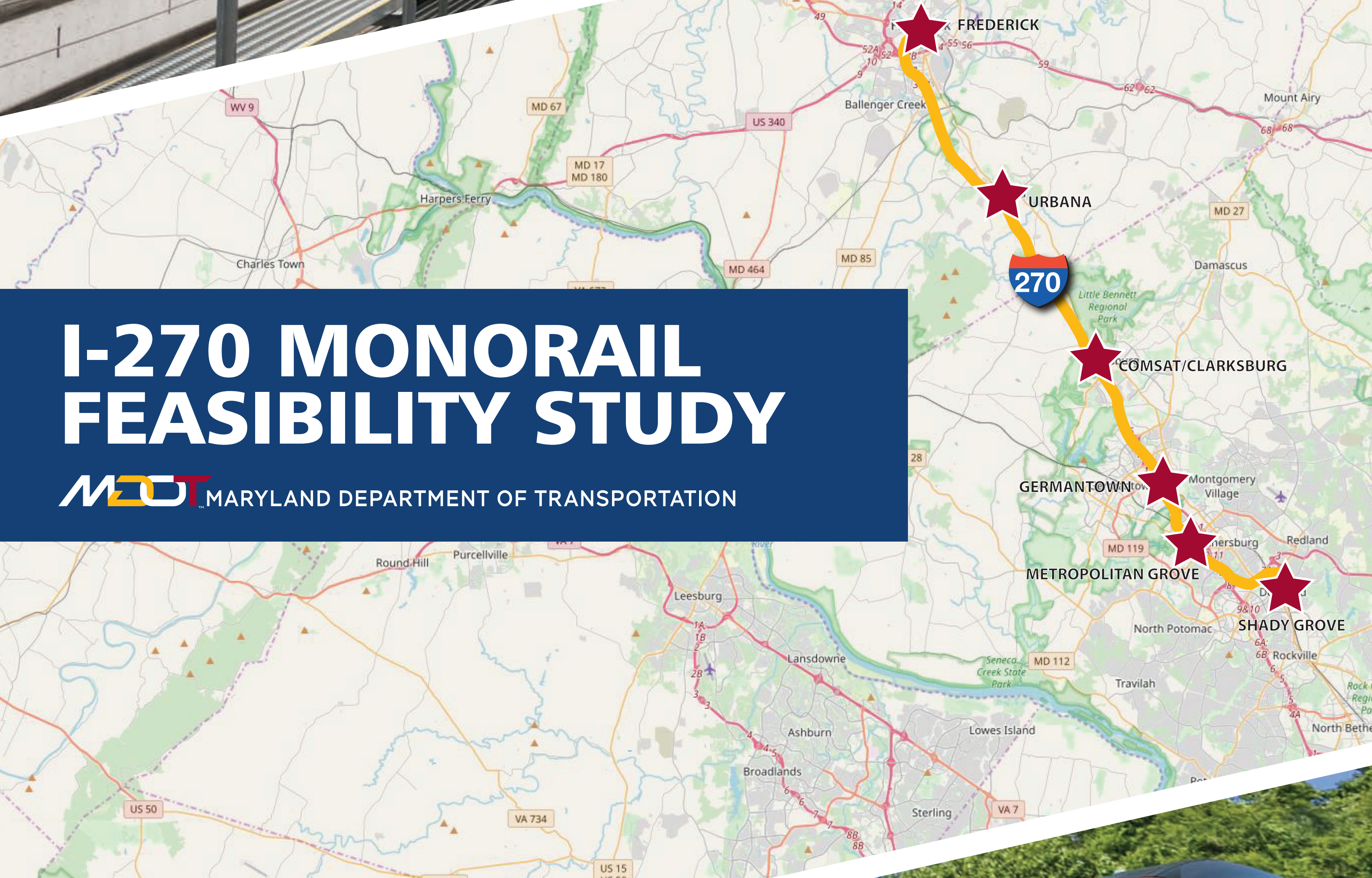
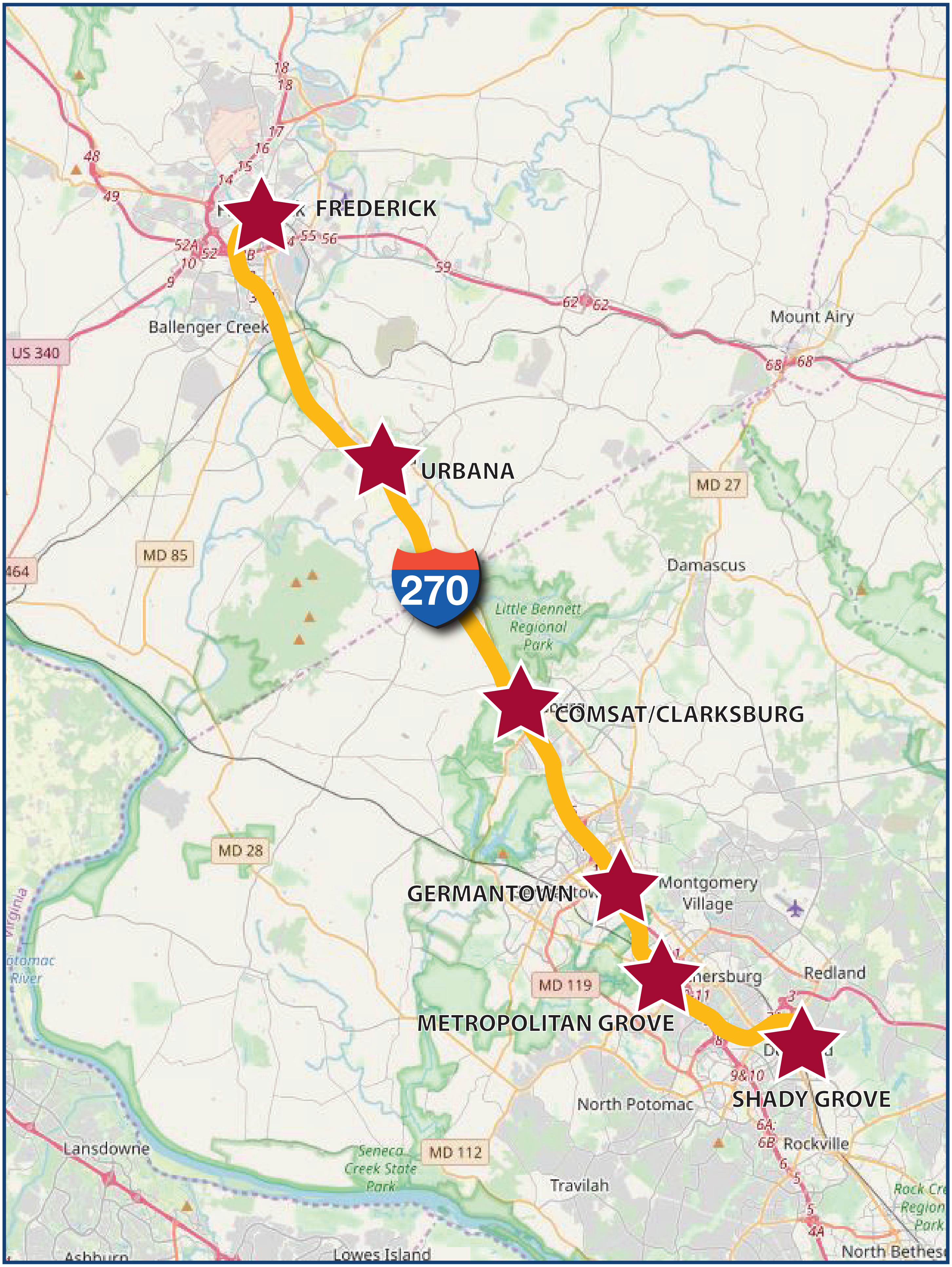
I-270 MONORAIL FEASIBILITY STUDY

MARYLAND DEPARTMENT OF TRANSPORTATION



FEBRUARY 2021


FREDERICK
URBANA
270
COMSAT/CLARKSBURG
GERMANTOWN
METROPOLITAN GROVE
SHADY GROVE
Ballenger Creek
Mount Airy
US 340
MD 27
MD 85
Damascus
Little Bennett Regional Park
MD 28
Montgomery Village
MD 119
Redland
North Potomac
Rockville
Lansdowne
MD 112
Seneca Creek State Park
Travilah
Lowes Island
Virginia
Potomac River

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ES | Executive Summary

The Maryland Department of Transportation (MDOT) has completed this Monorail Feasibility Study (Feasibility Study) looking at the feasibility of monorail within the I-270 corridor from the City of Frederick in Frederick County, Maryland to the Shady Grove Metro Station in Montgomery County, Maryland. This executive summary presents an overview of the analysis and information collected. Detailed information concerning the methodologies is included as part of the Feasibility Study report and supporting Appendices.

Purpose of the Feasibility Study

MDOT agreed to perform this Feasibility Study at the request of the Maryland Board of Public Works. The request for the Feasibility Study was made as a requirement of the Board's approval of the statewide Traffic Relief Plan, with a focus on relieving congestion in the I-270 and I-495 corridors.

MDOT has prepared this independent Feasibility Study for the I-270 corridor to assess the viability to construct, operate, and maintain a monorail system between the Shady Grove Metrorail Station and the City of Frederick, Maryland. The Feasibility Study evaluates existing monorail services around the world; alignment options; station locations and connectivity; frequency of service; ridership demand; environmental and land use considerations; operation and maintenance needs; and project costs for construction, operation, and maintenance.

MDOT's Response to COVID-19

The COVID-19 public health crisis has dramatically impacted all Marylanders and required that we all make difficult adjustments in our daily lives. This has been a challenging and disruptive time. At MDOT, employees at all of our transportation business units are on the front lines of a statewide transportation system providing vital service to allow essential employees to get to work. As always, ensuring our employees' and customers' safety and the safety of all Marylanders is our top priority. Maryland's economy has taken a hit due to the impact of the COVID-19 pandemic. That impact has also affected the State's transportation system, with declines in use of the system, which has further reduced revenue to the Transportation Trust Fund. The full breadth of the COVID-19 pandemic's effects have yet to be realized, including impacts to state and local revenue and funding sources.

What is a Monorail?

This report focuses primarily upon straddle-type urban monorail technology, although one suspended monorail system is mentioned. Straddle monorail vehicles are electrically propelled, and run on primary rubber load tires with lateral guidance tires that straddle the narrow guide beams. The narrow guide beams, which typically are between 27 and 36 inches wide and made of pre-cast reinforced concrete, are unique in that they both guide and structurally support the vehicles. This is a major factor that can reduce the construction cost, and visual and construction impacts of the technology as compared to other grade-separated transit modes.

Although straddle monorail systems generally are built in an aerial guideway configuration, some monorail systems also operate in underground sections, or close to ground level, with adequate fencing to prevent unauthorized access to the guideway.

First developed over 60 years ago, the technology has experienced broad and significant changes and enhancements through the ensuing years, to the point where there are well over 40 urban monorail systems in operation globally today.

Study Area

The study area is located northwest of Washington, D.C. in Montgomery and Frederick counties, Maryland. The study area includes the I-270 corridor and extends approximately 28 miles from the City of Frederick to Derwood (Shady Grove).

I-270 is an Interstate Highway within the State of Maryland that extends between I-70 in the City of Frederick and the Capital Beltway (I-495) just north of Bethesda. I-270 is the primary roadway within the study area with connections to I-70, I-370, and I-495. Other major routes cater to regional and local traffic such as MD 355 and MD 200, I-70 and I-495 connect the study area with the wider Mid-Atlantic region through I-70, I-95, I-66, US 15, and US 50.

Other modes of transit within the study area include the Maryland Area Rail Commuter (MARC) Brunswick Line which provides commuter train service between the Frederick Station and Union Station in Washington, D.C. Montgomery County's Ride On bus network provides local bus service throughout the study area with connections to Washington Metro Area Transit Authority (WMATA) Metrobus, MDOT Maryland Transit Administration (MDOT MTA) commuter bus, Metrorail, and MARC services. Bicycle infrastructure is present throughout the study area and consists of bike lanes, shared use lanes on local roadways, and paved off-road trails. Urban centers like Frederick and Rockville feature more extensive networks than more rural areas such as Clarksburg and Urbana.

Previous Studies and Analysis

Existing transportation projects within the study area include the *I-495 and I-270 P3 Program,* the *Corridor Cities Transitway (CCT), MD 355 Bus Rapid Transit (BRT),* and *North Bethesda Transitway BRT* systems.

This Feasibility Study is consistent with numerous planning efforts within Frederick and Montgomery Counties including the *2010 City of Frederick Comprehensive Plan,* the *2009 City of Gaithersburg Master Plan,* and the *2006 Shady Grove Sector Plan,* amongst others, which discuss transit improvements along the I-270 corridor.

In addition, The High Road Foundation **(thehighroadfoundation.org)**, a privately funded advocacy organization, has been looking at opportunities to promote consideration of monorail as a transit mode to improve transportation mobility along the I-270 corridor, including this segment from the City of Frederick to the Shady Grove Metro Station.

Methodology

The MDOT completed a separate global scan of monorail technologies, the *MDOT Monorail Global Scan and Assessment, November 2020* to identify existing design and operational characteristics for national and international monorail facilities. This assessment focused on a global scan and review of existing monorail systems that are currently operating. In addition to this review of existing systems, the MDOT Monorail Global Scan and Assessment lists characteristics of national and international monorails, discusses some lessons learned from planning, constructing, and/or operating monorail systems, and compares existing monorail systems to a potential I-270 monorail. This assessment concluded that monorails have a track record of providing viable urban transit, and the technology allows unique solutions for difficult alignment requirements, but the success of a transit system depends on urban densities and sound planning rather than the specific technology. The assessment found that monorail systems work best in areas of higher population density with concentrated urban development next to stations. The findings from the *MDOT Monorail Global Scan and Assessment, November 2020* were used as part of this Feasibility Study to help identify and develop the design criteria and measures of effectiveness.

Design Criteria

Based on our global scan, this study used two specific monorail system manufacturers to determine the basis of the design criteria: Bombardier's INNOVIA 300 and BYD's SkyRail Systems. Both systems are straddle beam, bi-directional, fully automated driverless trains, and operate on a grade-separated dual-track alignment. These manufacturers were selected as representative systems within the global monorail marketplace and for their existing operational presence in the North American region. We understand improvements to technology or new technology exist, but this method was undertaken to provide a conservative evaluation for the baseline design criteria. While these two systems are more conservative to meet FTA criteria, they can accommodate newer technology underway and increase design speeds around the globe. The design criteria (**Table ES.1**) for each manufacturer was analyzed and a single set of combined design criteria was developed. Using this developed criteria and previous studies, potential locations for stations and an alignment was developed and refined based on identified constraints, connections, and potential impacts within the corridor. All stations share common elements but were revised based on location characteristics and ridership analysis. Ridership analysis was used to determine how large the supporting parking facilities needed to be. A fully unconstrained scenario was assumed, meaning any potential monorail passenger that is reliant on a car to get to the station would be able to find a parking space there, and that all connecting transit systems have sufficient capacity.

Table ES.I – Design Criteria

Vehicle		Track	
Car Length	40′	Maximum Grade	10%
Car Width	10.3′	Recommended Max Grade	6%
Wheelbase	30′	Absolute Max Superelevation	12% max
Full Capacity @ 3.3 pass/m^2	76 pass/car	Desired Max Superelevation	8% max
Operational Top Speed	50-75 mph*	Minimum Turn Radius	150′
Consist Length	2 to 8 cars	Rail Beam Width	2.3′
		Pier Size	3.5′
		Avg. Span Length	100′ avg, 65′-120′
		Accel/Brake Rate	1 m/s^2

*At least one major monorail supplier, BYD, has fully tested and is offering its SkyRail technology globally with a top operating speed of 75 mph, with a recommended scheduled operating speed of 65 mph (to provide a schedule recovery capability for unanticipated passenger-caused delays)

Stations		Clearances	
Center Platform Width	18′	Tangent Center to Center	14′3″ at 50 mph
Side Platform Width	14′	Tangent to Fence	7′3″
Platform Length (One 3-car train)	150′	Vertical from Beam Top	17′
Platform Length (Two 3-car trains)	300′	2-Track Envelope	26′
		Beam Underpass	16′9″

Measures of Effectiveness

This Feasibility Study evaluates the feasibility of utilizing the monorail technology in this study area corridor. This Feasibility Study investigates and evaluates monorail in this corridor and measures the effectiveness of this system using the following metrics:

- Evaluates monorail technology and its appropriateness for the study corridor
- Evaluates the specific design requirements of monorail on this alignment and documents the alignment's potential cost, impact, and benefits
- Evaluates the I-270 corridor for the viability of a transit system

This Feasibility Study investigates and concludes whether constructing monorail in this corridor is feasible, not feasible, or if more study is needed. This Feasibility Study also documents factors that determine if monorail is a reasonable and cost-effective transportation improvement for this corridor.

Figure ES.1 – Feasibility Study Monorail Alignment

Monorail Operations

This Feasibility Study analyzed a range of operating characteristics. The frequency and speed of train service assumptions were based on current limitations of monorail technology and the current state of the industry; however, higher speeds could be accommodated on portions of this alignment in the future if desired, and could be assessed in a more detailed design study, as well as connections to other regional transit systems. Hours of service, parking charges, and fare assumptions were considered to be similar to the WMATA Metro Red Line service. The ridership analysis incorporated paid parking at monorail stations due to the capital and maintenance costs associated with the necessary parking structures, and to remain consistent with the connecting Metrorail service which features paid parking.

The operating assumptions were initially derived from the *2019 Frederick-Shady Grove Ridership* and *Revenue Study* (*2019 Ridership Study*), prepared by The High Road Foundation. The High Road Foundation's ridership study was based on operational characteristics that reflect future improvements of monorail technology. In order to analyze the full range of probable results, this Feasibility Study includes additional analysis of operational characteristics based on the current technology and design criteria.

Driverless Transit Systems:
Using a host of train control systems, trains can operate fully autonomously without a driver. With wayside sensors and on-board computer control systems, trains can automatically open and close passenger doors, follow speed limits between stations, and handle emergencies. This provides a safe system which eliminates the variability of human drivers, allowing for consistent on-time performance and higher train frequencies.

Feasibility Study Alignment

The alignment considered for this Feasibility Study was initially developed in the *2019 Ridership Study,* prepared by The High Road Foundation. For this Feasibility Study, the alignment and station locations were modified and developed to improve constructability, operations, and minimize potential impacts. The modifications focused on maximizing the use of the existing I-270 right-of-way, improving alignment curvature based on the design criteria, avoiding and minimizing potential impacts based on readily available data, and identifying locations for the proposed stations and maintenance facilities.

The alignment is approximately 28 miles long from Frederick to Shady Grove. The corridor utilizes as much right-of-way as possible from I-270 and other roads to minimize potential impacts and effectively link the six key station locations that the corridor connects: Frederick, Urbana, Clarksburg, Germantown, Metropolitan Grove, and Shady Grove (see **Figure ES.1**). While the alignment is largely within publicly owned land, there are still impacts to environmental resources and utilities within the right-of-way, and to private land, resources, and utilities outside the right-of-way at stations, maintenance and yard facilities, and some locations along the alignment. The alignment, elements, and options were developed to a level of detail appropriate for this Feasibility Study and should not be interpreted as the best and only option.

Operation and Maintenance

Monorail transit systems are flexible enough to allow routine operations and maintenance. Monorail service vehicles can be used by maintenance staff to perform inspections of the guide beam while also being used as a service platform, as maintenance staff or equipment transport, or as a recovery vehicle for other trains that break down. Adverse weather, disabled trains, safety and emergency access, etc., also are handled in a manner which is very much analogous to other fixed guideway technologies. These areas would be developed further during alternatives development should this Feasibility Study move to the next phase of evaluation.

Two locations were identified for potential maintenance and storage yards needed for the monorail near the northern and southern termini of the alignment, though both may not be needed ultimately. The locations were identified based on areas large enough to fit the facility and vehicle storage, where it would minimize potential impacts, and where the monorail could easily be designed to access the location. The northern maintenance and storage yard location is in the Frederick area, just south of the proposed Frederick Station along East South Street and South East Street. The southern maintenance and storage yard location is in the Gaithersburg area near the proposed Metropolitan Grove Station. The Operations Control Center (OCC) from which the system is monitored and controlled is normally housed in a building near the mainline and could be included in the design of either maintenance facility.

Land Use Analysis

All land use data for this Feasibility Study was analyzed and identified through the Maryland iMAP Geographic Information System (GIS) data catalog. The monorail is consistent with local and regional plans, which have considered and accounted for a transit system linking Frederick with Shady Grove. As a result, land use over the past 20 years has been implemented and zoned in a manner that is complimentary to transit development; however, this Feasibility Study does not evaluate the location and need, or their costs and impacts, for additional transit support services to provide access to the monorail stations from local residential and commercial land uses such as additional bus service or route changes.

Environmental Resources and Potential Impacts

Environmental resource information was obtained through desktop- accessible data and GIS mapping. Impact quantities were calculated based on a standard limit of disturbance (LOD) offset from the centerline developed alignment. For this analysis, the quantification of temporary construction and impacts assumes a 26-foot construction envelope, with an overall LOD of 40 feet around the centerline of the developed alignment. This standard offset may be reduced or expanded to apply to the actual topography and available land, if the study progresses beyond the feasibility level.

A summary of the environmental resource impacts related to the alignment can be found in **Table ES.2**. These values are preliminary and subject to revision during any subsequent design phases. It is likely that greater potential impacts would be identified as a result of more detailed environmental survey and monorail design.

Table ES.2 – Potential Environmental Resource Impacts

Potential Environmental Impacts		
Vehicle	Range of Impacts	Unit
Streams	846 - 2,536	Feet
Wetlands	1 - 3	Acres
100-year floodplains	1 - 2	Acres
Forest	13 - 37	Acres
Forest Conservation Act (FCA) Easements	1 - 1	Acres
Montgomery County Special Protection Area (SPA)	5 - 14	Acres
Sensitive Species Project Review Areas (SSPRA)	3 - 7	Acres
Historic	6 - 15	Acres
Parks	1 - 2	Acres
Total Right-of-Way	46 - 136	Acres

Project Costs

The I-270 monorail cost estimate was developed to follow Federal Transit Administration's (FTA) Standard Cost Categories (SCC). These categories establish a consistent format for reporting, estimating, and managing capital costs for FTA funded transit projects. The overall project cost of the monorail system along I-270 is a combination of capital costs, expenses such as engineering, legal fees and management, and ongoing operations and maintenance costs.

The total estimated project cost is the addition of the individual estimates for SCC 10 through SCC 100. This estimated total in the year 2020 is $3,726 million. While the project does not have a set schedule for design, construction, or revenue service, a project such as this could take 5 to 15 years to complete. This project would be subject to the National Environmental Policy Act (NEPA), which requires federal agencies to assess the effects of the project before making decisions. The NEPA and public outreach process can extend the time frame, but this would be the case for any project such as this. Assuming an aggressive design and construction schedule, the earliest that the construction can be complete is within five years. Inflation will escalate the total cost over the lifetime of the project.

Table ES.3 – Total Project Costs

SCC #	SCC Description	Subtotal $ (Million)
10-50	Construction Subtotal	$1,757
60	Right-of-Way, Land, Existing Improvements	$7
70	Vehicles	$170
80	Professional Services	$1,115
90	Unallocated Contingency	$677
100	Finance Charges	$0
	Subtotal Project Cost (2020):	**$3,726**
	Escalation	$630
	Total Project Cost (2025):	**$4,356**

The total estimated project cost shown in **Table ES.3**, including the individual estimates for SCC 10 through SCC 100, and accounting for inflation, is $4,356 million in 2025 dollars.

Utilizing the MDOT MTA light rail as a guide for yearly operating expenses, assuming a 30-year project lifespan, the total routine operating cost for the I-270 monorail is $1,260 million. The addition of minor and major midlife rehabilitations and upgrades, assumed to be an additional 15% brings the total operating cost to an estimated $1,449 million, in 2020 dollars. Utilizing the lower operating cost of the Las Vegas Monorail, results in a total estimated operating cost of $690 million in 2020 dollars.

Ridership Analysis

The monorail alignment was used for an operational efficiency analysis. Efficiency is a function of alignment length, vertical profile grades, horizontal curves, the number of stations, and the operating characteristics of the vehicles. The analysis of the alignment for this Feasibility Study included the development of a range of inputs that reflect the design criteria and operational assumptions used. The analysis includes a travel time analysis, potential ridership analysis, and system capacity analysis, detailed below.

The ridership analysis was conducted prior to the COVID-19 pandemic and the long term impacts on transit ridership has yet to be realized. MDOT MTA has seen a sharp decline in ridership and transportation revenues due to COVID-19. COVID-19 has dramatically reduced all travel modes, with transit being particularly adversely affected; however, MDOT MTA continues to focus on providing safe, efficient, and reliable transit service.

Travel Time Analysis

The travel time for monorails is a calculation based on a number of factors, including the limitations of the monorail technology, alignment characteristics, and boarding and alighting durations, commonly referred to as dwell time. The travel time analysis is a calculation of the speed of the vehicle along the entire length of the alignment, to determine the time needed to travel from one end to the other. This calculation considers acceleration/deceleration, top speed limitations of monorail trains, and dwell time.

While current US monorail technology facilitates speeds of 50 mph, some monorail technology across the globe may allow for speed greater than 50 mph. This Feasibility Study analyzed two top speed scenarios, 50 mph and 65 mph. The lower speed was based on current operating systems in the US, while the higher speed was based on technology enhancements currently in use around the globe. This top speed cannot be achieved throughout the entire alignment. Monorail trains need to slow down to enter stations, stop at stations, and slow down for some curves, so the average speed would be considerably lower.

Station dwell times, or the time that the monorail train is stopped to allow passengers to get on and off the train, affect the overall travel time. This may be a variable time, based on actual ridership at the time, but transit agencies seek to reduce this time as much as possible. Dwell time is generally higher at terminal and transfer stations. WMATA Metro Red Line trains have average dwell times in the range of 30 to 75 seconds, according to the *Metrorail Capacity White Paper, WMATA 2015*. This monorail Feasibility Study analyzed two scenarios for dwell time, 30 seconds and 60 seconds. The system can be automated with driverless operations, which provides reliable service that can reduce station dwell time over traditional transit systems.

All these factors were considered, and a speed profile was calculated for the feasibility alignment. This calculation results in a theoretical end-to-end travel time of 46 minutes, at an average speed of 37 mph in the conservative case, and a travel time of 42 minutes at an average speed of 41 mph in the more aggregative end.

Table ES.4 – Total Routine Operating Costs

Description	Cost $ (Million)
Total 30-year Routine Operating Cost	$1,260
Rehabilitations and Upgrades (assumed 15% of operating cost)	$189
Total Operating Cost	$1,449
Comparison Operating Cost of Las Vegas Monorail (lower value)	$690 (2020 dollars)

Ridership Forecast Methodology

Forecasting the number of passengers that may use this monorail system is an important factor in determining the viability of this system. Ridership forecast models account for many factors, such as population demographics, population density, future growth, major trip destinations like job centers and housing, connections to the local transportation network, and attractiveness of the transit system.

As part of their study, The High Road Foundation completed a ridership study and documented it in the *2019 Ridership Study*, which can be found in **Appendix A**. To evaluate the ridership forecast efficiently and independently, MDOT requested the National Capital Region Transportation Planning Board (TPB) to review and comment on the High Road Foundation's *2019 Ridership Study*. TPB is the federally designated metropolitan planning organization (MPO) for metropolitan Washington, D.C. Working with local, state, regional, and federal partners, the TPB coordinates future plans, by providing data and analysis to decision makers, and coordinating regional programs to advance safety, land-use coordination, and more. TPB provided MDOT with a memorandum that documents their review, titled *TPB Staff Assessment of Cambridge Systematics Report Prepared for High Road Foundation*, which can be found in **Appendix B**.

Following the TPB recommendation for further review of the assumptions used, MDOT requested additional modelling and analysis results be performed with an additional range of input assumptions based on the Feasibility Study criteria. The objective of this additional analysis is to evaluate the sensitivity of ridership to a moderate level-of-service assumption and the impacts relative to the no-build conditions in order to understand the effects of the monorail on the other regional transportation systems. The no-build case assumes that the monorail is not constructed, but other planned significant transportation projects are included in the future transportation network model, including:

- **I-270 Traffic Relief Plan**, construct 4 managed lanes, 2025
- **I-95/I-495 Traffic Relief Plan**, construct 4 managed lanes, 2025
- **CCT BRT** - from Shady Grove to COMSAT, 2020 (but currently on hold)
- **MD 355 BRT** - from Bethesda Metro to Clarksburg, 2040
- **North Bethesda Transitway BRT** - from Montgomery Mall to White Flint Metro, 2040

The no-build ridership analysis assumes the regional approved transportation model for no-build, which assumes that all of these projects will be in place. While it is possible that some or all of these projects may not be in place, it is standard practice and a requirement to use the approved land use and regional travel demand model for this assessment.

The revised analysis uses the base frequency assumptions, including:

- Average operating speed is assumed to be 35 mph, which is consistent with an average speed based on the current Red Line operations and also close to the average speed of 37 mph with a maximum design speed of 50 mph for the proposed monorail, in comparison with an average operating speed of 41mph in the initial study. Ridership information for both average operating speeds have been included for comparison.
- Parking cost is assumed to be charged at all stations (with parking rates assumed to be the same as that for Shady Grove--$5.20 per day for peak and $1 per day for off-peak), in comparison with the original assumption of parking being available and free of charge at every station (except for Shady Grove)

The average and top speeds have been based on current technology and are in line with similar systems currently operating. As detailed earlier in this chapter, the average speed is a calculation of many factors, and 35 mph was used as a conservative assumption for this system. The average speed calculation based on the feasibility alignment of 37 mph is a theoretical calculation, and the average speed of 35 mph was used as a conservative estimate accounting for some variability in actual travel times, for the additional ridership analysis.

All WMATA Metrorail stations in Montgomery County charge for parking. An analysis of parking requirements and available land for stations points to the need to provide parking structures at most of the monorail stations. The capital and maintenance cost of parking, along with the connectivity to Metrorail service point to this reasonable assumption that parking fees would be comparable to WMATA parking lots.

Ridership Forecast Results

This ridership analysis was conducted prior to the COVID-19 pandemic and the long-term impacts on transit ridership has yet to be realized. The effects of the pandemic on transit use and traffic volume may be long lasting, but cannot be determined at this time. This analysis optimistically assumes that traffic growth and patterns will return to normal, but that may not occur in the time frames noted.

The design and operational criteria of a monorail system and the 46-minute travel time, a reasonable frequency of six-minute peak headways, and comparable parking cost to Metrorail, results in a total ridership forecast of 34,800 per day in 2045. With more aggressive assumptions for speed and frequency, the system could attract up to 47,800 daily boardings.

However, adding the monorail into the transportation network would clearly effect changes in use of other transportation modes. The results of the changes to other system use modeled for the year 2045 with the I-270 monorail in place are reflected in **Table ES.5**.

Table ES.5 – Projected Changes In Daily Boardings For Major Transit Routes

Routes	2045 (Sensitivity Run)	2045 No Build	Difference (Latest vs NB)	% Difference (Latest vs NB)
CCT BRT	16,800	16,100	700	4%
MD 355 BRT	37,100	38,700	-1,600	-4%
N Bethesda BRT	4,200	4,100	100	2%
MT 505/515	100	2,700	-2,600	-96%
Ride On 70	1,400	1,800	-400	-22%
Ride On 100	0	1,800	-1,800	-100%
MARC Brunswick	7,700	11,100	-3,400	-31%
Metro Red Line	524,300	512,100	12,200	2%

The results of this analysis show that competing routes are expected to experience declines in daily boardings, especially the MARC Brunswick Line, MDOT MTA commuter bus MT 505/515, MD 355 BRT, and Ride On 100. CCT would see a slight increase in daily boardings as the transfers from the proposed monorail to the CCT would outnumber the replacement of CCT trips by the proposed monorail trips. Metrorail would also see an increase in riders transferring from monorail.

Regional trips were compared between the 2045 Build (sensitivity run) and No-Build scenarios, and the results are summarized in **Table ES.6**.

