new projects which have averaged $67 million/mile, ranging from $48 to 91 million/mile (2014 $) in total project cost.

- The estimated project cost to develop a monorail transit facility in the Southwest Corridor along the alignment described is approximately $1.63 billion in 2014 dollars and $2.06 billion in year of expenditure dollars for a 2020 revenue service opening date. These estimated costs include both hard and soft costs. The capital costs and their allocated contingencies account for 60% of the total project cost and soft cost account for the balance.

- In the Southwest Corridor, along the I-24 segment, there is the opportunity to build a premium transit line in public right-of-way in a near at-grade configuration with cuts and fills along the transit guideway profile, significantly reducing guideway costs. Constructing the I-24 segment of this alignment in a totally elevated configuration would add over $550 million in 2014 and $700 million to the project cost in 2020.

- The estimated annual operating cost for the monorail service, for the service assumptions listed, in 2014 dollars, is approximately $17.22 million. It is noted that the operational component of the annual operations and maintenance cost is a function of the proposed service plan for monorail operations in terms of the hours of operation, the service frequencies during the day, and the vehicle requirements based on the scheduled operating speed and passenger load.

- Ridership for the year 2040 in this hypothetical corridor as initially estimated by the MPO for a light rail transit option, with similar service characteristics to monorail, was 7,100 daily boardings, and 9,400 daily boardings with more transit supportive land uses around station areas. Desirably, ridership estimates should be much higher to support the more expensive transit technologies under consideration, including monorail. It is noted that the total forecast transit ridership in the corridor is approximately 16,000 daily boardings when the other proposed transit service components are considered. The MPO considers this value an upper end potential volume for the corridor, on the basis that the ridership for the other corridor services would be absorbed into the rapid transit option.

Development of a monorail transit facility in the Southwest Corridor along the alignment identified is generally feasible, although there are a great many design details that could not be addressed in this assessment. Moreover, an objective assessment of project impacts would also need to be conducted to determine if this particular concept causes any significant impacts that cannot be reasonably mitigated.

Monorail Assessment Report for the I-24 Southeast Corridor

1.0 INTRODUCTION AND PURPOSE

This report provides the results of a technology assessment of monorail systems. This report also explores the feasibility of a monorail system operating in the 33.7-mile long Interstate 24 (I-24) Southeast Corridor Regional Rapid/Urban Rail Transit Corridor (Southeast Corridor), as identified by the Nashville Area Metropolitan Planning Organization (MPO). The MPO's 2035 Regional Transportation Plan, adopted in December 2010, recommended rapid transit but did not identify a specific technology for the Southeast Corridor. This report was prepared as directed under Public Chapter 1009 (2014) and its language is provided as follows.

> *SECTION 1. The department of transportation is directed to conduct a preliminary study to determine the feasibility of a monorail public transportation system along the Nashville Southeast Corridor that connects downtown Murfreesboro to downtown Nashville along Interstate 24. The study shall identify all public and private funding sources, including amounts, that can reasonably be anticipated and estimated costs and revenues. The department shall report its findings and any recommendations resulting from the study to the transportation and safety committee of the senate and the transportation committee of the house of representatives on or before February 1, 2015.*
>
> *SECTION 2. This act shall take effect upon becoming a law, the public welfare requiring it.*

The Southeast Corridor includes the region's largest employment destinations: downtown Nashville, the Vanderbilt-West End area adjacent to downtown Nashville, and the Murfreesboro area. Other destinations within the corridor include Nashville Airport, Dell, Interchange City, Starwood Amphitheater, Nissan automobile plant, Treveca Nazarene University, Middle Tennessee State University, and the downtowns of LaVergne and Smyrna. A map of the Southeast Corridor is depicted on **Figure 1**.

This report includes the identification of monorail systems that are currently in operation and those that are in various stages of development. The developmental status of the various technologies has been discerned and the design and performance characteristic of each of the technologies has been documented for comparison. Available information on existing systems has been obtained and where commitments have been made to install new systems, these have been noted. A limited number of the monorail vendors were also identified to present information on their systems and provide further details on design, operation, costs and unique features.

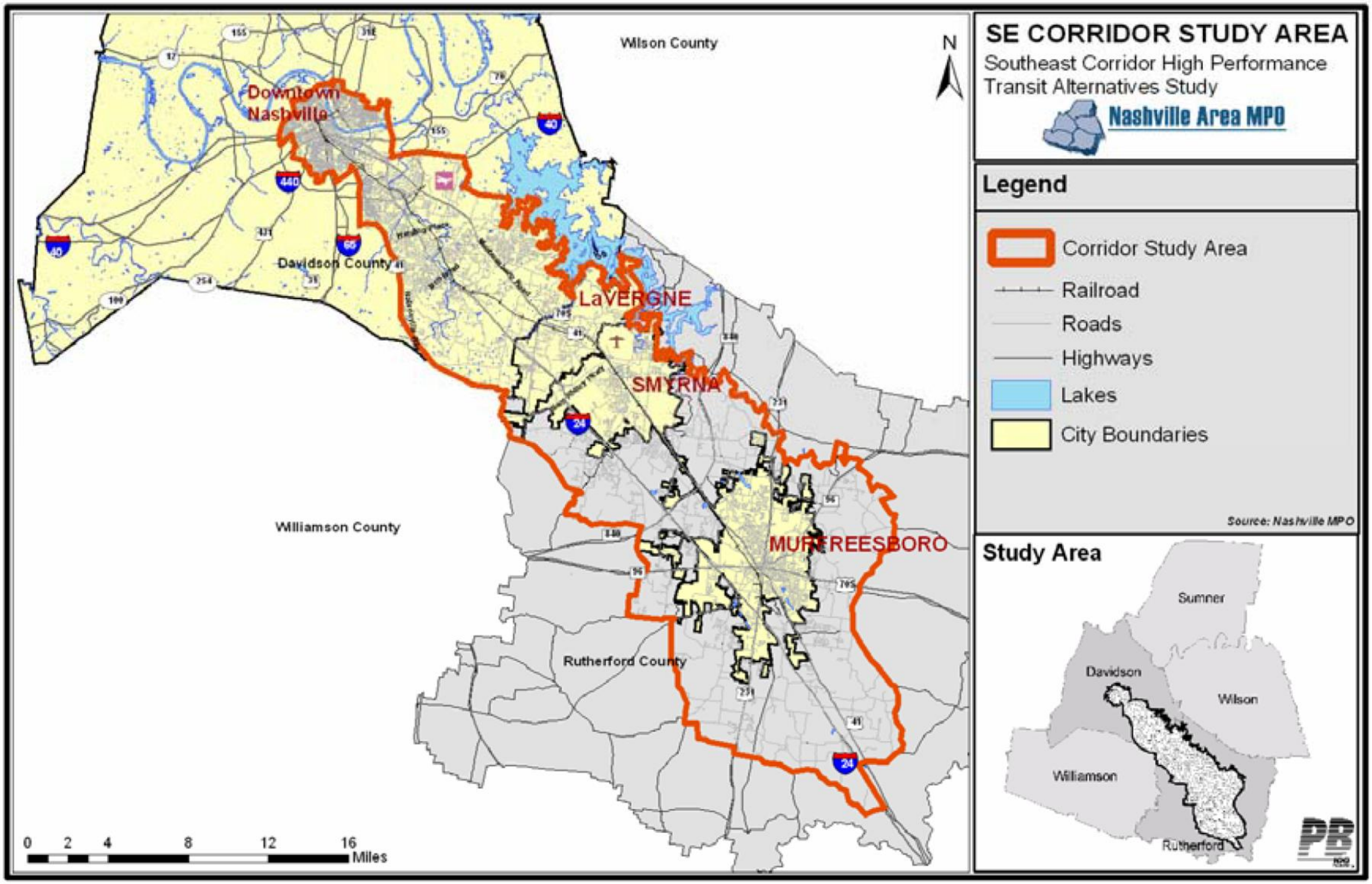
The best available information on monorail system capacities including capital and operating characteristics, guideway, vehicle and typical station characteristics is also presented in this report.

The intent of this monorail assessment is to assist the Tennessee Department of Transportation (TDOT) in answering the question of whether it is feasible to construct, operate, maintain, and finance a monorail system in the Southeast Corridor. It is important to note that this report is not an assessment of all possible public transit technologies nor does it provide an overview and comparison of premium transit technologies based on vehicle types, performance, stations, alignments, amenities and costs. It is not a sufficient document for the implementation of a monorail system, but it does provide an analysis of the conceptual feasibility of a monorail technology as a premium guideway transit service. It is also noted that transportation planning is a cooperative process designed to foster involvement by all users of the system, such as the business community, community groups, environmental organizations, the traveling public, freight operators, and the general public, through proactive public participation and technical coordination processes conducted by the Metropolitan Planning Organization with TDOT, local and regional jurisdictions, area transit operators, and other partners and stakeholders.

2.0 MONORAIL TECHNOLOGY OVERVIEW

The Monorail Society defines monorail as a single rail that serves "as a track for passenger or freight vehicles. In most cases rail is elevated, but monorails can also run at grade, below grade or in subway tunnels. Vehicles are either suspended from or straddle a narrow guideway. Monorail vehicles are wider than the guideway that supports them." However, this rather straightforward definition is somewhat misleading as it downplays the wide range of technologies, operating principles and appearances the definition includes.

Figure 1: Southeast Corridor Study Area



The first generally recognized monorail was the Schwebebahn (“swaying railroad”) in Wuppertal, Germany (see **Figure 2**). It is the only true “mono-rail.” A single steel rail is suspended from an elevated structure alonle rail runs. In this instance, the vehicle weight is both supported by the rail and guided by it. The position of the vehicle in respect to the rail is unlike traditional dual-rail systems but the basic technology by which the vehicle operates is no different from that of a railroad except that the wheels are double-flanged

Figure 2: Schwebebahn in Wuppertal, Germany

Modern versions of the Schwebebahn look similar in that the monorail is suspended from above. However, instead of using a single rail for support and guidance, the single rail is replaced by a hollowed-out concrete or steel beam, and rubber tires are used instead of metal wheels. Although this is the most common configuration, numerous combinations of steel or concrete running surfaces and rubber tires or steel wheels—both single- and double-flanged arrangements have been proposed.

The Townline Monorail, in Chiba Prefecture, Japan, is currently the longest suspended monorail system in the world (see **Figure 3**). The 9.4 mile long system opened in 1988 with 18 stations and operates daily carrying over 45,500 passengers daily. Building upon the knowledge and experience of the Shonan Monorail, in the Kanagawa Prefecture, Japan, which has been in operation for over 30 years, the Mitsubishi Company built this dual-tracked system to connect suburbs in the Chiba Prefecture with Chiba's main rail station downtown. It is currently the world's only dual-beamed SAFEGE[1]-suspended type system. It also has a spur line off the main

[1] Société Anonyme Française d'Etude de Gestion et d'Entreprises, and translated to English it means "French Limited Company for the Study of Management and Business. The consortium consisted of 25 individuals and firms who developed the suspended monorail system.

line, another example that monorail switches work fine. One of the reasons Chiba officials selected SAFEGE was because of the occasional inclement weather of the area. With SAFEGE, the running surfaces and train bogies (the bogie supports the monorail car on the track) are protected from the elements inside the beams. ALWEG[2]-straddled type monorails need heaters in the beamway or shovels on the train fronts during heavy snow or ice conditions.

Figure 3: Townliner Suspended Monorail in Chiba, Japan

The dual beams are hollow steel boxes about 6.09 feet by 6.18 feet in size. Note that this is much larger than the 2.2 feet by 4.0 feet used by the Bombardier Disney monorail beam. Trains are two cars long; each car is 50.5 feet long and 8.69 feet wide. Each car has two four rubber-tired bogies. There are two motors per bogie for a total of four per train. Power comes from a third rail inside the beam. On each bogie are four rubber guide wheels (see **Figure 4**). The gauge of the load/drive tires is about 2.85 feet. Electrical equipment and heating, ventilating, and air conditioning (HVAC) equipment are above the cabin. This helps lessen the risks of fire, as well as making it easy to maintain. The suspension system allows the cars to swing several degrees, like a pendulum, which makes it easier on standing passengers in curves. **Figure 5** illustrates single and twin suspension guideways.

[2] ALWEG was a transportation company who developed the straddle-beam monorail.

Figure 4: Suspended Monorail Bogie

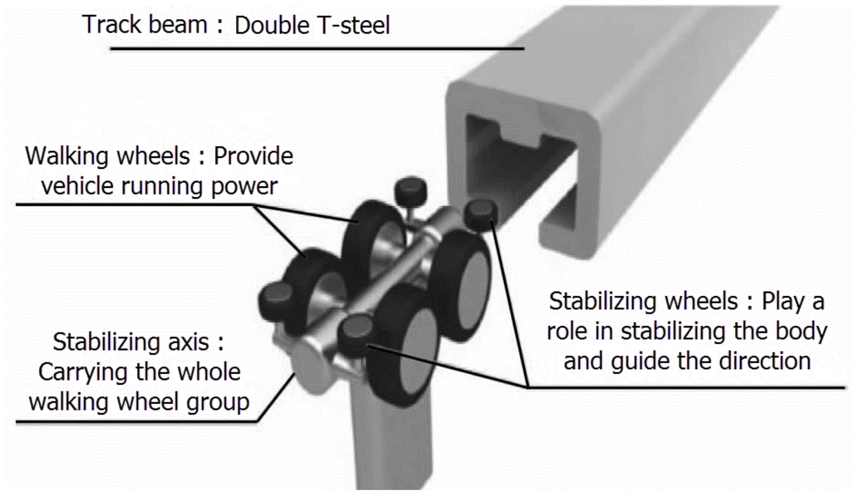
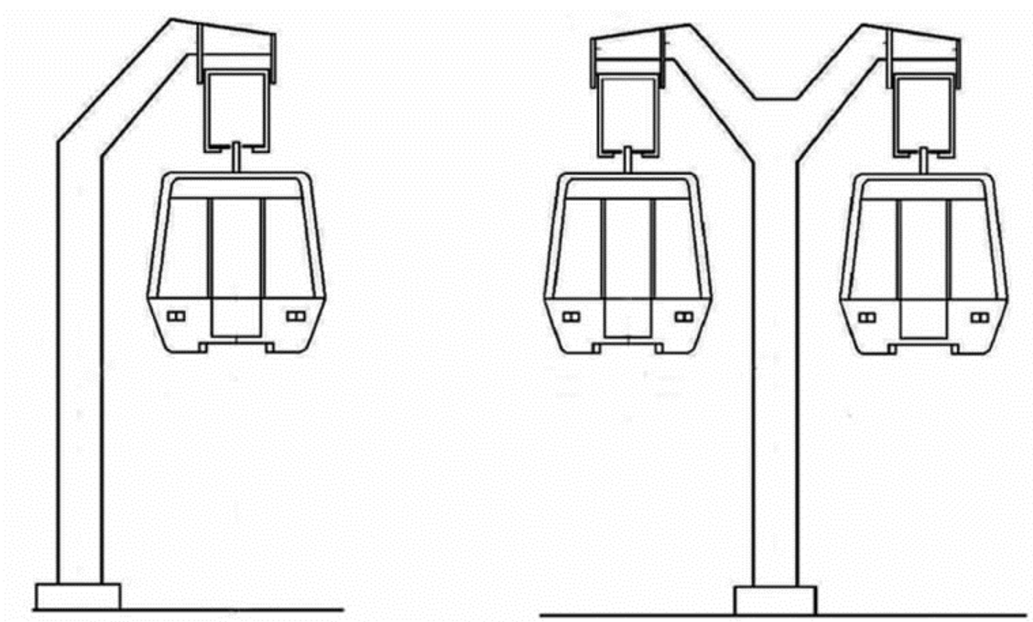


Figure 5: Different Ways of Suspending a Suspension Monorail

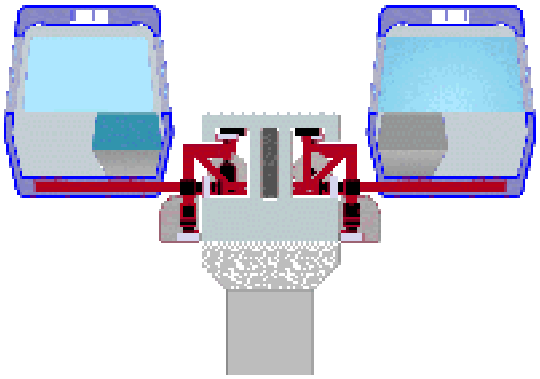


The straddle monorail is by far the most common monorail type that has been put into operation (see **Figure 6**). It is visually probably the most pleasing type and fits into urban environments better than suspended monorails which normally need to be taller to allow for the necessary vehicular clearance under the train. The straddle monorail is composed of a train running on a concrete or steel guideway. The train's load bearing tires run on top of the guideway beam while the guidance tires run along the two sides of the said beam. Proposals for high speed straddle monorails that use the straddle principle use slightly different configurations but the principle is roughly the same.

Figure 6: Seattle ALWEG Straddle Monorail

The Owen Transit Group (OTG) cantilevered or side-straddle monorail is similar in appearance and operation to the straddle monorail (see **Figure 7**). However, trains going in opposite directions can share a single (but rather large) beam since cantilevered monorails are balanced by wheels on surfaces found on the sides of beam. While several companies promote such monorails, they have not seen any applications as of yet.

Figure 7: OTG Transit Cantilevered Monorail



Most maglev (short for “magnetic levitation”) trains are essentially variations on the straddle monorail. Instead of on-board motors, the interaction of magnets on the vehicle and on the track moves the vehicle forward, while the vehicle itself is slightly levitated by other magnets (see **Figure 8**). While maglev is an interesting technology, its complexity suggests that it is best suited to intercity rather than intracity installations, placing it beyond the scope of this study. In addition, maglev monorail's dramatically different operating principles compared with other monorail types suggest that it serves little purpose to analyze maglev alongside more established monorails.

Figure 8: The Transrapid Levitating Monorail

The first record of a monorail was one patent in Britain in the 1820's, around the time the steam locomotive was first put into practical use. A motorize monorail line constructed in Ireland in 1888 carried passengers and freight over distance of about 9.3 miles and proved the feasibility of single-rail transportation system power by an engine. The suspended monorail was invented in Germany and put into operation in Wuppertal in 1901. By 1957, it was clear that the basic design of the ALWEG (straddle bean) monorail was safe and effective. This was also true for the SAFEGE (suspended) monorail by 1960.

Japan gave serious attention to the monorail when a suspended monorail was open in 1958 in Tokyo's Ueno Park. The Ueno Park monorail is similar to the Schwebebahn Wuppertal, but has rubber tires rather than steel wheels. It is 0.19-miles long and has two stations and a single track. One purpose of the project was to test monorail technology and determine how it could be used for urban transit.

During the 1960s, monorails were developed and built in different parts of the world. A number of Japanese companies developed their own systems, and this resulted in considerable variety in Japan. In the early days, monorails were considerable only for amusement parks, but this changed in 1964 when the 11.1 mile long, 11-station Tokyo Monorail system began running along the edge of Tokyo Bay between Hamamatsucho and Haneda Airport. It was constructed to serve as an urban transportation system. Research continued into making the monorail more suitable for urban transportation and the basic design was standardized by 1967.

The straddle bean monorail became a composite type that borrowed from a number of designs, especially ALWEG, Lockheed, and Toshiba. The suspended monorail also evolved with improvements to the SAFEGE design.

3.0 MONORAIL SYSTEMS

3.1 Systems in Operation

The following systems are currently in revenue operation throughout the world:

- **Hitachi:** The first Hitachi system was put in use in 1962. There are currently five systems operating in Japan in a transit capacity.
- **Bombardier:** The first Bombardier application occurred in 1971 and the firm now has more than 20 systems operating in Germany, England, Brazil, Saudi Arabia, United States, and Australia.
- **Intamin:** Had its first application in 1986 and now has systems operating in at least eight countries.
- **Severn Lamb:** Opened a system in Sunway City, Malaysia in 2000 and has a system in Italy.
- **Aerorail:** First system was opened in Germany (Wuppertal) in 1901, and it now has a system open in Japan.
- **Mitsubishi:** Opened its first full size system in Japan in 1988 and now has two systems in Japan.

3.2 Systems in Development

The following systems are under development and may meet the needs of the Southeast corridor:

- **Transport Ventures:** This is a consortium of international companies promoting a “New Century Transport.” Technology. This maglev straddle technology is under consideration by the Colorado Intermountain Fixed Guideway Authority.

- **Urbanaut:** This firm is developing a straddle-type technology on which patents have been issued. A scale model has been developed but no commitments have been made for full sized systems.

- **Owen Transport Group (OTG) HighRoad:** This is a side-straddle technology on which patents have been issued. No commitments have been made for full-sized systems.

- **Futrex System 21:** This is a developing side-straddle technology on which patents are being sought. A scale model has been built but no commitments have been made for full-sized systems.

4.0 VENDOR SYSTEM REVIEW

Four monorail technology vendor systems were studied in detail. The fours vendors are:

- Hitachi
- Bombardier
- OTG
- Futrex

4.1 Hitachi

Hitachi has been operating straddle type monorails for 37 years. There are six systems operating and at least two more are in development stages. The longest existing system (9.2 miles) is the Osaka system which opened in 1990 and carries 50,000 people per day.

Hitachi builds small, medium and large type vehicles for different service needs. The small vehicle systems are used in amusement park settings and the medium and large are both meeting transit needs.

4.1.1 Existing Locations

There are four double tracked Hitachi monorail systems currently in transit service. The largest system built for transit purposes is the Haneda Line in Tokyo. The Haneda Line opened in 1964 and carries 200,000 people per day and it serves 10 stations and operates 6-car consists.

An 8-mile system with 15 stations opened in Okinawa 2003 (see **Figure 9**) and a 9.3-mile KL Line in Malaysia opened in 2002 with 21 stations.

Figure 9: Okinawa Monorail

4.1.2 Vehicle, Guideway, and Station Description

Hitachi systems have a variety of vehicle styles to meet various needs. A typical large sized vehicle is approximately 45 feet long and can accommodate up to 50 seated and 60 standing passengers. The small vehicle is 30 feet in length. The vehicle shell is made of aluminum alloy with welded construction.

A Hitachi monorail uses the straddle beam system to carry a single direction of vehicle traffic along the guideway. The guideway may be constructed of pre-stressed concrete for standard spans and steel girders for both straight and curved sections over longer span lengths.

Hitachi's standard track beam is made of pre-stressed concrete. The beam way is 33.5 feet wide and 59 inches tall. The support structure is a T-shaped reinforced concrete column spaced 65.98 feet apart. Both the beam and the columns can be manufactured off-site and installed. The Hitachi beam has a slim structure which makes it less of an obstruction in urban settings.

Hitachi systems have been built in many large cities and stations are often built above roads. Typical terminal stations have 120 feet long center platforms and stairways and escalators at each end of the station. For intermediate stations, two 180 feet long platforms are used.

4.1.3 Capacity

As indicated in **Table 1**, Hitachi offers a variety of systems, each of which has its own capacity constraints. Passengers per hour per direction **(**PPHPD) is a common way of measuring the capacity of a transit system (PPHD=Vehicle per Hour x Capacity). PPHPD is a measure of passengers that can pass by a point at the system's maximum load, in one direction.

Table 1: System Load Capacity

Minimum Headway		3 min	4 min	5 min	6 min
Number of Trains per Hour		20	15	12	10
Loading Capacity (pphpd)	Small (2-car)	2,680	2,010	1,608	1,340
	Small (4-car)	4,960	3,720	2,976	2,480
	Medium (2-car)	4,920	3,690	2,952	2,460
	Medium (3-car)	7,680	5,760	4,608	3,840
	Medium (4-car)	10,440	7,830	6,264	5,220
	Large (2-car)	5,600	4,200	3,360	2,800
	Large (4-car)	11,960	8,970	7,176	5,980
	Large (8-car)	24,680	18,510	14,808	12,340

4.1.4 Costs

Hitachi reports that the operation and maintenance cost for their monorail system is at the same level as required for the light rail transit (LRT) system.

Capital costs were not available for this report.

4.1.5 Feasibility

Several of Hitachi’s monorail systems connect to heavy rail transit (HRT) systems, including Tokyo and Osaka. The options to interface with other systems and stations is possible similar to the interface between a transit bus and a commuter train.

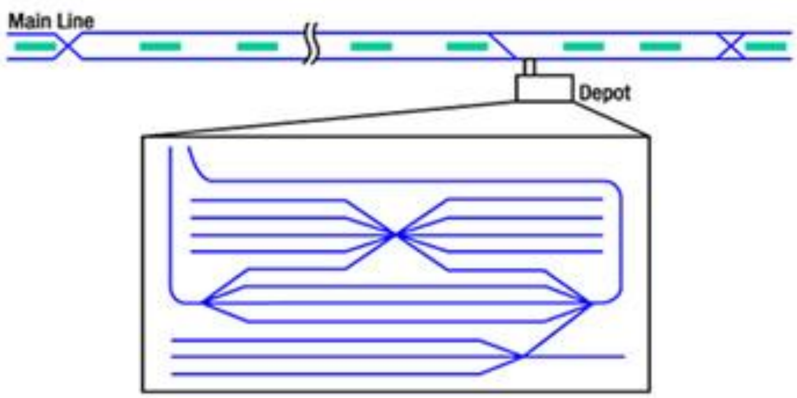
Hitachi systems are capable of operating at speeds of approximately 50 miles per hour and at a maximum grade of 6%. Hitachi claims the ability to achieve a minimum headway of two minutes for a system, if required. Guideways have pier spacing of between 82 feet and 100 feet.

The only proprietary technology utilized for a Hitachi monorail is the track switching system. The track switch designated for Hitachi monorail systems transforms the track beam itself as a switching mechanism by way of moving one end of each beam. The switching girders are supported firmly on the movable trucks. Fully automated electrical sequences operate in strict accordance with the train operation schedule and are monitored from the train operation control center.

The track switch is designed and manufactured in such a way as to ensure high reliability. Hitachi claims there have been no service disruptions due to a switch malfunction since 1964.

Hitachi has a wide range of track switch types for the purpose of turn back, crossover, emergency rescue and train storage. These include a two-point, three-point, five-point, or crossover type of switching mechanism. A combination of these can also be employed. By selecting from the various track switches offered by Hitachi, agencies may have more operational options, as well as the ability to reduce train yard and storage size, as **Figure 10** illustrates.

Figure 10: Train Yard and Storage Layout



4.1.6 Emergency Operations

Hitachi systems can be built with a minimum 180 feet turning radius along the main line and a 150 feet turning radius at the station.

Unlike other monorail vendors, Hitachi provides a walkthrough feature as a safety provision between adjacent vehicles. This enables the passengers on board to evacuate from one vehicle to other vehicles.

Hitachi guideways are supported by structures that can be spaced on average up to 75 feet apart on a curved section and up to 90 feet on a straight section.

4.1.7 Environmental Considerations

The average pier spacing for Hitachi support structures is 90 feet. This falls within the middle of the range for the four systems studied. The overall direct impact on land from Hitachi structures would also be in the middle range, with approximately 49,418 square feet impacted over a 33.7-mile corridor.

Hitachi systems are rubber tired and have lower noise levels than steel wheeled rail systems. Hitachi reports that the target noise level for the Kita Kyushu monorail system of 70dBa at 32.8 feet was achieved.

Pneumatic springs in the vehicle provide a smoother ride and less vibration. Precast concrete beams are cast in special molds providing high degree of accuracy which also eliminates vibration and noise.

4.2 Bombardier

Bombardier is a company that manufactures many different types of transit and recreational vehicles. Under the Bombardier framework there are several different types of systems that can be developed. This study has focused on the straddle-type monorail with which Bombardier has 30 years of experience.

4.2.1 Existing Locations

There are several different monorail systems currently in revenue service. Included is the Disney World Mark VI, which is the most widely known monorail in the continental United States. The Disney World system has 14.7 lane miles of track on 3 lines and a fleet of 12, six-car trains.

Bombardier has also designed the four-mile Las Vegas monorail system. The Las Vegas M-VI versions of the trains differ from the Walt Disney in both physical appearance and in that the trains are automated. Bombardier has built monorail systems in Germany, England, Brazil, Saudi Arabia, and Australia.

4.2.2 Vehicle, Guideway, and Station Description

The Las Vegas M-VI vehicles are bi-directional vehicles comprised of a composite shell with a steel truss and plate under frame. Each 4 car train has a length of 137 feet, a width of 9 feet and height of 11 feet. They accommodate 152 standing and 62-seated passengers per train with two dedicated wheelchair locations per train. The Las Vegas monorail has a four car train consist (a consist is a group of rail vehicles which together make up a train) utilizing a double tracked system. This system has an average line speed of 17.5 mph.

The guideway is composed of precast concrete beams as well as some pre-stressed and post-tensioned concrete where needed. Beams are typically spaced 100 feet apart, with a maximum span length of 120 feet where necessary.

There are seven elevated stations served by the system spaced an average of half a mile apart. The average platform length at the station is 240 feet long.

4.2.3 Capacity

The Bombardier system is able to accommodate up to 23,200 PPHPD (passengers per hour per direction) with a six-person per square meter density, eight-car train, and 90-second headway traveling at 50 miles per hour.

4.2.4 Costs

The cost for the four-mile Las Vegas system with seven stations was $350 million. Up to 25% of the cost for a system is associated with the vehicles. Operations and maintenance (O&M) costs for the Las Vegas system is in the $12 to $15 million annual range. The estimated cost of each station is $5 million.

4.2.5 Feasibility

The Bombardier systems are designed with the ability to increase capacity in stages as warranted. The Las Vegas system operates at an average speed of 17.5 miles per hour with a maximum grade of 6.5%. Bombardier is capable of achieving a 150-foot minimum horizontal turning radius, although a 175-foot to 200-foot turning radius is preferred. An operating speed of 53 miles per hour can be attained.

4.2.6 Emergency Operations

Emergency egress from the vehicle is handled either by use of a recovery train or vehicle which would take passengers to the next train station or by coupling a disabled train to another train and moving the entire vehicle to the next station.

4.2.7 *Environmental Considerations*

Bombardier compares favorably with the other systems studied with overall impact area equal to approximately half of the Hitachi system. This is possible because of the small footing area required for each support structure.

The Las Vegas system noise and vibration impact is approximately 70-75 dBa.

4.3 Owen Transit Group HighRoad

The OTG HighRoad Rapid Transit System is a patented side straddle system that uses each side of a single guideway beam to provide transportation in two directions simultaneously. It employs the use of components already being utilized by the rail industry. Each vehicle is independently propelled which offers flexibility in station design.

4.3.1 Existing Locations

There is no HighRoad system in operation.

4.3.2 Vehicle, Guideway, and Station Description

The HighRoad system uses relatively small, single vehicles on both sides of a two-sided T-shaped guideway beam. The vehicles have a composite body, 45 feet long by 8 feet wide by 9 feet high. Four sets of doors allow passenger ingress and egress. Windows on the guideway side provide access to the guideway for handle emergency evacuation. Each vehicle can carry 32-seated passengers, 64 standing passengers and can accommodate four wheelchairs.

Precast, pre-stressed, and post-tensioned concrete is used to create the guideway. The modular design allows for the guideway to be transported to the construction site, for simpler, faster construction. The HighRoad design is comprised of independently propelled vehicles so the number of vehicles is technically limited only by the size of the stations being serviced. The philosophy behind HighRoad is that long trains are less efficient and require larger stations so the recommended design would have a maximum two-car consist.

The stations are also modular in nature to allow for easy, less costly expansion when necessary. They are designed with a platform on each side of the vehicle and initially accommodate a single car consist.

4.3.3 Capacity

The OTG HighRoad system utilizes individual vehicles, coupled into no more than a two-vehicle consist, in an attempt to increase the flexibility of the system. Utilizing a 15 second headway and a two vehicle consist, the system can accommodate 46,080 PPHPD.

4.3.4 Costs

Costs information is not available for the OTG system.

4.3.5 Feasibility

OTG argues that because of the HighRoad size, it will be easier to integrate their system into the existing community without degrading the quality of the area. The smaller stations are conceivably easier to construct within neighborhoods. According to OTG a desirable station location is a span over a street and street widths up to 200 feet can be accommodated.

It is anticipated that the peak headway would be in the 15-second range. The HighRoad system is capable of attaining speeds of up to 70 miles per hour and has a minimum turning radius of 132 feet. The maximum attainable vertical grade is 12 % for climbing and the same grade can be attained for descending.

The design of the beam affects pier spacing. Since the guideway beam is post-tensioned, the post-tensioning can be varied to allow for longer spans. A span of 200 feet is considered reasonable for this type of construction. Longer spans may be possible by increasing the depth of the beam by use of a drop-keel on the bottom for increasing the structural moment of inertia and providing a location for additional post-tensioning cables. Supporting columns approximately 20 feet high could be spaced up to 200 feet apart.

The HighRoad system is to be composed of many parts that are already in existence by manufacturers in the railroad or related industry. Proprietary elements (patented) are guideway shape, vehicle attachment, brakes, vehicle support, column interface with guideway (seismic), dwell/headway procedure, quiet rail, power transport arrangement, emergency egress windows, cabin tilting, and cabin leveling.

4.3.6 Emergency Operations

In the event of a need to evacuate the vehicle, a passenger can unlatch a guideway-side window and pivot the window down to a horizontal position. Unlatching the window causes the vehicle to be emergency-stopped (three braking systems) and passengers can leave the vehicle via the windows to the top of the guideway, bridging the gap between the vehicle and the guideway. Once on the guideway (6.6 feet wide) the passengers can walk to safety at a station, can be picked up by a vehicle on the other side of the guideway, or can be attended by a top-of-guideway emergency vehicle. Stanchions and guidelines on the top of the guideway allow safe walking conditions in compliance with Federal handrail standards.

In the event of a disabled vehicle, OTG indicates that a turn back loop would be used. The radius for a turn-back loop is 132 feet, or 264 feet diameter, measured to the centerline of the guideway. An alternative turn-back is a rotating beam at the end of the line but OTG indicates that this would require about one minute for a 180-degree rotation with a vehicle on it. This would extend the headway such that the minimum headway would be at least one minute rather than the 15 seconds allowed by the loop.

4.3.7 Environmental Considerations

The OTG System requires 16 square feet of area for its foundation structures and an average distance of 140 feet between structures. For a 33.7-mile segment, this would result in a total impact of 20,320 square feet being impacted by the structures of the monorail.

The HighRoad system with its steel on steel and rail dampening system should have less noise than a typical roadway. High speed trains have low aerodynamic noise but have no means to eliminate the wheel flange squeal on the steel rails.

Noise and vibration information on the HighRoad system was not available.

4.4 Futrex

The System 21 technology uses a side straddle mono-beam system that operates on both sides of a 6 feet wide triangular guideway supported by 16 feet columns. Both center and platform stations are possible and train length can go as long as six cars.

Futrex has taken a deliberate phased approach to the development and marketing of its new System 21 technology. Research, conceptual design, preliminary engineering and evaluation have been completed under Phase I. In May 1996 Phase II was completed with the construction and evaluation of a ¼ scale model of System 21 in Charleston, South Carolina.

Phase III involves taking the System 21 to commercial manufacturing and has been guided by a consortium of individuals and firms.

4.4.1 Existing Locations

There is currently no System 21 in revenue operations.

4.4.2 Vehicle, Guideway, and Station Description

The System 21 vehicles are 28 feet long and made of a combination of aluminum and composite materials. There is a maximum ten-car consist to accommodate larger volumes of traffic. Each vehicle can accommodate 24 seated and 28 standing passengers, and there are provisions for handicapped passengers in each car.

A triangular beam carries vehicles in both directions on a solitary structure. The guideway may be constructed of steel, concrete, or composite. The modular nature of the guideway design provides portability and expandability of the system. Typically, the guideway is 6 feet wide at the base and is supported on 16 foot columns, which can be higher or lower based upon client expectations. Piers are usually spaced at 84 feet on center.

The four-car typical station requires a 12 feet by 120 feet landing for an at-grade location. As with the rest of the system, stations may be pre-fabricated off-site or built on location per client needs.

4.4.3 Capacity

Futrex systems will be able to accommodate approximately 20,000 PPHPD.

4.4.4 Costs

Operating costs are entirely dependent on the installation and operating profile. It is anticipated that the operating costs will be equal to or lower than that of other fixed guideway systems carrying comparable numbers of passengers/hour /direction.