The analysis shows that regional transit trips are forecasted to increase by nearly 10,000 in the Build scenario, in comparison with the No-Build scenario. These represent new transit trips, as a result of the proposed monorail. On the other hand, the daily auto person trips will decline by roughly 13,000 and vehicle trips will decrease by approximately 10,000, both a decrease of only 0.1%. The auto vehicle trip reductions are spread throughout the study area, with a small decrease in traffic volume on major roadways. For example, the southbound traffic on I-270 during the AM peak period would decrease by roughly 350 vehicles at the segment north of I-370 and by approximately 500 vehicles south of I-70. For comparison, the segment of I-270 north of I-370 currently carries an average of approximately 218,575 vehicles per day, and approximately 115,000 vehicles south of I-70. The relationship and affect on the regional transportation network would need to be analyzed in detail if this project moves to the next phase.

Ridership Forecast Summary

Ridership forecasting is necessary to determine the value of a transit improvement, and its accuracy is based on assumed inputs and criteria. The outcomes of the ridership forecast reflect the assumptions made during the modelling process, and may be greatly affected by the pandemic. This modelling assumes a completely unconstrained system, meaning passengers are not discouraged from riding the system due to a bottleneck or delay in getting to the system. The model assumes there is ample parking at each facility, and a robust network of pedestrian and bicycle access routes, as well as efficient and desirable transit networks feeding and being fed by the monorail.

The analysis shows that the monorail could see between 34,800 to 47,800 daily boardings. The more conservative end of the range represents approximately 10,000 additional regional transit trips, or a reduction of auto vehicle trips in the region of 10,300, less than 1% of the overall trips projected in 2045.

Table ES.6 – Projected Changes in Daily Trips Between Build and No Build

Routes	2045 Build	2045 No Build	Difference	% Difference
Regional Transit Person Trips	1,623,300	1,613,800	9,500	0.6%
Regional Auto Person Trips	22,449,600	22,462,100	-12,500	-0.1%
Regional Total Person Trips	24,072,800	24,075,900	-3,100	0.0%
Regional Auto Vehicle Trips	15,737,800	15,748,100	-10,300	-0.1%

System Capacity

The design criteria for the representative monorail system shows a carrying capacity of 76 passengers per car during peak hours. Assuming a three-car train, the total capacity for each train would be 228 passengers. At a peak frequency of three minutes, the system could carry up to 4,560 passengers per hour. At a frequency of six minutes, the system could carry up to 2,280 passengers per hour during peak hours with three-car trains, or 4,560 passengers with six-car trains. The ultimate carrying capacity of monorail systems can be much higher. Both BYD SkyRail and Bombardier INNOVIA 300 systems have the ability to carry up to 19,000 passengers per hour per direction with six-car trains operating at two-minute headways. A more detailed analysis of ridership and system capacity needs to be completed during a design phase, but an estimation of peak hour ridership suggests that the frequency of service would accommodate the ridership demand during peak hours.

Findings

MDOT has prepared this independent Monorail Feasibility Study for the I-270 corridor to assess the viability to construct, operate, and maintain a monorail system between the Shady Grove Metrorail Station and the City of Frederick, Maryland. As part of the feasibility assessment, the study evaluated existing monorail services worldwide and assessed alignment options; station locations and connectivity; frequency of service; ridership demand; environmental considerations; operation and maintenance needs; and costs for construction, operation, and maintenance.

Monorail Technology Evaluation

As part of this Feasibility Study, MDOT has prepared a separate assessment of Monorail technology both internationally and within the United States, *MDOT Monorail Global Scan and Assessment, November 2020*. Based upon the technology evaluation, monorail was determined to be physically feasible and should be considered similarly to other transit modes. In addition, several items were identified for further consideration which would apply to any transit mode, including:

1. Success in the I-270 corridor would require a behavioral shift from single-occupancy vehicle travelers to mass transit commuters, and greater land use densities at stations.
2. The specific characteristics highlighted for a successful monorail, can equally apply to Light Rail, Bus Rapid Transit, or even Rail Rapid Transit (Metro). The implication is that the success of a transit system rests more on urban densities and successful land use and transportation network planning, than it does with the transit type.
3. Monorail systems work best in areas of higher population density with concentrated urban development next to stations.
4. The proposed monorail alignment may impact a wide variety of environmental features such as wetlands, forests, streams, Special Protection Areas (SPAs), and parks. The monorail alignment would have potential impacts to three known large historic resources within the corridor: the Monocacy Battlefield, the U.S. Department of Energy, and the Metropolitan Branch of the B&O Railroad.

Monorail Alignment Evaluation

The monorail alignment analyzed in this study was developed to a level of detail required for this analysis, building from the preliminary alignment presented by The High Road Foundation. A horizontal alignment was developed that would meet the design criteria determined by MDOT. A vertical alignment was designed to meet clearances at key points such as road crossings, and to meet slope criteria for the preferred maximum grades and station platform grades. Stations were conceptually designed to relevant design standards to include all required facilities. Maintenance facilities were located and designed to a level needed to appropriately estimate the space required.

The evaluation of the specific design requirements of monorail on this alignment has found that this system is physically feasible to construct. The study corridor has undeveloped land that allows the monorail system to be constructed in a way that meets the design requirements. The alignment connects regional activity centers in a manner similar to other transit technologies (including the challenges of providing for the last mile) and would provide a public benefit to the communities it serves.

Monorail Cost Effectiveness Evaluation

The FTA uses standard minimum densities as a benchmark when considering whether transit can be supported: 9+ persons per acre and 30-40 employees per acre. The region falls well under these minimums, with a 1.81 persons per acre population density and 0.94 employees per acre employment density. While the ½-mile area surrounding each of the proposed stations are considerably denser, with an average of 7.46 persons per acre and 7.16 employees per acre, the density is still below the standard.

Although the monorail alignment would primarily utilize state and locally owned right-of-way along I-270 and other roads, there may be impacts to private residential and commercial property of up to 27 acres, needed to support the transit station and maintenance facility(ies).

Total capital costs in 2025 would be $4.426 billion, including construction, right of way, vehicles, professional services, and contingency. This figure equates to a cost of approximately $158 million per mile.

Total operating costs over 30 years would be between $690 and $1,449 million, in 2020 dollars based on an average annual cost of $23 to $48 million.

The FTA publishes Capital Improvement Grants guidance for cost-effectiveness based on a cost per trip measure. The cost effectiveness measure is defined as the annualized capital cost plus the annual operating and maintenance cost per trip on the project. Utilizing a conceptual calculation based on the anticipated ridership, capital and operating expenses, results in an annualized cost effectiveness ration of $10.12 to $11.39 per annual linked trip. This is a conceptual review, a more detailed analysis would be conducted as part of any federal grant application.

FTA rates projects based on cost effectiveness according to the breakpoints. The evaluation of the cost effectiveness of monorail on this alignment has found that this system will have "medium-low" cost effectiveness, according to the FTA rating guidance, compared to the MDOT MTA Purple Line, which had a FTA "high" cost effectiveness rating. Cost effectiveness is one of many criteria that FTA uses to evaluate federal grant applications for transit projects.

While monorail receives a cost effectiveness of "medium-low" as a stand-alone alternative, this does not take into consideration the impact to ridership and loss of service and revenue from other transit services. This operational analysis and ridership findings are summarized in the following section.

Monorail Operations and Ridership Evaluation

This Feasibility Study conducted an evaluation of operational efficiency and ridership demand modelling. The evaluation included a travel time analysis, potential ridership analysis and system capacity analysis, based on the *Maryland Constrained Long Range Plan*, which in 2045 includes the I-270 highway improvements opporating with managed lanes, and does not address ridership impacts due to changes in health. The ridership analysis showed that the monorail could see between 34,800 to 47,800 daily boardings. This analysis assumes a completely unconstrained system, meaning passengers are not discouraged from riding the system due to a bottleneck or delay in getting to the system. The ridership forecast relies on the construction of ample parking at each facility, robust network of pedestrian and bicycle access routes, as well as reconfiguration of an efficient and desirable transit networks feeding the monorail.

The more conservative of the ridership forecast range represents approximately 10,000 additional regional transit trips, or a reduction of auto vehicle trips in the region of 10,300, which is less than one percent of the overall single vehicle trips. The auto vehicle trip reductions are spread throughout the study area, with a small decrease in traffic volume on major roadways.

Competing transit system ridership would decline, especially the MARC Brunswick Line, commuter bus MT 505/515, MD355 BRT, and Ride On 100, which would collectively reduce in ridership by nearly 10,000 trips per day. The CCT and WMATA Metrorail would see a slight increase in daily boardings with the addition of a monorail system.

The evaluation of the operations and ridership of monorail on this alignment has found that this system is viable as a transit system, however, the ridership is anticipated to predominantly shift from existing transit systems and will have very little impact on existing road networks. Therefore, the ridership has been determined to be a concern due to the decrease in ridership anticipated from the other transit services and the overall lack of reduction of single occupancy vehicle trips from I-270.

Feasibility and Reasonableness

This Feasibility Study evaluated the feasibility of utilizing the monorail technology in this study area corridor. This Feasibility Study investigated and evaluated monorail in this corridor and measured the effectiveness of this system using the following metrics:

- Evaluation of monorail technology in general, and if it is appropriate for the study corridor
- Evaluation of the specific design requirements of monorail and the proposed alignment, and the alignment's potential cost, impact, and benefits
- Evaluation of the I-270 corridor for the viability of a transit system

Based on the evaluation completed as part of this Feasibility Study, the construction of monorail within this corridor is physically feasible. This feasibility determination is based on the technology and proposed alignment. Impacts to existing transit ridership and vehicle volume reductions on I-270 were not fully examined. At this point it is recommended that any future study of monorail in this corridor consider the full impact on these two factors. If this system is to be evaluated further, the next step would be a detailed evaluation consistent with the National Environmental Policy Act (NEPA), which requires federal agencies to assess the benefits and effects of the project, and conduct extensive public outreach. This detailed analysis would likely include the development of an Environmental Impact Statement.

1 | Introduction

Purpose of Study

The Maryland Department of Transportation (MDOT) has prepared this independent Monorail Feasibility Study (Feasibility Study) for the I-270 corridor to assess the viability to construct, operate, and maintain a monorail system between the Shady Grove Metrorail Station and the City of Frederick, Maryland (Project Corridor). It also evaluates existing monorail services around the world; alignment options; station locations and connectivity; frequency of service; ridership demand; environmental considerations; operation and maintenance needs and costs for construction, operation, and maintenance.

MDOT agreed to perform this Feasibility Study at the request of the Maryland Board of Public Works. The request was made when the Board approved the statewide Traffic Relief Plan, in which phase one will aim to relieve congestion on the I-270 and I-495 corridor. The COVID-19 public health crisis has dramatically impacted all Marylanders and required that we all make difficult adjustments in our daily lives. This has been a challenging and disruptive time. The impact has affected the State's transportation system, with declines in use of the system, which has further reduced revenue to the Transportation Trust Fund. The full breadth of the COVID-19 pandemic's effects have yet to be realized, including impacts to state and local revenue and funding sources.

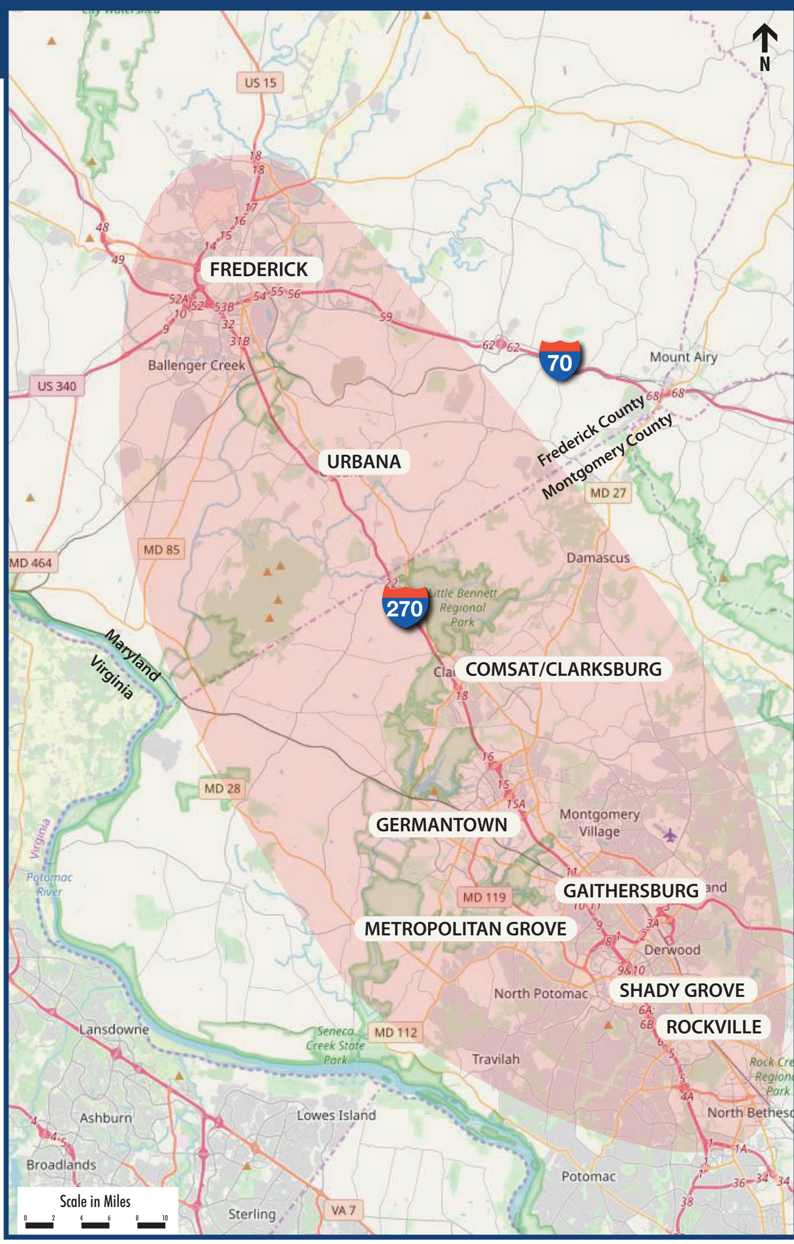


Figure I.1 – Study Area

Study Area

The study area is located in Montgomery and Frederick counties in Maryland. Situated northwest of Washington, D.C. and residing within the greater Metropolitan Washington region, the I-270 corridor is a significant location for commercial and industrial development with a notable presence of biomedical engineering companies. The corridor is surrounded by residential areas both urban and suburban and features the municipalities of Frederick, Clarksburg, Gaithersburg, and Rockville, in addition to the unincorporated area of Germantown. The corridor is an important local and regional center of economic activity and a home to commuters within the metropolitan region.

The study area is 28 miles in length along I-270, which runs northwest to southeast between I-70 in Frederick and the Capital Beltway (I-495). The study area includes the I-270 corridor and extends from Frederick to Derwood (Shady Grove; approximately halfway between Rockville and Gaithersburg). I-270 is an interstate highway within the State of Maryland that extends between I-70 in the City of Frederick in Frederick County and I-495 just north of Bethesda in Montgomery County.

I-270 is the primary arterial route within the study area for both local and through traffic. Other major roads include MD 355 (Frederick Road), which parallels I-270 and provides local access. I-370 conveys vehicles east of I-270 towards the Shady Grove Metro Station before turning into MD 200; a tolled freeway, that connects to I-95 and US 1 in Prince Georges County to the east. South of the study area, I-270 splits as it approaches I-495 with I-270 turning east and the I-270 Spur heading south. Both roads connect to I-495 approximately 2.5 miles apart.

Other major roads in the study area include:

- **MD 355** (Frederick Road/Rockville Pike), which parallels I-270 to the east, traveling between Shady Grove and Frederick
- **MD 109,** which travels southwest to northeast and passes through Hyattstown just south of the Frederick County line
- **MD 121,** which travels in the same direction 3.5 miles further south and terminates in Clarksburg
- **MD 118** (Germantown Road) travels east to west through the Germantown area and terminates at MD 355
- **MD 124** travels southwest to northeast just north of Gaithersburg
- **US 15** travels south to north from Point of Rocks through the City of Frederick to Gettysburg, PA

Other modes of transit within the study area include the Maryland Area Rail Commuter (MARC) Brunswick Line, which provides commuter train service between the Frederick Station and Union Station in Washington, D.C. Montgomery County's Ride On bus network provides local bus service throughout the study area with connections to Washington Metro Area Transit Authority (WMATA) Metrobus, MDOT Maryland Transit Administration (MDOT MTA) commuter bus, Metrorail, and MARC services. Bicycle infrastructure is present throughout the study area. See **Figure 1.2** for locations of major transit lines in the study area.

Bicycle infrastructure is present throughout the study area and consists of bike lanes, shared use lanes on local roadways, and paved off-road trails. Urban centers like Frederick and Rockville feature more extensive networks than more rural areas such as Clarksburg and Urbana.

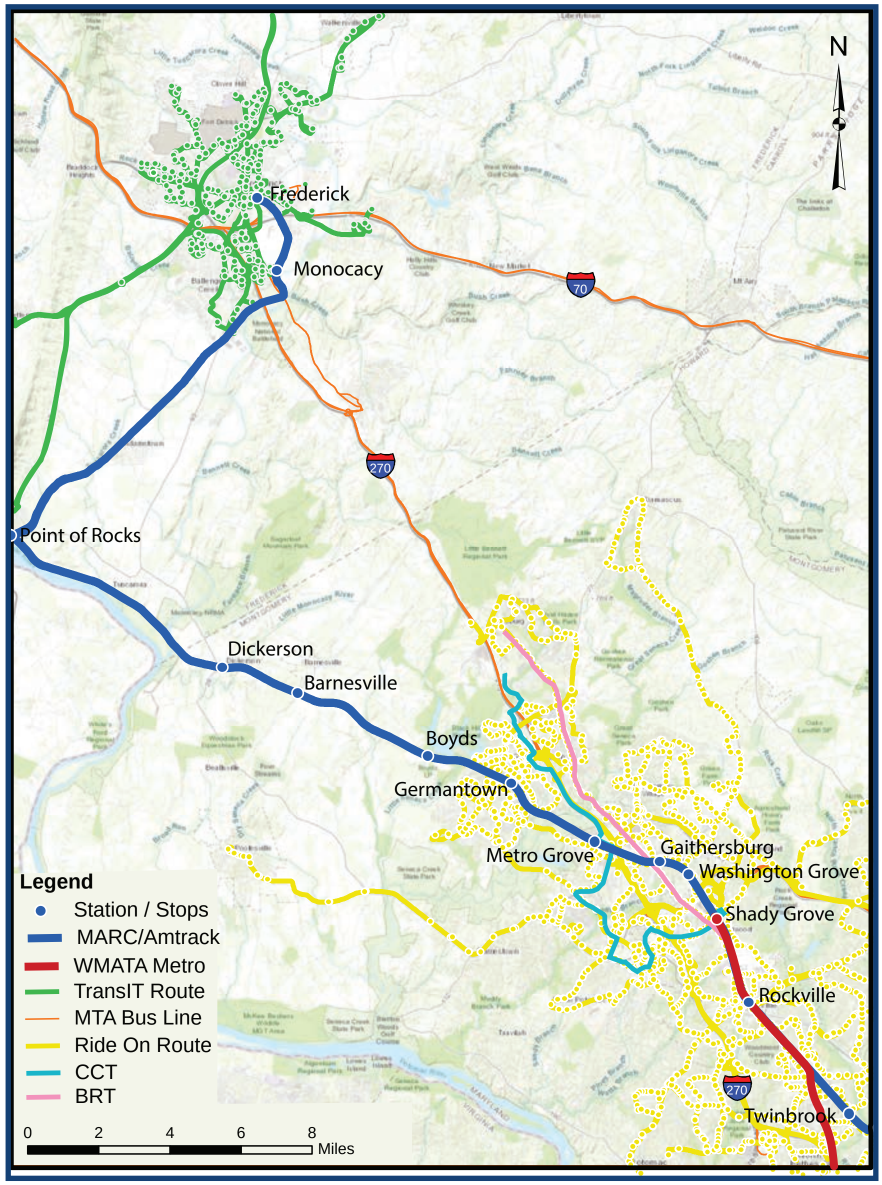


Figure I.2 – Major Transit in the Study Area

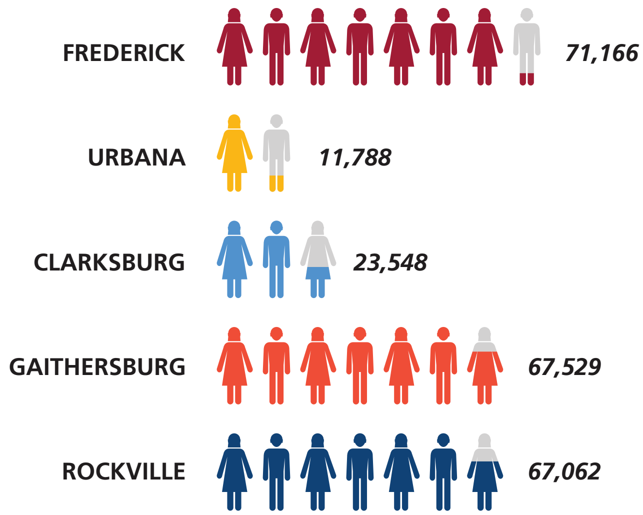
Regional Significance

I-270 is a regionally important road that connects I-495 just north of Bethesda to I-70 in the City of Frederick, traversing several urban and suburban areas. The project corridor connects 20 activity centers and includes agricultural, commercial, industrial, institutional, residential, and natural resource land uses. The largest activity centers include Frederick, Urbana, Clarksburg, Germantown, Gaithersburg, and Rockville. Currently, 65% of the region's jobs and 32% of households are located in activity centers. Metropolitan Washington Council of Government's (MWCOG's) Region Forward Coalition established regional targets to capture 75% of the square footage of new commercial construction and 50% of new households within activity centers. Outside of the activity centers, there are highly developed regional shopping centers, big box retailers, and large undeveloped parcels throughout the corridor.

Portions of the corridor are designated as growth or Priority Funding Areas (PFAs), where commercial and residential land uses dominate. The PFAs, where certain state agencies prioritize investments, support economic development, promote revitalization of older neighborhoods, and encourage infill development and planned expansions. The corridor also traverses the Old Towne Enterprise Zone within Gaithersburg as well as the 10 Mile Creek and Clarksburg Special Protection Areas (SPAs), where protections beyond standard environmental laws, regulations, and guidelines exist for land development and certain uses.

Planning for focused growth within existing or planned activity centers is central to achieving sustainable growth while promoting accessibility for a greater segment of the population and achieving health and environmental quality goals. Planning is key to managing this growth and increasing employment opportunities. The latest census data for major communities along the corridor are listed (US Census, 2014-2018 American Community Survey):

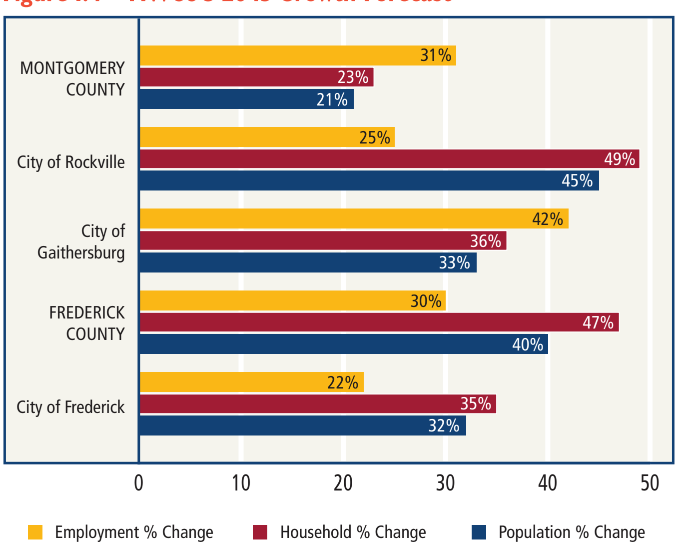
Figure I.3 – Current Population in Communities Along the Corridor



MWCOG's 2045 forecasts anticipate substantial growth in employment, population, and the number of households within Montgomery and Frederick Counties and the Project Corridor specifically.

As development continues to occur within the study area, the importance of adequate transportation infrastructure will become more pronounced. Available space for new or expanded infrastructure is likely to grow scarce and potential impacts may become greater. Monorail systems have the ability to deliver reliable transit service within the limited footprint available in suburban and urban areas, but they are most successful in urban dense areas where a lot of foot traffic can access the stations.

Figure I.4 – MWCOG 2045 Growth Forecast



The proposed monorail would connect Frederick to the developed I-270 corridor within Montgomery County, with a focus on providing greater connectivity for population centers and municipalities currently only served directly by the highway network, MARC service, and local buses. The addition of a more direct transit service between the areas would provide a public benefit to the communities it serves and provide them with a greater choice in terms of mode of travel than what currently exists. The monorail would link the Frederick, Urbana, Clarksburg, Germantown, Gaithersburg, and Rockville activity centers while also providing links to regional transit such as MARC and WMATA Metrorail. Monorails can provide design flexibility on alignments with large grade changes.

Monorail Technology

The first commercially viable monorail system opened in 1901 and is still in operation in Germany. Monorails currently operate across the world, predominantly in urban areas, at tourist attractions, and airports. Modern monorails use a "straddle-beam" configuration, where the train cars sit on and around an elevated single beam that acts as both the guide rail and support. The first monorail system built in the United States is at Disneyland in California, which first opened in 1959 and is still in operation. At the time of this Feasibility Study, 57 monorail systems are operational around the world, eight of which are in the United States.

Driverless Transit Systems:
Using a host of train control systems, trains can operate fully autonomously without a driver. With wayside sensors and on-board computer control systems, trains can automatically open and close passenger doors, follow speed limits between stations, and handle emergencies. This provides a safe system which eliminates the variability of human drivers, allowing for consistent on-time performance and higher train frequencies.

Monorails must operate in an exclusive right-of-way. Monorails are generally elevated but can operate close to the surface or even underground in tunnels. Monorails can operate driverless or with an in-car operator, similar to light rail and heavy rail metro systems that operate in exclusive right-of-way.

As part of this Feasibility Study, MDOT has prepared a separate assessment of monorail technology, *MDOT Monorail Global Scan and Assessment, November 2020*. This assessment focused on a global scan and review of existing monorail systems that are currently operating. In addition to this review of existing systems, the *MDOT Monorail Global Scan and Assessment* lists characteristics of national and international monorails, discusses some lessons learned from planning, constructing, and/or operating monorail systems, and compares existing monorail systems to a potential I-270 monorail.

This global scan and assessment will be discussed in more detail later in this report, but in general it has concluded that: monorails have a track record of providing viable urban transit; and the technology allows unique solutions for difficult alignment requirements; but the success of a transit system depends on urban densities and sound planning rather than the specific technology.

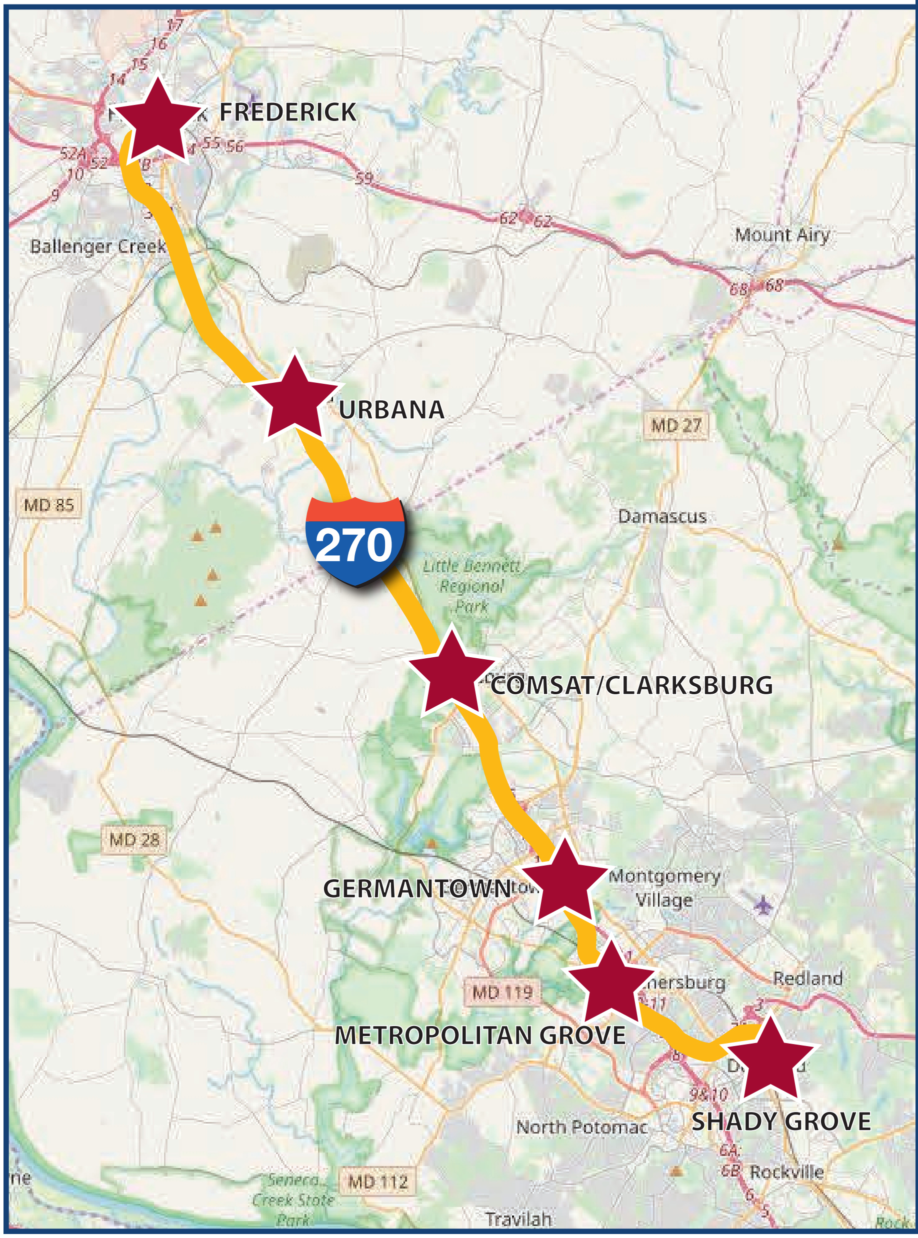
Monorail Alignment

The northern end of the study alignment is located within the City of Frederick, at a proposed station located on East South Street just east of South East Street. The southern end of the alignment is located at, and integrated with, the Shady Grove station on WMATA's Metrorail Red Line in Montgomery County (see **Figure 1.2**).

The alignment runs parallel to I-270 from south of Frederick to the interchange with I-370 with shifts away from the interstate to access the stations at Clarksburg, Germantown, and Metropolitan Grove. The alignment then runs parallel to I-370 until it turns south to connect with the Shady Grove Metro station. Approximately two-fifths of the proposed monorail alignment is within Frederick County (12 miles) and the remaining three-fifths is within Montgomery County (16 miles).

Stations along the alignment have been located based on the surrounding land use, potential for growth, connections with existing transit, accessibility from road networks, and available land. Each station prototype includes daily parking, kiss-and-ride short term parking, bus boarding area, and an elevated monorail station platform. There are six stations proposed on the monorail alignment, listed from North to South:

Figure I.5 – Proposed Station Locations



FREDERICK STATION

The Frederick Station is the northern terminus and would connect riders to the urban core of the City of Frederick. This station is located close to the MARC train station but would potentially be constructed on land that is partially occupied by industrial buildings. This location has also been identified for a maintenance and storage yard to support the monorail operations.

URBANA STATION

The Urbana Station would utilize an existing MDOT MTA operated park-and-ride lot at the interchange of I-270 and MD 80 (Fingerboard Road) and expand the parking area into adjacent undeveloped land.

CLARKSBURG STATION

The Clarksburg Station would be sited near the grounds of a former COMSAT facility at the interchange of I-270 and Clarksburg Road. This station is located near an area that is currently in development, and the exact location could be adjusted to accommodate access and growth.

GERMANTOWN STATION

The Germantown Station would be constructed in downtown Germantown, near an existing local bus transit center. This surrounding area is fully developed already, so this station would need to include a parking structure to meet the demand.