System 21 capital costs are largely dependent on the installation profile. Each “A” car is estimated to cost $750,000 and each “B” car is estimated to cost $500,000. The two cars are semi permanently coupled rail cars (married pairs). Married pairs have machinery necessary for full operation of the cars split between them. Items that are typically shared include transformers, motor controllers, dynamic braking grids, cabs, current collectors, batteries, and air compressors. This provides significant savings in both costs of equipment and weight, which increases performance and decreases energy consumption. The cost of operating such a pair may be slightly higher when the extra car in such a pair is not needed to meet level-of-service demands at a particular time.

4.4.5 Feasibility

System 21 is marketed as able to fit into an existing urban landscape due to the relatively small footprint of the elevated guideway. The stations can be built into or adjacent to an existing structure due to their modular nature.

A train may operate at headways as short as 90 seconds, reaching speeds of up to 70 miles per hour. The minimum horizontal turning radius is 90 feet which could be ideal in an urban setting.

A unique branching system, based on standard railroad switching, allows for trains to form a transit network. Switching between tracks utilizes a movable rail section for a grade-separated branch line.

System 21 offers a unique switch mechanism that allows grade separated branching in very compact areas. The ability of the system to make concurrent moves greatly reduces the impacts on service as trains do not have to wait for clearance on the opposite track to make a diverging move across oncoming traffic. It also eliminates the queuing behind the vehicle moving through the switch. The mechanism actually takes the switching vehicle over the oncoming traffic creating a greater degree of safety in the operation.

System 21 does not provide a typical crossover design to divert trains around a section of guideway for maintenance or emergencies. In those events a turn back shuttle on the opposite side of the guideway still in operation would be implemented to transport passengers around the outage. Other options are to use a two level bypass station design, or emergency sidings for the removal of disabled vehicles from active guideway.

4.4.6 Emergency Operations

Futrex offers numerous options for emergency evacuation including a guideway mounted walkway, and vehicle borne stairways and emergency slides. Passengers will also be able to move from car to car to flee a hazard or uncomfortable situation. Over water or busy highways, Futrex may introduce an open truss beam configuration which incorporates an emergency walkway internal to the beam.

In the event of a disabled vehicle, shuttles would be utilized since there are no crossovers in the system. If this were to be a normal operating practice, a loop would be integrated into the system to get the train off the main line. The minimum diameter for the loop would be 180 feet.

4.4.7 Environmental Considerations

The area required for structures is larger for System 21 than for the other technologies studied in detail—a total of approximately 103,760 square feet for the system's structures. This is primarily due to the larger land impact per structure (49 square feet per structure) and the tighter structure spacing—an average of 84 feet between structures.

Futrex indicates that pier spacing corresponds with beam length. The maximum pier spacing possible is 110 feet to 120 feet. Depending on the corridor, the aesthetic impacts of such a structure could offset the benefits accrued by using a longer span.

5.0 OPERATING CHARACTERISTICS

Monorail operates solely on exclusive right-of–way. In this respect monorail operates as a "rapid transit" system. Monorails cannot operate in mixed traffic as buses or trams do, because the guideway beams cannot be crossed by other vehicular or pedestrian traffic at ground level unlike rail tracks which can be imbedded into the street. However monorail guideways placed on aerials allow for unimpeded traffic flow below. Monorails are served by stations most commonly elevated, but also underground or a few feet above ground level. Although stations require considerably more investment than simple street level light rail platforms, stations do add to the public "visibility" of the transit system. A station can also provide other services, such as retail space that make public transportation a more pleasant and convenient method of travel.

5.1 Power

Like LRT vehicles, onboard electric motors power monorail vehicles. On a straddle-type monorail, trolley wires are suspended along the side of the guideway. A shoe behind the monorail skirt picks up electricity.

5.2 Speed

Transit monorails generally operate at maximum speeds of 40 to 55 mph, which is comparable to most applications of rail technology within urban areas. Average operating speeds of monorails are comparable to subways due to the fact that they are likewise grade separated and use similar station spacing distances. Speeds are generally in the range of 20 to 30 mph, very high for urban mass-transit.

5.3 Ride

Monorail ride is superior to cars and buses and similar to that of wielded rail. Suspension is usually provided by air-springs. Forces exerted in curves are reduced by banking the guideway slightly in straddle-systems. Suspended monorails can sway several degrees in curves, reducing forces. Both straddle and suspended monorails provide passengers with the sensation of smooth flight, especially since passenger's visual cues support the sensation.

5.4 Switching

One of the most common misconceptions about monorails is that monorails do not, or cannot, employ switches. In reality, switching is extremely important to monorail operations. The Shonan suspended monorail in Japan employs switches at stations so that a single guideway between stations can be used for bi-directional operation. Even the Disney monorails which operate in a loop must have switches to move trains to and from the maintenance yard. There are a wide range of switches for different purposes. For example, the straddle-type Las Vegas monorail utilizes turnout, crossover and pivot switches in its operation. Due to the weight and size of concrete or steel beams, the switching is slower—roughly 15 seconds compared to 0.6 seconds for traditional rail. This increase in switching time would likely result in increased minimum headways over traditional rail if the switching is to be used regularly in line operation.

5.5 Maintenance

Concrete monorail guideways require extremely low maintenance. Rubber tires last for approximately 100,000 miles. Monorail vehicles have a long life span, similar to trains riding on rails (30 years or more), whereas buses have a recommended life span of only 10-15 years.

5.6 Safety and Evacuation

Monorails have been shown to be one of the very safe forms of transportation. Grade-separated operation generally rules out collisions with automobiles, trucks and pedestrians. Since nearly all monorails built since the original Schwebebahn have not used a single rail as the term “monorail” would imply, and have instead used concrete guideways, derailment is extremely unlikely. The straddle monorail, in particular, hugs the guideway in such a way to almost rule out such a possibility.

5.7 Evacuation

The fact that monorail is usually elevated poses some evacuation challenges. Suspended monorails usually have doors in the floor linked to stairs or a slide as on commercial aircraft. Japanese straddle monorail standards require fully articulated vehicles to allow longitudinal evacuation through the front and rear of the train onto a waiting train. The Malaysian system uses lateral evacuation to a waiting train on the guideway that supports trains in the other direction. Older American monorails use another train to push the stranded vehicle to the next station but when that is not possible, rescue via ladder from the ground is necessary. The Las Vegas monorail provides an emergency walkway between dual monorail beams which is more in line with most rapid transit systems.

5.8 Seismic Codes

Monorails can be built to meet full seismic codes. In fact, monorails have a proven track record when it comes to earthquakes. The Seattle monorail withstood that region’s 2001 earthquake and the Osaka monorail withstood the nearby Kobe earthquake.

5.9 Rubber Tired Traction and Guidance

With few exceptions, like the Schwebebahn, monorail systems use rubber tires for traction. Aside from the guideway, this is the main technological difference between monorail and traditional rail. While rubber traction on steel rails is found on at least one monorail system (Aerobus), most systems with rubber tires run on concrete surfaces. In this regard, most monorail vehicles run more like road vehicles than railway trains. To be sure, such rubber on concrete traction can be found on the Paris, Montreal and Sapporo Metros as well as on most Automated Guideway Transit (AGT) systems. There are both advantages and drawbacks to this method.

5.10 Energy Consumption

Energy consumption is somewhat higher with rubber tired traction. Rubber tires on concrete (as well as rubber tires on steel) have a greater rolling resistance and rotational inertia than steel on steel rail technology. Common rail operation tactics such as coasting can be much less utilized by monorails. Since energy consumption varies with the particular operating regime of a line, exact figures are not possible. However, an estimate of 25 to 30 percent greater energy consumption over rail technology is given.

5.11 Acceleration and Breaking

Rubber-tired vehicles can achieve a much higher rate of acceleration and breaking than steel tired ones. For monorail systems, however, this is usually not a significant advantage since acceleration is limited much more by passenger comfort, especially by the passenger comfort of standing passengers. Also, high breaking rates are less necessary where exclusive right-of-way generally rules out collisions with street traffic, which happens to be the case for monorail.

5.12 Gradients

Theoretically, rubber tired traction can overcome gradients of more than 15% whereas rail technology cannot safely exceed 10%. In reality, steep gradients require very powerful motors and are uncomfortable for standing passengers. This means that rubber tired technologies do not have quite as strong an advantage over rail in this respect. In difficult alignments, however, monorail's climbing ability does stand out. An example of this is the Shonan suspended monorail in Japan, where 10 % gradients are found. And the authority responsible for designing Seattle's proposed system found that steeper gradients over water crossings would shorten bridges and thus lower bridge costs significantly.

5.13 Weather

Rubber-tired vehicles running on exposed surfaces, as with the straddle (but not with most suspended) monorail technology are much more susceptible to cold weather conditions (ice, snow) than rail. Under these conditions the guideway must be heated, entailing appreciable energy costs. The few suspended monorails built in the last few years, like the Chiba monorail in Japan were primarily built because their running surfaces are enclosed and are thus protected from the elements.

5.14 Noise

Rubber-tired systems are generally quieter in sharp curves than the best rail technology. When rail maintenance is lacking or postponed, as is far too often the case, the benefit of rubber tires can be appreciable. In addition, both straddle and SAFEGE-type monorail systems shield the tire noise unlike other rubber tired applications. Straddle monorails trains shield the tires since the train side stretches beneath the wheels to access the electric catenary, whereas SAFEGE-type monorails have the wheels shielded within the guideway. Rubber tired vehicles produce much less vibration than vehicles with steel tires. Furthermore, since rubber tired monorails produce basically no electromagnetic "pollution", they can be run near hospitals and scientific institutes without concern.

In general, monorail technology is suited to urban transit applications. It compares favorably to traditional rail technology on the whole. While monorails do have several significant disadvantages that cannot be outright dismissed—like somewhat higher energy costs (for rubber-tired systems) and slower switching as compared with similar rail systems, it is rare that these considerations would amount to a "fatal-flaw". In fact, these considerations should, more often than not, be minor in the general exercise of mass-transit planning. Indeed, it is in those very areas where monorail technology holds the advantage over steel-rail technology—most notably in its lower noise production and greater grade-climbing abilities—where monorail has the ability to make a fixed transit line feasible where it would not be otherwise.

6.0 STRUCTURE

6.1 Guideway

The most important structural element of a monorail system is the monorail guideway. The straddle monorail guideway is most often a concrete beam, occasionally a steel one. Each monorail beam acts as a small bridge; it must be built to support the load of the vehicle (including "live" loads like forces exerted when braking) while not buckling under its own weight. In addition, the beam's design must take its guidance function into account, the beam and the vehicle must fit like a hand and a glove, so that the contact guidance wheels and the sides are maintained. The beam's width must also be wide enough so that the monorail train can be balanced given the small wheelbase. Logically, wider beams allow for wider vehicles, but wider beams also make for less aesthetically pleasing guideways. Unlike beam width, which is approximately ¼ the width of the monorail train due to center-of-gravity and riding quality concerns, beam height and length are relatively flexible as long as the structural integrity of the span is maintained.

Guideways are considerably more complex than their initial appearance may suggest. Straddle monorail guideways are designed in three dimensions. In a curve, the guideway beam bends not only on the horizontal plane but also banks in the vertical plain. The amount of bend is also dependent on the radius of the particular curve. To allow for this variation, concrete beams are formed individually in various molds with set radii, banking and spans. Transit-grade monorails have a minimum curve radius of about 131.2 feet. However, such a tight radius is generally avoided, since running tire slip angles and the forces on the guide tires mean that vehicles must operate at significantly reduced speeds.

Modern developments in guideway design have been concerned with reducing the impact of the guideway on its surroundings because the relatively low visual impact of the straddle monorail structure on urban environments is perhaps its greatest potential asset.

While the weight of the vehicle would seem to be the major determinant of guideway dimensions, weight is only a part of the picture. Gross axle loading of transit-class monorail vehicles are comparable to most light rail and heavy rail rapid transit systems at 8 to 11 metric tons per axle. However, in spite of this, straddle monorail guideways are significantly less obtrusive than elevated rail, or AGT systems like the Vancouver Skytrain due to the distribution of the weight of the vehicle (not to mention the steel rails placed on top of those structures).

A very effective way to reduce the visual impact of guideways and to allow longer spans (and thus fewer columns) is to use arched guideway beams, or haunched girders. This is one of the major positive developments in guideway design. Such beams allow longer spans, and decrease the visual impact of the beams especially at the center point. Furthermore, any visual impact is much more likely to be perceived positively given the gracefulness of the arched design.

6.2 Columns

Columns are usually essential elements of a straddle monorail system. While guideways can run at ground level, or in a tunnel, the ability to use public right-of-way over streets requires that columns be used.

In general, column size and guideway length are inversely related to each other, with longer spans requiring less frequent but more massive columns, and shorter spans requiring frequent and lighter columns. While this may suggest many possible combinations, the matrix of column/guideway proportions in use is rather limited; a rough “golden” ratio based on visual appeal and the properties of concrete seems to exist. The agency responsible for designing Seattle’s new monorail believes that current technology and good design sense makes 120-foot spans supported by 36-inch diameter, 30-foot tall columns ideal.

The column profile is another important element. Rounded columns create a softer streetscape and allow for better sight lines. Another approach is to use rectangular columns. The short side of such a column would be visible to those on either side of the aerial, i.e. to those likely to be closest, while the long side is prominent only to observers standing directly under the guideway or looking further down the street. The Bombardier system makes very good use of this approach.

A third approach is to treat columns as sculptural elements. The Hitachi design for Kuala Lumpur takes this approach. The graceful, rectangular but curved columns create an elegant colonnade.

Where there is vehicular traffic under monorail guideways, the recommended minimum column height is approximately 16 feet. However, there is a trend towards using significantly taller columns in the range of 33 to 40 feet to reduce the visual impact of the guideway by placing it farther overhead. This approach also has a pleasant side-effect: it improves the view for monorail passengers but may be costs impacts.

"Straddle bents" are occasionally used in place of single columns, for example when crossing very wide streets, to allow vehicular passage underneath when a standard column would act as an obstruction. However, because of their size, they are avoided whenever possible.

7.0 AUTOMATION

While all straddle-class monorail systems share a basic set of operating principles and are all built using advanced composite materials and have state-of-the-art variable voltage, variable frequency motors (VVVF), there is a wide range of design features among monorail vehicles.

Just as automation has always needed a monorail-like system on which to be implemented, monorail can benefit greatly from automation. Whereas monorail's relatively costly, "inflexible" guideway made it appear inferior to light rail for the majority of medium capacity applications, light rail will not be able to benefit from automation due to its non-exclusive right-of-way.

What exactly are the benefits of automation? Automation allows transit operators to provide shorter headways between trains. Since drivers are not necessary, running two small trains every two minutes instead of one large train every four minutes is possible with equal, if not lesser resources. The benefits of automation are especially significant in providing high-quality service in off-peak times when transit economics do not usually allow frequent service. A reduction in headways from 15 to 5 minutes, for example, can encourage many more choice passengers to use public transit.

The ability to eliminate vehicle operators, normally the single greatest transit operating cost, means that transit subsidies or ticket prices can be reduced and services such as security and maintenance can be supplemented. The ability of automated guideway transit can operate with reduced employees and thus reduced operating costs. AGT systems such as the Vancouver Skytrain require no operating subsidies primarily because it can operate with just one employee per 150,000 annual passengers.

Automation also enables a slightly more efficient driving regime and greater passenger comfort for starts and stops. While this is not nearly as significant as operating at greater frequencies, it is nevertheless an advantage. Automated operating regimes have been shown to be extremely reliable and offer very high levels of safety.

While monorail transit has always had significant public support, drawbacks like slightly higher operating costs due to rubber-tired traction is partly to blame for transit operators' traditional skepticism of monorail technology. That automation addresses the operating costs in particular, thereby greatly improving system productivity, bodes well for future implementation of monorail rapid transit.

From an engineering point of view, the basic characteristics of a straddle monorail's guideway and support have undergone little drastic change over a 40-year period. Computer aided design, and improvements in concrete constructions have helped somewhat. Much more significant is the appreciable amount of attention that has been paid to mapping out the tradeoffs involved with monorail aerials that will undoubtedly make this transit mode much more competitive.

Likewise, while monorail vehicles have benefited from modern transit technology and are built to standards comparable to heavy and light rail vehicles, progress in design have been as impressive as improved technical standards.

Monorails have benefited from one major technological breakthrough: automation. While Asian monorails have increased automation tremendously since the monorails of the 1960's, they still have an operator on board. Full monorail automation is incorporated into the Las Vegas Monorail system.

8.0 GENERAL CONCERNS REGARDING MONORAIL TECHNOLOGIES

There are concerns usually expressed about monorail systems when undertaking a corridor study and attempting to identify the "ideal mode" for a specific corridor. Those concerns are noted below with a brief description of the nature of the concern followed by a response to the concern.

8.1 Proprietary Nature of Monorail Technology

- Concern: It was believed that the specialized components needed for monorails would be hard to find or only available from a limited number of distributors. The operator of such a system would be tied to that supplier or manufacturer. Introducing new technology into the study area would require a new, specialized work force or additional training for existing workers. Maintenance shops already in place would possibly not be able to provide service to the new technology if it required different parts than the existing systems.

- Response: It appears Hitachi and other vendors proprietary system used in their monorail systems is limited, i.e., Hitachi's track switching system. While this is a significant element of the total system, the fact that the remaining portions of the system are nonproprietary indicates that the availability of parts and support for the system may not be as great as feared.

8.2 Incompatibility with Existing Systems

- Concern: There were concerns about the idea of introducing another transit mode in a region - where other rail modes already exist.

- Response: While the introduction of a new technology to the regional transit network will require an investment in new systems, vehicles, and maintenance resources, similar investments would be required to expand any of the existing rail systems.

With regards to the compatibility of monorail technologies with existing stations: where a transit line is being extended, it does make more sense to extend the existing mode rather than introducing a second mode to the line. However, where a new transit service is being used to provide an intermodal link between two or more existing transit lines, the reduced guideway requirements of monorail technologies may make it easier to integrate a new service into the site design of existing stations.

8.3 Limited Capacity of Monorails

- Concern: Monorails have much smaller capacity than what might be needed.

- Response: The systems reviewed have demonstrated passenger capacities of up to 49,000 passengers per hour per direction. Used in the appropriate corridors, a monorail system should be ample for the needs of ridership demand in most transit corridors.

8.4 Safety and Reliability

- Concern: The safety and reliability of monorail systems has not been proven. A concern about monorail technology involved the ability of trains to execute a track switch when necessary. This raised questions about the safety of passengers in the event of an emergency and the reliability of the system in the event of a vehicle breakdown.

- Response: The National Fire Protection Association 130: *Standard for Fixed Guideway Transit and Passenger Rail Systems* code must be met in order to operate a rail system in the United States. Additionally, there are other standards that must be met in the United States.

  Existing monorail technologies may require additional research and development in order to adapt them to federal, state, and local safety requirements. The reliability of monorail services varies considerably among the technologies reviewed. The side straddle systems on the market today may require additional right-of-way for turn back loops in order to preserve service around disabled vehicles. As with other conventional rail services, the ability to preserve service will be dependent on the availability of crossovers and other system elements necessary to move around disabled vehicles.

In addition to the regulatory safety requirements of a system, there are two other practical issues which need to be taken into consideration:

- Evacuation Procedures: Both the vehicle and the guideway must allow passengers to exit the system in the case of emergency. This is an especially important point with automated systems since there may not be transit personnel on board a vehicle during the time of an accident.

- Operating Recovery Plans: In case of a disruption of service, it is crucial for a system to have mechanisms and procedures in place which would allow regular service vehicles to bypass the affected section of the system.

8.5 Weather Related Reliability

- Concerns: There are concerns that monorails are not proven to be reliable in adverse weather.

- Response: The presence of monorail systems in Germany, England, and Korea indicates that it is feasible to operate a monorail technology under a variety of climatic conditions.

9.0 MONORAIL IN THE SOUTHEAST CORRIDOR

The Nashville Area MPO provided certain relevant data for incorporation into this study. That information included the following:

- List of relevant reports, studies and plans available on the MPO website.

- Digital files providing information on travel demand model coding for analysis of hypothetical transit service in the Southeast Corridor being studied as part of the ongoing Southeast Area Transportation and Land Use Study, including alignment and station coding files, and transit ridership output files.

9.1 Prior Planning Relevant to the Southeast Corridor

As a frame of reference, it is useful to summarize prior transportation planning relevant to the Southeast Corridor running generally along I-24. These studies were led by the Nashville Area Metropolitan Planning Organization (MPO).

- **Nashville Southeast Corridor High-Performance Transit Alternatives Study (August 2007):** The MPO conducted this study to address the future transportation needs of this growing corridor. The study considered initially a broad range of transit technologies, including: bus rapid transit – light, bus rapid transit, light rail transit, heavy rail/subway transit, monorail, commuter rail and high speed rail. The study steering committee screened alignment and technology combinations to a reduced set of options which included commuter rail, light rail transit and bus rapid transit. Alignment options considered from downtown Nashville to Murfreesboro Road were Lafayette Street/Murfreesboro Road, I-24 and the CSX rail line. Monorail was determined to not be applicable to the Southeast Corridor for the following reasons: its aerial structural system and aerial stations are expensive on a per mile basis compared to at-grade transit service, its track record in providing urban/suburban transit service has not been demonstrated, and monorail is not applicable for express service when compared to proven bus and commuter rail modes. Further screening deleted the light rail transit option due to its relatively high capital cost compared to the other final options. Estimated ridership on the three final alternatives ranged from 770 to 1,690 daily boardings in 2030. The Locally Preferred Alternative selected for the corridor was a combination of phased bus service enhancements, including development of express bus and skip stop bus services on I-24 and Murfreesboro Road (US 41) and extended local bus service on Murfreesboro Road. Other improvements include bus stations at key locations, queue jump and signal improvements at intersections and interchanges, and ultimately short sections of busways to enhance transit operating speeds. The study area and potential transit alignments considered are shown in **Figure 11.**

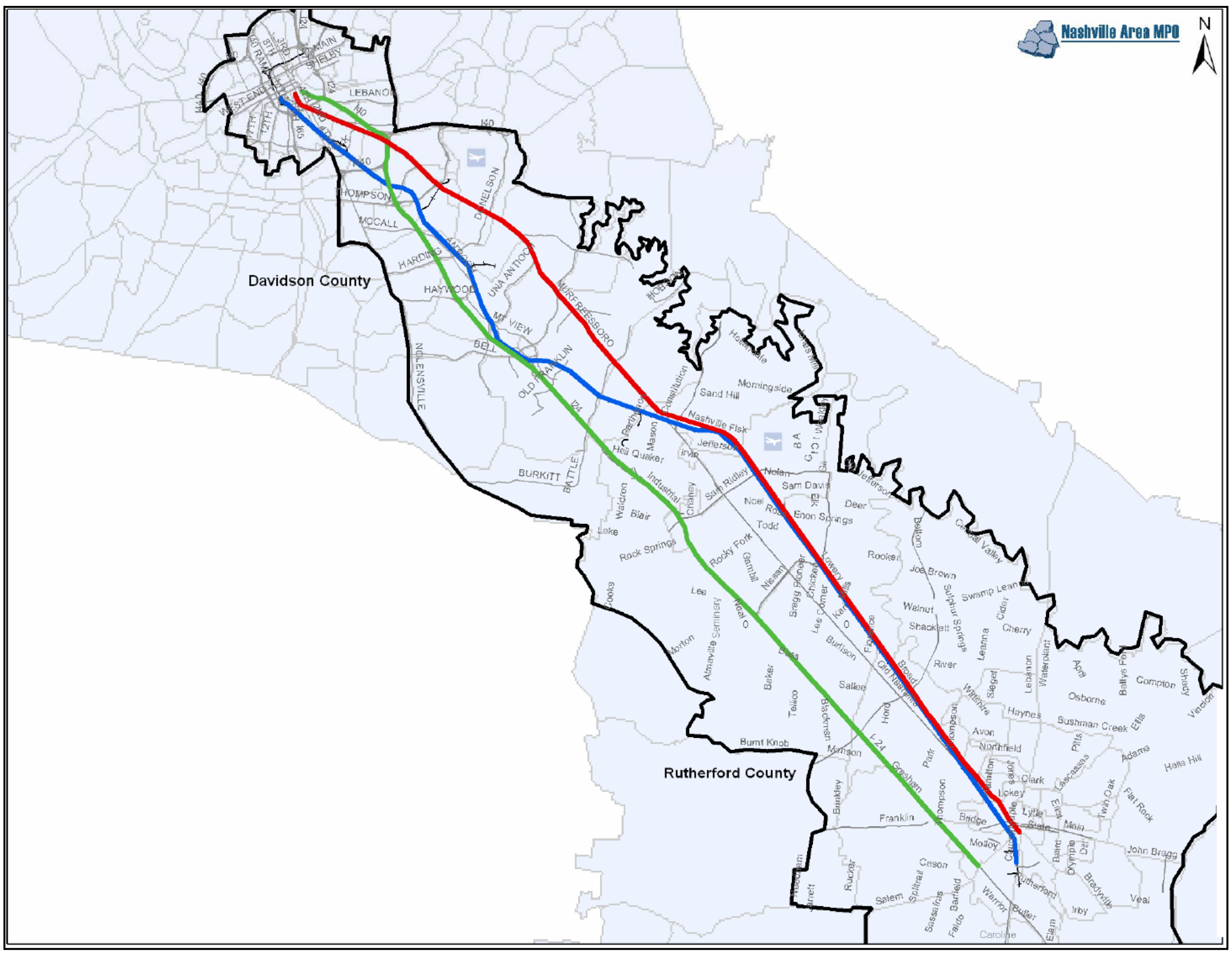
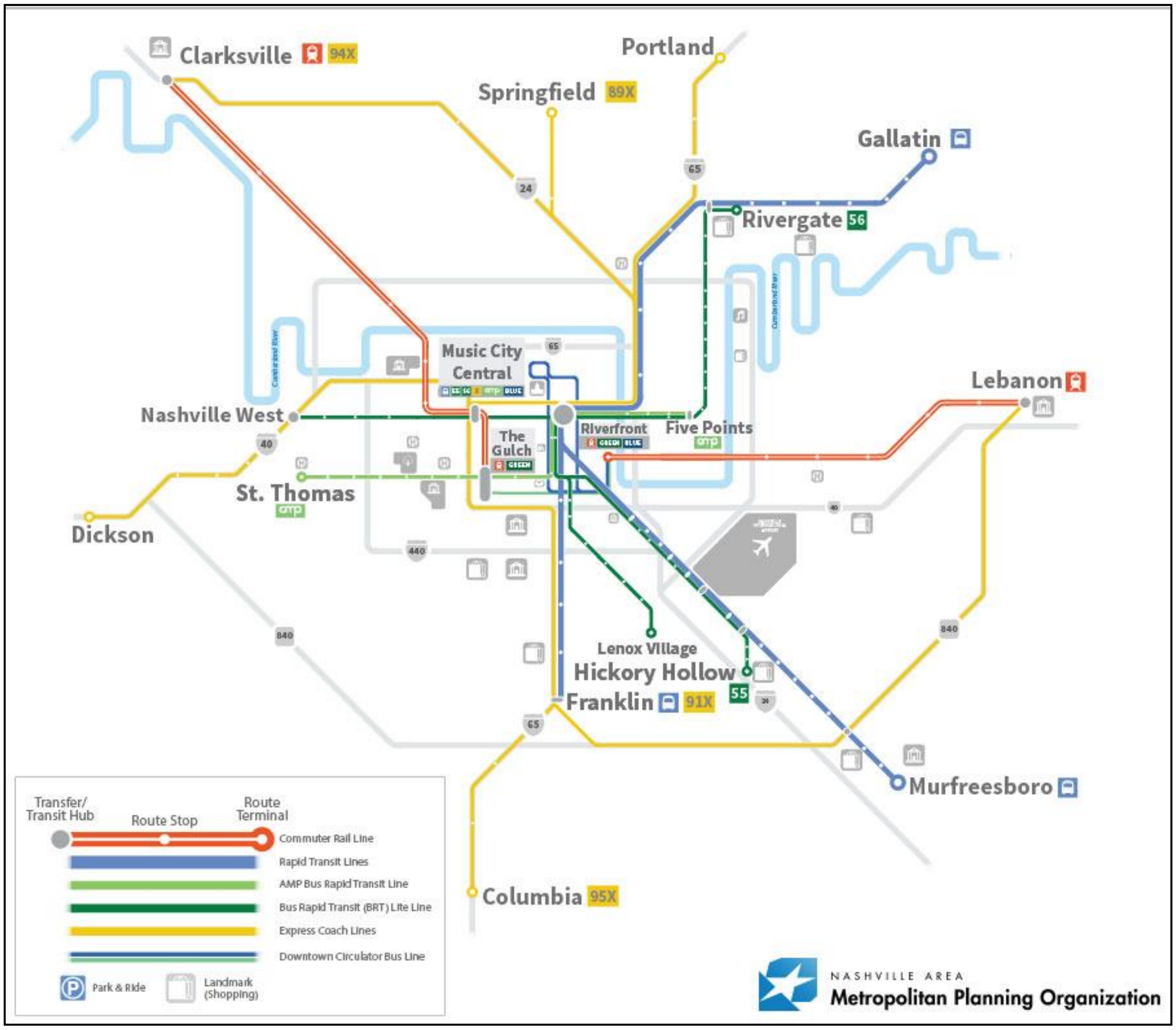


Figure 11: 2007 Study Area and Transit Alignments

- **Nashville Area MPO 2035 Regional Transportation Plan (December 2010):** This plan contained an expanded vision for public transportation in the greater Nashville region. This plan is the result of a cooperative process designed to foster involvement by all stakeholders, such as the business community, community groups, environmental organizations, the traveling public, freight operators, and the general public, through a proactive public participation process conducted by the Metropolitan Planning Organizations, TDOT, and the area transit operators. The plan identified a range of potential transit technologies and service configurations, but did not include the monorail technology. The long-range vision for transit incorporated commuter rail, rapid transit (either BRT or LRT), and express bus, in addition to standard fixed route bus service and supporting transit circulator services. For the Southeast Corridor, the plan called for in the short-term to develop express coach service from Murfreesboro to downtown Nashville using the I-24 High Occupancy vehicle (HOV) lanes, in the mid-term for enhanced and bus rapid transit service as delineated in the prior 2007 study, and in the long-term for further upgrading of bus services, and the reevaluation of the corridor within 5-10 years for possible fixed-guideway transit investments.

- The **Regional Transit Vision** was an integral component of the 2035 transportation plan. It included supporting documentation and a stylized depiction of future transit services across the region. The map was not intended to depict exact alignments and station locations, but rather convey a sense of the transit coverage and hierarchy of transit services that conceivably could serve the Nashville region of the future. For the long-range vision of the Southeast Corridor, the map (see **Figure 12**) identified a Bus Rapid Transit – Lite line extending from downtown southeasterly to the Hickory Hollow district, and a Rapid Transit Line (either LRT or BRT) extending from downtown to Murfreesboro.

Figure 12: Regional Transit Vision



- **Southeast Area Transportation and Land Use Study (Ongoing):** The charge of this study is to develop a preferred vision for growth and development in the area paralleling I-24 between I-40 and I-65 in Davidson, Rutherford, Williamson, and Wilson counties.

  Based on the shared vision for future growth identified through this planning process, the study's key outcomes will include general land use and multi-modal transportation recommendations that the Nashville Area MPO, cities and counties, transit agencies, and community partners can use to guide their own respective planning efforts.

  The study initially focused on land use trends and alternative land use scenarios, arriving at a consensus for an alternative land use configuration that would be more supportive of transit. The study is now engaged in examining premium transit service alternatives, continuing to look at rapid transit service – either light rail transit or bus rapid transit service in the corridor. Preliminary transit ridership forecasts to the year 2040 for Southeast Corridor transit service, including rapid transit service along a hypothetical alignment and a 13-station configuration traversing from downtown Nashville to Murfreesboro along Murfreesboro Pike, Bell Road, and I-24 have been developed and are reported elsewhere in this document.

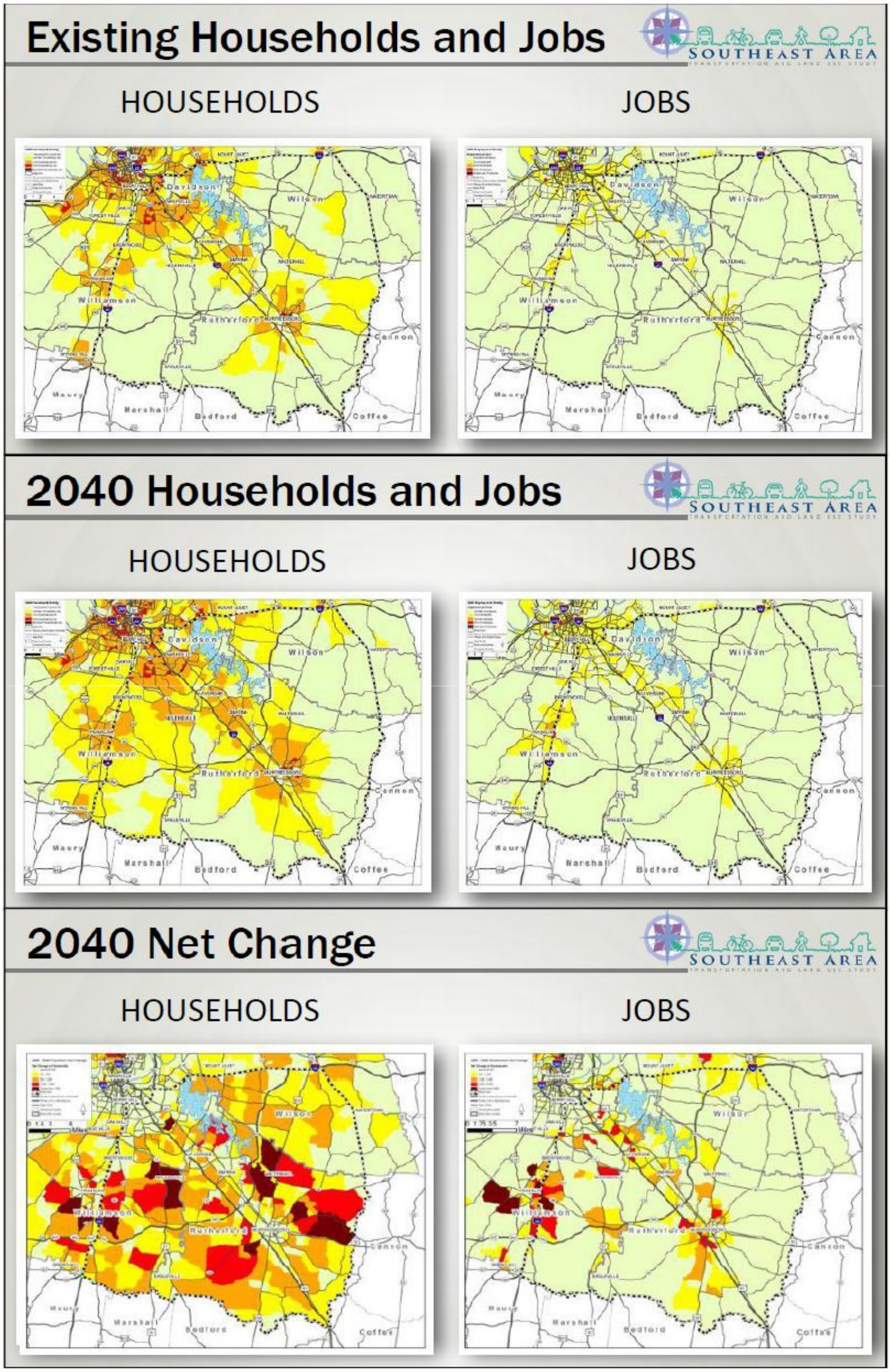
- **High Speed Rail:** Finally, it is noted that there have been high-level corridor studies of an Atlanta-to-Chattanooga high speed rail service (HSR), with a potential connection to Nashville along the I-24 corridor. HSR technology has not been and should not be considered for commuter-type service within the Southeast Corridor. HSR is intended for long-distance, intercity travel, and the proximity of stations within a suburban commuter corridor would defeat the intended benefit of high speed travel, as well as the economic and societal benefit expected from an HSR project.

9.2 Southeast Corridor Demographics and Land Use

The Nashville Area MPO service area, including Davidson, Maury, Robertson, Rutherford, Sumner, Williamson, and Wilson Counties, has a population of nearly 1.6 million, per the US Bureau of the Census 2013 estimate. Population in Davidson and Rutherford Counties along the Southeast Corridor was estimated by the US Bureau of the Census as 939,631 persons in 2013, and is forecasted to grow to 1,163,312 persons by 2035, according to the 2035 Regional Transportation Plan, continuing a trend of growth over recent decades. The MPO is in the process of updating regional demographic forecasts as part of updating the 2035 Regional Transportation Plan, adopted in December 2010, to the year 2040.