METROPOLITAN GROVE STATION

The Metropolitan Grove station would be located adjacent to the Metropolitan Grove MARC station, but on nearby undeveloped land. This station would be near an area that is currently in development and can be located to accommodate access. This station has undeveloped land close by that may accommodate a maintenance and storage yard.

SHADY GROVE STATION

The final station is at the Shady Grove Metro Station. The existing Metro station includes multiple parking garages, surface parking lots, a bus transfer facility, as well as a maintenance facility for both the Metro trains and the MARC trains, so space is limited. Additional parking for the monorail would need to be constructed with additional parking garages, and an elevated boarding platform would be constructed as close to the Metro platform as possible, but other facility features can utilize the existing station.

The monorail alignment and station locations were initially derived from the *2019 Frederick-Shady Grove Ridership and Revenue Study (2019 Ridership Study)*. This *2019 Ridership Study* was prepared by The High Road Foundation **(thehighroadfoundation.org)**, a group that is advocating for monorail in this region. The six proposed station locations and alignment have been updated slightly to improve constructability, operations, access to the stations, and reduce potential impacts.

A detailed description of the alignment and proposed station locations is contained in **Chapter 2**.

Monorail Operations

This Feasibility Study has analyzed a range of operating characteristics. The frequency and speed of train service assumptions were based on current limitations of monorail technology and the current state of the industry. Hours of service, parking charges, and fare assumptions were assumed to be similar to the Metro Red Line service. **Chapter 2** includes a detailed discussion of these factors.

The operating assumptions were initially derived from the *2019 Ridership Study*. This Study was based on operational characteristics that reflect future improvements of the monorail technology. In order to analyze the full range of probable results, this Study includes additional analysis of operational characteristics based on the current technology.

Figure I.6 – Planned Future Transportation Improvements

Related Transportation Improvements within the Project Corridor

There are a number of significant transportation projects that are being undertaken in the study area concerning both roadways and transit.

Roadways

I-270 Traffic Relief Plan, constructing four managed lanes (Planned Completion 2025)

The purpose of the I-495 & I-270 Managed Lanes Study is to develop a travel demand management solution(s) that addresses congestion, improves trip reliability on I-495 and I-270 and enhances existing and planned multimodal mobility and connectivity. The study will address the following needs.

- Accommodate existing traffic and long-term traffic growth
- Enhance trip reliability
- Provide additional roadway travel choices
- Accommodate Homeland Security
- Improve movement of goods and services

Transit

Corridor Cities Transitway (CCT) Bus Rapid Transit (BRT), from Shady Grove to COMSAT (Planned Completion 2020)

The purpose of the CCT Project is to improve connectivity, mobility, and livability; increase transit capacity; and improve regional air quality by providing premium transit service in the corridor.
The CCT Project would help to:

- Improve inter-modal connections in the corridor
- Increase transit capacity and meet transit demand
- Enhance mobility
- Support economic development and local government master plans to enhance the livability of communities in the corridor
- Improve regional air quality by increasing transit use

The need for the CCT Project results from:

- The lack of reliable connections among existing transit routes (including MARC, Metrorail, and local bus network)
- Existing transit service, which is at or near capacity and transit demand and ridership are forecasted to grow in the future
- Roadway congestion, which contributes to unpredictable and slow travel times for automobiles and buses in the corridor
- Demand for managed growth and economic development in the region which continues to grow
- A regional goal to improve air quality by providing alternatives to automobile usage

MD 355 BRT, from Bethesda Metro to Clarksburg (Planned Opening 2040)

The MD 355 Flash will provide upgraded, frequent, and reliable service between Downtown Bethesda and Clarksburg along the MD 355 (Wisconsin Avenue/Rockville Pike/Frederick Road) corridor. The *MD 355 Conceptual Alternatives Report*, completed in 2017 by Montgomery County and MDOT, documents the study to evaluate preliminary concepts for providing enhanced premium transit service along MD 355 from Clarksburg to Bethesda. According to the report, the purpose of the project was to provide a new transit service along MD 355 that would:

- Enhance transit connectivity and multimodal integration along the corridor as part of a coordinated regional transit system
- Improve the ability for buses to move along the corridor (bus mobility) with improved operational efficiency, on-time performance/reliability, and travel times
- Address current and future bus ridership demands
- Attract new riders and provide improved service options for existing riders as an alternative to congested automobile travel through the corridor
- Support approved Master Planned residential and commercial growth along the corridor
- Improve transit access to major employment and activity centers
- Achieve Master Planned non-auto driver modal share
- Provide a sustainable and cost-effective transit service
- Improve the safety of travel for all modes along the corridor

North Bethesda Transitway BRT, from Montgomery Mall to White Flint Metro (Planned Opening 2040)

According to the study documentation, this plan provided enhanced opportunities for travel by transit to support Montgomery County's economic development and mobility goals in an environmentally sustainable way, and in a way that preserves existing communities. As a Functional Master Plan, it makes no changes to current planned land use or zoning but recommends changes and additions to the transportation network that are needed to serve the County's most densely developed areas, areas planned for redevelopment, and areas planned for new dense development.

Master Plans

The monorail project supports, and is consistent with, numerous planning efforts. A sample of these efforts is noted below, along with the relationship to this study.

- **2010 City of Frederick Comprehensive Plan – Policy TE 5:** Publicly support projects developed by the Maryland Department of Transportation State Highway Administration (MDOT SHA) within the City Limits: I-270/US 15 multimodal/Alternatives Analysis.
- **East Corridor Small Area Plan** – Covers the location of the potential Monorail Frederick area terminal.
- **The Livable Frederick Master Plan** – Ensure that the County provides access to a sustainable and resilient multi-modal transportation network to move people, goods, and services to support the needs of Frederick County residents and economic, business, and educational activities throughout Frederick County.
- **Frederick County Master Transportation Plan** – Supports the preservation of right-of-way for a transitway along the I-270 corridor with connection to the Shady Grove Metro station.
- **City of Gaithersburg 2009 Master Plan: Transportation** – Supports a transit connection between Clarksburg and Shady Grove.
- **1994 Clarksburg Master Plan and Hyattstown Special Study Area** – Recommends accommodating a regional transitway linking Clarksburg with Frederick to the north and Shady Grove to the south.
- **2009 Germantown Employment Area Sector Plan** – Considers a transit route linking Germantown to the northern part of Montgomery County as a necessity to fulfilling the Plan's vision.
- **2006 Shady Grove Sector Plan** – Includes provisions for accommodating a transitway connection to the existing Shady Grove Metro Station.

Measurement of Effectiveness

This Feasibility Study evaluates the feasibility of utilizing the monorail technology in the study area corridor. This Feasibility Study investigates and evaluates monorail in this corridor and measures the effectiveness of this system using the following metrics:

- Evaluates the monorail technology in general, and whether it is appropriate for the study corridor
- Evaluates the specific design requirements of monorail on this alignment and documents the alignment's potential cost, impact, and benefits
- Evaluates the I-270 corridor for the viability of a transit system

This Feasibility Study investigates and concludes whether constructing monorail on this corridor is physically feasible, not feasible, or if more study is needed. This Feasibility Study also documents factors that may help determine if monorail presents concerns and is cost-effective transportation improvement for the corridor.

2 | Analysis

Design, Operations, and Maintenance

This chapter provides information concerning the analysis undertaken and the design criteria used in the development of the I-270 monorail alignment analysis. The analysis is based on similar characteristics identified as part of a global scan completed comparing existing monorail systems in operation around the world. This chapter provides a greater overview of monorail technology, the design criteria, alignment developed, station areas, operation and maintenance facility need, environmental consideration, land use analysis, and projected ridership.

Monorail Technology

Monorail Overview

A monorail system is defined as a transit service on an elevated fixed guideway with a single rail on which vehicles will balance or be suspended, using electric motors for propulsion. Monorail systems generally use one of two main configurations: straddle beam and suspended rail. For straddle beam, vehicles straddle a metal or concrete beam on either steel or rubber-tired wheels. In a suspended rail system, steel or rubber wheels ride on a steel rail while the carriages hang underneath. Monorail system design is highly dependent on the manufacturer with train dimensions and propulsion system configuration setting the criteria for system capacity and guideway design.

In recent years, the primary type of monorail construction and use has been the straddle beam type. Current manufacturers of monorail systems exclusively develop straddle beam technology. Consequently, this Feasibility Study assumes this type of design would be used for consideration in the I-270 corridor.

As a requirement of the design, monorails cannot be integrated with traffic and are separated by elevation, and/or separated by a protected right-of-way. Monorail systems provide design flexibility on alignments that include significant slope or grade changes in their route. Straddle beam systems can smooth out the ground elevation changes, but have a maximum grade of generally 10%, although 6% is the maximum grade typically used in practice. They can operate driverless or via an in-car operator, similar to characteristics of light rail and metro rail systems.

Monorail systems are typically seen as an alternative mode choice to light rail or metro systems when system performance dictates that the transit solution be grade-separated.

The MDOT has prepared a separate global scan of monorail technology, *MDOT Monorail Global Scan and Assessment, November 2020,* as part of this Feasibility Study (**Appendix C**). The global scan and assessment focused on a global scan and review of existing monorail systems that are currently operating. The scan includes information on vehicle types, performance, stations,

MONORAIL TYPES

SUSPENDED RAIL

STRADDLE BEAM

and costs of the monorail systems. In addition to the review of existing systems, the *MDOT Global Scan and Assessment* lists characteristics of national and international monorails, discusses some lessons learned from planning, constructing, and/or operating monorail systems, and compares existing monorail systems to a potential I-270 monorail system.

The MDOT study's review of national and international monorail systems yielded findings, which were incorporated into the I-270 monorail system under consideration. The findings applicable to this Feasibility Study include the need for integration with the existing transit network as a key component in making monorails attractive and easy to use for riders.

Monorail Use Worldwide

The first commercially viable monorail system, the Schwebebahn monorail in Wuppertal, Germany, opened in 1901 and is still in operation as part of Wuppertal's public transportation system. Today, monorails exist on every continent but Antarctica and are predominantly in urban areas or attraction centers, with some monorails in suburban areas and at airports.

Despite over 100 years of history, monorail systems did not spread globally until the latter half of the 20th century and were disregarded as a viable transit-oriented congestion relief solution. The first modern-era straddle beam type monorails began with the Alweg test track in Germany in the 1950s, leading to the first Disneyland monorail system in 1959. This in turn led to the first line haul, urban monorail system opening in 1964 (Tokyo's Haneda Line), which is still open and expanding.

Recently, several cities have begun investing in monorails as key components of their transit services. South America and Asia are the two regions with the most developed monorail systems. The Sao Paulo, Brazil and Chongqing, China monorail systems are prominent examples of successful monorails, having two of the highest monorail ridership rates in the world.

The MDOT's global scan of monorail technology identified 89 operational, closed, under construction, or planned monorail systems around the world. At the time of the study, 57 systems were operational, eight of which are in the United States.

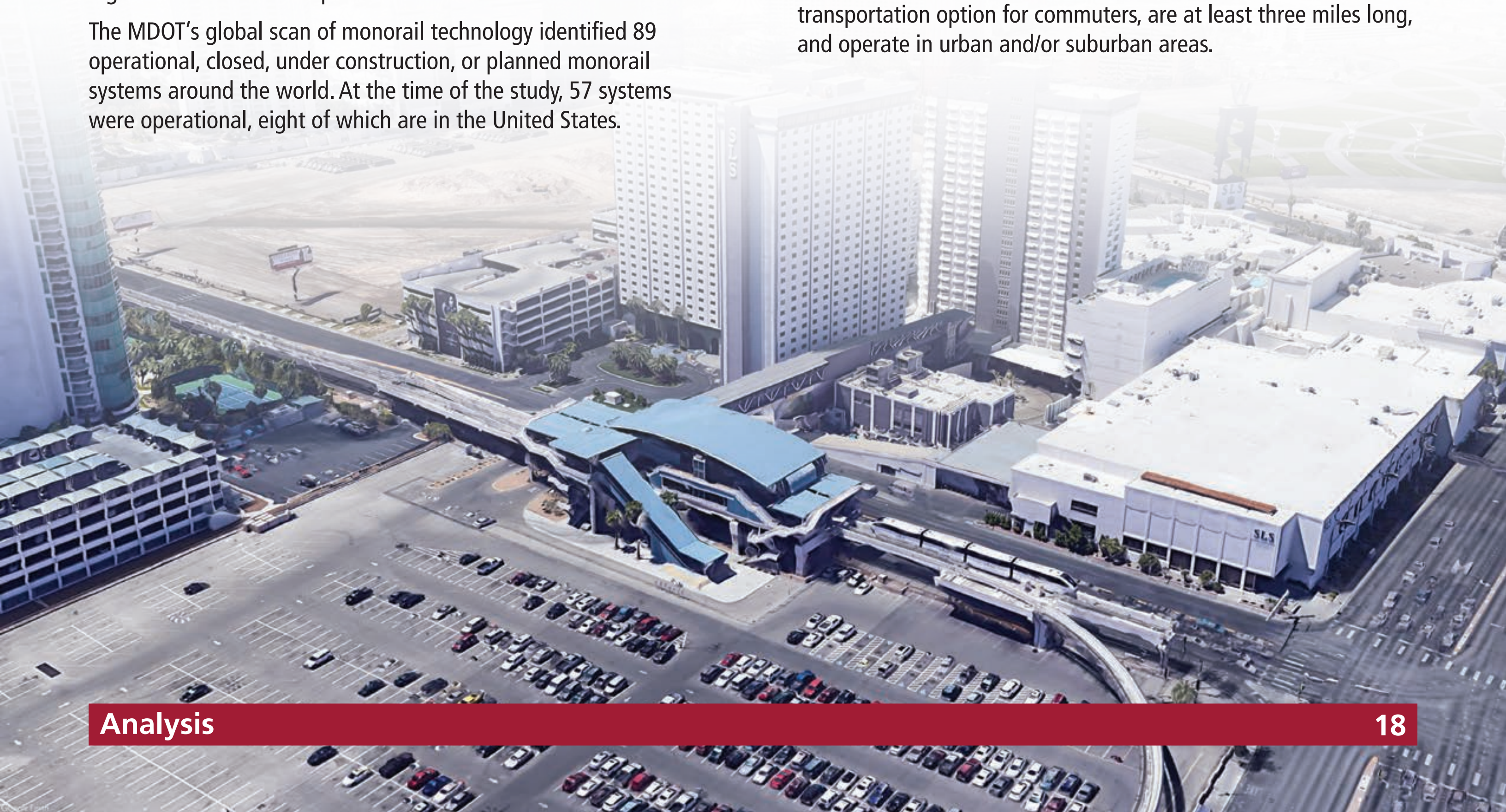
The MDOT's global scan and assessment includes detailed information on a smaller subset of eight monorail systems, with a focus on urban/suburban commuter monorail systems that are applicable to the I-270 corridor. The eight monorails were chosen primarily due to having three similar characteristics that are in line with what the I-270 corridor would require:

1. Serves as a transportation option for commuters
2. At least three miles long
3. Operates in both urban and suburban areas

The following eight monorails from around the world illustrate various levels of relevance to I-270:

- Chongqing, China
- Daegu, South Korea
- Las Vegas, United States
- Mumbai, India
- Osaka, Japan
- Sao Paulo, Brazil
- Tama, Tokyo, Japan
- Wuppertal, Germany

These monorail systems were selected to provide a broad representation of monorail systems around the world and present some lessons learned from these systems and how these could inform MDOT's I-270 monorail consideration. The selected locations include the world's first and oldest monorail system in Wuppertal, Germany, the world's largest monorail system in Chongqing, China, a fast-growing monorail system in Sao Paolo, Brazil, an underperforming monorail in terms of ridership, in Mumbai, India, and a domestic monorail in Las Vegas, United States. All of the monorails, with the exception of the Las Vegas monorail, were built with the intention to serve as a line haul transportation option for commuters, are at least three miles long, and operate in urban and/or suburban areas.



Monorail Lessons Learned

The MDOT's global scan and assessment identified a series of lessons learned from the eight monorail systems. These include:

1. Integration into the transportation network is key in making monorails attractive to riders
2. Monorail systems work best in areas of higher population density with concentrated urban development next to stations
3. Monorail systems can have low impact flexible designs
4. Success in the I-270 corridor would require a behavioral shift from single-occupancy vehicle travel to mass transit commuting, as well as greater densities at the stations

The specific characteristics highlighted for a successful monorail, can equally apply to Light Rail, Bus Rapid Transit (BRT), or even Rail Rapid Transit (Metro). The implication is that the success of a transit system rests more on urban densities and successful planning, than it does on the transit type.

Transportation Network Integration

The I-270 corridor connects to a large transit network that includes the Washington Metro Area Transit Authority (WMATA) Metro Rail, Metro Bus, Amtrak, Maryland Area Rail Commuter (MARC) train, and other local buses. Many commuters and tourists coming from the Frederick area will continue their journey south past the Shady Grove Metro Station, requiring a transfer to another transit mode to reach their destination. The amount of transfers required to reach a destination has an impact on how many people are willing to use it. A monorail system in the I-270 corridor will need to be easily accessible with direct access from other transit modes and provide sufficient parking at those stations located outside of concentrated urban areas.

High Population Density

The assessment found that monorail systems work best in areas of higher population density with concentrated urban development next to stations. The I-270 corridor is far more suburban in nature than the most successful monorail transit systems studied. Potential station areas identified for the I-270 corridor monorail include suburban town centers and areas of concentrated development. The stops at many stations will not be accessible by walking and would still rely on other transportation modes to access the stations. While park-and-ride and mobility hub designs for surrounding stops will need to be a part of the monorail stations, it is important that a clear Transit Oriented Development (TOD) strategy is developed to ensure a sustainable, smart, and walkable urban environment around each stop so that people are able to access the stations.

Low Impact Flexible Design

A common characteristic of monorails is their ability to occupy limited right-of-way, and easily accommodate curves and grade changes. I-270 has limited right-of-way, but the alignment is generally flat and straight. However, it does pass through some environmental features, such as parks, rivers, and creeks.

Behavior Shift from Cars

The I-270 monorail viability will require a behavioral shift from single-occupancy vehicle travel to mass transit commuting. Most successful monorails were deployed in areas where mass transit was already the main mode of transportation. Transportation Demand Management (TDM) strategies could help in creating this shift.

Design Analysis

Design Methodology

Building upon the findings from the *MDOT Monorail Global Scan and Assessment*, this Feasibility Study investigated the specific criteria of two manufacturers' latest monorail systems: Bombardier's INNOVIA 300 and BYD's SkyRail systems. These straddle beam systems feature bi-directional, fully automated driverless trains, operating on a grade-separated dual-track alignment. These manufacturers were selected as representative systems within the global monorail marketplace and for their existing operational presence in the North American region.

After initially determining the potential locations for stations based on previous studies and available data, the design criteria for each manufacturer was analyzed and a single set of design criteria based on both systems was developed for use in this Feasibility Study. Using this design criteria, an alignment was developed and refined based on identified constraints, maximizing connections to local transit, and minimizing potential impacts.

Design Criteria

Sample Monorail Systems

Based on our global scan, this study used two specific monorail system manufacturers to determine the basis of the design criteria: Bombardier's INNOVIA 300 and BYD's SkyRail are commercially available designs that are comparable to each other in size, capacity, and configuration and can be considered typical applications of a monorail system for the purposes of this Feasibility Study.

Due to the technical complexity of monorail systems, many aspects are proprietary to the private enterprises that manufacture or license designs. As a result, publicly available information is less detailed, and designs are more unique to each system than other forms of transit. The design criteria used in this Feasibility Study should therefore not be construed as the eventual design criteria of a potential I-270 corridor monorail system but rather as a guide to what could be used in such an implementation.

Availability of Monorail Systems

Both Bombardier and BYD have interest in supplying transit vehicles also to existing transit systems in the United States. Bombardier supplies steel wheel subway and intercity rolling stock, as well as rubber-tired people movers. BYD is significantly invested in the transit bus market but is not supplying any rail rolling stock. The Las Vegas Monorail uses Bombardier technology.

The Federal Transit Administration's (FTA) Buy America requirements will apply to any transit vehicle procurement. These requirements stipulate that "the steel, iron, and manufactured goods used in the project are produced in the United States," (49 U.S.C. § 5323(j)(1)). These requirements apply to rolling stock, train control systems, communication, and traction power, and require that the final assembly for the rolling stock must occur in the United States.

Vehicle Design Characteristics

The monorail vehicle straddles a single guide beam and uses rubber tires that ride directly on the top and sides of the beam. The vehicles are powered by electric motors running on 750-volt direct current (DC) or higher, gaining power through a third rail contactor system on the edge of the guide beam. Wayside electrical traction power substations would provide power to the third rail. Substation locations would be designed for the specific power requirements of the system, however there should generally be a substation for every mile of track.

Train sets generally consist of two end cars and one middle car, but additional middle cars can be added for additional capacity. Both end cars would have driver cabs and controls, but these control cabs could be eliminated if the monorail was fully autonomous.

The capacity of the vehicles depends on the floor spaces allotted for passengers, the number of seats, and the standing area. The Transportation Research Board's (TRB) publication "Transit Capacity and Quality of Service Manual" states that five standing passengers per square meter is an uncomfortable "crush load" for North Americans, requiring frequent body contact and making moving to and from doorways difficult. The manual states that 3.3 passengers per square meter is a more reasonable peak hour load, but still requires occasional body contact and some effort to move to and from doors. For reference, the TRB publication lists WMATA's passenger space as 0.9 to 2.0 passengers per square meter.

Utilizing the above calculation for capacity in North America, the capacity of the two representative systems based on the manufacturers published size specifications would be:

Table 2.1 – Design Capacity - Number of Passengers

BYD "Skyrail"		Bombardier "INNOVIA 300"	I-270 Monorail Design Criteria
End Car	Mid Car		
Standing: 64 Seated: 16 Total: 80	Standing: 75 Seated: 18 Total: 93	Standing: 60 Seated: 16 Total: 76	Standing: 60 Seated: 16 Total: 76

Car dimensions of the representative systems are similar. Both systems have 10.3-foot-wide vehicles, the car length ranges from 39 feet to 43 feet, and the wheelbase is approximately 30 feet for both. A three-car train set would be approximately 120 feet long. Both systems currently have an operational top speed of 50 mph but may travel faster with technology improvements in the future.

BYD SKYRAIL

Skyrail is a straddle-rail system from Chinese transportation conglomerate BYD that is being made available worldwide but so far has only seen implementation in China. Skyrail is being promoted as featuring state-of-the art driverless technology, having high yet flexible capacity, and being highly energy efficient.

BOMBARDIER INNOVIA 300

Bombardier's INNOVIA 300 straddle-rail system is an evolution of their previous INNOVIA 200 series with advancements in automation, rider comfort, and carriage design. There is a 300-series system in Sao Paulo, Brazil and other systems are being implemented in Saudi Arabia, Thailand, and China. There is also a 200-series system in the U.S. in Las Vegas, Nevada which was opened in 2004.

Guideway Design Characteristics

The guideway for these monorail systems consists of a precast concrete beam for each direction of travel, set on concrete piers. Monorails can operate at grade; however, the at-grade guide beam system would be the same system as the elevated section.

The guide beam is approximately five feet tall, by 2.3 feet wide. The average beam span can range from 65 feet to 120 feet long. Pre-cast piers are generally circular columns, with diameters of 3.5 feet. A bent cap is constructed on top of the pier, and the guiderail is attached to the cap. Pier foundation types can vary depending on soil conditions, but the preferred method is a drilled shaft cast-in-place system. The bottom of the guide rail should be a minimum of 16 feet 9 inches high to provide required clearances for roadway vehicles traveling under the monorail system, but can be much higher if required by topography or aesthetics.

The monorail alignment design is based on the characteristics of the vehicles, fire and life safety regulations, desired operation speed, as well as land constraints. The representative systems published specifications include an absolute maximum alignment grade of 10%, with a recommended maximum grade of 6%. The absolute minimum corner radius for both systems is 150 feet, and the recommended minimum radius is 200 feet. Alignments can be superelevated at a rate of up to 12%, but 8% is the recommended maximum to ensure rider comfort at lower speeds. Alignment curves should be circular, with spiral transitions, like steel rail transit systems.

Clearances between the center of the two guiderails are generally 14 feet 3 inches in tangent sections, and widen out in curved sections, based on the degree of curvature. A walkway is provided either between the guiderails or on the outside, to facilitate maintenance access and emergency egress. Periodic access points from ground level to this safety walk need to be provided with secure gates. The required clearance from the center of the guiderail to any outside fence is seven feet three inches. The vertical height clearance from the top of the beam to any obstruction is 17 feet. These characteristics add to a two-track envelope of 26 feet wide, by 25 feet high from the bottom of the guiderail.

Switches to transfer vehicles between tracks vary by manufacturer. Two common configurations of switches include a segmented concrete or steel guide beam allowing the beam to bend from straight to curved, and a beam replacement switch that allows two separate beams to replace each other. Switches need to be placed periodically along the alignment to facilitate varying operating conditions. Track maintenance, train breakdowns, or express running may require trains to switch tracks. At a minimum, switches should be provided at each station, and at the end of the monorail service line. Tail tracks are also provided at the end of the monorail service line to allow for vehicle storage or layover.

Station Design Characteristics

Monorail stations can be either on the outside of the vehicle, or between the two directions in the center. Center platforms can be a more efficient use of limited space, and allow for easy passenger transfers, but can be a challenge to provide access and can be confusing for passengers.

Level boarding from station platforms to monorail vehicles is provided. Gaps between the vehicles and platforms can be minimized, and boarding ramps can be used if needed. Platform boarding gates can be provided to increase safety and efficiency of the boarding process, if desired. Monorail vehicles generally have two passenger doors per car. The overall station design can influence the dwell time of the vehicles. Making the boarding process faster allows for faster overall travel times for the system.

The center platform should be at least 18 feet wide, and a side platform should be at least 14 feet wide. The length of the platform is designed for the longest train consistently used for the system. To accommodate a single three-car train, the platform length is approximately 150 feet, and to accommodate two, three-car trains, the platform should be 300 feet long.

I-270 Monorail Design Criteria

Table 2.2 summarizes the technical properties of the Skyrail and INNOVIA 300 systems along with the design criteria that was developed for the alignment evaluation as part of this Feasibility Study.

Table 2.2 – I-270 Feasibility Study Monorail Design Criteria

VEHICLE			
	BYD SKYRAIL	**INNOVIA 300**	**I-270 DESIGN CRITERIA**
Car Length	39.3′	End Car: 43.3′ Mid Car: 38.9′	40′
Car Width	10.3′	10.3′	10.3′
Wheelbase	30′	30.2′	30′
Full capacity @ 3.3 pass/m2	80 / end car 93 / mid car	76 pass / car average	76 pass / car
Operational Top Speed	75 mph	50 mph	50-75 mph*
Consist Length	2 to 8 cars	2 to 8 cars	2 to 8 cars
TRACK			
	BYD SKYRAIL	**INNOVIA 300**	**I-270 DESIGN CRITERIA**
Maximum Grade	10%	10%	10%
Recommended Max Grade		6%	6%
Absolute Max Superelevation			12% max
Desired Max Superelevation			8% max
Curve Type			Circular curve and spiral transitions
Minimum Turning Radius	148′	150′	150′
Rail Beam width	2.3′	2.3′	2.3′
Pier Size	3.5′		3.5′
Average span length			100′ average, 65′ to 120′
Accel / Brake Rate		1 m/s^2	1 m/s^2
STATIONS			
	BYD SKYRAIL	**INNOVIA 300**	**I-270 DESIGN CRITERIA**
Center Platform Width			18′
Side Platform Width			14′
Platform Length (One 3-car train)			150′
Platform Length (Two 3-car trains)			300′
CLEARANCES			
	BYD SKYRAIL	**INNOVIA 300**	**I-270 DESIGN CRITERIA**
Tangent center to center			14′ 3″ at 50 mph
Tangent to Fence			7′ 3″
Vertical from beam top			17′
2-Track Envelope			26′
Beam Underpass			16′9″

*At least one major monorail supplier, BYD, has fully tested and is offering its SkyRail technology globally with a top operating speed of 75 mph, with a recommended scheduled operating speed of 65 mph (to provide a schedule recovery capability for unanticipated passenger-caused delays)

Alignment Analysis

Alignment Development

The I-270 Monorail Feasibility Study alignment was developed to carry passengers between the Frederick MARC Station area and the Shady Grove Metro Station. The goal of the alignment is to provide station access at the major population centers, while utilizing the I-270 state-owned right-of-way as much as possible.

The alignment was initially developed in the *2019 Frederick-Shady Grove Ridership and Revenue Study (2019 Ridership Study),* prepared by The High Road Foundation. As part of this Feasibility Study, the alignment and station locations have been modified to improve constructability, operations, and minimize potential impacts. The focus for the modifications is to maximize use of the I-270 right-of-way, improve alignment curvature based on the design criteria, avoid and minimize potential impacts based on readily available data, and to identify locations for the proposed stations and maintenance facilities in locations which provide adequate capacity for access and parking, while minimizing impact to existing socio-economic and environmental resources. While the alignment is largely within publicly owned land, there are still impacts to environmental resources and utilities within the right-of-way, and to private land, resources, and utilities outside the right-of-way at stations, maintenance and yard facilities, and some locations along the alignment.

The monorail alignment was developed to a level of detail appropriate for this Feasibility Study. A horizontal alignment was developed that would meet the design criteria. A vertical alignment was designed to meet clearances at key points such as road crossings, and to meet slope criteria for the preferred maximum grades and station platform grades. If the development of a monorail system continues beyond this Feasibility Study, additional alignment options and alternatives should be developed, to greater detail, to optimize the alignment performance, cost, and impacts. The single alignment and options described in this Feasibility Study should not be interpreted as the best or only option.

Alignment Description

The following is a description of the monorail alignment, starting from the northern terminus in Frederick to its southern terminus at the Shady Grove Metro Station. The alignment has been split into segments that primarily span between the station locations.

Frederick to Urbana

The monorail alignment begins just south of the existing Frederick MARC Station, in an unimproved industrial storage lot along East South Street between South Wisner Street and South East Street. The Frederick monorail station and northern monorail storage and maintenance facility is proposed at this location. A lead track from the station platform allows trains to enter the storage and maintenance facility. A detailed description of stations and maintenance facilities are found later in this chapter.

When leaving the station, the alignment travels south down the western side of East Street for approximately 1.5 miles until it intersects and crosses over Monocacy Boulevard and heads west. An overhead power line crosses the alignment on South East Street, and again at Monocacy Boulevard, which includes a double set of local poles carrying power and communications, as well as a larger high voltage line. The alignment is in direct conflict with these lines, which would need to be raised, lowered, or rerouted. The alignment can be lowered to pass under these power lines, however the conflict would still exist, as these power lines require additional clearances.

The alignment from the station to I-70 would be constructed primarily on private property, requiring easements or partial property acquisition. The station and maintenance shop are entirely located on private property and would most likely require a full parcel acquisition.