Figure 13 presents the existing and projected (2040) distribution of households and jobs across the southeast area of the Nashville region according to the ongoing Southeast Area Transportation and Land Use Study. It is seen that the I-24 corridor and its fringes are projected to continue to grow significantly in the years to come.

Figure 13: Existing and Projected Households and Jobs



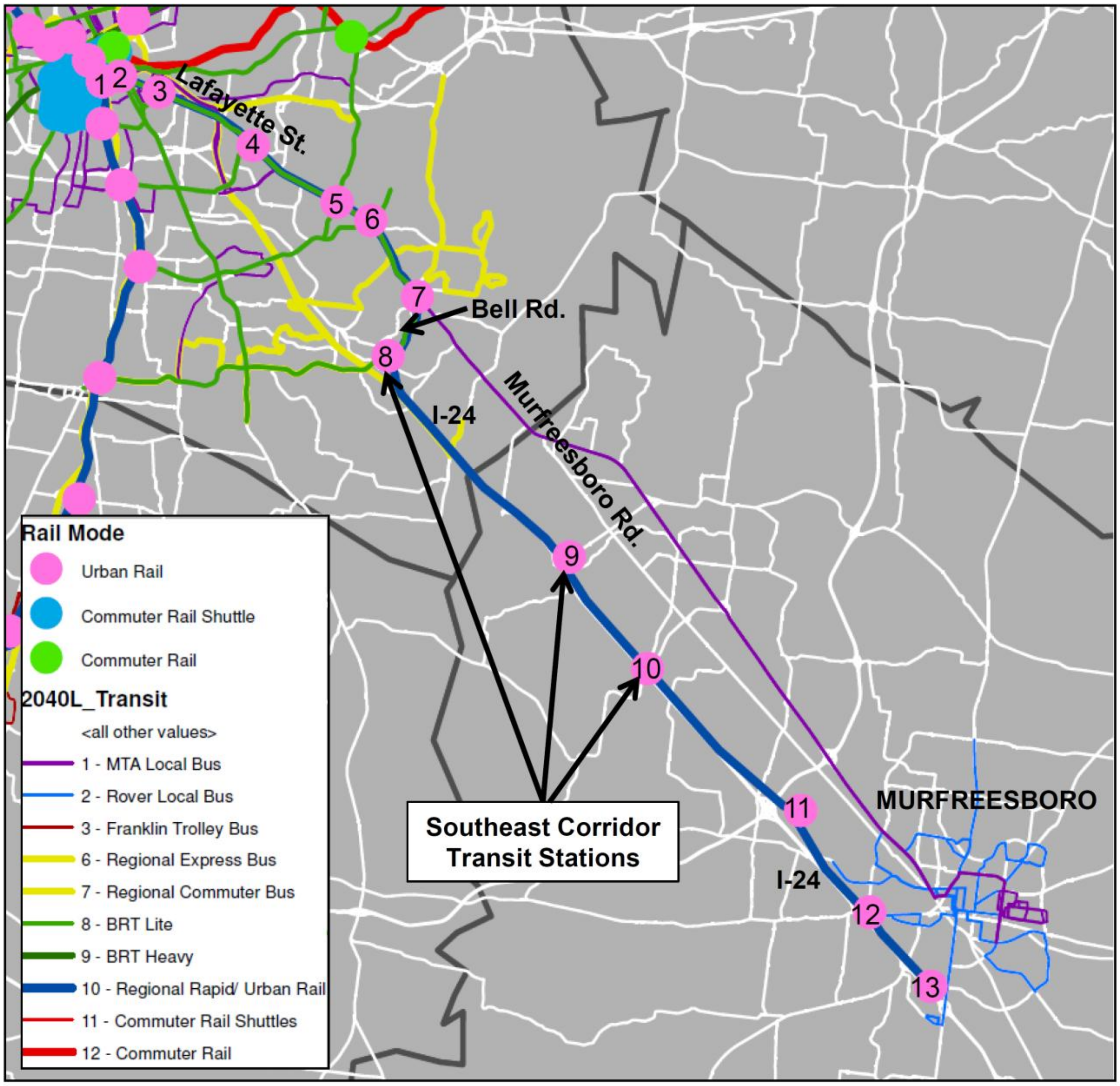
9.3 Potential Transit Alignments and Stations

The prior 2007 Southeast Corridor transit study considered three final options, each coupled with a unique transit technology (along with a lower cost Transportation Systems Management phased bus service alternative). Those options were commuter rail on the CSX rail line, bus rapid transit along I-24, and bus rapid transit along Murfreesboro Road. The ongoing Southeast Area Transportation and Land Use Study is initially investigating a hypothetical Rapid Transit Service that extends southeasterly from downtown Nashville along Lafayette Street and Murfreesboro Road to Bell Road, where the path turns south along Bell Road and Mountain View Road to I-24, and thence southeasterly along I-24 to Murfreesboro.

To reiterate, the Rapid Transit Service being studied would be either bus rapid transit or light rail transit. In its travel demand modeling work thus far for the current corridor study, the MPO has coded this premium transit service corridor as “urban rail/light rail transit”. It is also noted that the MPO has not addressed at this time the configuration of light rail transit that would be utilized to insert the service into the arterial street segments of the hypothetical alignment. That is to say, it is not yet been analyzed if portions of the light rail transit alignment would be at-grade or elevated, in the median of the street or to the side, in mixed traffic flow or segregated from vehicular traffic. These are considerations of some importance as they can affect station configuration, extent of street reconstruction, need for right-of-way, utility impacts (both underground and overhead), and ultimately the capital cost of the facility.

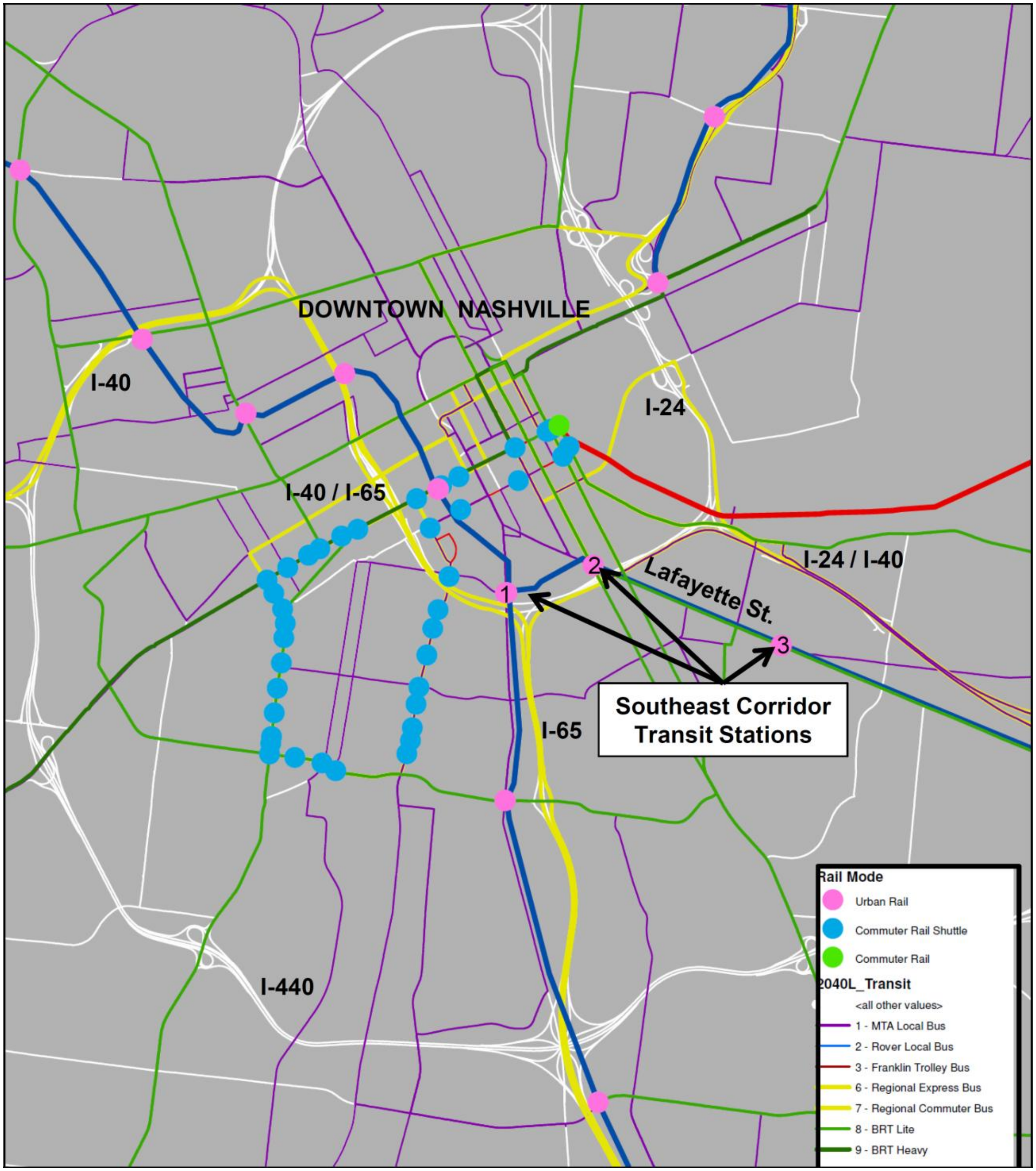
The hypothetical Southeast Corridor alignment and hypothetical station locations in the MPO travel demand modeling work are shown in **Figure 14** and **Figure 15**. The hypothetical station locations are listed in **Table 2**. In **Table 3**, the proposed configuration of a monorail technology lying within the hypothetical alignment for Rapid Transit Service in the Southeast Corridor is described across 12 corridor segments defined by the hypothetical station locations. This configuration of hypothetical alignment and station locations is assumed for the monorail technology scenario for consistency with current MPO transit corridor planning, including initial transit ridership forecasting.

Figure 14: Potential Southeast Corridor Premium Transit Alignment and Stations



Source: Nashville Area MPO

Figure 15: Potential Southeast Corridor Premium Transit Alignment and Stations Downtown Inset



Source: Nashville Area MPO

Table 2: Hypothetical Southeast Corridor Station Locations

Station	Location
1	Fogg Street at Railroad
2	Ash Street at Lafayette Street
3	Lafayette Street at Fairfield Avenue
4	Murfreesboro Pike at East Thompson Lane
5	Murfreesboro Pike at Donelson Pike
6	1900 Murfreesboro Pike
7	Murfreesboro Pike at Bell Road
8	Bell Road at Mountain View Road
9	I-24 at Sam Ridley Parkway West
10	I-24 at Lee Victory Parkway
11	I-24 at TN 840
12	I-24 at Old Fort Parkway.
13	I-24 at Shelbyville Highway

Table 3: Potential Southeast Corridor Monorail Configuration

SEGMENT	Station X to Station Y		Start Point	End Point	Approx. Length (miles)	Profile	Configuration	ROW
1	1	2	Fogg St. at RR	Ash St. at Lafayette St.	0.33	Elevated	40-foot street ROW: straddle bents and narrow roadway lanes.	Assume no ROW for guideway.
2	2	3	Lafayette St. at Ash St.	Lafayette St. at Fairfield Ave.	0.87	Elevated	Columns in median of Lafayette St.; use new ROW for station 2 outside of street for vertical circulation ease.	ROW needed for stations.
3	3	4	Fairfield Ave. at Murfreesboro Pike	Murfreesboro Pike at East Thompson Lan	3.06	Elevated	Tight street cross-section south to Menzler Rd.: Use columns in median, TWLTL reworked for columns; stations to be offset to side of the road to remove vertical circulation from street. South of Menzler Road: wider median, elevated in median; fly over I-24; at Station 4 deviate to west side of street using excess ROW in front of Family Dollar in the 1109-13 block; rework driveways.	ROW needed for stations.
4	4	5	Murfreesboro Pike at East Thompson	Murfreesboro Pike at Donelson Pike	2.60	Elevated and at-grade	Use columns in the medan in general; near Briley Pkwy. deviate west out of median and flyover the overpass, returning to the median. At airport runway underpass, drop to median at-grade between intersections closest to the underpass, use barriers to separate monorail guideways on either side of central column, shift remaining two lanes outward as needed reducing outside shoulders. For Station 5, Deviate out of median to in front of Dell or the diagonal corner for station vertical circulation.	ROW needed for stations.
5	5	6	Murfreesboro Pike at Donelson Pike	1900 Murfreesboro Pike	0.88	Elevated	Use columns in the median, reworking with curb and gutter. At Station 6 deviate outside of median to new ROW for station.	ROW needed for stations.
6	6	7	1900 Murfreesboro Pike	Murfreesboro Pike at Bell Road	2.33	Elevated and at-grade	Alignment to be situated at the east edge of the I-24 right-of-way. The profile will be at-grade and in cuts and fills with retaining walls as needed, with elevated sections over intersecting roads and interchanges and at stations.	ROW may be needed for some stations and park-and-ride lots.
7	7	8	Murfreesboro Pike at Bell Road	Bell Road at Mt. View Road	1.76	Elevated and at-grade	Same as for Segment 6.	Same as for Segment 6.
8	8	9	Bell Road at Mt. View Road	I-24 at Sam Ridley Pkwy. West	6.95	Elevated and at-grade	Same as for Segment 6.	Same as for Segment 6.
9	9	10	I-24 at Sam Ridley Pkwy. West	I-24 at Lee Victory Pkwy.	3.54	Elevated and at-grade	Same as for Segment 6.	Same as for Segment 6.
10	10	11	I-24 at Lee Victory Pkwy.	I-24 at TN 840	4.87	Elevated and at-grade	Same as for Segment 6.	Same as for Segment 6.
11	11	12	I-24 at TN 840	I-24 at Old Fort Pkwy.	3.26	Elevated and at-grade	Same as for Segment 6.	Same as for Segment 6.
12	12	13	I-24 at Old Fort Pkwy.	I-24 at Shelbyville Hwy.	3.25	Elevated and at-grade	Same as for Segment 6.	Same as for Segment 6.
				Total Length	**33.70**			

Mention had been made of the monorail technology being applied to the I-24 corridor in an elevated configuration within the median of that roadway. It is noted that from I-40 southward to Rock Springs Road just south of the Sam Ridley Parkway, a distance of 14.6 miles, the median of I-24 is approximately 21 feet wide with a separating barrier. Conceivably, monorail could be installed in the median of I-24 either in an elevated configuration, or at-grade in the median area of the freeway.

Construction of the monorail in the median would require a reduction in the inside shoulder widths due to placement of monorail support columns. This change would require review and approval by TDOT and FHWA. Construction of monorail would also be complicated due to the presence of high speed, high volume traffic and the inaccessibility of this area for construction activities and movement of construction materials. In addition, placement of stations in the freeway median would involve additional structural components adding to cost and connecting pedestrian bridges across the I-24 roadway to transit stations along the side of the roadway providing connecting transit service and potentially park-and-ride lots. Another factor for consideration is that where there are crossing roadways or intersecting roadways along I-24, the monorail guideway profile would have to be further elevated to pass over the upper of the two intersecting roadways; stations could not be practically located on the sloped approaches to these monorail overcrossings. The presence of several freeway-to-freeway interchanges and their multilevel ramps along this pathway would also complicate guideway geometry and increase cost. Since monorail would typically need to be elevated in urban settings, adopting the hypothetical MPO alignment for the corridor would not alter the overall project capital cost estimate significantly.

Alternatively, the monorail could be constructed in the area occupied by the I-24 interior shoulders, but this would require outward shifting and reconstruction of the I-24 roadways and structures over the affected distance which could be cost-prohibitive. Some overpasses might require reconstruction as well due to the reconfigured I-24 roadways. The outward shifting of travel lanes would be greater at station locations to accommodate the added width of station platforms and vertical circulation.

In addition the benefits of transit-oriented development in station areas would likely be lessened with station placement in the freeway median.

For a monorail installation in this alignment, it is presumed that the guideway will be in an elevated configuration for those segments with an urban or suburban setting with intersecting streets and driveways. All crossings of a monorail facility must be grade-separated either over or under the monorail guideway.

Consequently, the monorail will be elevated above the street between its downtown origin and the point at which it enters the I-24 corridor just south of the Hickory Hollow interchange. South of this point, the monorail could carry an alignment profile along the east border of the I-24 right-of-way that would generally follow the existing embankment profile. The monorail would require a vertical alignment of curves and tangents within its acceptable parameters, but this appears feasible along

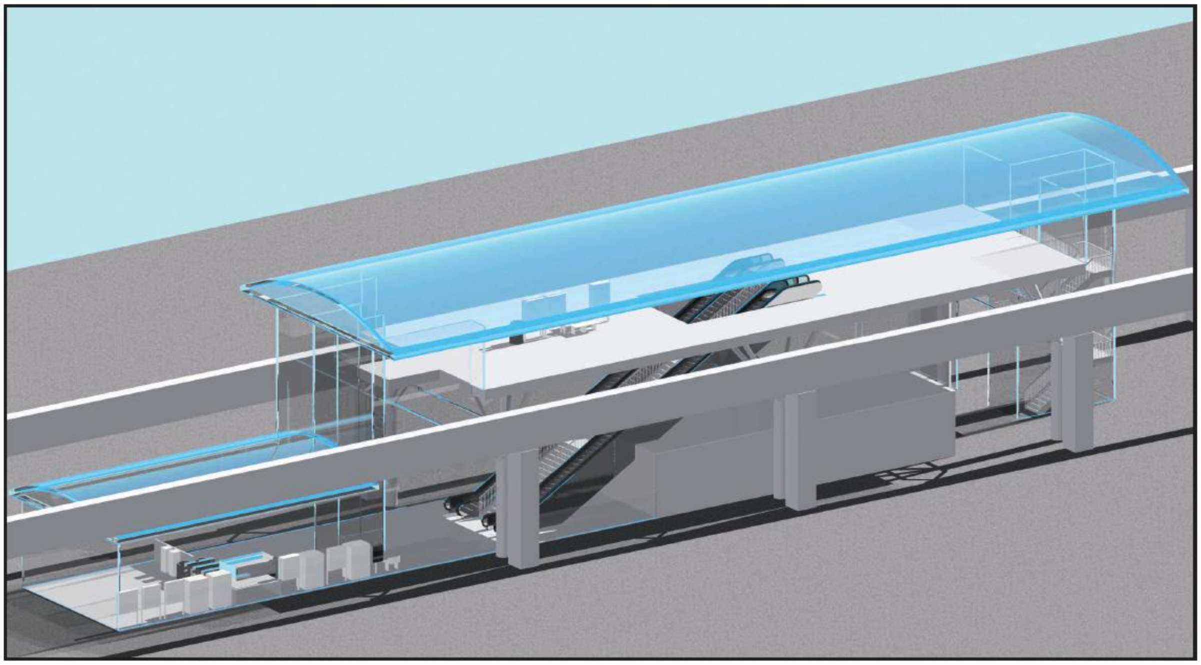
I-24. Where there are cross roadways at interchanges or roadways crossing I-24 between interchanges, the monorail guideway profile would need to be elevated over these roadways, and at locations near these roadways at the hypothetical station locations.