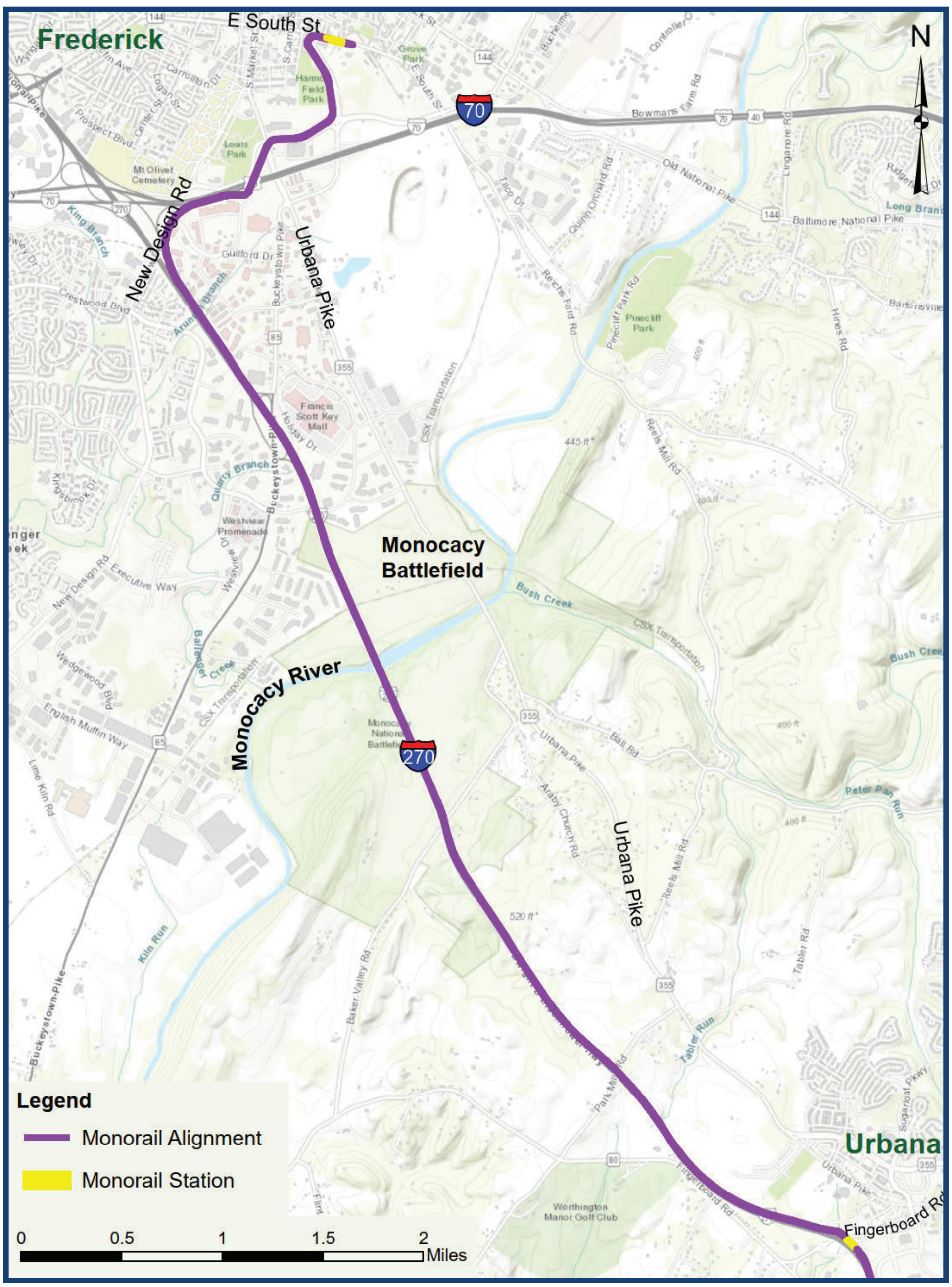
The alignment then crosses over South Market Street (MD 355) and I-70 and follows along the southern side of New Design Road to I-270. This segment is primarily within the existing right-of-way for I-70, as well as I-270.

The vertical alignment in this section between the Frederick Station and the I-70/I-270 interchange needs to be elevated to at least 25 feet to allow clearance under the guide beam for the road and highway crossings. The existing ground in the segment is fairly flat from one end to the other but has rolling topography of up to 50 feet in height difference.

The alignment then follows the east side of I-270 for approximately six miles to Urbana. This segment can potentially be built utilizing the existing I-270 right-of-way. The alignment then passes by the Monocacy Battlefield National Monument, over the Monocacy River, over the CSX/MARC train tracks, and three local roads. The vertical alignment does not need to be elevated to allow underpass clearances for the majority of this section, so it could be fenced to allow for an exclusive right-of-way.

At the Fingerboard Road interchange with I-270, the alignment crosses over the exit/entrance loop, over Fingerboard Road, and into the station located at the existing Urbana park-and-ride lot. This alignment through this interchange is entirely within state-owned right-of-way The Urbana station is located in the existing MDOT SHA owned park-and-ride lot.

Figure 2.1 – Frederick to Urbana Map



Urbana to Clarksburg

When exiting the Urbana Station, the alignment continues south along the eastern side of I-270 for approximately four miles. This section of the alignment then crosses over eight streams, one high voltage power line, and two local roads. Most of this section is located within state-owned right-of-way, but some easements or strips of property acquisition may be required. The alignment then crosses over the border from Frederick County to Montgomery County just north of Old Hundred Road in Clarksburg. The alignment then crosses over the on and off ramp for the interchange between Old Hundred Road and I-270.

Approximately half a mile south of Old Hundred Road, the alignment shifts into the median of I-270. The median in this section of I-270 widens out to approximately 150 feet wide, allowing construction of the monorail. By crossing into the median here, the monorail alignment avoids impacts to private property, as well as conflicts with the truck weigh station and rest area on the east side of I-270. The median section then passes over two streams, one that follows the length of the median. The alignment is in the median for about 1.5 miles until it crosses over the southbound lanes to the western side of I-270, as the median narrows to 40 feet wide.

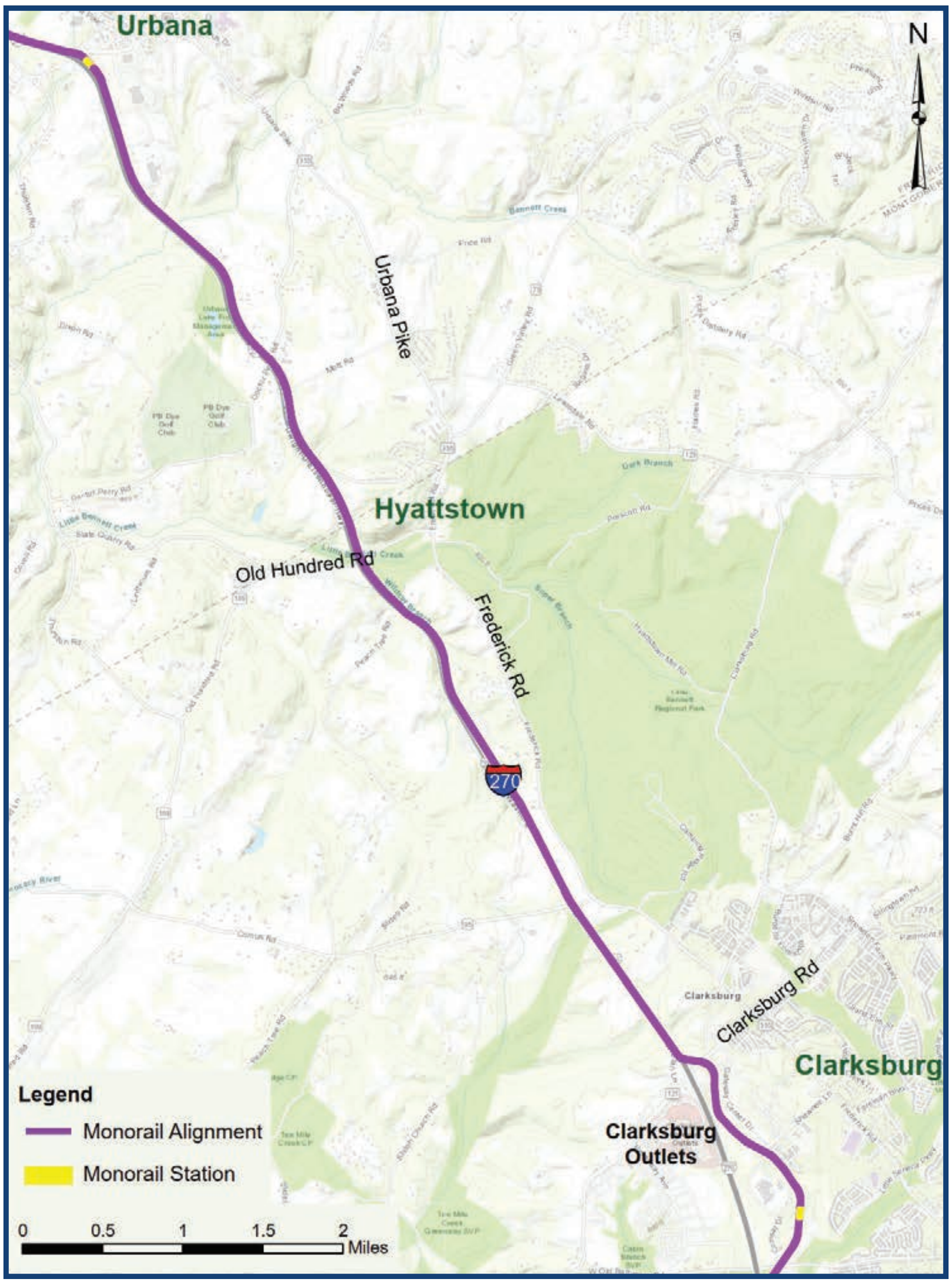
After crossing from the median, the alignment is on the west side of I-270 for this section as there is more available state-owned right-of-way, and it also avoids developed land on the east side. Most of this section is proposed in state-owned right-of-way, but some property easements or strips of property acquisition may be needed. This section of the alignment crosses over four streams and one local road (Comus Road). Comus Road crosses over I-270, therefore the monorail alignment is needed to be much higher than I-270 for this overpass, with pier heights in the range of 50 feet. South of Comus Road, the alignment then passes by the Montgomery County Correctional Facility, and directly over the access road to the facility. Careful design and coordination will be needed for this location. The alignment then continues along the western side for approximately two miles until it reaches the interchange of I-270 and MD 121 (Clarksburg Road).

At the interchange, the monorail alignment passses over the entrance and exit loop ramps, over Clarksburg Road, and crosses back to the east side of I-270. Here the alignment crosses through seven parcels of privately-owned property. The area of the alignment in these parcels, however, is undeveloped and currently includes a stream and stormwater facility, as well as overhead power lines.

The alignment then enters the Clarksburg Station near Gateway Center Drive, in a large undeveloped parcel, which is part of the former COMSAT facility. These privately-owned properties will require either strips of land acquisition or full parcel acquisition. The Clarksburg Station is located in the same vicinity as the Corridor Cities Transitway (CCT), a planned dedicated guideway for BRT, which runs from Clarksburg to the Shady Grove Metro Station.

This segment of the alignment is in rolling terrain and has some sections requiring grades reaching up to 6% for sustained lengths of up to a mile. The profile elevation changes up to 350 feet through the length of this segment.

Figure 2.2 – Urbana to Clarksburg Map



Clarksburg to Germantown

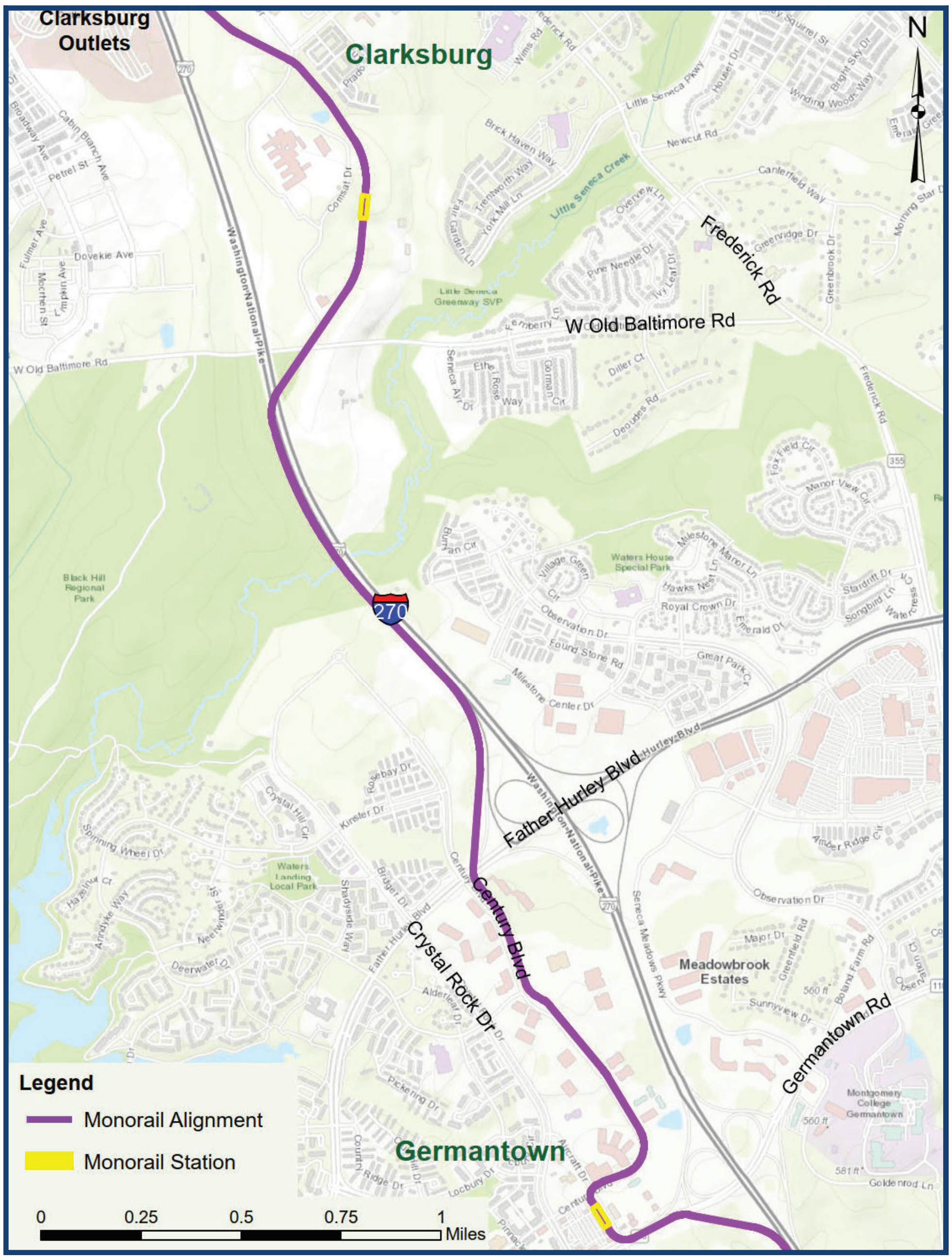
As the monorail alignment exits the Clarksburg Station to the south, it passes through the former COMSAT facility, over West Baltimore Road, and crosses over I-270 to the west side. The alignment continues on the west side of I-270 for approximately one mile. Once along the west side of I-270, the alignment is primarily within state-owned right-of-way, but may require some strip acquisitions for construction and maintenance access. The alignment in this section then crosses over Little Seneca Creek, and a planned road, and the CCT crossing of I-270 at Dorsey Mill Road.

At the interchange of I-270 and Father Hurley Boulevard, the alignment diverges from I-270 to the west, following the southbound off ramp towards Germantown. At the south end of the off ramp, the alignment crosses over Father Hurley Boulevard, and utilizes land set aside for the CCT along Century Boulevard, and into the downtown area of Germantown. This section is the first part of the monorail alignment that travels through a developed population center. Current and future development of this area will require careful design and coordination in this section, as there are many driveway entrances, as well as the planned CCT.

The monorail alignment then enters the Germantown Station at the intersection of Aircraft Drive and Century Boulevard. This segment of the alignment is approximately three miles long, and generally follows the CCT route, but only shares the alignment along Century Boulevard.

This segment of the monorail alignment is in fairly level terrain, with no significant difference in elevation between stations. The elevation changes are in the range of 50 feet, and the vertical profile does not have any significant sustained grades.

Figure 2.3 – Clarksburg to Germantown Map



Germantown to Metropolitan Grove

The monorail alignment departs the Germantown Station, and follows Aircraft Drive to the intersection of MD 118 (Germantown Road) and crosses over Germantown Road, and parallels the southbound on ramp to I-270, and then south along the western side of I-270. Along Germantown Road, the alignment passes next to a U.S. Department of Energy office complex.

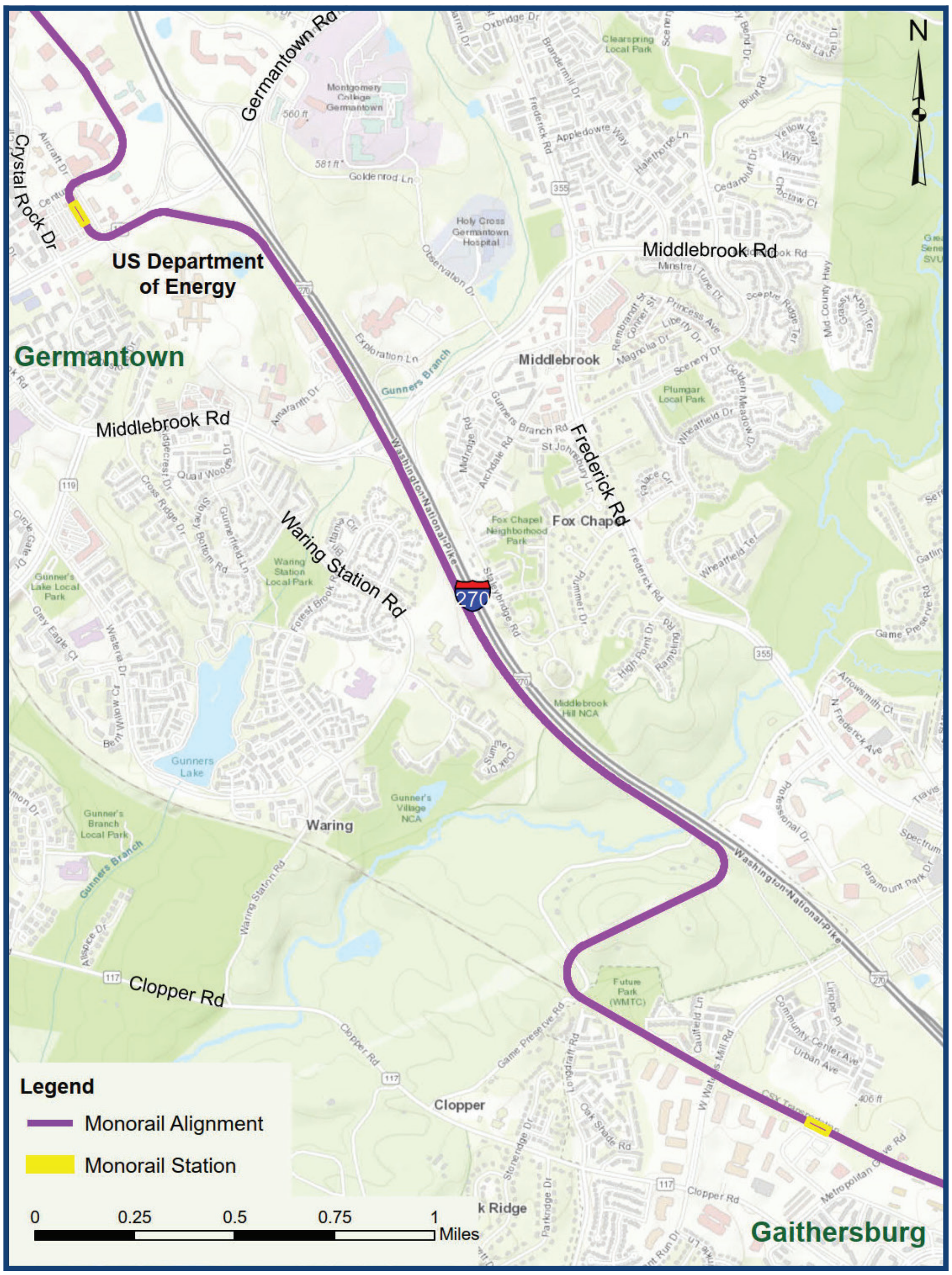
The alignment then travels along I-270 for about two miles before it turns west after passing Game Preserve Road. In this section along I-270, the alignment crosses over Middlebrook Road, and at least one stream. In addition, the alignment parallels an overhead power line, which may need to be relocated. This section is primarily within state-owned right-of-way for I-270, but there is development close to the edge of the right-of-way, so sight and noise impacts will need to be further evaluated should this alignment be carried forward for additional study. After crossing over Game Preserve Road, the alignment veers away from I-270, paralleling a wide utility easement that houses four separate overhead power transmission lines. As the monorail crosses these power lines, the alignment may need to be at grade to avoid major impacts to the power lines.

The alignment then turns to the south to parallel the CSX and MARC train tracks. Crossing over Game Preserve Road again, and then over Watkins Mill Road, the alignment enters the station at Metropolitan Grove. This station is proposed parallel to the existing MARC Metropolitan Grove park-and-ride, on the northern side of the CSX rail line, between Watkins Mill Road and Metropolitan Grove Road.

The undeveloped area to the east of the alignment and Game Preserve Road, just north of the CSX rail line, is a potential location for the southern monorail maintenance facility. This maintenance facility is described later in this chapter.

This segment between stations is approximately 3.75 miles and is in rolling terrain. The overall elevation drops 90 feet between stations, requiring sustained grades up to 6% for up to half a mile.

Figure 2.4 – Germantown to Metropolitan Grove Map

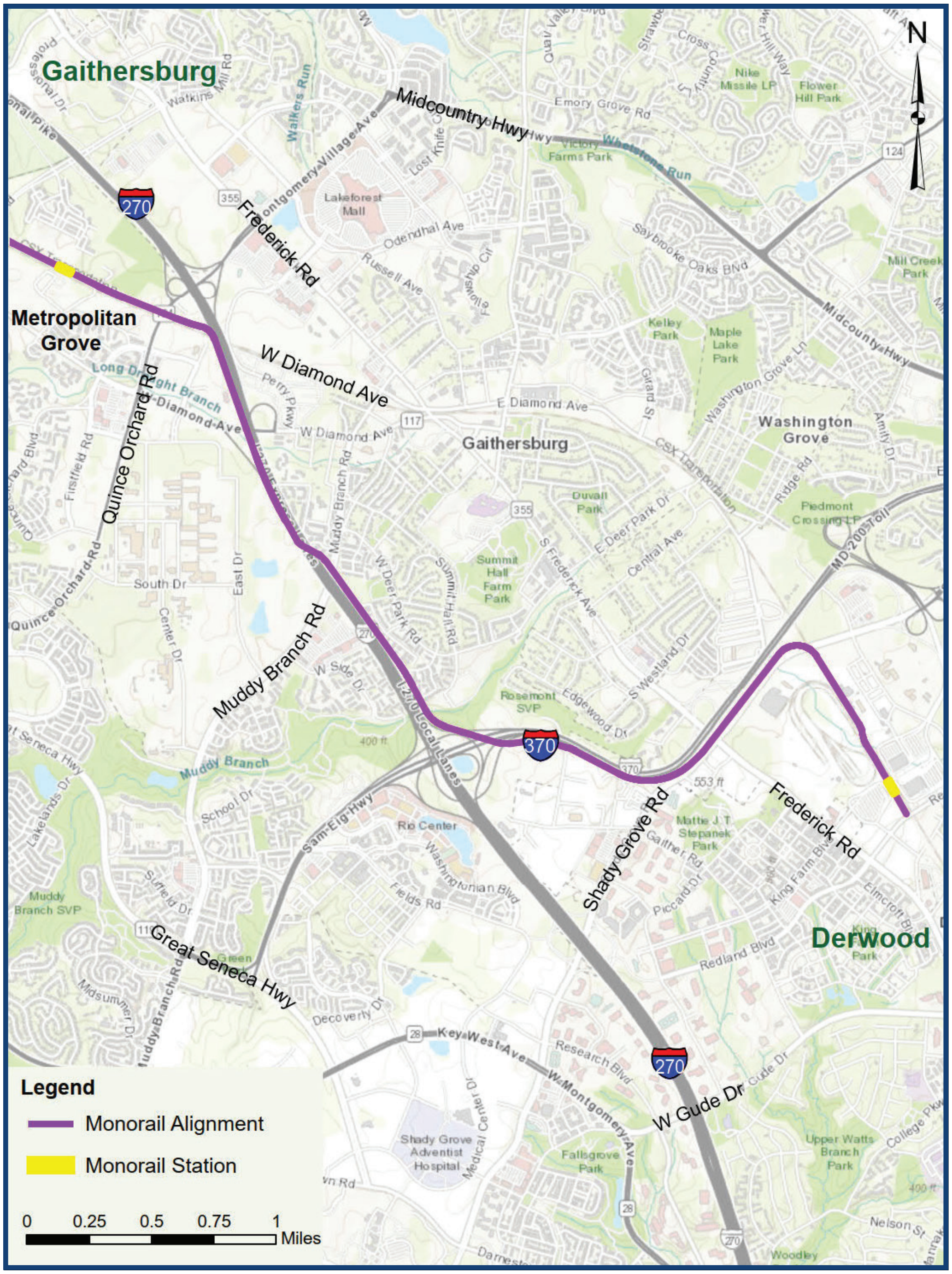


Metropolitan Grove to Shady Grove

The monorail alignment leaves the Metropolitan Grove Station, continuing south along the CSX alignment. After a mile of following the CSX rail, the alignment curves towards the southeast and crosses over the rail line to follow I-270 on the western side for approximately one mile.

The section along I-270 is almost entirely within state-owned right-of-way. The section along the CSX tracks requires partial acquisitions from multiple properties, and potentially from CSX as well. The station area is entirely located on private property which is planned for future development of a town center and would require a full parcel acquisition.

Figure 2.5 – Metropolitan Grove to Shady Grove Map



The alignment then continues south along I-270 crossing over Clopper Road, an on ramp to southbound I-270, and a stormwater management pond. South of Clopper Road, the alignment parallels the National Institute of Standards and Technology (NIST) facility. Mitigating any impacts to NIST during construction and operations would require careful coordination during design, but may include electromagnetic shielding, vibration dampening systems, or noise reductions.

At Muddy Branch Road, the alignment crosses to the east side of I-270 and parallels I-270 south to the interchange of I-270 and I-370. This section of the alignment is not able to be constructed within the state-owned right-of-way for I-270. The entire width of the right-of-way is currently occupied by I-270 travel lanes. Noise barriers are on either side of the highway, which separate the highway from residential developments. Residences are within 30 feet of the edge of I-270. This configuration may require these properties to be acquired. There is a possibility that the monorail alignment could be constructed over I-270 through this area, but the current configuration of medians does not allow enough space for the piers within or between travel lanes. This section of the monorail alignment is approximately 3,500 feet long.

At the interchange of I-270 and I-370, the alignment crosses over the Muddy Branch stream, and veers to the east to follow the westbound I-370 to northbound I-270 ramp. It then crosses over I-370 to parallel the highway on the south side. The alignment crosses over Industrial Drive, the eastbound I-370 off ramp, Frederick Road, and Oakmont Avenue before turning south to travel along the CSX rail line into Shady Grove. The proposed corridor ends at a station in the Shady Grove Metro location, near Redland Road.

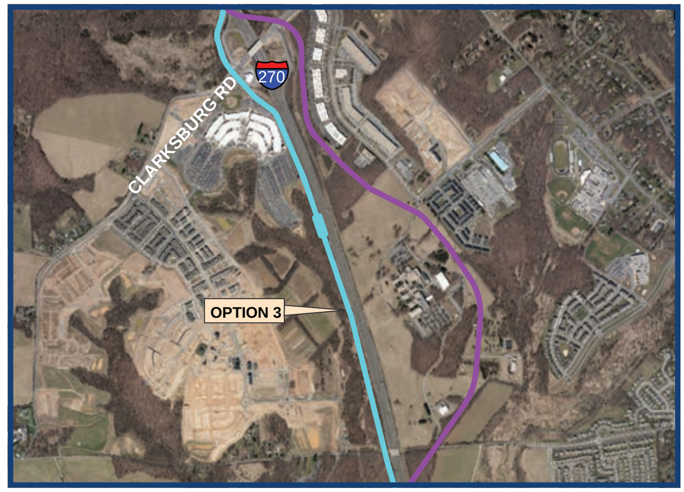
The section of the alignment that parallels the CSX tracks would pass over Shady Grove Road, lead tracks to WMATA's Shady Grove rail yard, and a CSX transfer facility. Formal agreements or property acquisitions would need to be in place between MDOT, CSX, and WMATA for shared use in this congested area.

Additional Alignment Options

In addition to the main monorail alignment, additional alignment options were developed during the design process. These options were created as potential considerations for future design but were not analyzed as alternatives to the alignment.

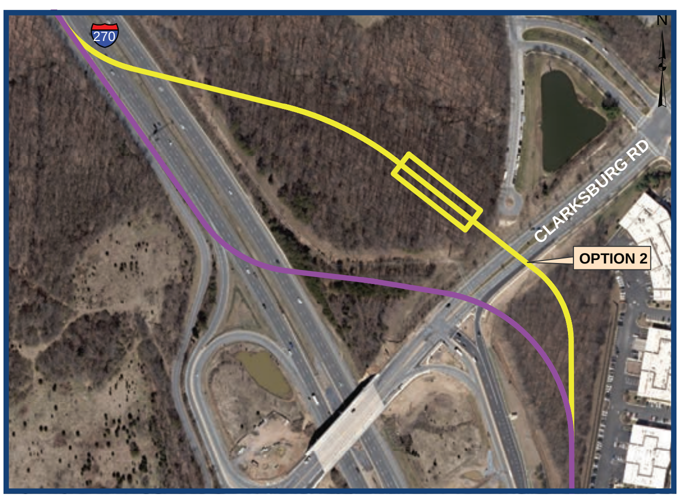
Tail Track at Frederick

This option is located at the northern end of the alignment in Frederick and includes a 90 degree turn in the tail track to avoid impacts to additional properties. This allows a direct connection to the maintenance facility and the station in the lot south of the station.



Clarksburg Station Location West

This option is also in the Clarksburg area, and includes keeping the monorail on the west side of I-270. The alignment crosses over Clarksburg Road and passes by the Clarksburg Premium Outlets. The Clarksburg Station is contained within or adjacent to the outlet development on the west side of I-270. The alignment then continues south along the west side of I-270, to connect to the alignment.



Clarksburg Station Location North

This option is located just north of Clarksburg Road in Clarksburg. This option presents a different way to cross over I-270 and Clarksburg Road to get the alignment on the western side of I-270 to connect to the Clarksburg Station location. The Clarksburg Station may be constructed in this undeveloped area, with a more direct access to I-270.

Clarksburg Station Location Central

This option is a central location for the Clarksburg Station. This moves the alignment closer to Gateway Center Drive. The Clarksburg Station is proposed in the undeveloped area with a direct connection to the existing residential and office development. This station option was used as reference for the potential Clarksburg Station site plan, as shown later in this chapter.

Germantown Station Location

This option is a different location for the Germantown monorail station, but still utilizes Century Boulevard, running over to Aircraft Drive and through the parking lot area between buildings to connect to Germantown Road. It utilizes the middle of the existing parking lot for the surrounding businesses and Germantown Transit Center for the station location and additional parking in a parking garage. This alignment eliminates direct impact to existing businesses. This station option was used as reference for the potential Germantown Station site plan, as shown later in this chapter.

Gaithersburg Station Location

This option is in the Gaithersburg area, and is an alternative location for the station in Metropolitan Grove. Instead of the alignment shifting west after passing Game Preserve Road, it continues along the western edge of I-270. The option moves slightly west from I-270 in the right-of-way between Game Preserve Road and Watkins Mill Road to allow space for a potential station location. The structure over I-270 for Watkins Mill Road has recently completed construction. This station location provides a more direct connection to local collector roads and reduces the potential impact to environmental features and utilities, but would not provide a direct connection to MARC trains.

U.S. Department of Energy Alignment

This option follows the CCT alignment south from Germantown, along the west side of the Department of Energy complex, and then in the median of Middlebrook Road to connect to the western side of I-270. This option shifts southwest of Waring Station Road to avoid additional road crossings and potential impacts to the existing solar panels.

Gaithersburg Alignment

This option is an alternate way to connect the monorail to the proposed Metropolitan Grove Station. This option still heads west after Game Preserve Road and utilizes some of the CSX rail right-of-way to connect to the proposed Metropolitan Grove Station. Instead of the alignment travelling along the utility right-of-way to connect to the station, it travels more diagonally through undeveloped land and a small neighborhood before connecting to the CSX rail right-of-way.

Modifications to The High Road Foundation Alignment

An alignment for the I-270 monorail was initially developed in the *2019 Ridership Study* prepared by The High Road Foundation. As part of this Feasibility Study, the alignment and station locations have been modified to identify locations to improve constructability, operations, and reduce potential impacts. The focus for the alignment modifications were independently developed to maximize use of the I-270 right-of-way, improve alignment curvature based on the design criteria, avoid potential impacts based on readily available information, and to design the proposed stations and maintenance facilities locations based on feasibility for acquisition and constructability. While many of the alignment updates were minor in nature, the alignment was shifted in some locations away from the I-270 right-of-way and onto private property due to construction constraints. The following updates were more significant:

Frederick Station Area

In the northern Frederick region, the alignment was modified to avoid impacts and reduce main road crossovers. The alignment was shifted in this area to help reduce potential pedestrian sidewalk impacts and to avoid right-of-way impacts to the Mount Olivet Cemetery. The High Road alignment initially impacted the cemetery by travelling along the northern side of I-70. By moving the alignment to the southern side of I-70, it avoids major impacts to the cemetery and eliminates the three New Design Road crossovers needed to access I-270 right-of-way.