In its at-grade configuration, the monorail would occupy a typical 25-foot minimum width section to include the two guideways, a central walkway, dynamic envelope clearance, and outside security/safety fences. The profile would follow the I-24 side slope longitudinal profiles in general, with cuts and fills to maintain reasonable grades. Special structures would be needed for crossing the Stones River near the south end of the alignment and other such situations.

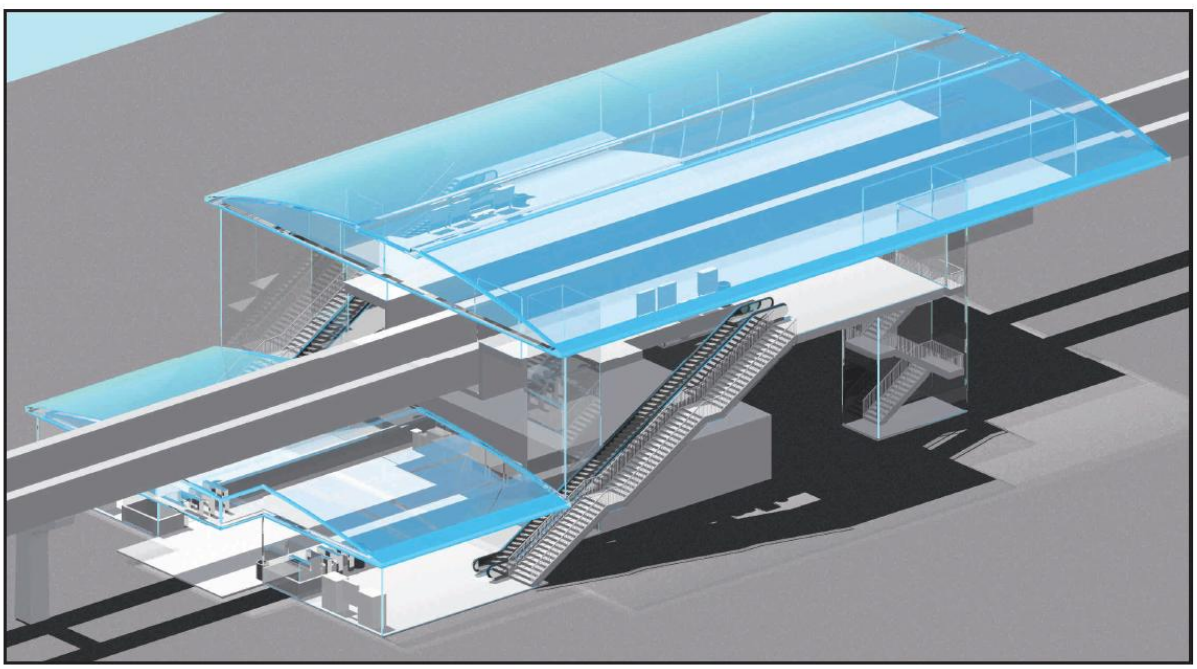
In terms of placement of the monorail structure along arterial street segments, a position in the central median would likely be most feasible, as this location would reduce conflicts with aerial utilities on one or both sides of the street. Supporting columns would be located approximately 100 to 150 feet apart depending on final design parameters, and their placement would need to be coordinated with location of left turn lanes in the median area. Some modifications of the street access management and street reconstruction may be needed as a result of the column placements. Straddle bents would likely be needed in some locations due to conflicts in locating support columns, where the alignment turns through intersections, or were other conditions preclude columns in the median. Conflicts and relocations can be expected with various underground utilities near support columns and overhead power lines, traffic signal installations and other features crossing the arterial roadway.

It is assumed that stations will be elevated with center platform configurations. The monorail system requires a continuous separation from other crossing movements, whether vehicular or pedestrian. Transit users cannot cross the monorail guideway at-grade, so grade separation with the monorail and transit users is necessary. This need is generally better accommodated with the monorail elevated as that is a general condition for this technology. A center platform configuration allows for a single set of vertical circulation elements - stairways, elevators, and possibly escalators – to serve both directional guideways. **Figure 16** shows center platform and side platform station configurations.

Figure 16: Station Configurations



Center Platform Station



Side Platform Station

Where the guideway is traversing Lafayette Street, Murfreesboro Road, and Bell Road, the stations could be located in either the street median, or the monorail alignment could deviate slightly from the street centerline to one side of the street on property to be acquired for the station site.

For stations within the street median, it is likely that the directional roadways would need to be flared approximately 15-25 feet further apart toward the outside of the roadway to create sufficient room in the median for supporting columns as well as vertical and horizontal pedestrian circulation. From this median station location, users would pass to the outside edge of the roadway by way of crosswalks at signalized intersections. Connecting buses would utilize bus bays on the side of the roadway at the station locations. This configuration could require right-of-way acquisition along the roadway in the station vicinity.

For stations to the side of the street, acquisition of land would be needed. At these sites the elevated station configuration would remain. On the acquired land, there could be areas for kiss-and-ride parking as well as bus bays for interconnecting transit service. If appropriate, park-and-ride spaces could also be provided. In this configuration for the station, pedestrian movements would occur within the station area footprint for connections to other modes, with on-foot access occurring by way of sidewalks and crosswalks along the surface streets.

Along the I-24 right-of-way, since the alignment would be elevated over crossing roads and the five hypothetical stations would be located at crossing roads; these stations would also be elevated. However, it is expected that they would not be located within street medians but rather in freestanding sites with kiss-and-ride spaces as well as bus bays for other interconnecting transit services. Some stations would also have relatively large park-and-ride lots.

There are two particular locations along the potential monorail alignment that require further attention: 1) The crossing of I-40 near downtown, and 2) The underpass of Murfreesboro road at the Nashville International Airport runway and taxiway, which is approximately 1,000 feet long. These two locations are shown in **Figures 17 and 18**.

Figure 17: View Northbound on Lafayette Avenue at I-40

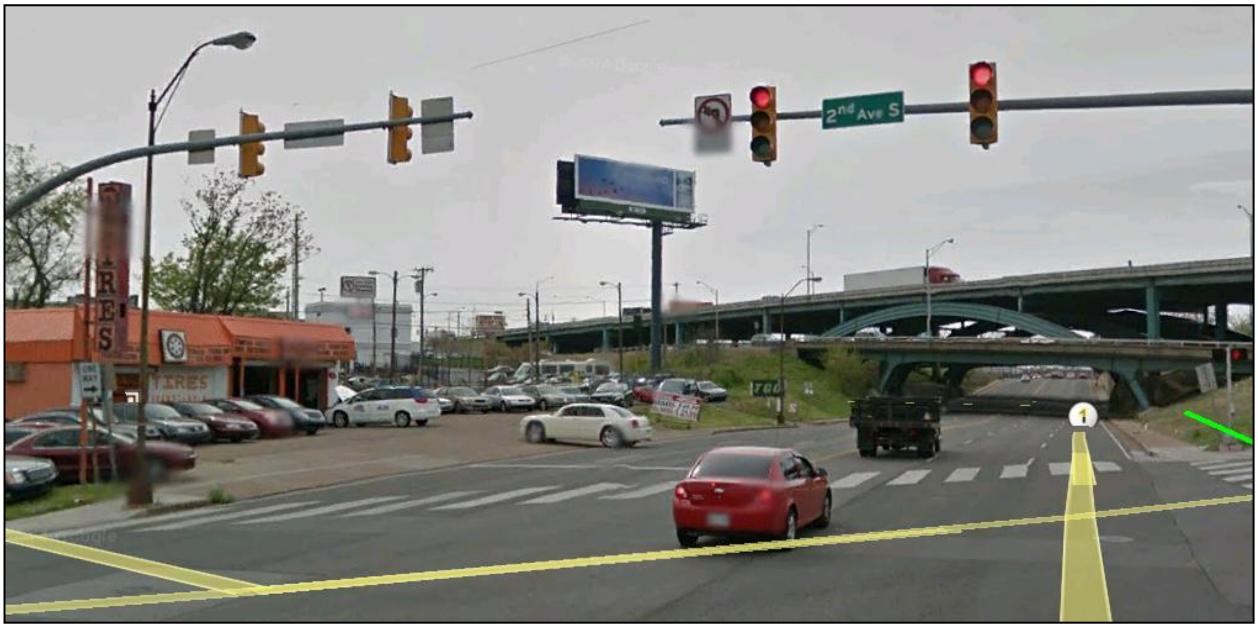


Figure 18: View Southbound on Murfreesboro Road at Airport Runway Underpass

Along the proposed alignment at I-40, options are to pass under the roadways within Lafayette Street, flyover the elevated I-40 mainline roadway with a very high structure, or shift the alignment slightly west and cross I-40 where it is closer to ground level. The latter option makes the most sense for monorail. To do so, the monorail could turn westerly from Lafayette Street and run along the south edge of the I-40 freeway, and then cross I-40 in the vicinity of 5th Avenue South or 6th Avenue South, returning to Ash Street and continuing to the end station on Fogg Street.

Approaching the airport runway underpass, the monorail guideways would be elevated in the median of Murfreesboro Road. However, between McGavock Pike to the north of the runway and Dell Parkway to the south, the monorail guideways would need to profile to existing grade and follow the roadway profile under the runway. It may be necessary to profile the guideway underneath McGavock Pike on the north side of the underpass due to glide slope clearances for the other parallel runway, and underneath the Dell Corporation warehouse access drive on the south side of the underpass due to its proximity. Detailed profiles were not developed but geometric resolution appears feasible. Vertical clearance in the underpass is adequate to accommodate the monorail as its power takeoff is under the vehicle along the guide beam. A typical monorail vehicle would have a dynamic clearance envelope 8.5 feet in width, and allowing for another 1 foot of clearance on both sides as well as for a separating barrier, each monorail guideway would have a horizontal clearance envelope of approximately 10.5 feet excluding a separating barrier and emergency walkway which would add another 4 to 4.5 feet.

The existing roadway under the runway consists of two 3-lane roadways 36 feet in width, a median of 12 feet which includes two narrow shoulders and the central support column of the underpass, and two outer unpaved shoulders of 10 feet in width. The monorail guideways could be configured near the median on either side of the middle column, shifting the roadway lanes outward, or could be positioned in the outer shoulder areas, and likewise adjusting the roadway travel lanes. Roadway travel lanes would either need to be restriped for very narrow lanes, or one travel lane in each direction would be given over to the monorail guideways. As the roadway in this area has six through traffic lanes passing through traffic signals which reduce the throughput, four traffic lanes through the tunnel operating in free flow condition would provide sufficient capacity.

It is noted that there may be issues with underground utilities, drainage and subsurface foundation systems for the underpass that could affect the viability of this proposal. All associated issues with this configuration of the monorail through the existing airport runway underpass would need to be examined and approved by TDOT, the Federal Highway Administration (FTA), the Federal Aviation Administration, the Nashville International Airport and others.

The use of TDOT highway right-of-way for public transportation is guided by provisions in the Code of Federal Regulations (23 CFR, Chapter 1, Part 810) entitled Mass Transit and Special Use Highway Projects. This guidance indicates that such use may be possible, provided that the use does not restrict future needed highway improvements nor impair highway safety. For the purposes of this analysis, it is noted that the alignment geometry of the hypothetical Rapid Transit Service being examined by the MPO follows US 41 and I-24 corridors, and it is assumed that such use of public highway right-of-way for mass transit projects can be achieved.

9.4 Corridor Transit Ridership

The current Southeast Area Transportation and Land Use Study has initiated examination of potential premium transit services in the Southeast Corridor. The estimates of transit ridership in 2040 for the Southeast Corridor are tentatively based on hypothetical transit service alignments and hypothetical station locations selected based on perceived ridership potential to test initial results and are expected to lead to various further refinements as the transit alternatives analysis process continues. At this point in time, only the initial transit ridership forecasts are available; for the Southeast Corridor Rapid Transit Service concept, the MPO has tested only the "urban rail/light rail transit" technology thus far. In addition to Rapid Transit Service in the corridor, the study is also examining several other transit service elements, including:

- BRT Lite service from downtown Nashville to the Hickory Hollow district,
- Route 15 standard bus service to be continued,
- Route 96 Express bus service, and
- Route 96 Community Circulator bus service.

The initial results from the current MPO study for projected 2040 ridership on these various services is summarized in **Table 4.**

Table 4: Projected Transit Ridership for "Urban Rail" Technology

Transit Service Component	2040 Daily Transit Boardings		
	Trend Land Use Scenario	Alternative Land Use Scenario	Difference
Murfreesboro Rapid Transit	7,107	9,420	+32.5%
BRT Lite	3,431	3,556	+3.6%
Route 15 Standard Bus Route	936	947	+1.2%
Route 96 Express Bus	1,555	1,212	-22.1%
Route 96 Community Bus	3,021	2,353	-22.1%
Southeast Corridor Subtotal	16,050	17,488	+9.0%
Region-wide	84,145	94,332	+12.1%
Market Share of Southeast Corridor	19.1 %	18.5%	-3.1%

Source: Nashville Area MPO

Because monorail transit service parameters for Rapid Transit Service in the Southeast Corridor can be considered similar for the purposes of this analysis, it is therefore assumed that ridership on a monorail technology in this corridor would be very similar. To clarify, monorail can match the Rapid Transit Service option in terms of service frequency and schedule, station locations, corridor capacity, available park-and-ride facilities, and vehicle operating speed, such that it is equally attractive to prospective transit users in terms of the mode choice decision (auto vs. premium transit). It is also assumed that fares between Rapid Transit Service and monorail would also be comparable.

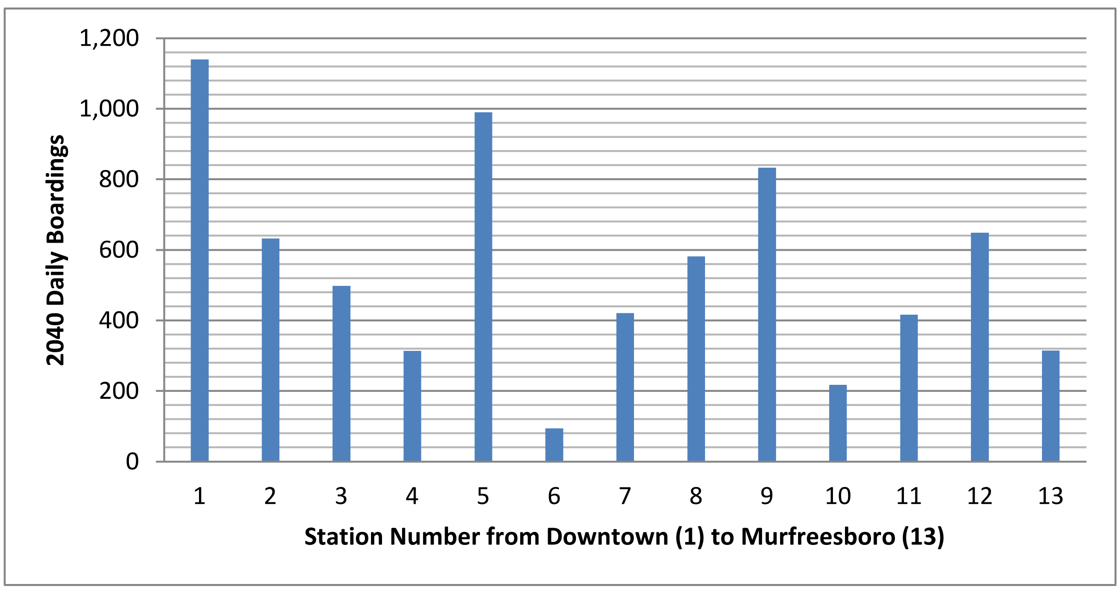
From the summary in **Table 5**, it is seen that the premium transit service in the Southeast Corridor in the form of the Rapid Transit Service (to date modeled as urban rail/light rail transit) attracts approximately 7,100 daily boardings in 2040 under the trend land use scenario, and 9,400 daily boardings, or about 32% higher, under the alternative land use scenario that was tested. It is noted that the total forecast transit ridership in the corridor is approximately 16,000 daily boardings when the other transit service components are considered. The MPO considers this value an upper end potential volume for the corridor, on the basis that the ridership for the other corridor services would be absorbed into the rapid transit option. This level of ridership would roughly double the vehicle requirement for an additional cost of $38 million, an incremental added cost for capacity at the maintenance facility, and would roughly double the annual operating cost.

To further characterize projected transit ridership for the Rapid Transit Service element, projected daily 2040 boardings by station as developed using the regional travel demand model for the trend land use scenario are listed in **Table 6** and depicted graphically in **Figure 19**. It is noted that in the ridership forecasting, the MPO incorporated park-and-ride lots at several locations to support the drive access mode to transit stations.

Table 5: 2040 Projected Rapid Transit Service Ridership by Hypothetical Station Location for Trend Land Use Scenario

Station	Location	2040 Daily Boardings
1	Fogg Street at Railroad	1,144
2	Ash Street at Lafayette Street	633
3	Lafayette Street at Fairfield Avenue	498
4	Murfreesboro Pike at East Thompson Lane	314
5	Murfreesboro Pike at Donelson Pike	990
6	1900 Murfreesboro Pike	94
7	Murfreesboro Pike at Bell Road	421
8	Bell Road at Mountain View Road	582
9	I-24 at Sam Ridley Parkway West	833
10	I-24 at Lee Victory Parkway	218
11	I-24 at TN 840	416
12	I-24 at Old Fort Parkway.	649
13	I-24 at Shelbyville Highway	315
	TOTAL	**7,107**

Figure 19: 2040 Projected Rapid Transit Service Ridership by Hypothetical Station Location for Trend Land Scenario



From this ridership summary it is seen that boardings vary by station, ranging from 94 to over 1,140 daily boardings. As noted, it is expected that the MPO will continue to review corridor transit service planning assumptions and travel demand modeling to refine and enhance ridership forecasts.