I-270/I-370 Interchange Area

The southern end of the alignment, from approximately three miles north of Clarksburg to the end of the alignment, starts the design efforts to utilize as much right-of-way of I-270 as possible while minimizing I-270 and surrounding road crossovers. A few large sections of the alignment near Clarksburg and Shady Grove were moved in or out of the median area or to the opposite side of I-270 so that the alignment would fit in the existing right-of-way more efficiently. An example of this is seen near Shady Grove where the alignment moves from I-270 to I-370 right-of-way. The High Road alignment travelled along the grass median of I-370. The new design moves the alignment to the southern side of I-370 to minimize a high vertical alignment crossing of Industrial Drive, avoids potential impacts to road signage, and avoids potential issues with constructing the alignment in a restricted median and on existing overpasses along I-370.

Metropolitan Grove Station Area

The only analyzed station location that changed from The High Road alignment was Metropolitan Grove. The alignment was moved from the southern side of the CSX rail line to the northern to reduce residential and commercial right-of-way impacts and rail crossovers. In doing so, it allowed the Metropolitan Grove Station to be designed in an undeveloped section of land on the opposite side of the existing Metropolitan Grove MARC station.

Station Analysis

The proposed stations were designed to incorporate many facilities that are expected at transit stations in suburban locations. Stations share a common design with some exceptions for location-specific aspects.

Station Elements

The location of each station features varying geography, available space, constraints, and needs, which are discussed in detail in the next section. All stations do share common elements, which were developed as a prototypical station and then revised for each specific station location.

The prototypical station features an elevated, covered island platform with ground-level access and ticket facilities. Bicycle and pedestrian access are provided to local routes. Parking facilities for bicycles and cars are sized per calculated needs with a kiss-and-ride provided near the station entrance. Connections to other transit systems such as local bus, Metrobus, and Metrorail are provided either on-site or with access to adjacent facilities.

Standard dimensions for stations are contained in **Table 2.3**:

Table 2.3 – Standard Station Dimensions

Station Feature	Dimension
Platform Width	18′ (Center island)
	14′ (Side)
Platform Length	150′ (one 3-car train)
	300′ (two 3-car trains)

Station Design Methodology

The following guideline documents were used in developing the design criteria for the facilities in this Feasibility Study:

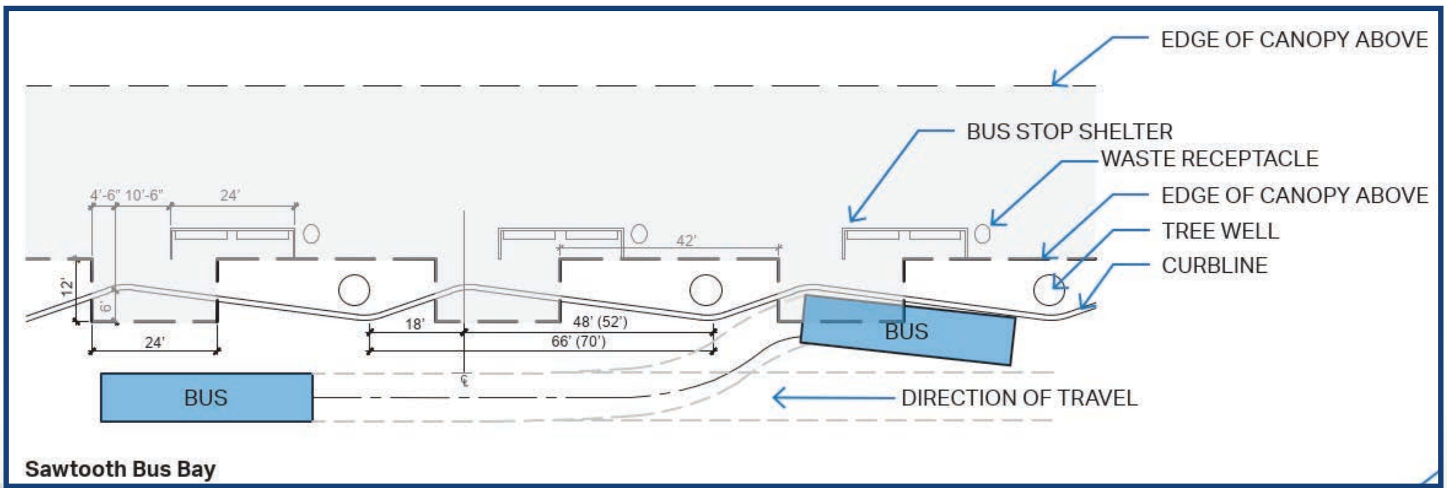
- The American Association of State Highway Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets, 2018*
- Washington Metropolitan Area Transit Authority (WMATA) *Station Area Planning Guide, 2017*

AASHTO's manual specifies that park-and-ride facilities should be designed adjacent to streets and located as close to residential areas as possible. The design should include bicycle and pedestrian facilities and should be placed in locations with minimal vehicle conflicts. Parking areas should also provide short-term parking and a drop-off facility close to the station entrance (kiss-and-ride). The size of these parking facilities is determined by design volume, land availability, and surrounding land uses. Each station facility in this Feasibility Study considered pedestrian facilities and designed general transit facilities, a park-and-ride, and a kiss-and-ride. All station locations should be Americans with Disabilities Act (ADA) compliant with platform slopes no greater than 2%.

Since the design of the monorail shares characteristics with existing Metrorail, the WMATA Station Area Planning Guide was used as guidance for further design of the stations. The manual states that bus and kiss-and-ride facilities should be designed closest to the station entrance and that all designs should optimize the level of service and pedestrian safety. Transit or bus facilities were assumed to be high ridership with more than two or three buses at a time and designed as a 15-foot width one-way sawtooth bus bays accommodating a standard commuter bus (45-feet long). **Figure 2.6** shows an example layout of a typical sawtooth bus bay from the *Station Area Planning Guide*. All bus bays were designed with five bus bays for the larger lots and three or four bus bays for the smaller lots. Park-and-ride and kiss-and ride facilities were designed with 9-feet wide and 18-feet long parking spaces to accommodate all car sizes. All non-bus lanes were two-way, space permitting, and at least 11-feet wide. In areas where only one-way traffic was permitted the lane width was increased to at least 13 feet. Parking access was placed with the guidance that access should be minimal and placed along collector or arterial street systems to increase safety and reduce traffic in residential areas.

After station design elements were determined, the ridership analysis was used to determine the supporting parking facilities needs (see **Table 2.4 and 2.5**). Since the ridership forecast assumes a network unconstrained by the amount of parking, the worst case scenario was assumed, so desired spaces were based off the high ridership values in the analysis.

Figure 2.6 – Sawtooth Bus Bay Example



Parking and Kiss-and-Ride Size Analysis

Table 2.4 – Metrorail Montgomery County Station Analysis

Station	Average Weekday Passenger Boardings (in 2019) (c)	Parking Spaces	Parking Cost Per Day	Parking Utilization (in 2019) (b)	Mode Share Percentage (in 2005) (a)				Calculated Parking Spaces Desired (e)	Calculated Kiss-and-Ride Spaces Desired (d)
					Walk / Bike	Bus and Connecting Rail	Drop-Offs	Drove and Parked		
Grosvenor	4,949	1,894	$5.20	88%	31%	10%	23%	36%	1,603	80
White Flint	3,576	1,270	$5.20 / $8.70	59%	37%	15%	9%	39%	1,255	23
Twinbrook	4,076	1,097	$5.20 / $8.70	60%	37%	14%	9%	40%	1,467	26
Rockville	3,930	524	$5.20 / $8.95	96%	24%	28%	14%	33%	1,167	39
Shady Grove	11,480	5,745	$5.20	70%	3%	29%	14%	54%	5,579	113
Glenmont	5,654	2,998	$5.20	63%	10%	15%	13%	62%	3,155	52
Wheaton	3,586	977	$4.45	25%	24%	14%	10%	51%	1,646	25
Forest Glen	2,074	596	$5.20	74%	38%	4%	16%	42%	784	23
			Average Terminus:		7%	22%	14%	58%		
			Average Mid-Line:		32%	14%	14%	40%		

a. Source: Guidelines for Station Site and Access Planning, WMATA 2005
b. Source: Quarterly Progress Report, FY 2019 Q1, WMATA 2019
c. Source: Historical Metrorail Ridership, WMATA 2019
d. 2 x Kiss-and-Ride Customers / Trains per Peak PM Hour / 0.85 = Estimated Kiss-and-Ride Spaces, Source: Station Area Planning Guide, WMATA 2017 Calculation assumes 60% of weekday boardings exit during peak period, and the peak hours are 5pm-7pm, and six-minute train frequency.
e. Calculation assumes a target utilization of 90%, and one vehicle per daily boarding customer that drove and parked

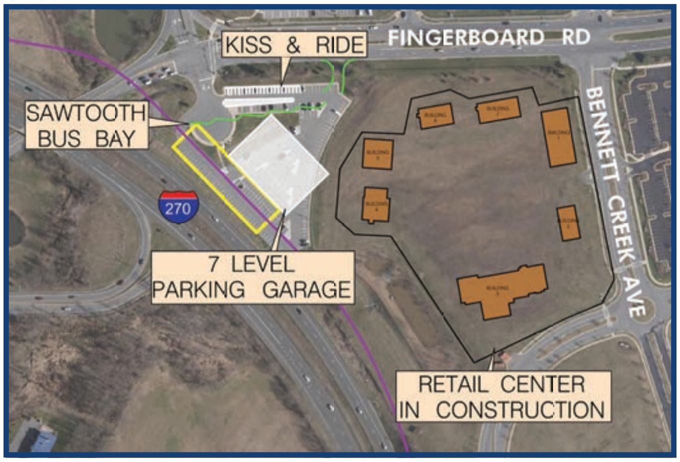
Table 2.5 – Monorail Station Analysis

Station	Average Weekday Passenger Boarding (in 2045) (b)		Parking Cost Per Day	Assumed Mode Share Percentage (a)				Low Ridership		High Ridership	
	Low	High		Walk / Bike	Bus and Connecting Rail	Drop-Offs	Drove and Parked	Calculated Parking Spaces Desired (d)	Calculated Kiss-and-Ride Spaces Desired (c)	Calculated Parking Spaces Desired (d)	Calculated Kiss-and-Ride Spaces Desired (c)
Frederick	12,400	14,300	$5.20	5%	20%	15%	60%	6,696	131	7,722	151
Urbana	1,800	2,000	$5.20	30%	15%	15%	40%	648	19	720	21
Clarksburg	2,000	2,600	$5.20	30%	15%	15%	40%	720	21	936	28
Germantown	3,600	4,000	$5.20	30%	15%	15%	40%	1,296	38	1,440	42
Metropolitan Grove	5,100	5,700	$5.20	30%	15%	15%	40%	1,836	54	2,052	60
Shady Grove	22,900	26,400	$5.20	5%	55%	15%	25%	5,153	242	5,940	280

a. Based on Metrorail Mode Share at Montgomery County stations, and assumption that the majority of boardings at Shady Grove would be transfers.
b. Source: Frederick-Shady Grove Ridership and Revenue Study & Supplements, Cambridge Systematics 2019
c. 2 x Kiss-and-Ride Customers / Trains per Peak PM Hour / 0.85 = Estimated Kiss-and-Ride Spaces, Source: Station Area Planning Guide, WMATA 2017 Calculation assumes 60% of weekday boardings exit during peak period, and the peak hours are 5pm-7pm, and six-minute train frequency.
d. Calculation assumes a target utilization of 90%, and one vehicle per daily boarding customer that drove and parked

Station Site Plan

Urbana



The Urbana monorail station would be located at the existing MDOT SHA owned Urbana park-and-ride facility just east of the interchange of I-270 and Fingerboard Road and feature a platform elevated above the existing ground. Pedestrian connections to sidewalks on the north side of Fingerboard Road and Bennett Creek Avenue to the east would be provided. Bicycle access to the existing shared use path on the north side of Fingerboard Road would be provided, as well as parking facilities at the station. The existing bus stops within the park-and-ride facility would be reconfigured to accommodate the monorail station but would remain near the proposed station to minimize the distance users would have to travel. Structured parking for approximately 720 cars is proposed that would use available space within the existing parking lot. A total of 21 kiss-and-ride spots are proposed and would be added to the existing kiss-and-ride spots of the park-and-ride facility. Station access for buses would be from the existing access point on Fingerboard Road. Access for cars would be from the same existing access point and one new access point on Fingerboard Road.

This park-and-ride lot is currently served by three MDOT MTA bus lines; the 204, 505, and 515. All of which travel from the Frederick area to the suburbs on the north side of Washington, D.C.

Clarksburg

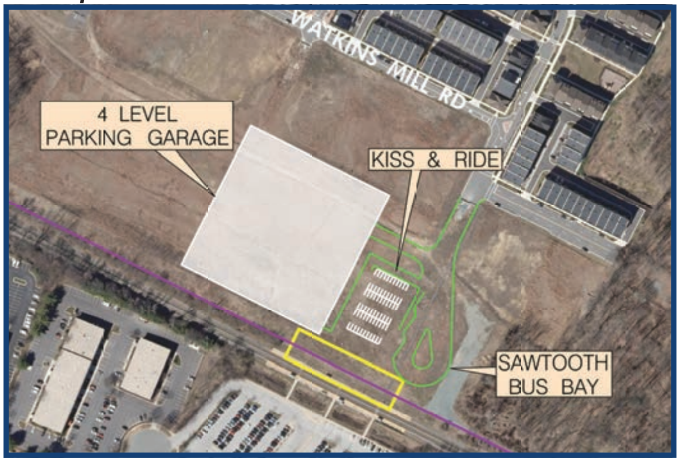
The Clarksburg monorail station would be located at a greenfield location between I-270 and Gateway Center Drive and feature an island platform elevated above the existing ground. Pedestrian connections to sidewalks on Gateway Center Drive would be provided. Bicycle access to the existing shared use path on the east side of Shawnee Lane would be provided, as well as parking facilities at the station. A new bus stop within the park-and-ride facility would be provided. At-grade parking for approximately 936 cars is proposed that would use available open space to the southwest of the proposed station. A total of 28 kiss-and-ride spots are proposed and would be located just north of the bus stop. Station access for buses and cars would be from two new access points on Gateway Center Drive.

Frederick

The Frederick monorail station would be located on the south side of East South Street and feature an island platform elevated above the existing ground. Pedestrian connections would be to adjacent sidewalks, which form part of the urban Frederick network. Bicycle connections to the proposed on-street facilities would be easily implementable. Bus stops within the station facility are proposed to minimize the distance that transit users would have to travel when transferring between systems. Three parking garages for at least 7,772 cars are proposed that are limited to six stories in order to minimize their visual impact on the surrounding area. An existing overhead electric transmission line means that two of the garages are separated from the station itself, but direct pedestrian access to the station would be provided. A total of 151 kiss-and-rides are proposed immediately adjacent to the bus stops. Station access for buses and cars would be from East South Street. No access from South East Street is proposed.

Rendering of Frederick monorail station

Metropolitan Grove



The Metropolitan Grove monorail station would be located at a greenfield location on the north side of the existing CSX tracks and Metropolitan Grove MARC station and feature an island platform elevated above the existing ground. Pedestrian connections to sidewalks within the existing Parkland community would be provided in addition to pedestrian access to the MARC station. Access to bicycle facilities on West Watkins Mill Road would be by way of the local Parkland streets. A new bus stop within the park-and-ride facility would be provided at the end of the proposed extension to Parkview Avenue. A parking garage for approximately 2,052 cars is proposed that would use available open space to the west of the proposed station. A total of 60 kiss-and-ride spots are proposed and would be located just north of the monorail station. Station access for buses and cars would be from the extension to Parkview Avenue.

Shady Grove

The Shady Grove monorail station would be located within the existing WMATA Shady Grove Metrorail station and feature an island platform elevated above the existing ground. Pedestrian connections would be provided by existing sidewalks within the Metrorail station. Bicycle parking would be provided and connections to the existing on-street facilities on Redland Road would be easily implementable. The proposed station would be above the existing bus stop immediately adjacent to the existing Metrorail tracks and access would be provided between that station and the monorail station. A parking garage for approximately 5,940 cars is proposed that would be located over the existing at-grade Metrorail station parking lot. A total of 280 kiss-and-rides are proposed between the monorail station and the parking garage. Station access for cars would be from the existing site access points on MD 355 (Frederick Road) and Somerville Drive. Buses would continue to use the existing bus stop at the Metrorail station.

Germantown

The Germantown monorail station would be located within the existing developed block between Aircraft Road and Crystal Rock Drive and feature an island platform elevated above the existing ground. Pedestrian connections would be to adjacent sidewalks which form part of the Germantown Town Center network. Bicycle parking would be provided and connections to the existing on-street facilities on Germantown Road and Crystal Rock Drive would be easily implementable. The proposed station would be adjacent to the existing Germantown Transit Center located on the west side of Aircraft Road and access would be provided between the transit center and the monorail station. A parking garage for approximately 1,440 cars is proposed that is limited to five stories in order to minimize their visual impact on the surrounding area. A total of 42 kiss-and-rides are proposed between the monorail station and the parking garage. Station access for cars would be from the existing site access points on Century Boulevard and Crystal Rock Drive. Buses would continue to use the existing Germantown Transit Center.

Rendering of Germantown monorail station

Access to Transit Stations

Integrated access to future transit systems improves service appeal and is beneficial for the long-term viability of transit systems. Potential monorail station locations were chosen due to their proximity to existing transit stations and systems. Some potential stations exploit the opportunity to use the facilities of existing transit systems, while others would require reasonable changes, such as new routes or revisions to existing routes in order to provide transit connectivity at the proposed stations. **Table 2.6** details the available or proposed available transit systems served at each monorail station. All services are buses unless otherwise noted. Italics denote nearby services that could be served by the monorail stations.

Table 2.6 – Available/Proposed Available Transit Systems

Monorail Station	WMATA	MDOT MTA	Local
Frederick	-	515 *Brunswick (MARC rail)*	40 (TransIT) *20, 51, 50 (TransIT)*
Urbana	-	204, 505, 515	-
Clarksburg	-	-	75 (Ride On)
Germantown	-	-	55, 61, 74, 75, 83, 97, 98, 100 (Ride On)
Metropolitan Grove	-	Brunswick (MARC rail)	61 (Ride On)
Shady Grove	Q1, Q2, Q5, Q6 Red Line (Metrorail)	201, 202, 505, 515	43, 46, 53, 55, 57, 58, 59, 60, 61, 63, 64, 65, 66, 67, 71, 74, 76, 78, 79, 90, 100 (Ride On)

Operations and Maintenance Analysis

Driverless Operations

Monorails can operate fully autonomously and it is likely that this feature would be included in this corridor. This system increases safety and reliability and reduces staff requirements. There are a number of train control systems that could be utilized for driverless operations.

Weather

Monorails are as susceptible to extreme weather conditions as other modes of transportation, despite the apparent benefits of an elevated alignment. Monorail systems can be negatively impacted by high winds, which could reduce passenger comfort and require vehicles to operate at lower operating speeds than normal. Monorail systems are less impacted by snow and ice than bus or rail if snow and ice melt systems are provided in the beam, adding cost and complexity, but deicing and snow clearing must be performed regularly if not. The risks to passengers travelling to and from stations remains the same and must be taken into consideration during extreme weather conditions.

During hot weather, vehicle breakdowns present a special concern as passengers must either remain in the vehicle until help arrives or walk along the emergency walkway to a stairway. Groups who are vulnerable in hot weather (such as the very young and the elderly) could face difficulty if a monorail vehicle encounters operational issues and cannot be reached in a short amount of time.

Routine Maintenance

Any transit system needs to be flexible enough to allow for routine maintenance operations. Routine cleaning and sanitizing of transit vehicles is required. Beyond daily cleaning, the COVID-19 pandemic has required transit systems to step up the health and safety protocols, including installing air filtering systems and disinfecting high-touch surfaces on a regular basis. The guide beam and power rail must be inspected and maintained on a routine basis. Vehicles are available to perform this function, which can also be used as a service platform, maintenance staff and equipment transport, and as a recovery vehicle for trains that break down.

The elevated guideway may have maintenance platforms for access, which are sometimes also used as an emergency evacuation route. If they are used as evacuation platforms, then they likely would not be ADA compliant.

The use of a recovery vehicle in lieu of a vehicle evacuation would allow passengers to safely remain in the train if the vehicles can be adequately ventilated in an emergency. A standard monorail train can be used as a recovery vehicle, but this assumes electrical power is available. An alternative would be a diesel recovery and maintenance vehicle.

Operations and Control Center

The monorail transit system must be controlled by a central control center, commonly referred to as an Operations Control Center (OCC). The OCC serves as a central control center that houses dispatcher employees and systems, the primary coordinator for train service, maintenance operations, access controls, and emergency response. The OCC should be housed in a building near the mainline and could be included within a maintenance facility.

Traction Power Systems

Monorail trains are generally powered by 750-volt DC. Power is brought to the trains utilizing a contactor rail, which is shielded and attached to the monorail beam. A contactor in the monorail engine picks up power from the rail. Power must be fed into the contactor from traction power substations along the alignment. Traction power substations must be placed in strategic locations, in order to provide the power needed. Detailed electrical loading design must be performed to finalize specific locations, but generally, these substations must be placed at either end of the alignment, and up to every mile in between. These substations are the size of a large tractor trailer, and need to be sited in a secure location, with ample power feeding into them. These substations can also house equipment needed for regenerative braking, which allows the monorail systems to generate power and feed it back to the grid, into batteries, or into other trains in the system during braking.

Maintenance and Storage Facilities

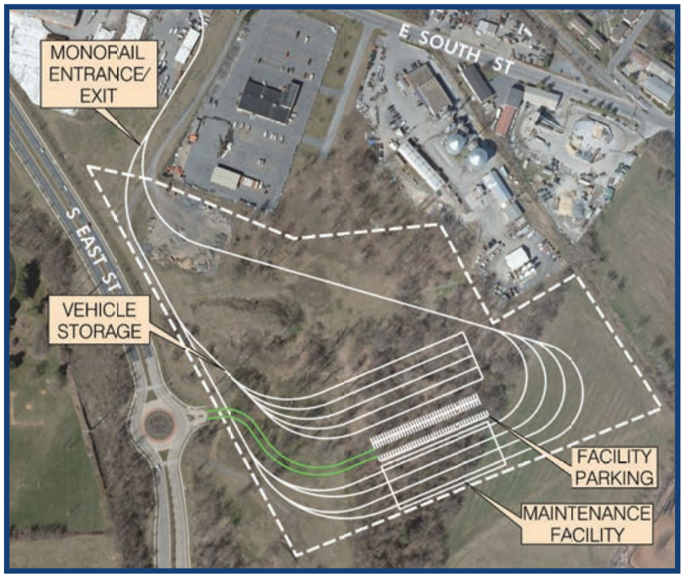
The monorail system must be maintained and operated by a large team and specialized equipment. Monorail vehicles must be stored off the alignment during off-peak hours, and overnight. Maintenance and vehicle storage facilities must be provided as part of this monorail system. Maintenance facilities can consist of light repair shops that can provide for cleaning and fueling, and light maintenance, up to a heavy repair shop that could perform major overhaul and repair work.

Vehicle storage should be as close to the terminal stations as possible, to reduce the travel time prior to service starts. The space requirement for storage may require two facilities, one close to either end. These two facilities may be completely redundant, or one facility could house light repair service only, and the other a full repair facility. For the purposes of this Feasibility Study, two facility locations were identified that could be completely redundant, or all services could be combined into one location.

Facility Site Plans

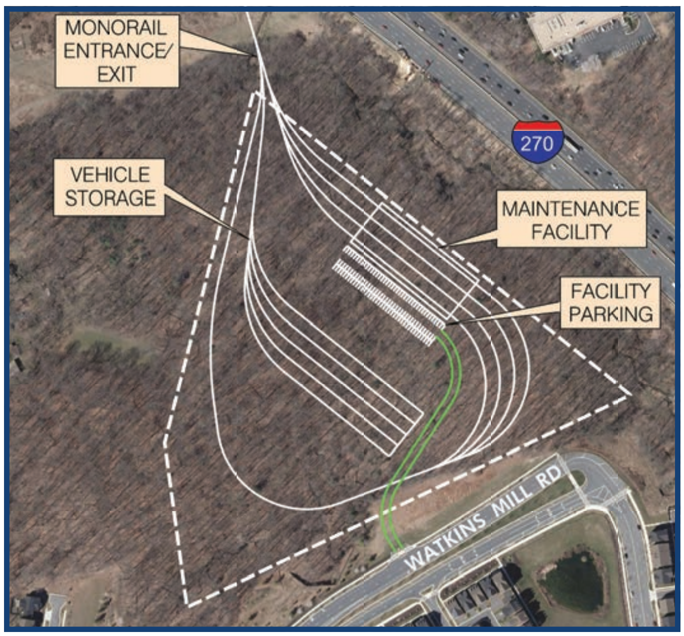
Two locations were identified for the potential maintenance and storage yards needed for the monorail. Facilities were needed in the East northern and southern termini of the alignment. The locations were identified based on areas large enough to fit the facility and vehicle storage, where it would have the least amount of potential impacts, and where the monorail could easily be designed to access the location. Facility sizes were based on the size of the existing WMATA Shady Grove Rail Yard near Shady Grove Road. Facility shapes were based on size and best fit in the existing right-of-way but could be adjusted for viability and access.

Figure 2.7 – Northern Maintenance and Storage Yard



The northern maintenance and storage yard is in the Frederick area, just south of the proposed Frederick Station along East South Street and South East Street. This area is an undeveloped piece of land located behind partially occupied industrial buildings.

Figure 2.8 – Southern Maintenance and Storage Yard



The southern maintenance and storage yard is in the Gaithersburg area near the proposed Metropolitan Grove Station. This area is an undeveloped piece of land that has few surrounding residential properties and is adjacent to I-270.

Environmental Inventory

A desktop analysis was conducted, compiling a baseline environmental inventory, to identify natural resources that might be affected by the proposed project. This effort involved a review of existing available scientific literature and readily available Geographic Information System (GIS) databases. Based on the minimum width required to accommodate the monorail envelope, a corridor was evaluated along the centerline of the alignment to capture potential natural resource impacts. No detailed fieldwork, such as wetland delineations, was completed for this Feasibility Study. GIS database information was obtained from Maryland's Environmental Resources and Land Information Network (MERLIN), which is provided by the Maryland Department of Natural Resources (DNR), and Montgomery County Department of Planning.

Specific information regarding data gathering sources and approach are presented within the discussion of each resource in the following sections. All resources are included on the base map showing the proposed monorail alignment included in **Appendix D**.

Waters of the U.S. Including Wetlands

A desktop analysis was conducted to identify general locations and extents of potential waterways and wetlands within the potential monorail alignment. The locations of these resources were determined based on a review of United States Fish and Wildlife Service (USFWS) digital National Wetlands Inventory (NWI) maps, DNR Wetlands maps, and the DNR Rivers and Streams dataset.

The monorail alignment under consideration is located within the Potomac River drainage basin and crosses four subwatersheds. These subwatersheds include, Rock Creek, Potomac River, Seneca Creek, and Lower Monocacy River (Maryland iMAP GIS Data Catalog [MD iMAP]). The desktop analysis identified both wetlands and waterways within the proposed alignment. A total of 15 named waterways were identified within the limits of the alignment and are listed in **Table 2.7**.

Table 2.7 – Waterways Identified Within the Proposed Alignment

Stream Name	
Arundel Branch	Monocacy River
Bennett Creek	Muddy Branch
Crabbs Branch	Quarry Branch
Great Seneca Creek	Soper Branch
Gunners Branch	Tabler Run
Little Bennett Creek	Urbana Branch
Little Seneca Creek	Wildcat Branch
Long Draught Branch	

Floodplains

Digital Federal Emergency Management Agency (FEMA) flood-plain data from the Digital Flood Insurance Rate Map (DFIRM) Database was obtained from MERLIN and the proposed alignment was overlaid to determine the location and extent of floodplain areas. Within the proposed monorail alignment, FEMA-designated 100-year floodplains were identified along Long Draught Branch, Gunners Branch, Little Bennett Creek, Bennett Creek, and Monocacy River.

Forests

High resolution tree canopy cover mapping (2011), obtained from MD iMAP, was utilized to determine the location and extent of forest stands and dense vegetative cover. To increase the accuracy of this dataset, 2017 aerial imagery (six-inch resolution) was used to help identify vegetative cover types.

The monorail alignment would cross a variety of forest cover types in the study area including mature forests, transitional forests, nearly monotypic fringe stands, open fields containing grasses and other volunteer vegetation, and maintained areas associated with residential, commercial, and institutional land uses. Other than the open space provided by the human-maintained landscapes, the majority of vegetative cover is deciduous forest, found principally along the edge of major highways or in fragmented stands of varying size surrounded by residential and commercial uses. Non-forested vegetative cover is limited to open fields that are either fallow or serving as maintained utility corridors. The extent of tree canopy within the proposed monorail alignment is shown on the base map for the proposed monorail alignment included in **Appendix D**.

Special Protection Areas (SPAs)

SPAs are areas within a watershed that have high quality natural features, such as streams or wetlands, which need special protection measures beyond existing laws and regulations to ensure that their high quality will be maintained. The Montgomery County Special Protection Areas Law was established to provide special protection measures within these areas for new development and land use under Montgomery County Code Chapter 19, Article V (Water Quality Review-Special Protection Areas, Section 19-67).

Several regulations and guidelines have been established for land development projects within SPAs. The Director of Environmental Protection is responsible for implementing a stream monitoring program within the watershed before, during, and after each development project that takes place in the SPA.

Digital SPA data was obtained from the Montgomery County Department of Planning website and overlaid in GIS to determine if the proposed monorail alignment would be in the vicinity of these high-quality areas. Currently, the County has classified six areas as a SPA. The monorail alignment would cross two of these areas. These areas include the Clarksburg SPA and the Ten Mile Creek SPA, which are both located in western Montgomery County.

Sensitive Species Project Review Areas (SSPRA)

Digital mapping maintained by the DNR Wildlife and Natural Heritage Service, was used to identify the potential for rare, threatened, and endangered species within the vicinity of the proposed alignment. This data layer primarily represents the general locations of documented rare, threatened, and endangered species; however, the data layer also includes other types of regulated areas of concern statewide, including natural heritage areas, listed species sites, other significant habitat areas, nontidal wetlands of special state concern, and geographic areas of particular concern.

Land Use Analysis

A desktop analysis was conducted to evaluate the compatibility of the proposed project with local planning goals. This effort involved a review of the most recently adopted comprehensive plans and readily available GIS databases. The monorail corridor, adjacent land areas, and station sites were evaluated to identify land use compatibility. GIS database information was obtained from the Maryland Department of Planning (MDP), Frederick County, Montgomery County, City of Frederick, and the City of Gaithersburg.

Comprehensive Master Plans

Numerous comprehensive and master plans were reviewed to evaluate whether the proposed monorail would be consistent with their goals and objectives. This analysis reveals that the monorail project supports, and is consistent with, numerous planning efforts. A sample of these efforts are noted below, along with the relationship to this Feasibility Study.

- **2010 City of Frederick Comprehensive Plan – Policy TE 5:** Publicly support projects developed by MDOT SHA within the City Limits: c. I0270/US 15 Multimodal/Alternatives Analysis.
- **East Corridor Small Area Plan:** Covers the location of the potential Monorail Frederick area terminal.
- **The Livable Frederick Master Plan:** Ensure that the County provides access to a sustainable and resilient multimodal transportation network to move people, goods, and services to support the needs of Frederick County residents and economic, business, and educational activities throughout Frederick County.
- **Frederick County Master Transportation Plan:** Supports the preservation of right-of-way for a transitway along the I-270 corridor with connection to the Shady Grove Metro station.
- **City of Gaithersburg 2009 Master Plan – Transportation:** Supports a transit connection between Clarksburg and Shady Grove.
- **1994 Clarksburg Master Plan and Hyattstown Special Study Area:** Recommends accommodating a regional transitway linking Clarksburg with Frederick to the north and Shady Grove to the south.
- **2009 Germantown Employment Area Section Plan:** Considers a transit route linking Germantown to the northern part of Montgomery County as a necessity to fulfilling the Plan's vision.
- **2006 Shady Grove Sector Plan:** Includes provisions for accommodating a transitway connection to the existing Shady Grove Metro Station.

Existing Land Use & Zoning

Land use is a process of organizing the use of land to meet occupant's needs, while respecting the land's capabilities. Land use planning balances private property rights with desired community character. Zoning defines the rules and laws governing what and where people and institutions can and cannot build. Zoning is a planning control tool and the way governments regulate the physical development of land based on its usage, purpose, etc.

Land use patterns are regularly considered during the development of transportation projects, not only because they influence underlying traffic and transit patterns, but also because changes to the transportation system can themselves alter land use characteristics and, therefore, community activity. In urban areas, this feedback loop is buffered by the amount of development that is already present. In more rural areas, development is sparser and there is the potential for proposed improvements to generate a more substantial effect. **Figure 2.9** identifies the region's existing land uses, **Figure 2.10** identifies the region's generalized zoning, and **Figures 2.11-2.16** show the existing land use and zoning patterns surrounding each of the station locations.

Figure 2.9 – Existing Land Use

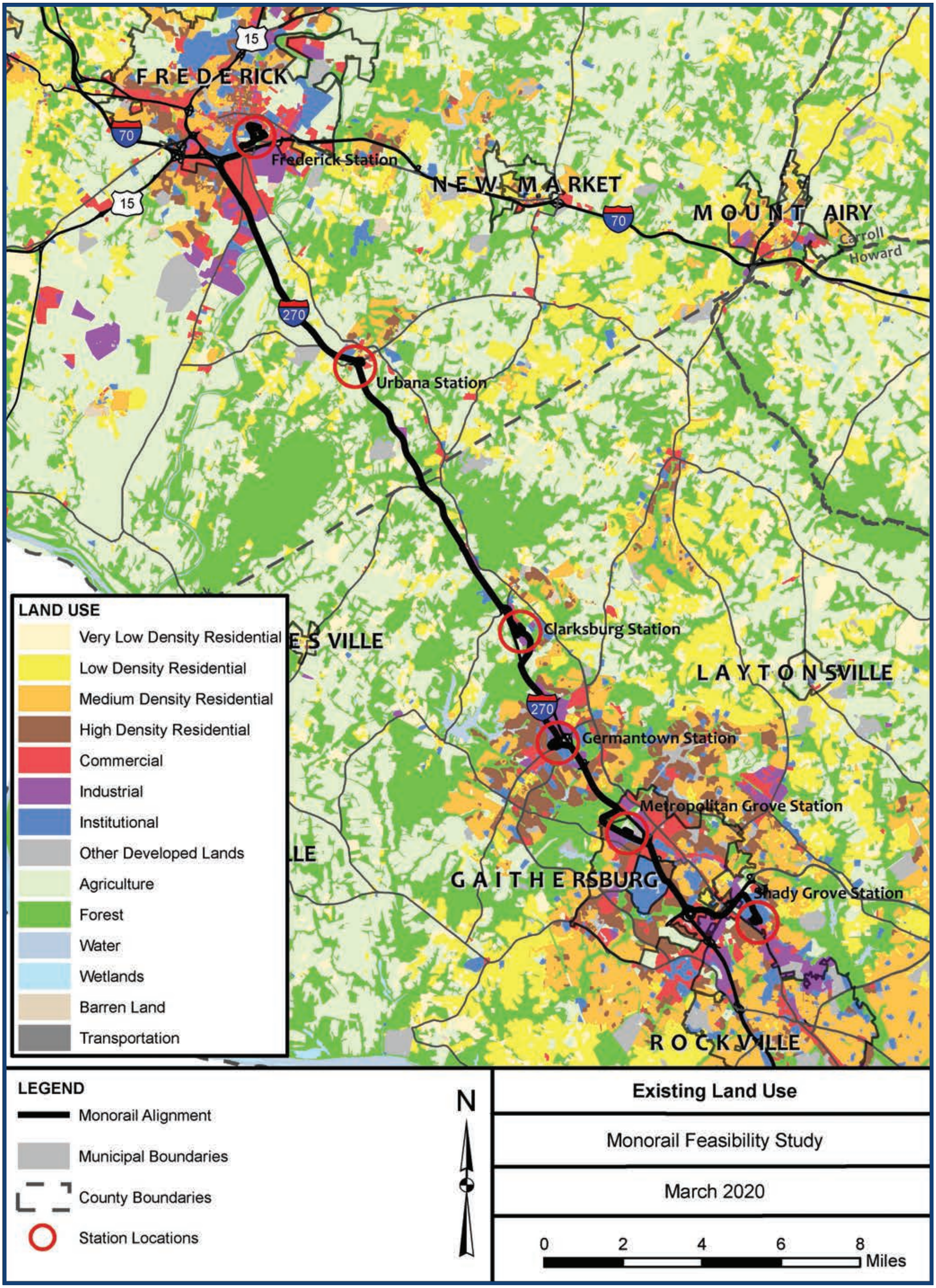


Figure 2.10 – Generalized Zoning

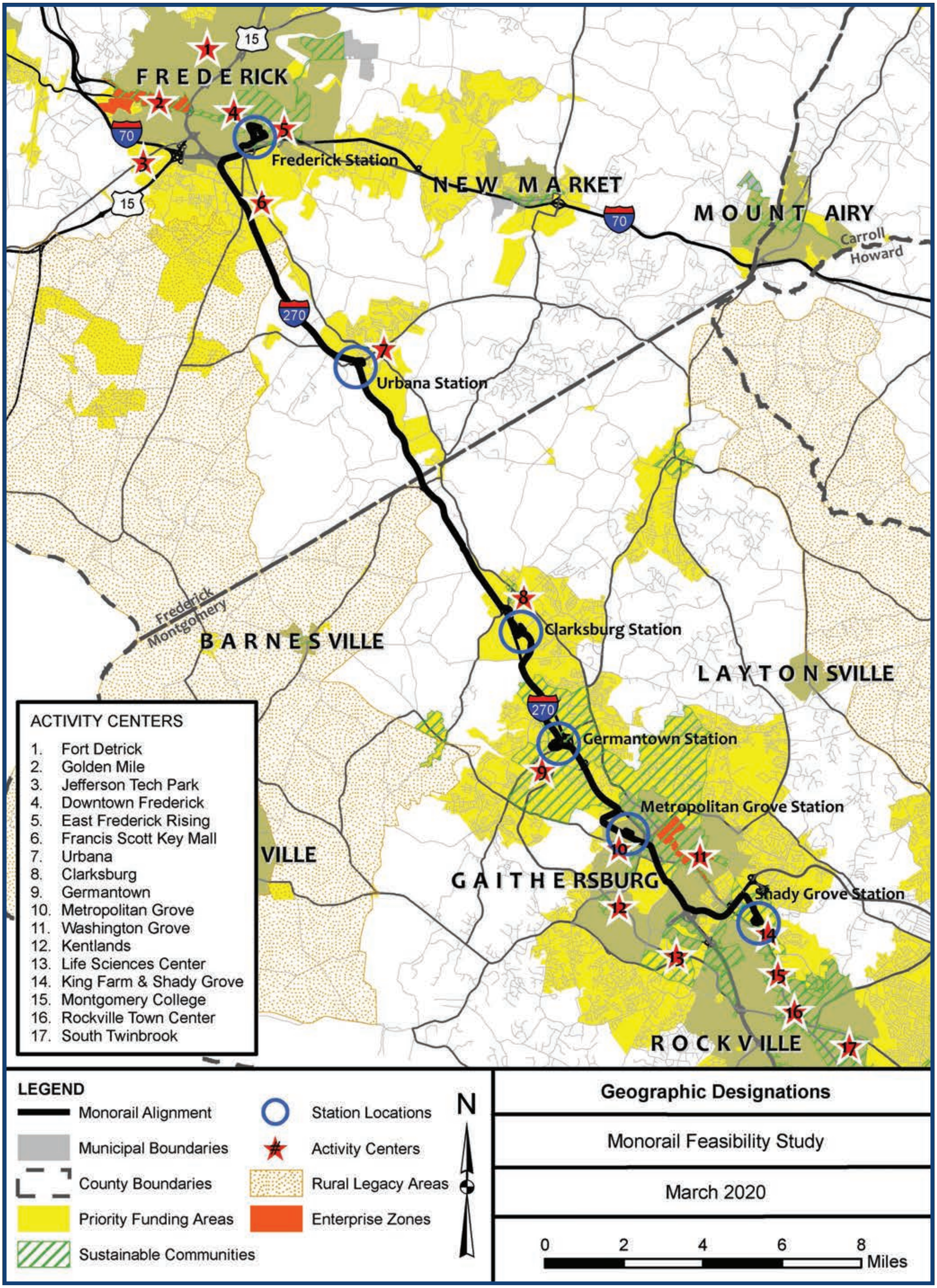
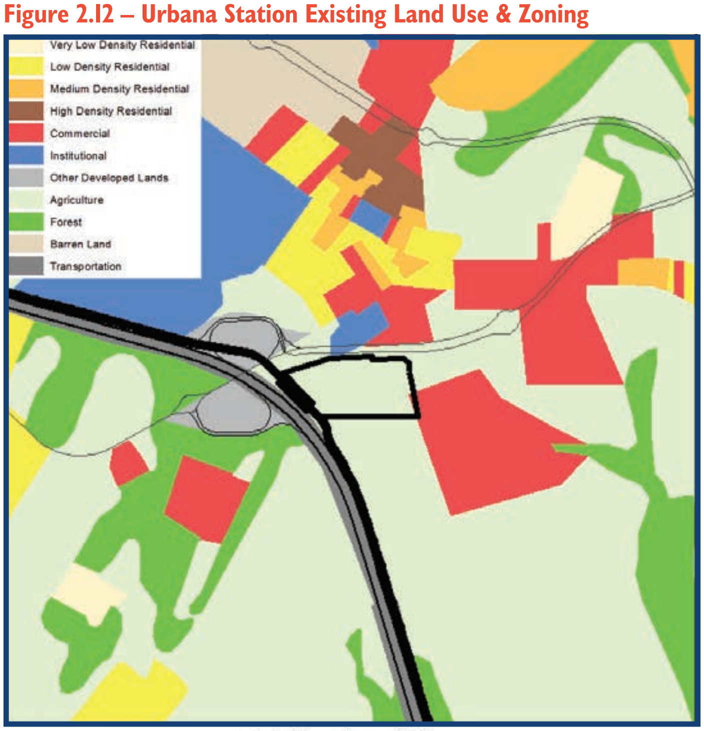


Figure 2.11 – Frederick Station Existing Land Use & Zoning

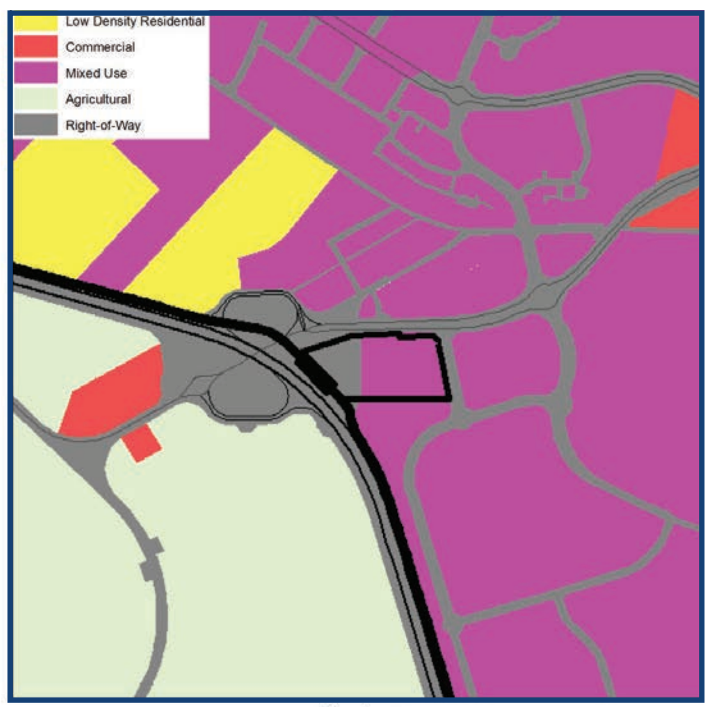
Existing Land Use

Zoning

Figure 2.12 – Urbana Station Existing Land Use & Zoning



Existing Land Use



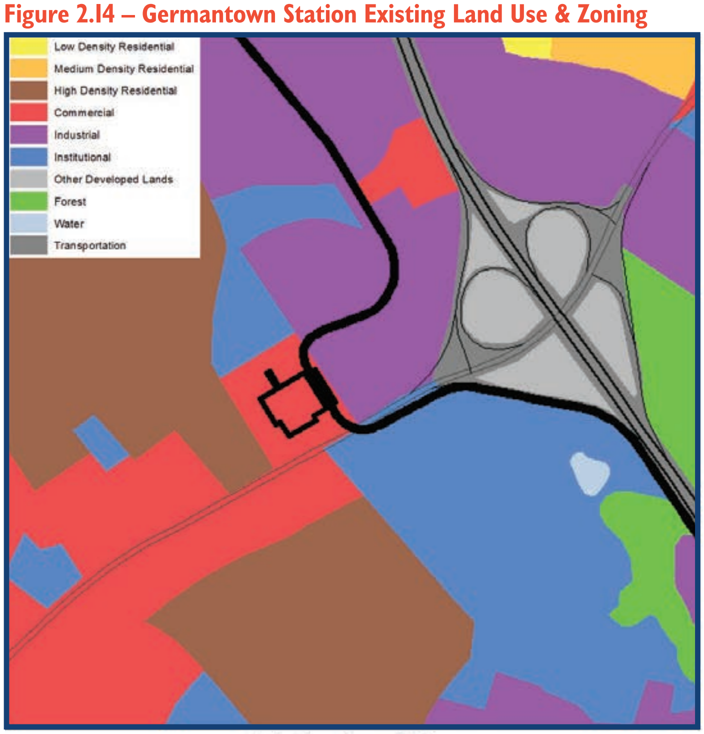
Zoning

Figure 2.13 – Clarksburg Station Existing Land Use & Zoning

Existing Land Use

Zoning

Figure 2.14 – Germantown Station Existing Land Use & Zoning



Existing Land Use

Zoning

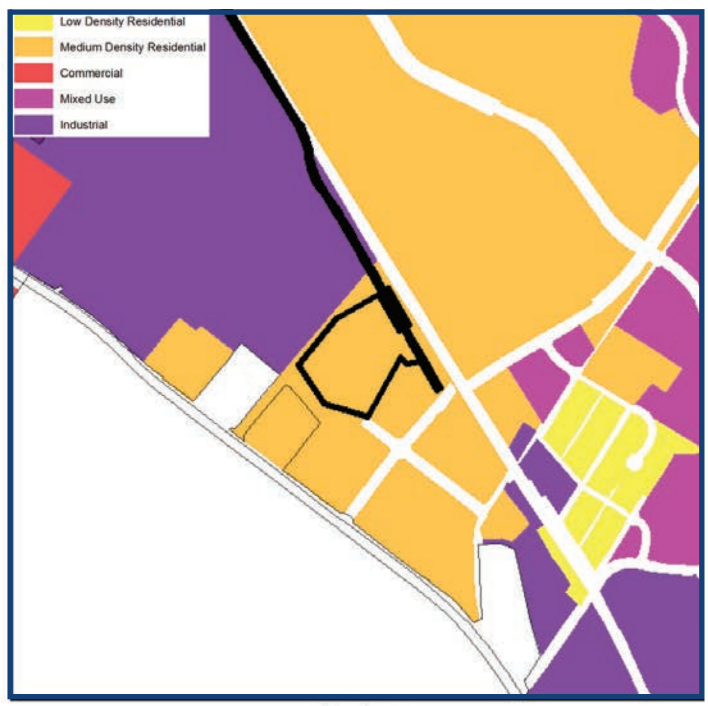
Figure 2.15 – Metropolitan Grove Station Existing Land Use & Zoning

Existing Land Use

Zoning

Figure 2.16 – Shady Grove Station Existing Land Use & Zoning

Existing Land Use



Zoning

Priority Funding Areas (PFAs)

In 1997, the Maryland General Assembly passed a package of smart growth legislation that directs the State to target programs and funding to support established communities and locally designated growth areas, as well as to protect resource and rural areas. One component, the Priority Funding Areas (PFA) Act, directs State funding for growth-related infrastructure (e.g., highways and transitways) to PFAs, giving a geographic focus to the State's investment in growth-related infrastructure. By requiring all counties to identify and map areas that meet the legislation's requirements, the PFAs identify existing communities and places where local governments want State funding support for existing and planned growth.

Digital PFA data from MDP was obtained from MD iMAP. Overlaying the proposed alignment and station locations in GIS showed seven PFA areas would be crossed and all six station locations would be located within a PFA, where development and revitalization is encouraged (see **Figure 2.17**).

Activity Centers

Activity Centers are locations that will accommodate the majority of the region's future growth and play a central role in achieving prosperity, sustainability, accessibility, and livability goals. They include existing urban centers, priority growth areas, traditional towns, and transit hubs.

Digital Activity Center data from Metropolitan Washington Council of Government (MWCOG) was obtained from MD iMAP. Overlaying this data in GIS showed all six station locations were located within Activity Centers and 17 Activity Centers, overall, were in close proximity with the proposed alignment (see **Figure 2.17**).

Sustainable Communities

The Maryland Department of Housing and Community Development's (DHCD) Sustainable Communities Program is a place-based designation that offers a package of resources to support strategies for community development, revitalization, and sustainability. The program provides local governments with a framework to promote environmentally, economically, and socially responsible growth and development in existing older communities. Designation as a Sustainable Community places special emphasis on infrastructure improvements, multimodal transportation, and development to strengthen existing communities.

Digital Sustainable Community data from DHCD was obtained from MD iMAP. Overlaying this data in GIS showed four designated Sustainable Communities that include either stations or the overall alignment: City of Frederick, Clarksburg, Gaithersburg, and Germantown (see **Figure 2.17**).

Rural Legacy Areas (RLA)

The Rural Legacy Program was created in 1997 to protect large, contiguous tracts of Maryland's most precious cultural and natural resource lands through grants made to local applicants.

The proposed monorail alignment transects two RLAs (see **Figure 2.17**):

- Carrollton Manor: This RLA creates an agricultural reserve/greenway through Central Maryland, connecting two other RLAs: the Mid-Maryland Montgomery RLA and Mid-Maryland Frederick RLA. This area includes farmland, river systems, scenic byways, and historic communities, and supports the local agricultural economy that produces beef, milk, hogs, horses, and turkeys, as well as corn, wheat, soybeans, alfalfa, and a variety of vegetables. The Potomac National Heritage River and Monacacy Scenic River are within the RLA, as are two scenic byways – Route 15 and Route 28. Civil War battlefield sites, the C&O Canal, and the land of Declaration of Independence signer Charles Carroll are part of the historic significance of Carrollton Manor.
- Mid-Maryland Montgomery: This RLA protects farmland, open space, and natural resources located within the heart of the County's agricultural reserve. The area contains large contiguous tracts of rural lands, numerous agricultural operations, and forest resources rich in both aquatic and terrestrial wildlife. Conservation within the RLA provides water quality benefits to the Potomac River, a Maryland-designated Scenic River.

Enterprise Zones

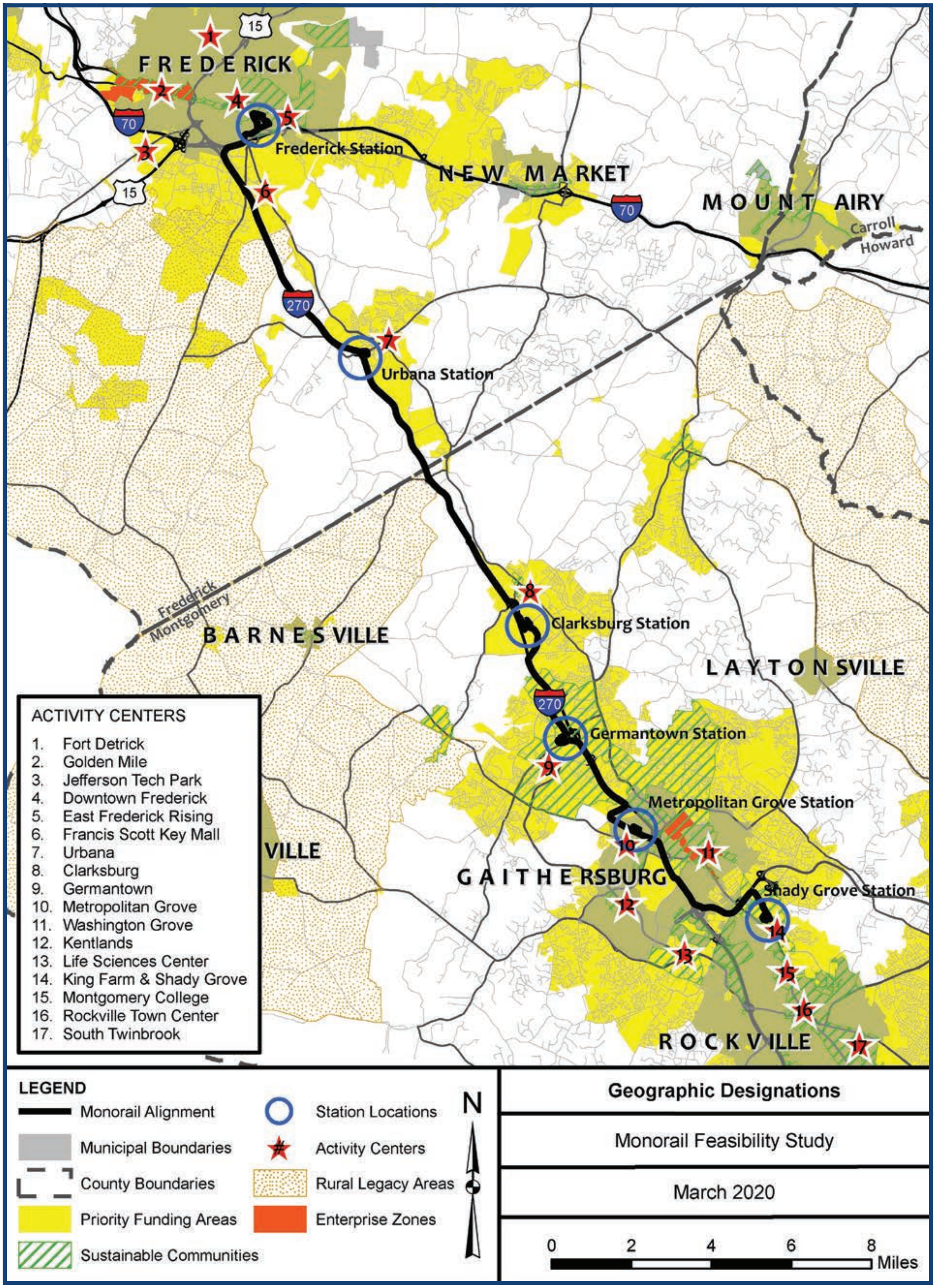
Enterprise Zones are geographic areas that are granted special tax breaks, regulatory exemptions, or other public assistance to encourage private economic development and job creation. They are often established in neighborhoods that have experienced a decline in essential businesses, quality housing, or both. Incentives are often customized to entice particular industries or companies to the area with hopes of creating jobs, boosting tax revenues, and increasing overall economic activity.

Digital Enterprise Zone data from the Maryland Department of Commerce was obtained from MD iMAP. Overlaying this data in GIS showed that the proposed alignment is in close proximity to the Old Town Enterprise Zone within Gaithersburg (see **Figure 2.17**).

Geographic Designations

Figure 2.17 provides graphical representations of the geographic designations discussed in this section.

Figure 2.17 – Geographic Designations

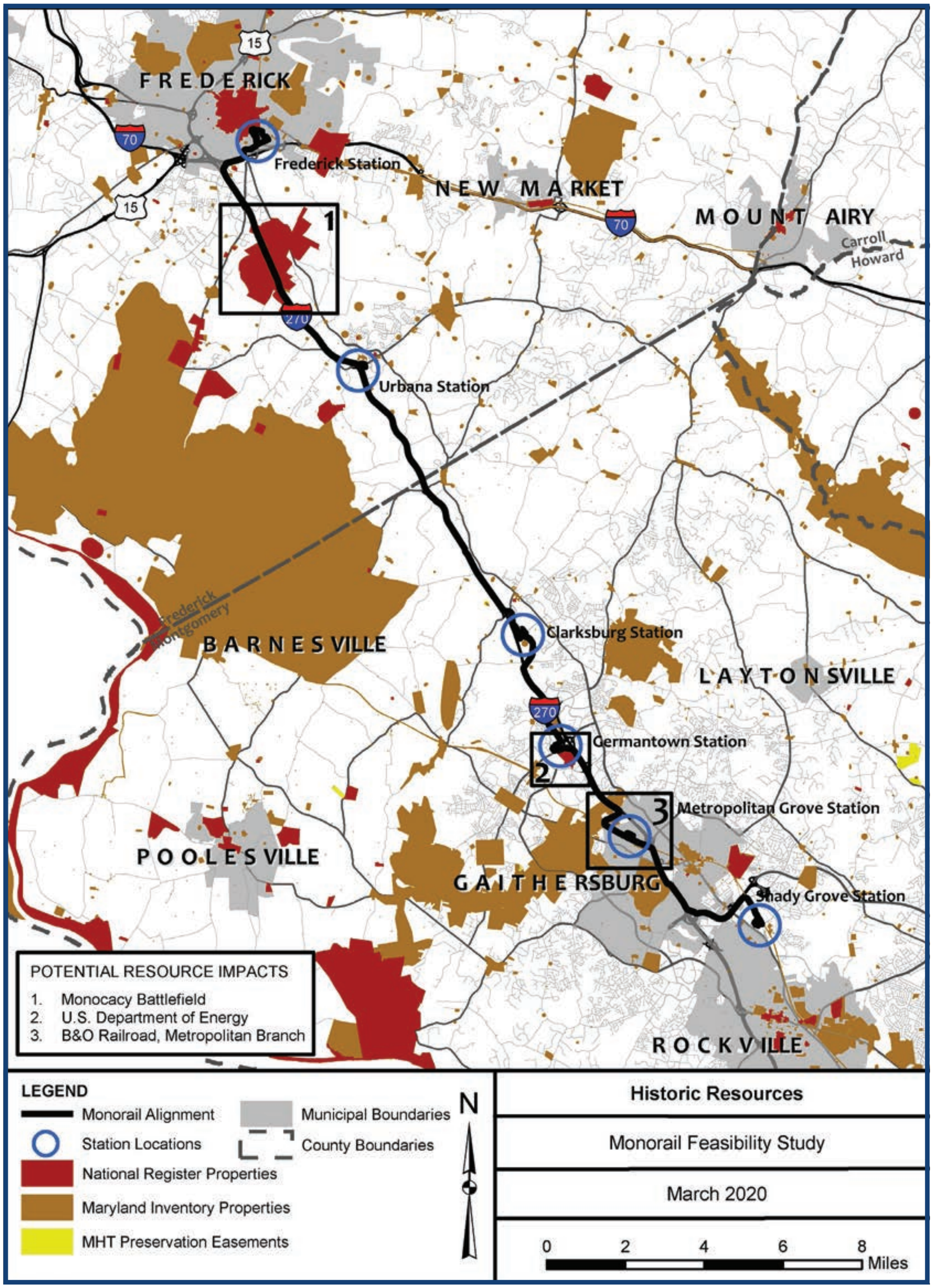


Historic Resources

The National Historic Preservation Act (NHPA) [16 USC §470) defines a historic property as any "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion in, the National Register of Historic Places (NRHP), including artifacts, records, and material remains related to such a property or resource." For the purposes of this analysis, historic properties are defined as archaeological sites and architectural resources eligible for listing or listed in the NRHP.

GIS data obtained from MDP through MD iMAP was evaluated to determine the presence of historic resources (see **Figure 2.18**). Three large historic resources were identified along the proposed alignment: the Monocacy Battlefield and U.S. Department of Energy properties that are listed on the NRHP and the Metropolitan Branch of the B&O Railroad, which is listed on the Maryland Inventory of Historic Properties (MIHP).

Figure 2.18 – Historic Resources



Growth Potential

Demographics

Over the past few decades, the National Capital Region's healthy economy has fueled consistently strong population and job growth and that trend is expected to continue well into the future. The COVID-19 pandemic has created economic uncertainty, but the long-term effects are unknown. The pandemic's impacts continue to challenge all aspects of life – from public health to individuals' employment status, the full breadth of this disease's effects have yet to be realized. Since 1970, the region's population has nearly doubled and the total number of jobs in the region has grown at an even faster rate. From 2000-2017, the region gained over one million residents at a steady rate (from 4.4 million to 5.6 million) over the 17-year span. Total regional employment has grown by almost 400,000 jobs from 2000-2016, although the recession of the late 2000s slowed growth and resulted in reductions in regional employment for a few years. The economy has since recovered and the region is adding more jobs every year.

Today, there are 5.7 million people living in the National Capital Region. By 2045, that number is expected to grow to more than 6.9 million, an increase of 23%, according to MWCOG's Cooperative Forecasts Round 9.1. The number of jobs in the region will grow from 3.3 million to 4.3 million in 2045, an increase of 29%. Changes to each of the involved jurisdictions can be found in **Tables 2.8 - 2.10**.

Both population and employment density are important statistics when considering whether transit can be supported. The standard minimum densities used by FTA to support light rail transit are 9+ persons per acre or 30-40 employees per acre. The region as a whole has a population density of 1.81 persons per acre and 0.94 employees per acre, well below FTA's standard minimum densities. When looking at just the ½-mile surrounding each of the proposed monorail stations, the average population density is 7.46 persons per acre and 7.16 employees per acre; this indicates that the areas around the proposed stations are considerably more dense than the region as a whole, but still below FTA standard minimum densities.

While these density statistics on their own do not support light rail-style transit, the overall population and employment statistics and forecasts were incorporated into the ridership forecast developed for the *2019 Ridership Study* and discussed later in this chapter.

Future Land Use

Future land uses are identified in the respective jurisdiction's comprehensive master plans. Identifying future land uses provides essential guidance for local decision-making regarding a community's future growth and character. It provides property owners and the overall community predictability in the future built environment and identifies a future build-out scenario supported by the community vision that is based on market realities.

Figure 2.20 identifies the region's overall future land uses, while **Figure 2.21** provides a closer look at future land uses surrounding station locations. As shown, all of the station locations are located in areas designed for higher intensity uses (e.g. institutional, industrial, commercial, mixed use), except for the Clarksburg Station, whose future land use is designated as agricultural.