A review of light rail transit service corridors around the country indicates that most established urban/suburban light rail transit lines on mature routes produce 1,000 or more daily boardings per mile of route service. For the 33.7 mile long Southeast Corridor, the ratio is approximately 211 boardings per mile for the trend land use alternative, and 280 boardings per mile for the alternative land use scenario. Continued refinement of travel demand modeling in the corridor considering station locations, feeder bus service, park-and-ride lots will hopefully yield further improvement in projected transit ridership levels in this corridor.

10.0 CAPITAL AND OPERATIONS COSTS

10.1 Capital Costs

Capital cost estimates were developed for a monorail system in a configuration within the Southeast Corridor parameters as described previously. It is noted that this estimate was developed at the conceptual level of project definition where many aspects of inserting a monorail facility into the Southeast Corridor have not yet been developed in much detail. The estimating process uses the Federal Transit Administration (FTA) Standard Cost Categories (SCC) worksheet tables which include 10 general cost categories, each with two or more cost line items. Allocated cost contingencies were added to each individual cost line item; these contingencies were set at 20% except for utilities which was 30% and right-of-way which was 50%. A standard general unallocated contingency of 15% was added to all cost category subtotals. It is noted that these costs are conceptual in nature as the monorail technology concept has not been articulated in any significant detail at this stage of discussion. Each of the SCC elements are described below along with pertinent assumptions:

- SCC Category 10 – Guideway and Track Elements: Includes all portions of the transit guideway and supporting structure if applicable, including costs associated with excavation, fill retaining walls and other elements related to the guideway.

  For the monorail technology, these costs include conceptual level estimates of basic guideway elements based on the identified broad assumptions regarding alignment and profile, including sections along I-24 where the system would be in a partially at-grade configuration.

- SCC Category 20 – Stations, Stops, Terminals, Intermodal: These costs include work associated with transit stations, including platforms, finishes, equipment, and mechanical, electrical and safety systems.

These costs include basic station configurations with center platforms, vertical circulation, canopies, ticketing machines, furnishings, lighting, security and information systems, pedestrian access and lighting. This category also includes park-and-ride lots at four stations.

- SCC Category 30 – Support Facilities (Yards, Shops, Administrative Buildings: Includes all associated construction costs for all support facilities, such as storage and maintenance facilities and administration buildings.

  This item includes an allowance for a maintenance and storage facility sized for the size of the monorail vehicle fleet.

- SCC Category 40 – Sitework and Special Conditions: Includes site civil elements associated with the project, including clearing and demolition, utilities relocation, and other miscellaneous project requirements.

  This cost category includes an allowance for utility relocation for guideway installation, traffic signal adjustments, and modification of median areas along arterial street segments.

- SCC Category 50 – Systems: Includes all systems related elements such as communications and security systems, transit signal priority equipment, traffic signal modifications, train control and signaling, and traction power supply substations and distribution.

  This category includes the above as well as train controls, power supply, and fare collection equipment.

- SCC Category 60 – Right-of-Way, Land, Existing Improvements: Includes the purchase or lease of real estate, relocation of businesses or households, and associated professional services.

  This category includes allowances for land to site maintenance and storage facility, and land acquisition near stations.

- SCC Category 70 – Vehicles: Includes the cost of the transit vehicles to be used on the project, both peak service requirement vehicles and spare vehicles (at 20% of the peak need).

  This category includes the number of required monorail vehicles based on initial MPO ridership forecasts.

- SCC Category 80 – Professional Services: Includes all professional, technical and management services related to the design, construction and implementation of the project, such as preliminary and final engineering, project management, construction administration, liability insurance, legal/permits/fees, survey/testing/inspection, and start-up.

  For this project, a collective allowance of 34% was used, matching the total and individual percentages of total project construction cost (SCC 10 to 50).

- SCC Category 90 – Unallocated Contingency: Includes a standard unallocated contingency to account for undefined project items in early stages of project planning and design. This contingency is in addition to specific allocated contingencies for individual cost line items.

  An unallocated contingency factor of 15% was collectively applied to SCC Cost Categories 10 to 80.

- SCC Category 100 – Finance Charges: Includes finance charges expected to be paid by the project sponsor/grantee prior to the completion of the project.

  Given the unknown approach to financing the project costs, no finance changes are included in the project cost estimates.

A conceptual level cost estimate was prepared for a monorail system in the Southeast Corridor, and summarized for project budget purposes. Unit costs used to develop the estimates were based upon recently completed transit systems and modified as required for the monorail transit investments envisioned for the Southwest Corridor. Source information was derived from recent available comparable project cost estimates. The cost estimate was developed using 2014 base year costs and escalated to 2020 (presumed opening year) at a rate of 3.0 % per year based on recent construction cost trends. The FTA SCC spreadsheet includes an inflation worksheet that addresses this calculation step.

Unit costs for specific project components were drawn from data available to the consultant for project estimates for other similar recent projects. Certain costs associated specifically with monorail are not commonly available, and reasonable unit costs were identified by the consultant based on research and in-house estimates.

Basic assumptions include the following:

General

- The alignment is 33.7 miles long between downtown Nashville Station at Fogg Street/CSX rail line and the last station in Murfreesboro, with additional length for guideway extension at corridor terminal stations (0.1 mile at each end, for a total length of 33.9 miles of twin directional guideway.

- No alignment extension (0.7 miles in length) from Fogg Street station northward along CSX rail line to a station connecting with the proposed Regional Rapid Transit lines (South and Northwest Corridors).

- 13 passenger station stops.

- 4 park-and-ride lots with capacity for 500 vehicles each, and a bus terminal.

- 8 peak 2-car consists, with 2 spare consists, for a total of 20 peak vehicles required.

- Base ridership in 2040 of 7,100 daily boardings.

Service

- All days from 5:30 a.m. to 11:30 p.m.,

- Weekday peak periods: from 6:30 a.m. to 9:30 a.m. and from 4:00 p.m. to 7:00 p.m.,

- Headways – 15 minutes weekday peak periods; 20 minutes the rest of the service day, except 30 minute headways from 8:30 p.m. to 11:30 p.m.; 30 minute headways Saturdays and Sundays.

Features Included

- Allowance for street median reconstruction for segments in arterial streets,

- Station stops include ticket vending machines and real-time vehicle arrival information,

- Allowance for typical utilities relocations,

- Streetscape improvements and landscaping near stations,

- Property acquisition (generally minor takings near stations as needed),

Guideway Facilities

Construction of monorail in the typical elevated configuration is similar to a roadway bridge, requiring support columns with suitable foundations and guide beams spanning from column to column. A safety pathway would be installed between the two guideway beams along the length of the project. Where the monorail would be constructed in an at-grade configuration, the guideway beams would be installed on a prepared bed with the required foundation. Retaining walls would be constructed on either side of the guideway path to accommodate cut or fill conditions based on the lay of the land. This work would include the necessary excavation and fill work as well as basic drainage elements. The guideway would be fenced for security purposes. For the purposes of this analysis, a straddle beam monorail configuration was assumed.

Utilities

A reasonable allowance is included in this estimate for relocation of public and private utilities features that could be expected to be in conflict with the monorail improvements, especially along arterial streets. Utilities may include storm drains, sanitary sewers, electric power, water, gas, communications conduits, television cable conduit, and others.

Systems

The electrical power system will deliver electric power to the transit guideway from nearby locations from the area electrical grid. Electrical substations are assumed to be small facilities located at approximately 1 to 1-½-mile intervals depending on system design requirements. Systems include switching, protection, rectifier-transformers, feeder, grounding and bonding systems, batteries and chargers, local and/or remote controls, and equipment supervision. Estimates include minimal ductbank length for power feed to monorail substations.

Communications equipment includes a simple GPS vehicle location system that provides “next bus” information via a variable message sign (VMS) system at passenger station stops. Radio equipment is installed on all vehicles and at a central dispatch center located within the storage/maintenance facility.

Stations

It is assumed that station platforms will be 150 feet long, and in a center platform configuration between the two guide beams. It is suggested that a door system for entry and exit movements with the monorail vehicles be employed for passenger safety reasons. Station platforms would be approximately 25 feet wide. Construction costs include signage, lighting, seating, and overhead weather canopy. The station design would be part of the service branding in terms of logos, colors and design aesthetic. Allowance is made for special finishes, custom pavers, and landscaping nears the stations. Fare collection equipment is assumed to include full service, heavy duty ticket vending machines at all station stops.

Miscellaneous Items

An allowance for maintenance of traffic during construction includes temporary signage, electric sign boards, barrels, separation fencing, safety barricades, movable “Jersey barriers,” etc. and occasional use of traffic control officers. The estimate does not specifically include potential environmental mitigation items such as hazardous materials remediation (soil and/or water) or special noise-control measures.

Vehicles

For the purposes of this analysis, vehicles are assumed to be compatible with a straddle beam monorail configuration. Vehicle capacity is taken at 66 patrons sitting and 110 maximum capacity with standees.

Other Project Costs

Selected property acquisition costs are included in this estimate, including an allowance for additional street right-of-way station stops and the maintenance facility. Preliminary engineering, final design, construction phase professional services are included in the costs, with the assumption that the project will be a conventional design-bid-build project. The cost estimate includes allowances for liability and accident insurance policy coverage, as well as for other insurance, legal services, permits, and review fees.

Contingencies

A general (unallocated) cost contingency factor of 15% was applied to all project costs given the early stage of the project and to account for market fluctuations and unforeseen features and occurrences related to construction. Construction items contain standard allocated contingency factors. These are rated at 20% for all items except for utilities (30%) and right-of-way (50%).

The conceptual level cost estimate is a summarized format derived from the SCC worksheets and suitable for conceptual project budget purposes. **Table 6** provides a summary of estimated capital costs, including both hard and soft costs. The estimated cost of the monorail system as described for the Southeast Corridor including all hard and soft costs for the 2014 base year is approximately $1.63 billion ($48.0 million/mile) and $2.06 billion ($60.6 million/mile). It is noted that the northern 40% of the defined alignment is completely elevated while the remainder is mostly near-grade with intermittent overpasses and retained earth embankment sections.

Constructing the I-24 segment of this alignment in a totally elevated configuration would add over $550 million in 2014 and $700 million to the project cost in 2020.

Table 6: Summary of Monorail Capital Costs

MAIN WORKSHEET-BUILD ALTERNATIVE				
Southwest Corridor (I-24 Nashville)			Today's Date	12/1/14
Monorail Concept			Yr of Base Year $	2014
			Yr of Revenue Ops	2020
	Base Year Dollars TOTAL (X000)	Base Year Dollars Percentage of Construction Cost	Base Year Dollars Percentage of Total Project Cost	YOE Dollars Total (X000)
10 GUIDEWAY & TRACK ELEMENTS (route miles)	602,734	62%	37%	764,871
20 STATIONS, STOPS, TERMINALS, INTERMODAL (number)	90,000	9%	6%	114,210
30 SUPPORT FACILITIES: YARDS, SHOPS, ADMIN. BLDGS	44,000	5%	3%	55,836
40 SITEWORK & SPECIAL CONDITIONS	115,451	12%	7%	146,508
50 SYSTEMS	119,205	12%	7%	151,271
Construction Subtotal (10 - 50)	971,390	100%	60%	1,232,696
60 ROW, LAND, EXISTING IMPROVEMENTS	45,000		3%	55,356
70 VEHICLES (number)	60,000		4%	77,146
80 PROFESSIONAL SERVICES (applies to Cats. 10-50)	338,436	35%	21%	422,587
Subtotal (10 - 80)	1,414,825		87%	1,787,786
90 UNALLOCATED CONTINGENCY	212,224		13%	268,168
Subtotal (10 - 90)	1,627,049		100%	2,055,954
100 FINANCE CHARGES	0		0%	0
Total Project Cost (10 - 100)	1,627,049		100%	2,055,954
Allocated Contingency as % of Base Yr Dollars w/o Contingency	20.70%			
Unallocated Contingency as % of Base Yr Dollars w/o Contingency	48.30%			
Total Contingency as % of Base Yr Dollars w/o Contingency	69.00%			
Unallocated Contingency as % of Subtotal (10 - 80)	15.00%			
YOE Construction Cost per Mile (X000)				$36,363
YOE Total Project Cost per Mile Not Including Vehicles (X000)				$58,372
YOE Total Project Cost per Mile (X000)				$60,648

Assuming the upper end potential volume per the corridor of 16,000 daily boardings in 2040, the capital costs would be increased by the need for twice the fleet of vehicles and an incrementally larger maintenance facility.

10.2 Operations and Maintenance Costs

There is limited data for the operations and maintenance costs for monorail systems in North America. Information secured from selected manufacturers suggests that the operations and maintenance costs for monorail are similar to those for light rail transit (LRT). It is noted that this estimate presumes an operator for each train consist.

It is noted that the operational component of the annual operations and maintenance cost is a function of the proposed service plan for monorail operations in terms of the hours of operation, the service frequencies during the day, and the vehicle requirements based on the scheduled operating speed and passenger load. This estimate is based on a ridership forecast of 7,100 daily boardings in 2040.

The MPO corridor travel demand modeling for the Urban Rail option in this corridor as LRT was coded in the model with an overall operating speed of 44 mph. This speed is assumed to be the scheduled operating speed which needs to take into account the optimum technology operating speed adjusted for deceleration and acceleration time losses as well as dwell time losses at transit stations, as well as adjustments for horizontal curves and vertical curves which may affect operating speed. Typically achievable scheduled operating speeds for guideway transit in an urban and suburban environment given station spacing distances and common alignment curvatures is in the 30-35 mph range. The northern third of this hypothetical corridor alignment and station location layout is in the realm of prototypical corridor layouts, but the southernmost two-thirds of this corridor is a relatively straight alignment with widely separated station locations which are more widely spaced.

Based on this corridor characterization, the northern one-third of the corridor should operate near a 30 mph scheduled speed with its more closely spaced stations. To satisfy the overall scheduled operating speed of 45 mph, the southern two-thirds of the corridor would need to operate at a scheduled speed of 52.2 mph. This would require an average operating speed of 57.4 mph allowing for station stopping delays. For the purposes of this analysis, an overall corridor schedule operating speed of 35 mph was assumed.

This value was applied to the calculated revenue hours of service and adjusted to an annual basis, for an estimated operating cost of $17.22 million per year in 2014 dollars. It is noted that the operational component of the annual operations and maintenance cost is a function of the proposed service plan for monorail operations in terms of the hours of operation, the service frequencies during the day, and the vehicle requirements based on the scheduled operating speed and passenger load. For the upper end potential corridor ridership of 16,000 daily boardings as considered by the MPO, the estimated annual operating cost would be approximately double, or about $34.44 million per year in 2014 dollars.

The capital and operating and maintenance (O&M) costs estimates for the monorail system in this corridor are all inclusive. There may be some economies of scale by having all premium transit corridors served by the same transit technology in terms of facilities, vehicle fleet and employee training. To ascertain these potential differences would require analysis of hypothetical network scenarios in greater detail, which was not possible within the scope of this study.

11.0 FINANCING THE PROJECT

Project finance refers to specially designed techniques and tools that supplement traditional transit financing methods, improving governments' ability to deliver transportation projects. Project finance typically entails borrowing money, either through bonds, loans or other financing mechanisms. Borrowing money for project implementation helps accelerate implementation of needed infrastructure. But just like borrowing money for a mortgage, project finance tools require a repayment source. In many instances, using project finance tools requires the development and imposition of new revenue streams to pay back bonds or loans issued to support investment.

Project finance is typically used for large capital projects in cases where using "pay-as-you-go" does not make good planning and programming sense; that is, because the project's capital needs would consume most if not all available funding - and still often fall short of being fully funded. Further, given long-term benefits of transportation infrastructure, it can be economically sound to spread the project costs over the asset's life-cycle. However, project finance comes at a cost, because interest is paid over the long-term for the money that is borrowed today. But the additional cost of financing might be justified if it is less than the potential project cost increase due to inflation, or it is outweighed by the benefits of having the project available in the near-term.

Project finance has evolved at the federal level as a product of dialogue between policy and administrative officials at United States Department of Transportation (USDOT) and partners at the state and local levels. Most of the programs and tools have been enabled by legislative changes to the U.S. Code, Title 23. As transportation finance needs evolve, new tools and programs are likely to add to the field of project finance.

11.1 Federal Funding

Federal Transit Administration's (FTA) New Starts competitive grant program is the primary source of federal funding for fixed guideway transit projects. Individual projects from throughout the country compete against each other for limited funding. Also, the availability of New Starts program funding may decline in the near future due to overall program funding reductions as a result of federal spending pressures and new program funding limits.

Specifically, the New Starts program is funded out of the federal general fund. Just as the State's projects will need to compete against other projects across the country, New Starts funding will need to compete with other federal government priorities. With Congress focusing on reducing federal government spending, federal funds for New Starts projects could be reduced. As a result, fewer projects may receive federal matching funds. The FTA website link (http://www.fta.dot.gov/documents/FY15_Annual_Report_3_3_14_final.pdf) presents FTA's FY 2015 New Starts Core Capacity and Small Starts project funding recommendations to Congress.

Assuming the federal funds are approved for the Southeast Corridor project (whether it is a LRT or monorail project) the federal contribution for the Southeast Corridor would be in the range of $1.03 billion (2020 year of expenditure cost) and the remainder of $1.03 billion would fall to

State, regional, local and other funding sources. It is noted that any Southeast Corridor premium transit project seeking FTA New Starts funding would first need to be listed in the currently adopted MPO long range transportation plan as cost-feasible.

While motor fuel taxes have been the primary revenue source at both the state and federal level for transportation, the buying power of this revenue source has eroded significantly with inflation and will continue to as fuel efficiency standards increase. Other traditional transportation revenues, such as the titling tax or registration fees, have declined or stagnated in recent years due to the recession. In response to increasing demands for new projects and maintenance of aging systems, and declining availability of state and federal funds, state and local governments across the country are considering a variety of alternative strategies to finance transit project development. Transportation financing strategies that involve public-private partnerships (P3) continue to receive significant attention.