Table 2.8 – Population Growth Forecasts (Thousands) (2015-2045)

Jurisdiction	Population		Growth		MWCOG Region Share
	2015	2045	No.	% Change	
Frederick County	246.5	344.1	97.6	39.6%	6.4%
Frederick	70.4	93.1	22.7	32.2%	1.5%
Montgomery County	1,015.3	1,223.3	208.1	20.5%	13.6%
Gaithersburg	67.1	89.3	22.2	33.0%	1.4%

Table 2.9 – Household Growth Forecasts (2015-2045)

Jurisdiction	Population		Growth		MWCOG Region Share
	2015	2045	No.	% Change	
Frederick County	89.5	131.2	41.7	46.6%	6.4%
Frederick	27.3	36.7	9.5	34.8%	1.5%
Montgomery County	374.9	461.9	87.1	23.2%	13.4%
Gaithersburg	24.7	33.4	8.8	35.5%	1.4%

Table 2.10 – Employment Growth Forecasts (2015-2045)

Jurisdiction	Population		Growth		MWCOG Region Share
	2015	2045	No.	% Change	
Frederick County	111.8	145.5	33.7	30.1%	3.0%
Frederick	50.7	62.0	11.3	22.2%	1.0%
Montgomery County	520.2	678.8	158.6	30.5%	14.2%
Gaithersburg	46.4	65.7	19.3	41.5%	1.7%

Figure 2.20 – Future Land Use

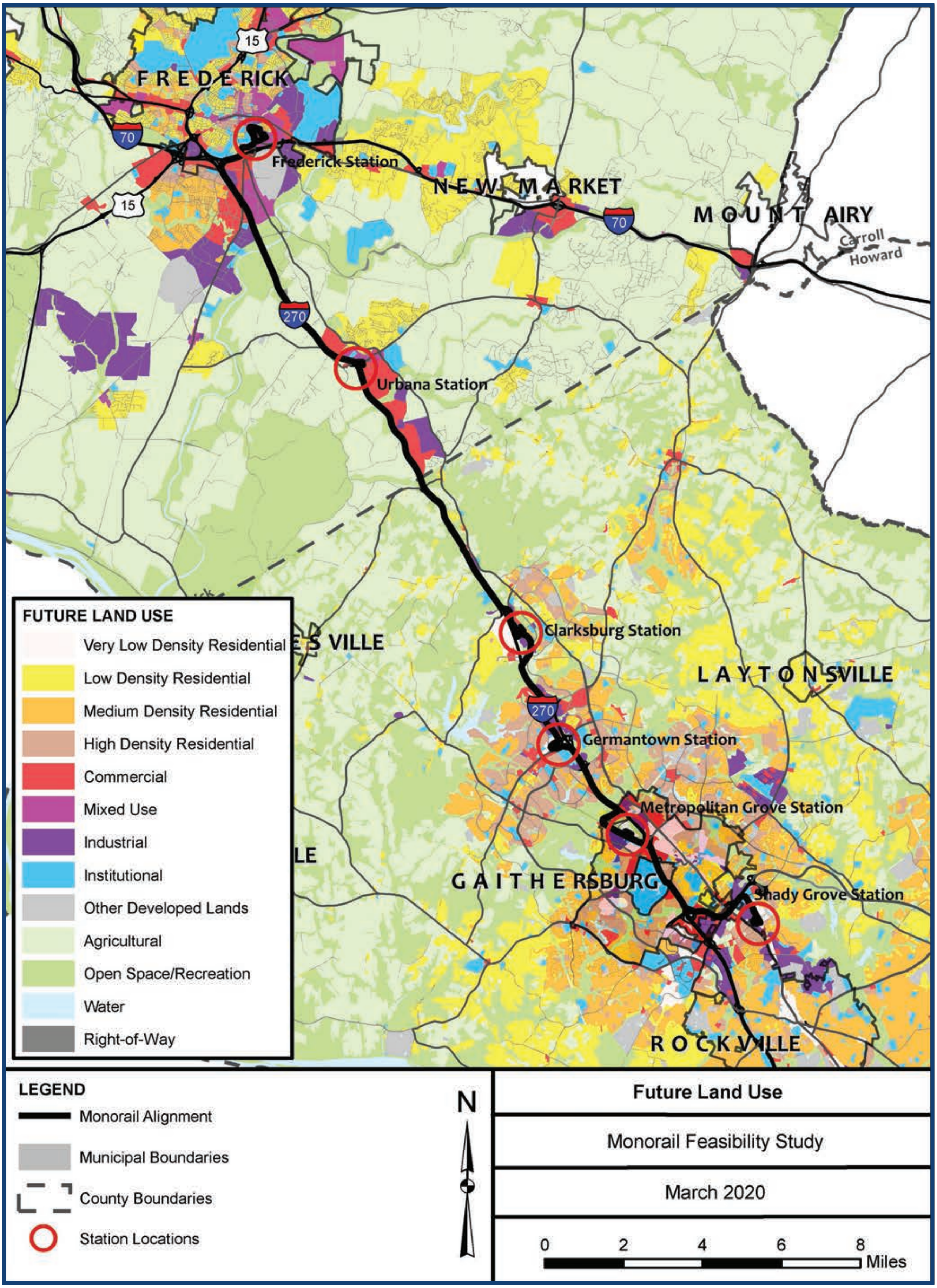


Figure 2.21 – Future Land Use Surrounding Station Locations

Transit Oriented Development (TOD) Potential

TOD is a form of urban planning that emphasizes development within walking distance of transit stations. TOD is generally mixed-use with residential, commercial, retail, and recreational uses co-existing within the same geographical area. A guiding philosophy of TOD is to prioritize pedestrian, bicycle, and transit modes of transportation over private automobiles.

Opportunities for TOD at monorail stations are numerous. The proposed Frederick, Germantown, and Shady Grove stations are within existing urban or suburban environments. These stations represent a high favorability for TOD due to existing transit services and pedestrian and bicycle facilities in the local vicinity. The Urbana and Clarksburg stations represent a high favorability for new TOD due to their greenfield locations and the opportunity to provide improved facilities for pedestrians and bicyclists alike.

Ridership Analysis

The monorail alignment described earlier in this section was used for an operational efficiency analysis. Alignment efficiency is a measure of how quickly transit passengers can make the trip from origin to destination. Efficiency is a function of alignment length, vertical profile grades, horizontal curves, the number of stations, and the operating characteristics of the vehicles. The analysis of the alignment for this Feasibility Study included the development of a range of inputs that reflect the design criteria and operational assumptions used. The analysis includes a travel time analysis, potential ridership analysis, and system capacity analysis, based on the *Maryland Constrained Long Range Plan*, which in 2045 includes I-270 highway improvements including managed lanes, and does not address ridership impacts due to changes in health requirements. This ridership analysis was conducted prior to the COVID-19 pandemic and the long-term impacts on transit ridership has yet to be realized. The effects of the pandemic on transit use and traffic volume may be long lasting, but cannot be determined at this time. This analysis optimistically assumes that traffic growth and patterns will return to normal, but that may not occur in the time frames noted.

Travel Time Analysis

The travel time for monorails is a calculation based on a number of factors, including the limitations of the monorail technology, alignment characteristics, and boarding and alighting durations, commonly referred to as dwell time. The travel time analysis is a calculation of the speed of the vehicle along the entire length of the alignment, to determine the time needed to travel from one end to the other. This calculation considers acceleration, top speed limitations of monorail trains, and dwell time.

While current US monorail technology facilitates speeds of 50 mph, some monorail technology across the globe may allow for speed greater than 50 mph. This Feasibility Study analyzed two top speed scenarios, 50 mph and 65 mph. The lower speed was based on current operating systems in the US, while the higher speed was based on technology enhancements currently in use around the globe. This top speed cannot be achieved throughout the entire alignment. Monorail trains need to slow down to enter stations, stop at stations, and slowdown for some curves, so the average speed would be considerably lower.

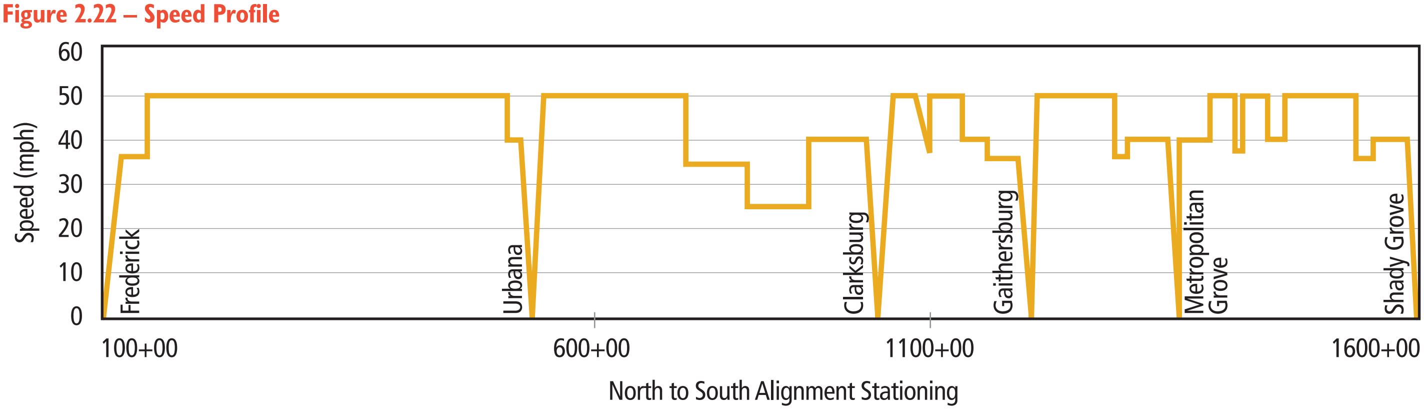
Limits of lateral acceleration of the monorail vehicles in curves are affected by the design of the monorail and guide beam, as well as rider comfort. Superelevation, or the tilting of the guide beam toward the center of a curve, can counteract the centrifugal force from lateral acceleration, allowing the train to travel at high speed through curves. There is a limit of superelevation, which is largely based on the comfort of riders when the train travels at lower speeds. At low speeds with a high amount of superelevation, passengers can feel overly tilted towards the inside of a curve. For this Feasibility Study the superelevation limit is set at 8%. This limits the speed a monorail train can travel through some curves to less than 50 mph.

Linear acceleration and deceleration limits are affected by both the monorail technology, as well as rider comfort. The physical limitation of the rubber tires, motors, and braking systems of monorail trains can be a limitation for how quickly a train can accelerate and brake. Monorails generally use a high voltage electrical system to drive the motors, and a regenerative braking system to recapture energy from braking. Rider comfort is an important consideration as well, as quick jerks of acceleration may provide an unsafe situation. The design criteria used for this Feasibility Study has set the acceleration limit at 1 m/s^2.

Station dwell times, or the time that the monorail train is stopped to allow passengers to get on and off the train, affect the overall travel time. This may be a variable time, based on actual ridership at the time, but transit agencies seek to reduce this time as much as possible. Dwell time is generally higher at terminal and transfer stations. WMATA Metro Red Line trains have average dwell times in the range of 30 to 75 seconds, according to the *Metrorail Capacity White Paper, WMATA 2015*. This monorail Feasibility Study analyzed two scenarios for dwell time, 30 seconds and 60 seconds. The system can be automated with driverless operations, which provides reliable service that can reduce station dwell time over traditional transit systems.

All of these factors were considered, and a speed profile was calculated for the alignment. A graphical representation of the more conservative speed along the alignment is presented in **Figure 2.22**. This calculation results in a theoretical end to end travel time of 46 minutes, at an average speed of 37 mph, which is less than the peak hour drive time.

Figure 2.22 – Speed Profile



Ridership Forecast Methodology

Forecasting the number of passengers that may use this monorail system is an important factor in determining the viability of this system. Ridership forecast models account for many factors, such as population demographics, population density, future growth, major trip destinations like job centers and housing, connections to the local transportation network, and attractiveness of the transit system.

As part of their study, The High Road Foundation completed a ridership study and documented it in the *2019 Ridership Study,* which can be found in **Appendix A**. To evaluate the ridership forecast efficiently and independently, MDOT requested the National Capital Region Transportation Planning Board (TPB) to review and comment on The High Road Foundation's *2019 Ridership Study*. The TPB is the federally designated metropolitan planning organization (MPO) for metropolitan Washington. The TPB works with local, state, regional, and federal partners to coordinate future plans, by providing data and analysis to decision makers, and coordinating regional programs to advance safety, land-use coordination, and more. The TPB provided MDOT with a memorandum that documents their review, titled *TPB Staff Assessment of Cambridge Systematics Report Prepared for The High Road Foundation,* which can be found in **Appendix B**.

The TPB memorandum stated that, "upon careful review of the report, TPB staff have determined that the [High Road] modeling analysis was conducted using state-of-the-practice tools and methods used elsewhere in the region, and that the monorail ridership estimates are reasonable given the assumptions. However, the reasonableness of assumptions may need to be evaluated further given that there are very few existing similar monorail projects operating anywhere in the world at this time." The assumptions used in the original ridership study may have been overly optimistic, so additional sensitivity analysis is needed to validate the results and determine the effect of certain assumptions on ridership and on the surrounding transportation network.

Following the TPB recommendation for further review of the assumptions used, MDOT requested additional modelling and analysis results to be performed by the original author of the *2019 Ridership Study,* with an additional range of input assumptions. The objective of this additional analysis is to evaluate the sensitivity of ridership to a moderate level-of-service assumption and the impacts relative to the no-build conditions in order to understand the effects of the monorail on the other regional transportation systems. This additional analysis is documented in a series of memorandums, which can be found in **Appendix A**, and are summarized below.

The *2019 Ridership Study* included the following main set of service assumptions:

- Higher Frequency (headway, or the elapsed time between train arrivals in the same direction at each station) assumed service more aggressive than Metrorail, with three-minute headways for peak periods and 10-minute headways for midday and evening periods
- Top speed of 65 mph with an average speed of 41 mph
- An end to end travel time of 42 minutes, including a station dwell time of 30 seconds
- Fare prices equivalent to the Metrorail service for comparable trips
- Transit attractiveness would be similar to a system like WMATA's Metrorail, as opposed to MDOT MTA's Light Rail (LRT) systems
- No fee for parking

Significant transportation projects are included in the future transportation network model, including:

- **I-270 Traffic Relief Plan**, construct four managed lanes, 2025
- **I-95/I-495 Traffic Relief Plan**, construct four managed lanes, 2025
- **CCT BRT** - from Shady Grove to COMSAT, 2020
- **MD 355 BRT** - from Bethesda Metro to Clarksburg, 2040
- **North Bethesda Transitway BRT** - from Montgomery Mall to White Flint Metro, 2040

Ride On Route 100, currently providing express bus service from Germantown to Shady Grove, is assumed to be closed as it would be made redundant by the monorail.

The revised analysis uses the Base Frequency assumptions, but includes more conservative service assumptions, such as:

- Average operating speed is assumed to be 35 mph, which is consistent with an average speed based on the current Red Line operations and also close to the theoretical average speed of 37 mph calculated for a maximum design speed of 50 mph for the proposed monorail, in comparison with an average operating speed of 41 mph in the initial study. Ridership information for both average operating speeds have been included for comparison.
- Parking cost is assumed to be charged at all stations (with parking rates assumed to be the same as that for Shady Grove--$5.20 per day for peak and $1 per day for off-peak), in comparison with the original assumption of parking being available and free of charge at every station (except for Shady Grove)

The average and top speeds have been based on current technology and are in line with similar systems currently operating. As detailed earlier in this chapter, the average speed is a calculation of many factors, and 35 mph is a reasonable assumption for this system. The average speed calculation based on the feasibility alignment of 37 mph is a theoretical calculation, and the average speed of 35 mph was used as a conservative estimate accounting for some variability in actual travel times, for the additional ridership analysis, in comparison with an average speed of 41 mph in the initial study.

All of the WMATA Metrorail stations in Montgomery County charge for parking. An analysis of parking requirements and available land for stations points to the need to provide parking structures at most of the monorail stations, as detailed later in this chapter. The capital and maintenance cost of parking, along with the connectivity to Metrorail service point to this reasonable assumption that parking fees would be similar to WMATA parking lots.

Ridership Forecast Results

The ridership forecast results are presented below for the range of assumptions used:

The current transit modelling methods do not have data on the attractiveness for monorails, so an assumption on the attractiveness must be made. LRT is typically seen as a less desirable type of transit service, so it, therefore, attracts fewer riders. Metro rail is a more desirable system which generally attracts more riders. For this study, the ridership analysis uses the higher "attractiveness" factors of metro rail.

Assuming a 42-minute travel time, three-minute peak headways but with 10-minute off-peak headways results in a total ridership forecast of 47,800 per day in 2045 (**Table 2.11**).

Table 2.11 – Daily Boarding (High Frequency)

Station	2045
Frederick	12,400
Urbana	1,800
Clarksburg	2,000
Germantown	3,600
Metropolitan Grove	5,100
Shady Grove	22,900
Total	**47,800**

Table 2.12 Assuming the more conservative 46-minute travel time, a conservative frequency of six-minute peak headways, and comparable parking cost to Metrorail, results in a total ridership forecast of 34,800 per day in 2045.

Table 2.12 represents a range of 13,000 in forecasted daily ridership in 2045, based on the range of assumptions.

Table 2.12 – Daily Boarding (Sensitivity Run)

Station	2045	Difference	% Difference
Frederick	10,400	-2,000	-16%
Urbana	1,600	-200	-11%
Clarksburg	1,500	-500	-25%
Germantown	2,700	-900	-25%
Metropolitan Grove	2,000	-3,100	-61%
Shady Grove	16,600	-6,300	-28%
Total	**34,800**	**-13,000**	**-27%**

Adding the monorail into the transportation network would clearly effect changes in use of other transportation modes. In addition to performing additional sensitivity analysis for assumptions, results of the changes to other system use was reported for the year 2045 in **Table 2.17**.

Table 2.13 – Projected Changes in Daily Boardings for Major Transit Routes

Routes	2045 Build	2045 No Build	Difference (Latest vs NB)	% Difference (Latest vs NB)
CCT BRT	16,800	16,100	700	4%
MD 355 BRT	37,100	38,700	-1,600	-4%
N Bethesda BRT	4,200	4,100	100	2%
MT505/515	100	2,700	-2,600	-96%
Ride On 70	1,400	1,800	-400	-22%
Ride On 100	0	1,800	-1,800	-100%
MARC Brunswick	7,700	11,100	-3,400	-31%
Metro Red Line	524,300	512,100	12,200	2%

The results of this analysis show that competing routes are expected to experience declines in daily boardings, especially MARC Brunswick Line, commuter bus MT 505/515, MD 355 BRT, and Ride On 100. Corridor Cities Transitway (CCT) would see a slight increase in daily boardings as the transfers from the proposed monorail to the CCT would outnumber the replacement of CCT trips by the proposed monorail trips. WMATA Metrorail would also see an increase in riders transferring from monorail.

Regional trips were compared between the 2045 Build (sensitivity run) and No-Build scenarios, and the results are summarized in **Table 2.18**.

Table 2.14 – Projected Changes in Daily Trips Between Build and No Build

Routes	2045 (Sensitivity Run)	2045 No Build	Difference	% Difference
Regional Transit Person Trips	1,623,300	1,613,800	9,500	0.6%
Regional Auto Person Trips	22,449,600	22,462,100	-12,500	-0.1%
Regional Total Person Trips	24,072,800	24,075,900	-3,100	0.0%
Regional Auto Vehicle Trips	15,737,800	15,748,100	-10,300	-0.1%

The analysis shows that regional transit trips are forecasted to increase by nearly 10,000 in the Build scenario, in comparison with the No-Build scenario. These represent new transit trips, as a result of the proposed monorail. On the other hand, the auto person trips will decline by roughly 13,000, and vehicle trips will decrease by approximately 10,000 vehicle trips, both a decrease of only 0.1%. The auto vehicle trip reductions are spread throughout the study area, with a small decrease in traffic volume on major roadways. For example, the southbound traffic on I-270 in the AM peak period would decrease by roughly 350 vehicles at the segment north of I-370 and by approximately 500 south of I-70. For comparison, the segment of I-270 north of I-370 currently carries an average of approximately 230,000 vehicles per day, and approximately 265,000 vehicles south of I-70.

Ridership Forecast Summary

Ridership forecasting is a useful and necessary tool to determine the value of a transit improvement, but it is based on assumed inputs and criteria. The range of scenarios modelled in the ridership forecast show the range of possible outcomes, given the range of assumptions made. This modelling assumes a completely unconstrained system, meaning passengers are not discouraged from riding the system due to a bottleneck or delay in getting to the system. The model assumes there is ample parking at each facility, and a robust network of pedestrian and bicycle access routes, as well as efficient and desirable transit networks feeding and being fed by the monorail.

The analysis shows that the monorail could see between 34,800 to 47,800 daily boardings. The more conservative of the range represents approximately 10,000 additional regional transit trips, or a reduction of auto vehicle trips in the region of 10,300, less than 1% of the overall trips projected in 2045.

The analysis was done before the COVID-19 pandemic and the impacts of the pandemic are unknown. The affects on growth and travel patterns may be long-lasting, but predictions at this time are not possible.

System Capacity

The design criteria for the representative monorail system shows a carrying capacity of 76 passengers per car during peak hours. Assuming a three-car train, the total capacity for each train would be 228 passengers. At a peak frequency of three minutes, the system could carry up to 4,560 passengers per hour. At a frequency of six minutes, the system could carry up to 2,280 passengers per hour during peak hours with three-car trains, or 4,560 passengers with six-car trains. The ultimate carrying capacity of monorail systems can be much higher. Both BYD SkyRail and Bombardier INNOVIA 300 systems have the ability to carry up to 19,000 passengers per hour per direction with six-car trains operating at two-minute headways. A more detailed analysis of ridership and system capacity needs to be completed during a design phase, but an estimation of peak hour ridership suggests that the frequency of service would accommodate the ridership demand during peak hours.

3 | Impacts and Costs

This section summarizes the potential impact and cost identified as part of the I-270 Monorail Feasibility Study. Previous sections have evaluated the specific design requirements of the system, detailed a potential alignment based on those requirements, and identified the natural and socioeconomic resources in the alignment area. This section utilizes this alignment as a guide to quantify the potential impact and cost of the system. These impacts and costs should be considered as order of magnitude quantities, as alignment alternatives would need to be further developed, detailed field investigations for resources would need to be conducted, and the alternative alignment refined if this Feasibility Study progresses beyond the feasibility level.

Natural Environmental Impacts

The potential impacts to natural resources are an important guide for the public and agencies to evaluate a mega-project such as the I-270 monorail. Natural environmental impacts were evaluated based on the potential alignment discussed in **Chapter 2**. The impact quantities were calculated based on a standard offset from the alignment. For this feasibility analysis, the quantification of temporary construction and permanent impacts assumes a 26 foot construction envelope, with an overall limit of disturbance (LOD) of 40 feet around the alignment. This standard offset may be reduced or expanded to apply to the actual topography and available land, if this Feasibility Study progresses beyond the feasibility level.

An impact to a specific resource, for the purposes of this feasibility analysis, collectively refers to any permanent, perpetual and/or temporary impacts resulting from the footprint of the alignment overlapping a resource.

This section highlights potential consequences of the project on environmental resources that will be considered in subsequent stages of the project. Environmental inventory resources assessed include:

- Waters of the U.S. including wetlands
- Floodplains
- Forests
- Special Protection Areas (SPAs)
- Sensitive Species Project Review Areas (SSPRA)

Detailed mapping showing the I-270 monorail alignment with the environmental features are shown in **Appendix D**.

Waters of the U.S. Including Wetlands

A summary of potential impacts to wetlands and waterways within the I-270 monorail alignment are included in **Table 3.1**. The alignment crosses a total of 38 streams and two wetlands. Potential impacts to wetlands would range from 1-3 acres and may include loss of vegetation, grading, filling, and disruption of hydrology. Potential impacts to streams would range from 846-2,536 linear feet and may include increased sedimentation from instream construction work, and the potential for placing natural streams into culverts due to crossings for temporary and/or permanent access roads and the construction of the guideway.

A Joint Permit Application (JPA) would be needed for impacts to wetland and waterways and should be prepared in the detailed design phase. The permitting agency for a JPA is the Maryland Department of the Environment (MDE), and is closely coordinated with the federal government, specifically the Army Corps of Engineers (USACE). The permit is needed to protect Maryland wetlands and waterways from loss or degradation, and often requires mitigation in the form of wetland and stream restoration or improvement. Depending on the impacts, the project could qualify for the Maryland State Programmatic General Permit (MDSPGP) or an Individual Permit (IP). Wetland mitigation or stream restoration may be required.

Floodplains

Impacts to the 100-year floodplain will potentially occur at seven locations along the I-270 monorail alignment. These occurrences would be from the perpendicular crossing where possible of floodplains, not from longitudinal encroachments. Perpendicular crossings generally result in less floodplain fill, maximizing floodwater conveyance and storage compared to longitudinal encroachments. The monorail alignment is proposed to be completely aerial, so the actual encroachment may be different based upon the total extent of fill required for construction. Efforts to minimize floodplain encroachment would be considered during advanced design to avoid or minimize impacts. **Table 3.1** summarizes the acres of possible floodplain impacts for the alignment. Impacts would range from approximately 1-2 acres.

A JPA would be needed for impacts to the 100-year floodplain and should be prepared in the detailed design phase. Future design phases of the monorail system should aim to avoid changes to the 100-year floodplain boundary.

Forests

Impacts to forests will potentially occur at many locations along the I-270 monorail alignment. Impacts to forests occur primarily at existing forest edges and not within forest interiors, which may cause forest fragmentation and impact to Forest Interior Dwelling Species habitat. The total area of forest impacts would range from 13-37 acres. Based on the amount of potential forest area impacted, this project would be regulated under the State of Maryland's Natural Resources Article 5-103, Reforestation Law, adopted 1989, amended 1990 and 1991.

Forest mitigation is required for any state project that requires one or more acre of impact. Replacement is required on an acre-for-acre (1:1) basis and must be accomplished on public land.

Special Protection Areas (SPAs)

The Maryland-National Capital Park and Planning Commission (M-NCPPC) and the Montgomery County Department of Park and Planning (MCDPP) have developed guidelines for the protection of natural resources within environmentally sensitive areas designated as SPAs. The alignment would cross the Clarksburg SPA and the Ten Mile Creek SPA, which are located adjacent to I-270. Impacts from the I-270 monorail alignment would range from 5-14 acres (**Table 3.1**). To protect water resources within the SPA, implementation of these guidelines in conjunction with County water quality regulations could result in expanded wetland buffers, expanded and accelerated forest conservation, and imperviousness limitations.

Expanded wetland buffers are dependent on the watershed use category. The Little Seneca Creek watershed is designated as Use IV for recreational trout waters. Within this designated use, the expanded buffer could extend up to 125 feet from the edge of the stream bank or wetland depending upon whether the wetland is a wetland of special state concern, the proximity of steep slopes, and the presence of highly erodible soils.

Expanded and accelerated forest conservation would be required for alternates within the SPA that are subject to Montgomery County Forest Conservation requirements. These requirements would include the retention or establishment of forest in all buffers on a site and will include a five-year maintenance plan.

The Clarksburg SPA has an impervious limit of 15% to the entirety of each site. The imperviousness coverage must be calculated over the entire project site within the SPA, and the monorail impacts to impervious areas may need to be offset.

In summary, impacts within the SPAs will require detailed coordination with M-NCPPC, mitigation, and permit authorizations.

Sensitive Species Project Review Areas (SSPRA)

The I-270 monorail alignment would cross one mapped SSPRA. This area is located along both sides of I-270 within the Monocacy National Battlefield Park, in Frederick County. Further coordination with the Maryland Department of Natural Resources (DNR) Wildlife and Natural Heritage Service will be necessary prior to any development.

While not definitive, the potential for Rare and Threatened (RTE) species exists within the proposed alignment. Additional field surveys will be required to make this determination.

Table 3.1 – Potential Natural Environmental Impact Summary

Potential Environmental Impact		
	Range of Impacts	Unit
Wetlands	1 - 3	Acres
Streams	846 - 2,536	Feet
100-year floodplains	1 - 2	Acres
Forest	13 - 37	Acres
Forest Conservation Act (FCA) Easements	1 - 1	Acres
Montgomery County SPA	5 - 14	Acres
SSPRA	3 - 7	Acres

Historical Resources Impacts

The I-270 monorail alignment will potentially impact three large historic resources within the corridor: the Monocacy Battlefield, the U.S. Department of Energy, and the Metropolitan Branch of the B&O Railroad.

The Monocacy Battlefield is located on the eastern and western sides of I-270, surrounding the Monocacy River. The monorail may create visual impacts as a result of its elevated alignment which may be a concern in areas such as the Monocacy National Battlefield where such visible impacts may be undesirable. Such concerns would be addressed during detailed design in coordination with the National Park Service and other stakeholders. The alignment may impact approximately 4-10 acres of the Battlefield on the eastern side of I-270. The U.S Department of Energy is located on the western side of I-270, between MD 118 (Germantown Road) and MD 119 (Middlebrook Road). The alignment may impact approximately less than an acre of land on the outer edge of the property. The B&O Railroad enters the project corridor just south of Germantown and travels through Gaithersburg to the end of the alignment in Derwood/Shady Grove. The alignment may impact 2-4 acres of the railroad from running adjacent to or crossing over the tracks. A summary of these impact ranges is shown in **Table 3.2**. The remaining historic properties that would be impacted are smaller sites listed in the National Register of Historic Places (NRHP) and Maryland Inventory of Historic Properties (MIHP).

The alignment would impact approximately 1-2 acres of park within Frederick and Montgomery County. The majority of the park impacts are located on the southern end of the alignment in Montgomery County.

Table 3.2 – Potential Historic Impact Summary

Historic/Parks Impacts		
	Range of Impacts	Unit
Monocacy Battlefield	4 - 10	Acres
U.S. Department of Energy	0.1 - 0.2	Acres
Metropolitan Branch, B&O Railroad	2 - 4	Acres
Total Historic	6 - 15	Acres
Parks	1 - 2	Acres

Right-of-Way Impacts

The proposed alignment may have permanent and temporary impacts to approximately 46-136 acres of right-of-way. Land impact was quantified by three different categories: State-owned right-of-way along I-270, state or locally-owned road right-of-way, and privately-owned property. Many of the land impacts would be to state or locally owned land; however some privately-owned property will be impacted. A summary of these categorized impacts is shown below in **Table 3.3**.

Table 3.3 – Potential Right-Of-Way Impact Summary

Potential Right-of-Way Impacts		
	Range of Impacts	Unit
I-270	30 - 89	Acres
All Other Roads	7 - 20	Acres
Private	9 - 27	Acres
Total right-of-way required	46 - 136	Acres

Capital Cost Estimate

The overall feasibility cost of the monorail system along I-270 is a combination of capital costs, soft costs, and ongoing operations and maintenance costs. Capital costs are one-time expenses, including the purchase or construction cost of any element needed to bring the monorail system into operation. Soft cost encompasses the expenditures not associated with any direct construction or goods, including financing, architectural and engineering design, administration and project management, and legal fees. Operation and maintenance costs include the ongoing cost to operate the system, which includes day-to-day operations cost including wages of workers, consumable costs like fuel and electricity, routine maintenance, as well as mid-life rehabilitation of assets, such as vehicles, stations, and systems.

The I-270 monorail has not been fully designed or optimized, so accurately estimating these costs is inherently challenging. A variety of methods have been used to estimate the probable range of costs for each of these elements.

Capital Cost Estimate

The I-270 monorail cost estimate has been developed to follow Federal Transit Administration (FTA) Standard Cost Categories (SCC). These categories establish a consistent format for reporting, estimating, and managing capital costs for FTA funded transit projects. The SCC are numbered and include the following high-level cost categories, along with more detailed categories:

SCC #	SCC Description
10	Guideway & Track Elements
20	Stations, Stops, Terminals, Intermodal
30	Support Facilities: Yards, Shops, Administration Buildings
40	Sitework & Special Conditions
50	Systems
60	Right-of-Way, Land, Existing Improvements
70	Vehicles
80	Professional Services
90	Unallocated Contingency
100	Finance Charges

Construction capital cost has been estimated utilizing a blend of unit cost and parametric estimating methods. Some elements of the construction have been classified as a typical element, which are defined by a typical cross section or other typical unit, such as a parking space. The cost for typical elements has been estimated by quantifying the construction cost of a typical unit and applying it to the length or quantity of the item. The monorail guideway and parking lots are examples of a typical element. Other construction elements can be classified as a per-each element, which includes similar items that are used multiple times throughout the construction. The cost for one of these per-each items can be estimated, and then applied each time that item is used. Traction power substations or station platforms have been estimated using this method.

Additional construction elements can be considered as non-typical and must be estimated individually for the specific item. These elements include the monorail train control and communications systems, utility impacts, and maintenance facility and storage yards, among others. These non-typical elements have been estimated using one of two methods: unit cost analysis, and parametric cost analysis.

Unit cost analysis includes dividing the project into major components, estimating the cost and quantity, and summing to create a composite cost. Cost of the major quantity items have been estimated by analyzing historic construction bid prices for similar units. This method requires adjusting unit costs for the location, complexity of work, anticipated production rates and construction staging, as well as site specific requirements. This is a "bottom-up" cost estimating method, which builds up a cost for the larger element by breaking it into smaller pieces and estimating each of them separately.