The following section summarizes information about four broad transportation revenue generation strategies the State could pursue to help finance the Southeast Corridor project specifically: P3/availability payments, federal loans, value capture, and local option revenues. It is important to keep in mind, however, that these strategies are neither exhaustive nor mutually exclusive. In addition, a short case study of how Denver, Colorado is trying to integrate alternative financing with more traditional financing tools is provided.

11.2 Public-Private Partnerships Utilizing Availability Payments

Public-Private Partnerships (P3) are long-term agreements in which the public sector assigns to a private sector company the right to design, build, finance, operate, and/or maintain an infrastructure asset for a defined period per some type of financial arrangement. Although the private sector may finance the project up front, it receives a return on its investment through project revenues or payments from the public sector over the life of the contract. If project revenues are nonexistent or insufficient to provide an appropriate return on investment, the public sector may make payments directly to the private partner. These payments may take the form of availability payments.

Availability payments provide compensation to the private sector on a periodic basis (*e.g.* quarterly or annually) based on the project being available for use and performance standards being met as per the contract. Availability payments may be used for capital costs, ongoing operating costs, or both depending on the contract.

Advantages

The public sector makes periodic, pre-established payments to the private sector, thus providing predictability in budgeting. Payments typically do not begin until the facility construction has been completed and operations begin. Availability payments are useful for projects that have unpredictable revenue streams or where service quality is more important than revenue maximization. Availability payments for capital construction costs are similar to debt service on bonds, in that in exchange for an upfront amount of cash, repayment of funds takes place over time at a set, predicable payment level; however, the key difference with availability payments is that payment levels are performance-based. Deductions to the operating portion of the payment may be made as necessary if the facility is not available or the quality of service does not meet established standards. By providing availability payments to the private sector rather than pledging project revenues, the public sector retains the ability to set user fee levels, such as transit fares or toll rates. P3s utilizing availability payments are typically for a shorter term (25 to 30 years) than P3s utilizing project revenues or concessions (50 years).

Disadvantages

The use of P3s is simply an alternative financing technique; it is not a source of revenue. Like other debt, availability payments require annual appropriations, and the source of funding for those availability payments still needs to be identified. Existing funding in the Transportation Trust Fund (TTF) is not sufficient to make these availability payments without severely curtailing spending on the capital program. Thus, a revenue increase would be necessary to make such payments.

Currently, state legislative action is required to permit P3 transit project financing in Tennessee. Also, the impact of availability payments on Tennessee State debt is unclear at this time. If the State's debt capacity is constrained, the use of availability payments in Tennessee may be a nonstarter issue if it is determined that it must be limited to 15 years and will be factored into the State's debt affordability guidelines.

When structured properly, P3s can provide substantial risk sharing benefits. Risk should be assigned to the party best able to control or mitigate that risk. For example, design-build contracts often move the risk of construction cost overruns and time delays to the private sector. However, this risk sharing comes at a premium; the private sector will want to be compensated for sharing this risk, thus increasing project costs. Rates for private sector financing are typically higher than for traditional tax-exempt financing; however, these additional costs may be somewhat mitigated by whole life-cycle cost efficiencies provided by the private sector.

11.3 Transportation Infrastructure Finance and Innovation Act Credit Assistance

The federal Transportation Infrastructure Finance and Innovation Act (TIFIA) program provides credit assistance at below market rates through direct loans, loan guarantees, and lines of credit. The TIFIA program targets large projects, generally in excess of $50 million. To date, 27 projects nationwide have been partially funded with TIFIA credit assistance, including 4 intermodal projects, 18 highway projects, and 5 transit projects.

Under the recently passed federal transportation authorization, several significant changes were made to expand the TIFIA program. First, the amount of funding available to the program increased significantly, from $120 million in federal fiscal 2012, to $750 million in federal fiscal 2013, and $1 billion in federal fiscal 2014. Second, the percent of TIFIA financing that may cover total project costs increased from 33 to 49%. Finally, the project selection criteria, which were previously used to select projects for funding, have been eliminated. Projects will now be funded on a first come, first served basis.

Advantages

The TIFIA program provides various credit products, improved access to capital markets, favorable interest rates, flexible repayment terms, and supplemental and subordinate debt. Thus, projects that might have been delayed or not constructed at all because of difficulty in obtaining financing can move forward. TIFIA credit assistance is useful for projects that have unpredictable revenue streams and, therefore, may have difficulty obtaining financing in traditional capital markets. For example, TIFIA loans allow for maximum loan maturities of 35 years after completion of a project and flexibility to begin repayment up to five years after substantial completion to allow time for facility construction and ramp-up of operations and revenue. In addition, the ability to make TIFIA credit assistance supplemental and subordinate to other debt allows additional project financing flexibility. Interest rates for TIFIA credit assistance are fixed and are equivalent to Treasury rates, often providing more favorable rates than may be obtained in private markets.

Disadvantages

TIFIA loans and lines of credit are an alternative form of borrowing money, and thus must still be repaid. Federal law requires dedicated revenue for repayment, but State law goes one step further stating that the revenue must come from the facility constructed. Under federal law, it is likely that the TTF would qualify as a dedicated revenue source; however, a transit facility would not generate enough funding to cover the repayment costs. It is likely that State law would need to be changed given the revenue flow of a transit project being less than a toll project.

Historically, demand for the TIFIA program has far exceeded available funding, so obtaining funding has been difficult; however, with the recent increase in funding for the program, demand and available resources may equalize. Additionally, it is unclear at this time how recent changes to the process of selecting projects for funding, moving from selection criteria to a first come, first served basis, will impact the program. Projects eligible for assistance are restricted to larger projects (generally $50 million) and must meet several federal requirements, including meeting transportation and highway standards established in federal law, National Environmental Policy Act requirements, Buy America provisions, and others. Another potential is that if a TIFIA loan is a junior lien and the project defaults, the TIFIA springs forward to a senior lien. While this has never occurred, the possibility exists. Finally, depending on how a TIFIA loan is structured or issued, it may count towards the State's debt limit and be subject to the 15-year constitutional limit on the maturity.

11.4 Value Capture

Value capture generally refers to the concept of using the increase in land value from the construction of a transit line/station to pay for the construction of that transit line/station. Many mechanisms are used to capture the increase in land value including special taxing districts and tax increment financing. Typically, debt is issued for the capital costs and backed by the additional revenue generated in property tax revenues from construction.

Mechanisms used for value capture include:

- Developer Fees: A one-time fee paid by a developer based upon the relationship between the construction of a project and the projected increases in land values.
- Tax-Increment Financing (TIF): *A* designated area around a project where the existing tax base is frozen and the additional increase in property values from the project are used to pay debt service on bonds used to pay for the construction of a project.
- Special taxing district: An area is designated around a project and property owners pay an additional tax on the value of their property.
- Joint development: An agreement between the public and private sector where the public sector leases or sells an asset to the private sector to assist in the construction of a project.

Advantages

Value capture strategies allow those individuals or properties that benefit from the construction of a transit line to contribute to the construction costs. This reduces the State's need to invest limited revenues for the construction of the transit lines.

Disadvantages

Current use of value capture techniques to fund transportation infrastructure is fairly limited. TIF has been used on the local level in some cases to assist in redevelopment but has limited use for transportation construction.

Estimating what the potential benefit, or increase in land value, resulting from transportation infrastructure is difficult; therefore, if value capture strategies are utilized but revenues are not sufficient, the State may need to backfill the revenue loss.

11.5 Local Option Revenues

Local governments throughout the United States are using a variety of funding sources including:

Traditional taxes and fees, such as the local option sales tax, vehicle registration fees, advertising revenues, and the motor fuel tax; less common business, activity, and related sources such as the income/payroll/employer tax, hotel/lodging tax, real estate transfer tax, mortgage recording tax, and car rental fees; and

Revenue streams from projects such as Transit Oriented Development, land value capture, impact fees, and special assessment districts.

Local governments are also using a variety of long-term debt instruments to help finance major local and regional transit projects and programs, including general obligation bonds, Grant Anticipation Revenue Vehicle bonds, and State infrastructure bank loans. In addition, local governments are partnering with each other to develop transportation authorities that manage local transportation planning and funds.

The following are examples of local revenue options funding techniques:

- Sales Taxes: In 1987, San Diego County residents approved the 20-year *TransNet* program, a one-half cent sales tax to fund a variety of transportation projects. In November 2004, voters approved an extension to 2048 that is expected to generate approximately $14 billion for highway, transit, and local road projects. The San Diego Association of Governments administers *TransNet* funding.

- Motor Fuel Tax: The Northern Virginia Transportation District (NVTD) in Virginia is a multijurisdictional agency representing Arlington, Fairfax, and Loudoun counties and the cities of Alexandria, Fairfax, and Falls Church. NVTD provides funding for the Virginia share of WMATA’s costs. NVTD’s member jurisdictions rely on a 2.1% motor fuels tax to meet their respective local subsidy obligations.

- Payroll Taxes: The Tri-County Metropolitan Transportation District (TriMet) provides bus, light rail, and commuter rail transit services in the Portland, Oregon metro area. Payroll and self-employment taxes provide operating revenue for TriMet and are collected and administered by the Oregon Department of Revenue on behalf of TriMet and the Lane County Mass Transit District. TriMet has the authority to increase the tax rate over 10 years to help pay for new transit service throughout the region.

Advantages

Local option transportation taxes often produce highly visible results and reassure voters that funds will be used only for specified projects. In addition, locally funded projects (1) may be able to circumvent expensive labor requirements that State and federally funded projects must abide by; and (2) use more flexible and innovative contracting process that expedites project implementation.

Another advantage of local option revenue is that the primary beneficiaries of the transit project are contributing to the cost of the project. In doing so, local jurisdictions and citizens are financially invested in the projects.

Disadvantages

Focusing resources and decision making at the local level may serve to undermine the influence and authority of metropolitan planning organizations, which are nominally charged under federal law with coordinating the development of regional transportation plans. Also, local option transportation taxes (1) may limit the authority of local officials by requiring them to fund projects only in the manner specified in a ballot measure, usually over a long period of time; and (2) may be used to fund projects that are locally favored but do not reflect extensive analytical work by transportation planners and engineers to determine, among other things, the most cost effective projects.

11.6 Case Study: Eagle P3 Project

In 2004, Denver's RTD embarked on a major transit expansion program. The program, called FasTracks, is a $7.4 billion, 12-year program to build 122 miles of new commuter and light rail service, 18 miles of bus rapid transit service, 21,000 new parking spaces at rail and bus stations, enhanced bus service, and new and expanded maintenance facilities. Most of the funding is generated from a voter-approved sales tax increase of 0.4%. In addition, RTD has utilized several innovative financing techniques, including the use of TIFIA loans and P3s. The

FasTracks program includes several different projects, each with their own funding mechanism. The Eagle P3 project consists of a concession agreement to design, build, finance, operate, and maintain the 22.8-mile East Corridor, the 11.2-mile Gold Line, the electrified segment of the Northwest Line, and a commuter rail maintenance facility. The $2 billion project has received substantial attention because it is the country's first transit project to use an availability-based payment stream and because of the mix of financing sources that was used to fund the project. Availability payments allow RTD to repay the private capital and pay for ongoing operations and maintenance while still retaining control over fare policies and revenues.

The P3 winning bid was from Denver Transit Partners and was $300.0 million lower than RTD's estimated project cost. The agreement spans 34 years, which includes a five-year design and build period followed by 29 years of operation and maintenance. Financing the construction of the project will come from a variety of sources including: federal, state, local, or private sources, it is important to note that both the $280.0 million federal TIFIA loan and the $397.8 million private debt both require repayment from state and local sources.

Sources of funding include:

- Just over one-half of construction funding comes from a $1.0 billion federal grant from the New Starts program and a $62.1 million grant from the federal Congestion Mitigation and Air Quality Improvement program. These funds are federal grants and, therefore, do not require repayment.

- $280.0 million are from a federal TIFIA loan. TIFIA loans from the federal government offer favorable interest rates and flexible repayment terms. RTD estimates that it saved $164.0 million in financing costs by using the lower interest rate of the TIFIA loan rather than revenue bonds. Repayment of the TIFIA loan will come from RTD's sales tax revenues.

- $487.8 million are in private equity and debt, including $397.8 million in private activity bonds and $91.7 million in private equity. Private activity bonds are tax-exempt bonds issued by a state or local government with the proceeds passed through to a private entity. Private activity bonds typically receive more favorable interest rates than private debt, but less favorable rates than municipal bonds. The private activity bonds will be repaid with sales tax revenues and mature in 30 years.

Over the next 34 years of the term of the contract, RTD will make $5.3 billion in payments to Denver Transit Partners. Approximately $1.2 billion of these payments are for construction and occur in the first 8 years of the contract. The majority ($1.0 billion) of these funds will come from federal New Starts grant money. In years 6 through 34 of the contract, RTD will make service payments that will repay the private activity bonds and pay for operations and maintenance of the transit lines. In addition to making these construction and service payments, RTD is also responsible for paying the debt service on the TIFIA loan.

By utilizing several different financing techniques, RTD was able to move forward on this $2 billion project much sooner than if it had waited for traditional funding. However, as noted previously, it is important to remember that P3s, TIFIA loans, and private activity bonds are simply *alternative* methods of financing; they are not forms of funding. Although these alternative financing sources may allow governments to make payments over extended periods of time, tax revenues ultimately pay for these projects.

Local and regional financial support is critically important to support transit state of good repair projects, new major transit infrastructure projects and on-going transit O&M costs. There is an ongoing effort in the Middle-Tennessee region, as noted by the MPO, to pursue local dedicated revenue sources for major transit projects in this and other regionally significant corridors. Typical revenue sources include the following: (1) traditional tax- and fee-based funding sources; (2) common business, activity, and related funding sources; (3) revenue streams from projects; (4) new "user" or "market-based" funding sources; (5) financing mechanisms; and (6) fare policy and strategy.

Summary

While Tennessee has relied on traditional transportation revenue sources in the past, new revenue sources and more innovative transportation financing strategies may be required to expand Tennessee's transit infrastructure. This section of the report identified a number of transportation financing mechanism strategies that could be implemented to help the State as well as regional and local governmental entities realize their transit goals.

12.0 FINDINGS

Based on the analyses conducted in this assessment, the following findings are offered:

- Monorail technologies are capable of providing operating speeds and passenger capacities comparable to those of other modes of premium transit. They have a demonstrated history of reliable operations.

- There are a number of monorail manufacturers, some of which have established a business presence in the United States, with a proven history of operations to minimize some of the risks associated with introducing a new technology to the regional transportation network. In areas where at-grade transit technologies or aerial heavy rail transit may pose serious physical impacts to a corridor, the lower impacts of monorail systems may offset some of the costs of building such systems.

- The side-straddle systems under development pose a service reliability issue as they are unable to maneuver around disabled or stopped trains by "switching tracks" as rail and straddle-system monorails do. However, if this issue can be resolved, side-straddle monorails may offer savings in costs and impacts, since they are able to fit two guideways on a single narrow structure.

- Although there is uncertainty about the reliability of the monorail technologies still under development, the existing systems have demonstrated a sufficient record of reliability and effectiveness. Because of this, monorail technologies may be considered as a technology alternatives for new transit alignments in the Southeast Corridor.

- The MPO's 2035 Regional Transportation Plan, adopted in December 2010, recommended rapid transit but did not identify a specific technology for the Southeast Corridor. The prior 2007 MPO study (Nashville Southeast Corridor High-Performance Transit Alternatives Study of the Southwest Corridor) discounted the monorail technology for various reasons, including: its aerial structural system and aerial stations are expensive on a per mile basis compared to at-grade transit service, its track record in providing urban/suburban transit service has not been demonstrated, and monorail is not applicable for express service when compared to proven bus and commuter rail modes. These reasons are legitimate in terms of the project context, namely that there is very limited application of monorail to the daily commuter environment of suburban corridors in North America. There are optimistic citations by some monorail developers as to the cost economy of their technology, but these often do not include full project cost components and the associated soft costs of projects. Cost comparisons are often apples-to-oranges situations, causing confusion as to actual facts. Cost/mile of light rail transit, has in fact grown significantly over recent years based on new projects which have averaged $67 million/mile, ranging from $48 to $91 million/mile (2014 $) in total project cost.

- The estimated project cost to develop a monorail transit facility in the Southwest Corridor along the alignment described is approximately $1.63 billion in 2014 dollars and $2.06 billion in year of expenditure dollars for a 2020 revenue service opening date. These estimated costs include both hard and soft costs. The capital costs and their allocated contingencies account for 60% of the total project cost and the balance are soft costs.

- In the Southwest Corridor, along the I-24 segment, there is the opportunity to build a premium transit line in public right-of-way in a near at-grade configuration with cuts and fills along the transit guideway profile, significantly reducing guideway costs. Constructing the I-24 segment of this alignment in a totally elevated configuration would add over $550 million in 2014 and $700 million to the project cost in 2020.

- The estimated annual operating cost for the monorail service, for the service assumptions listed, in 2014 dollars, is approximately $17.22 million. It is noted that the operational component of the annual operations and maintenance cost is a function of the proposed service plan for monorail operations in terms of the hours of operation, the service frequencies during the day, and the vehicle requirements based on the scheduled operating speed and passenger load. For the higher upper end potential ridership of 16,000 daily boardings per the MPO, operating costs would be approximately doubled.

- Ridership for the year 2040 in this hypothetical corridor as initially estimated by the MPO for a light rail transit option, with similar service characteristics to monorail, was 7,100 daily boardings, and 9,400 daily boardings with more transit supportive land uses around station areas. Desirably, ridership estimates should be much higher to support the more expensive transit technologies under consideration, including monorail. It is noted that the total forecast transit ridership in the corridor is approximately 16,000 daily boardings when the other proposed transit service components are considered. The MPO considers this value an upper end potential volume for the corridor, on the basis that the ridership for the other corridor services would be absorbed into the rapid transit option. Continued refinement of travel demand modeling in the corridor considering station locations, feeder bus service, park-and-ride lots will hopefully yield further improvement in projected transit ridership levels in this corridor.

Development of a monorail transit facility in the Southwest Corridor along the alignment identified is generally feasible, although there are a great many design details that could not be addressed in this assessment. Moreover, an objective assessment of project impacts would also need to be conducted to determine if this particular concept causes any significant impacts that cannot be reasonably mitigated.