Parametric cost analysis compares a major work item to similar items already constructed or estimated elsewhere. This method is a "top-down" approach, basing the estimate on a large item itself, instead of building up the cost of the pieces. These parametric estimates need to be adjusted for time, escalating the cost comparison to the current year, and location, by adjusting the cost of construction or procurement differences across the country or globe, and complexity. This method relies on published construction cost for similar transit systems. The FTA gathers information from projects across the country and maintains a Capital Cost (database), which includes costs for transit system SCC. This database has been used for certain elements of the I-270 monorail cost estimate.

SCC 10 – Guideway & Track Elements

The monorail guideway includes elements of construction directly and indirectly related to the construction of the monorail elevated tracks. Direct costs include elements such as concrete and steel reinforcement for footings, columns, pier caps, and superstructure, as well as passenger access and protection. Special tracks such as switches and crossovers are included in this category as well. Indirect elements include site work, clearing, demolition, excavation, fill, support of excavation, traffic and access controls, erosion and sediment controls, system duct banks, and corrosion control.

The elevated monorail guideway cost estimate was created with a typical unit estimating approach. The cost of a typical unit was estimated by determining the materials and components necessary for a 65-foot section of the alignment. The major quantity typical unit consists of a reinforced concrete footing, a reinforced concrete pier column with two tapered haunches, two precast concrete track beams an average of 65 feet in length, and an emergency walkway between the track beams with railings. The average pier height used in this calculation is 22 feet, calculated from a conceptual track profile. Longer or shorter spans may be needed for this alignment, so 65 feet was used as a conservative average. In addition to these direct costs, the indirect cost was calculated by adding a percentage, and added as an allowance. The total cost for each section of track alignment is approximately $150,000 per 65-foot section and were estimated using available comparable recent construction bid prices. The total cost for the 28-mile guideway is estimated at $342 million in the year 2020.

SCC 20 – Stations, Stops, Terminals, Intermodal

This category includes all elements associated with monorail stations. This includes the elevated stations, structured parking, and related indirect work. The platforms include the structural foundations, supports and floor decks and walls, canopies or roofs, architectural elements and finishes, ticketing areas, vertical circulation like escalators and elevators, lighting, plumbing, and electrical systems.

The station cost estimates are based on both parametric estimates, using costs from similar systems, as well as major quantity unit costs. Station platforms and structures were estimated parametrically, since the design of stations can vary widely architecturally, but all aerial transit stations include similar elements.

Station platform costs were estimated based on data from the FTA database. Light rail systems were selected as the representative comparison, as they are similar in scale and requirements. According to the database, the average cost for an aerial station in 2020 dollars is approximately $10.5 million. In comparison, the MDOT MTA Purple Line, currently under construction, includes aerial stations that were projected to cost approximately $13 million in 2020 dollars including vertical circulation, which is comparable to the national average. The total estimated cost for six monorail stations based on the national average is $63 million.

Station costs also include the associated site work for parking and access. The monorail system is anticipated to require structured parking at many stations, to meet the ridership demands. Multi-story garages are needed for all locations except Clarksburg, which has enough available land for a surface lot. Costs were estimated using the FTA database, which reports an average cost per parking space for similar systems of approximately $28 thousand in 2020 dollars. A unit cost estimate for structured parking from recent construction bid prices estimates the cost of structured parking to be approximately $65 per square foot, which compares similarly to the FTA database. Following the national average price, the total cost for structured parking is $500 million in order to meet the future demand in the design year of 2040. In order to meet the project opening year demand, the total cost for structured parking is $345 million. Not all the parking structures needed for future projected demand would be built for opening day, but some excess inventory would be constructed during the initial construction, to meet the needs of expected growth. With that assumption, the capital cost for parking structures is estimated at $423 million.

Surface parking lots, access, and circulation associated with stations are included in SCC 40.

The total estimated cost for monorail stations, stops, terminals, and intermodal is $486 million.

SCC 30 – Support Facilities: Yards, Shops, Administration Buildings

This category includes an administration building, light and heavy maintenance facilities, storage building, yard, and yard tracks. The administration building includes several activity centers; including a central control, revenue control and counting, and administration offices.

The monorail support facilities are conceptually designed for this Feasibility Study, in order to estimate the size and location, so the best way to estimate the cost it to use average costs from the FTA database. The database includes average cost for light rail facilities, based on the length of the guideway. Light rail facilities include similar elements; therefore, they are a good substitute for the cost estimate. The FTA database reports a cost for this SCC of $1.7 million per linear foot of guideway. The monorail alignment is approximately 28 miles long, which results in a total estimated cost for this category of $249 million.

SCC 40 – Sitework & Special Conditions

The sitework and special conditions category includes elements of the entire system construction associated with site work, clearing, demolition, excavation, fill, support of excavation, traffic and access controls, and erosion and sediment controls. This category includes sitework, surface construction, utility relocations, hazardous waste disposal, environmental mitigation, site structures including retaining walls and sound barriers, pedestrian and bicycle access, landscaping, automobile, bus, and van roads, stops and parking lots, and temporary facilities during construction.

This category is estimated by combining cost estimates for each major element contained within:

- **Demolition, Clearing, Earthwork**

  This category includes the demolition of any existing building or structure that will be impacted by the monorail system, clearing land needed for the system, and earth moving and grading. The majority of the monorail alignment will be elevated, so earthwork for the alignment would only be needed for construction access roads. The construction of stations and maintenance facilities may require demolishing existing structures. The system alignment and facilities will require clearing land of trees. This can be estimated using the FTA database, which has an average cost per foot of guideway of $200. This results in a total cost for this category of $29 million. Assuming a 10% discount to account for the aerial guideway construction method that would disturb less earth than at-grade transit systems results in an overall cost for this category of $26 million.

- **Site Utilities, Utility Relocation**

  The monorail alignment crosses two major utility corridors, which include multiple overhead electric distribution lines. In addition, underground utilities may be impacted by station structures, and service utilities must be constructed for stations and maintenance facilities. The level of design for the monorail does not allow for estimating each individual utility, as generally these impacts and needs are not defined until the final design stage. The FTA database includes a unit cost per linear foot of guideway of $791. This results in a total cost for this category of $117 million.

- **Hazardous Material, Contaminated Soil Removal and Mitigation, Ground Water Treatments**

  Due to the nature of monorail construction, this subcategory may be less expensive than other transit systems. Most of the monorail alignment will be elevated, only requiring excavation for pier foundations. However, the station areas and maintenance facilities will include significant sitework, as well as excavations for building foundations and land leveling. The FTA database includes a cost per linear foot of guideway of $108, which results in an estimated cost for the monorail of $16 million. Assuming a 10% discount to account for the aerial guideway construction method that would disturb less earth than at-grade transit systems results in an overall cost for hazardous material of $14 million.

- **Environmental Mitigation, e.g. Wetlands, Historic/Archeologic, Parks**

  The anticipated order of magnitude of environmental impacts for the monorail are detailed in the previous section. The impacts that would require mitigation include floodplains, forest, streams, and wetlands. Historic and archeological impacts may require design accommodations to reduce the impact, or special mitigations to accommodate special requirements. These accommodations are all included in this SCC item. While these costs can vary widely from project to project, the FTA database includes an average cost per linear foot of guideway of $105, resulting in a total cost for this category of $15 million.

- **Site Structures Including Retaining Walls, Sound Walls**

  This category includes miscellaneous structures for the monorail alignment, maintenance facility, and stations. This includes cast-in-place and precast retaining walls, sound barriers, and other miscellaneous structures required to support the system. Most of the monorail alignment will be elevated, only requiring earthwork and retaining walls for construction access, but the stations and maintenance facilities may require retaining walls. Sound barriers may be required in some locations, but the monorail technology uses rubber tires, which are significantly quieter than steel rail transit systems. The FTA database includes a cost per linear foot of guideway of $228, resulting in an estimated cost for the monorail of $34 million. Assuming a 75% discount to account for the aerial guideway construction method that would require fewer retaining wall structures and noise barriers than at-grade steel wheel transit systems, results in an overall cost for this category of $9 million.

- **Pedestrian/Bike Access and Accommodation, Landscaping**

  The monorail system will include accessible pedestrian and bicycle access, bicycle parking areas, and landscaping elements to create an inviting and safe system that will be open to all users. Attracting pedestrians and cyclists to use the system is important to realize the ridership estimates. These facilities would be fully designed in preliminary and final design phases, but all transit systems include these elements, so the FTA database will provide a good estimate for this category. The database includes a cost per linear foot of guideway of $253, resulting in an estimated cost for the monorail system of $37 million.

- **Automobile, Bus, Van Accessways Including Roads, Parking Lots**

  The station areas for the monorail have been conceptually designed, so major quantities can be calculated at this stage. Parking and sitework can be estimated using a combination of per-each costs and major quantity unit cost estimates. Pavement for surface parking lots, multimodal bus stops, and roads can be estimated as a square foot cost. An average of $2.75 per square foot was used as a pavement estimate, and the conceptual station layouts were used for quantity take-offs. The pavement cost for surface lots and roads range from $730 thousand for opening day demand, to $1 million to account for future 2040 ridership demand. This category also includes supporting construction such as curbs, signing and pavement striping, drainage systems and stormwater management, etc., so the total cost would be significantly higher. The FTA database reports a cost per parking space for this category of $15 thousand, resulting in an estimated cost for the monorail of $22 million for the estimated 1,500 surface parking spaces required.

- **Temporary Facilities and Other Indirect Costs During Construction**

  Temporary works during construction include the construction of construction access roads, phasing of construction, mobilizing construction equipment, maintenance of traffic, sediment and erosion controls, and other unspecified work to support the construction activities. The cost for this category cannot be accurately measured for the monorail at this point of this Feasibility Study but would be similar to other transit systems. The FTA database includes a cost per linear foot of guideway of $1,457, resulting in an estimated cost for the monorail of $215 million.

  The total estimated cost for SCC 40 Sitework and Special Conditions is $455 million.

SCC 50 – Systems

Monorail train systems include train control and signals, traffic signals and crossing protection, traction power supply and distribution, communications, fare collection, central revenue counting and collections, and a central control system. Since the monorail alignment is completely grade separated, traffic signals and crossing protection would not be required. The level of design for the monorail does not allow for estimating each individual system, as generally these needs are not defined until the final design stage. The FTA database includes a total systems unit cost per track foot without traffic signals and crossing protection, of $1,187. This results in a total cost for this category of $225 million. In comparison, the MDOT MTA Purple Line, currently under construction, includes systems that were projected to cost approximately $294 million in 2020 dollars, which is comparable to the national average.

Total Construction Cost

The total estimated construction cost is the addition of the individual estimates for SCC 10 through SCC 50. The breakdown of construction cost per SCC is show in **Table 3.4**. This estimated total cost for construction is $1,757 million.

Table 3.4 – Total Construction Cost

SCC #	SCC Description	Subtotal $ (Million)
10	Guideway & Track Elements	$ 342
20	Stations, Stops, Terminals, Intermodal	$ 486
30	Support Facilities: Yards, Shops, Administration Buildings	$ 249
40	Sitework & Special Conditions	$ 455
50	Systems	$ 225
	Total Construction Cost:	**$1,757**

SCC 60 – Right-of-Way, Land, Existing Improvements

Acquiring land will be required for the monorail system. Much of the alignment can be constructed within state or local right-of-way; however, stations, maintenance facilities, and some portions of the alignment will need to be on private property. The median estimate for required right-of-way is approximately 18 acres. According to the Federal Housing Finance Agency data detailed in *The Price of Residential Land for Counties, ZIP Codes, and Census Tracts in the United States, Revised February 2020,* the average land value in Montgomery County is $986 thousand per acre, and the value in Frederick County is $204 thousand per acre. The monorail alignment traverses both counties fairly evenly, and the land cost in Montgomery County can be assumed to be higher when closer to the more urban southern region. The median land value between Frederick and Montgomery Counties is a reasonable estimate. With this assumption, the cost of acquiring private property for the monorail is $7 million.

SCC 70 – Vehicles

A conceptual estimate of the total number of vehicles needed to meet the anticipated peak hour demand relies on the assumed headway of six minutes, average speed of 35 mph, and capacity of a three-car consist of 228 passengers. Assuming peak hour trains will need to be double length to provide the capacity for a portion of the peak hours, a total of 32 vehicles are needed, plus 15% spare capacity for a total of 37 vehicles.

Monorail vehicle cost data is not available, as the systems are proprietary and there is not a large sample of recent systems in the United States. Using the light rail vehicle cost in the FTA database is a good estimate for this stage of design, as the vehicles are similar in size, system requirements, and design. The database includes an average cost for a light rail vehicle of $6 million. The total estimated cost for monorail revenue vehicles is $222 million.

This category also includes the cost of non-revenue vehicles and spare parts. Non-revenue vehicles include maintenance vehicles to maintain the guideway, as well as on-road vehicles to transport workers. Purchasing spare parts is generally included in the capital cost of a transit project, as many parts need to be in stock at the start of revenue service to avoid delays in procuring long-lead items. Both of these costs are estimated based on the number of revenue vehicles, and for the monorail system the total estimated cost is $5 million for spare parts, and $3 million for non-revenue vehicles.

The estimated total for this SCC is $230 million.

SCC 80 – Professional Services

This category includes design and management of the project from preliminary design through the start of revenue service. This category includes Preliminary Engineering; Final Design; Project Management for Design and Construction; Agency Project Management; Project Management Oversight Support; Construction Administration and Management; Professional Liability and other Non-Construction Insurance; and Legal, Permits, Review Fees by other agencies.

At this stage of a project these costs are estimated as a percentage of the hard construction cost, according to the average percentages included in the FTA database, as noted in **Table 3.5**. The total estimated cost for this category is $1,115 million. It should be noted that this estimate is conservative, and may be reduced depending on the type of construction contract.

SCC 90 – Unallocated Contingency

The estimated cost of a mega project like the monorail can fluctuate greatly throughout the project lifecycle. The scope and requirements of the project can change according to the sponsor and stakeholders: differing conditions can be found along the alignment that were not originally accounted for, permitting agencies could require additional work, are just a few examples of risks that may affect the overall cost of the project. Unallocated contingency is built into the overall project cost to account for these unforeseen issues. This contingency is calculated as a percentage of the project hard construction cost. The FTA guidance, detailed in Oversight Procedure 40 – Risk and Contingency Review for total contingency at the beginning of the Project Design phase, which begins with Planning and ends at Preliminary Design (approximately 30% design) is 35% contingency. The estimated contingency for the monorail following this guidance is $677 million.

SCC 100 – Finance Charges

Funding a mega project such as the monorail can oftentimes require the sponsoring state to issue bonds, borrow funds from the federal government, or enter into a public-private partnership (P3). At this point of the monorail project, the delivery method and funding source has not been identified for the monorail. The best funding source would be state and local funds, along with federal grant funds, which would not require any financing. Therefore, at this point the finance charges are assumed to be $0.

Table 3.5 – Total Professional Services Costs

SCC #	SCC Description	% of Hard Cost	Subtotal (Million)
80.010	Preliminary Engineering	4.46%	$ 86
80.020	Final Design	12.90%	$ 249
80.030	Project Management for Design and Construction		
80.031	Agency Project Management	6.79%	$ 131
80.032	Project Management Oversight Support	1.52%	$ 29
80.033	Agency Force Account	0.07%	$ 1
80.034	Unspecified	10.50%	$ 203
80.040	Construction Administration & Management	10.59%	$ 205
80.050	Professional Liability and other Non-Construction Insurance	1.82%	$ 35
80.060	Legal; Permits; Review Fees by other agencies, cities, etc.	2.02%	$ 39
80.070	Surveys, Testing, Investigation, Inspection	0.36%	$ 7
80.080	Start up		
80.081	Training/Start up	2.53%	$ 49
80.082	Safety Certification	0.33%	$ 6
80.083	Off-Site Vehicle Testing, Test Runs	1.90%	$ 37
80.090	Other	1.86%	$ 36
		Total:	**$1,113**

Total Project Cost

The total estimated project cost is the addition of the individual estimates for SCC 10 through SCC 100. This estimated total in the year 2020 is $3,784 million.

However, inflation will increase the total cost over the lifetime of the project. While the project does not have a set schedule for design, construction, or revenue service, a project such as this could take 5-15 years to complete. Assuming an aggressive design and construction schedule, the earliest that the construction can be complete is within five years. Escalating the total cost over five years would increase the cost of the project. This project would be subject to the National Environmental Policy Act (NEPA), which requires federal agencies to assess the effects of the project before making decisions. The NEPA and public outreach process can extend the time frame up to 15 years, but this would be the case for any large project.

The total estimated project cost shown in **Table 3.6**, including the individual estimates for SCC 1 through SCC 100, and accounting for inflation, is $4,356 million.

Table 3.6 – Total Project Costs

SCC #	SCC Description	Subtotal $ (Million)
10-50	Construction Subtotal	$ 1,757
60	Right-of-Way, Land, Existing Improvements	$ 7
70	Vehicles	$ 230
80	Professional Services	$ 1,113
90	Unallocated Contingency	$ 677
100	Finance Charges	$ 0
	Subtotal Project Cost (2020):	**$3,784**
	Escalation	$642
	Total Project Cost (2025):	**$4,426**

Capital Cost Comparison

FTA publishes the cost and general specifications of all currently funded transit development projects, so the monorail price can be compared directly to other transit modes. Understanding that there are differences in complexity, scope, and site-specific details, the projects shown in **Table 3.7** are a selection of similar systems.

Table 3.7 – Similar Project Cost Comparison

Project Name	Location	Project Type	Length (Miles)	Capital Cost (Million)	Cost Per Mile (Million)
South Central Light Rail Extension/Downtown Hub	Phoenix, Arizona	Light Rail Transit	5.5	$1,345	$245
Transbay Corridor Core Capacity Project	San Francisco, California	Heavy Rail Transit	112	$2,705	$24
SunRail Connector to the Orlando International Airport	Orlando, Florida	Commuter Rail	5.5	$225	$41
SunRail Phase II North	Orlando, Florida	Commuter Rail	12.2	$68	$6
Red and Purple Modernization Phase One Project	Chicago, Illinois	Heavy Rail Transit	1.3	$2,066	$1,589
West Lake Corridor	Lake County, Indiana	Commuter Rail	7.8	$933	$120
Double Track Northwest Indiana	Gary, Indiana	Commuter Rail	26.6	$456	$17
Green Line Extension	Medford, Massachusetts	Light Rail Transit	4.7	$2,297	$489
Maryland National Capital Purple Line	Bethesda, Maryland	Light Rail Transit	16.2	$2,407	$149
METRO Blue Line Extension (Bottineau LRT)	Minneapolis, Minnesota	Light Rail Transit	13.5	$1,536	$114
Southwest Light Rail Transit Project	Minneapolis, Minnesota	Light Rail Transit	14.5	$2,003	$138
Canarsie Line Power and Station Improvements	New York City, New York	Heavy Rail Transit	6	$372	$62
MAX Red Line Extension and Reliability Improvements	Portland, Oregon	Light Rail Transit	7.8	$206	$26
Southwest Corridor Light Rail Transit Project	Portland, Oregon	Light Rail Transit	12	$2,800	$233
TEX Rail	Fort Worth, Texas	Commuter Rail	26.8	$1,034	$39
Federal Way Link Extension	Seattle, Washington	Light Rail Transit	7.8	$3,160	$405
Lynnwood Link Extension	Seattle, Washington	Light Rail Transit	**8.5**	**$3,260**	**$384**

The average cost per mile for light rail transit is $151 million per mile. The nearby MDOT MTA Purple Line is reported to be $149 million per mile. In comparison, the preliminary estimate for the monorail is in line with similar systems at $158 million per mile.

Operating Expense Estimate

An estimate of yearly operating expenses for the monorail is based on data available from FTA's National Transit Database (NTD) Operating Expense dataset. Six agencies reported 2018 data to NTD in the category of monorail/automated systems including Seattle Center Monorail Transit, Morgantown Personal Rapid Transit, Miami-Dade Transit, Detroit Transportation Corporation, Jacksonville Transit Authority, and San Francisco. Las Vegas submitted information in 2017 but did not report 2018 data, therefore any numbers cited for Las Vegas are from 2017.

Farebox recovery ratio is the proportion of total operating expenses covered by fare revenues. A farebox recovery ratio of 100% means the fares collected exactly cover the operating expense of the system. A ratio lower than 100% indicates the fares do not cover operating expenses and a ratio higher than 100% indicates the fares collected exceed the operating expenses. It is important to note that transit agencies do not establish passenger fares simply based on the cost of each trip, and farebox revenues do not cover the initial cost of construction.

Farebox recovery for existing monorail/automated systems listed in the NTD vary widely. Some systems are either free or nominal fares ($0.75/trip), resulting in farebox recovery ratios of 0 - 6.6%. Two systems are very successful, the Seattle Center Monorail and Las Vegas Monorail, with farebox recovery ratios of approximately 100%. These two systems are in urban areas with major attractions, are relatively short in length (approximately 1.0 and 3.9 miles) and have very high ridership carrying over 2.5-2.9 million riders annually. As a comparison, one of the most successful subway systems, the New York City Subway has a farebox recovery ratio of 73%. On average heavy rail (61.1%), commuter rail (50.7%), and commuter bus (47.9%) have the highest farebox recovery ratios. Vanpools are the highest at 73.6%.

Other financial metrics including service efficiency (operating expenses per vehicle revenue mile), service effectiveness (operating expenses per unlinked passenger trip), and operating expenses per passenger mile can be evaluated.

The average operating expenses per vehicle revenue mile for all the monorail/automated systems who reported ($22.62) is higher than the averages for bus ($11.15), heavy rail ($13.23), commuter rail ($18.30), Bus Rapid Transit (BRT) ($19.18), and light rail ($19.70). However, it should be noted that the two most successful systems from a farebox recovery standpoint, Seattle and Las Vegas, are below the average in this category ($20.57 and $10.73, respectively).

Operating expenses per unlinked passenger trip for all the monorail/automated systems who reported ($4.18) is lower than the average for light rail ($4.78), bus ($4.92), and commuter rail ($12.73) and is higher than the average for heavy rail ($2.44) and BRT ($3.53). Both Seattle ($2.13) and Las Vegas ($4.06) are below the average in that category.

Finally, operating expenses per passenger mile for all the monorail/automated systems who reported ($3.46) is higher than commuter rail ($0.51), heavy rail ($0.54), light rail ($0.92), bus, and BRT ($1.31). And although Seattle and Las Vegas are lower than the average ($2.37 and $2.00, respectively), they are still higher than the other modes.

These metrics are standard methods of evaluating a system's effectiveness, but they do not provide a direct estimate of the total cost for operations. While many factors will influence these expenses, a general estimate can be ascertained by comparing the system to a similar system in the region. For example, the MDOT MTA reports a total operating expense of $42 million per year for the light rail system, a system that is comparable in size and scope as the monorail. The MDOT MTA light rail system is supported by a network of other transit modes in close proximity, which lower the operating cost of the light rail system, so it can be assumed that a monorail would be costlier to operate, since it would require dedicated operations and maintenance forces and facilities. The database reports a national average operating expense of $89 million for all light rail systems in the database. The Las Vegas Monorail reports a total operating expense of $20 million.

Utilizing the MDOT MTA light rail as a guide for yearly expenses, and assuming a 30-year project lifespan, the total routine operating cost for the I-270 monorail is $1,260 million. The addition of minor and major midlife rehabilitations and upgrades, assumed to be an additional 15% brings the total operating cost to an estimated $1,449 million, in 2020 dollars. Utilizing the lower operating cost of the Las Vegas Monorail, results in a total estimated operating cost of $690 million in 2020 dollars.

4 | Findings

Introduction

MDOT has prepared this independent Monorail Feasibility Study (Feasibility Study) for the I-270 corridor to assess the viability to construct, operate, and maintain a monorail system between the Shady Grove Metrorail Station and Frederick, Maryland. As part of the feasibility assessment, the study evaluates existing monorail services around the world; alignment options; station locations and connectivity; frequency of service; ridership demand; environmental considerations; operation and maintenance needs; and costs for construction, operation, and maintenance.

The monorail alignment under consideration would connect Frederick to the developed I-270 corridor within Montgomery County, and provide greater connectivity for population centers and municipalities currently only served directly by the highway network, Maryland Area Rail Commuter (MARC) service, and local buses. The addition of a more direct transit service between the areas would provide a public benefit to the communities it serves and provide them with a greater choice in terms of mode of travel than what currently exists.

The COVID-19 public health crisis has dramatically impacted all Marylanders and required that we all make difficult adjustments in our daily lives. This has been a challenging and disruptive time. At MDOT, employees at all of our transportation business units are on the front lines of a statewide transportation system providing vital service to allow essential employees to get to work. As always, ensuring our employees' and customers' safety and the safety of all Marylanders is our top priority. Maryland's economy has taken a hit due to the impact of the COVID-19 pandemic. That impact has also affected the State's transportation system, with declines in use of the system, which has further reduced revenue to the Transportation Trust Fund. The full breadth of the COVID-19 pandemic's effects have yet to be realized, including impacts to state and local revenue and funding sources.

Monorail Technology Evaluation

As part of this Feasibility Study, MDOT has prepared a separate assessment of monorail technology both internationally and within the United States, *MDOT Monorail Global Scan and Assessment, November 2020*. In general, the *Monorail Assessment* concluded that: monorails have a track record of providing viable urban transit; and the technology allows unique solutions for difficult alignment requirements; but the success of a transit system depends more on urban densities, sound planning, and other transportation in the corridor than it does on the specific technology. The assessment stated that the I-270 monorail will require a behavioral shift from single-occupancy vehicle travelers to mass transit commuters, as well as greater densities at the stations. Most successful monorails were deployed in areas where mass transit was already the main mode of transportation. Transportation Demand Management (TDM) strategies could help in creating this shift; however, the area would need more urban land use densities.

In addition, the assessment identified a series of lessons learned from eight monorail systems. These include:

1. Integration into the transportation network is key in making monorails attractive to riders
2. Monorail systems work best in areas of higher population density with concentrated urban development next to stations
3. Monorail systems can have low impact flexible designs

Based upon the technology evaluation, monorail was determined to be physically feasible and should be considered similarly to other transit modes. In addition, several items were identified for further consideration, including:

1. Success in the I-270 corridor would require a behavioral shift from single-occupancy vehicle travelers to mass transit commuters, and greater land use densities at stations.
2. The specific characteristics highlighted for a successful monorail, can equally apply to Light Rail, Bus Rapid Transit (BRT), or even Rail Rapid Transit (Metro). The implication is that the success of a transit system rests more on urban densities and successful planning, than it does with the transit type.
3. Monorail systems work best in areas of higher population density with concentrated urban development next to stations
4. The proposed monorail alignment may impact a wide variety of environmental features such as wetlands, forests, streams, Special Protection Areas (SPAs), and parks. The monorail alignment would have potential impacts to three known large historic resources within the corridor: the Monocacy Battlefield, the U.S. Department of Energy, and the Metropolitan Branch of the B&O Railroad.

Monorail Alignment Evaluation

Monorails must be in exclusive right-of-ways and are primarily elevated. Monorails provide design flexibility on alignments that include significant slope or grade changes in their route. Straddle beam systems can smooth out the ground elevation changes, but have a maximum grade of generally 10%, although 6% is the maximum grade typically used in practice. Monorail systems can operate driverless or via an in-car operator, similar to characteristics of light rail and metro rail systems in exclusive rights-of-way. Monorails are typically seen as an alternative mode choice to light rail or metro systems when system performance dictates that the transit solution be grade-separated.

The monorail alignment analyzed in this study was developed to a level of detail required for this analysis, building from the preliminary alignment presented by The High Road Foundation. A horizontal alignment was developed that would meet the design criteria determined by MDOT. A vertical alignment was designed to meet clearances at key points such as road crossings, and to meet slope criteria for the preferred maximum grades and station platform grades. Stations were conceptually designed to relevant design standards to include all required facilities. Maintenance facilities were located and designed to a level needed to appropriately estimate the space required.

The monorail would connect Frederick to the developed I-270 corridor within Montgomery County, and provide greater connectivity for population centers and municipalities currently only served directly by the highway network, MARC service, MDOT MTA commuter bus service, and local buses. The addition of a more direct transit service, such as monorail, between the areas would provide a public benefit to the communities it serves and provide them with a greater choice in terms of mode of travel than what currently exists. The monorail would link the Frederick, Urbana, Clarksburg, Germantown, Gaithersburg, and Rockville activity centers while also providing links to regional transit such as MARC and Washington Metropolitan Area Transit Authority (WMATA) Metrorail.

The evaluation of the specific design requirements of monorail on this alignment has found that this system is physically feasible to construct. The study corridor has undeveloped land that allows the monorail system to be constructed in a way that meets the design requirements. The alignment connects regional activity centers and would provide a public benefit to the communities it serves.

Monorail Cost Effectiveness Evaluation

The Federal Transit Administration (FTA) uses standard minimum densities as a benchmark when considering whether transit can be supported: 9+ persons per acre and 30-40 employees per acre. The region falls well under these minimums, with a 1.81 persons per acre population density and 0.94 employees per acre employment density. While the ½-mile area surrounding each of the proposed stations are considerably denser, with an average of 7.46 persons per acre and 7.16 employees per acre, the density is still below the standard.

Although the monorail alignment would primarily utilize state and locally owned right-of-way along I-270 and other roads, there may be impacts to private residential and commercial property of up to 27 acres needed to support the transit stations and maintenance facility(ies).

Total capital costs in 2025 would be $4.426 billion, including construction, right-of-way, vehicles, professional services, contingency, and finance charges. This figure equates to a cost of approximately $158 million per mile.

Total operating costs over 30 years would be between $690 and $1,449 million, in 2020 dollars based on an average annual cost of $23 to $48 million.

The FTA publishes Capital Improvement Grants guidance for cost-effectiveness based on a cost per trip measure. The cost effectiveness measure is defined as the annualized capital cost plus the annual operating and maintenance cost per trip on the project. Utilizing a conceptual calculation based on the anticipated ridership, capital and operating expenses, results in an annualized cost effectiveness ration of $10.12 to $11.39 per annual linked trip, as shown in **Table 4.1.** This is a conceptual review, a more detailed analysis would be conducted as part of any federal grant application.

Table 4.I – Monorail Cost Effectiveness Calculation

Cost Effectiveness		
Item	**Current Year (2020)**	**Horizon Year (20 years)**
Annualized Project Capital Cost	$100,970.54	$100,970.54
Annual Project Operating and Maintenance Cost	$23m to $48m	$23m to $48m
Annualized Linked Trips	10 million	15 million
Annualized Project Capital and Operating Cost	$124m to $148m	$124m to $148m
Annualized Cost Per Annual Linked Trip	$11.91 to $14.32	$8.32 to $9.99
Cost Effectiveness Rating	$10.12 to $12.15	

FTA rates projects based on cost effectiveness according to the breakpoints, as shown in **Table 4.2**.

Table 4.2 – FTA Cost Effectiveness Break Points

Rating	Range
High	< $4.00
Medium-High	Between $4.00 and $5.99
Medium	Between $6.00 and $9.99
Medium-Low	Between $10.00 and $14.99
Low	> $15.00

The evaluation of the cost effectiveness of monorail on this alignment has found that this system will have "medium-low" cost effectiveness, according to the FTA rating guidance, compared to the MDOT MTA Purple Line, which had a FTA "high" cost effectiveness rating. Cost effectiveness is one of many criteria that FTA uses to evaluate federal grant applications for transit projects. Grant applications are highly competitive but are a necessary funding source for large projects such as monorail.

While monorail receives a cost effectiveness of "medium-low" as a standalone alternative, this does not take into consideration the impact to ridership and loss of service and revenue from other transit services. This operational analysis and ridership findings are summarized in the following section.

Monorail Operations and Ridership Evaluation

This study conducted an evaluation of operational efficiency and ridership demand modelling. The evaluation included a travel time analysis, potential ridership analysis and system capacity analysis, based on the *Constrained Long Range Plan*, which in 2045 includes the I-270 highway improvements including managed lanes, and does not address ridership impacts due to changes in health requirements.

The travel time analysis concluded that the monorail alignment has a theoretical end to end travel time of 42 to 46 minutes, at an average speed of 37 to 41 mph respectively, which is less than the current peak hour drive time. This factor was applied to the ridership analysis.

The ridership analysis showed that the monorail could see between 34,800 to 47,800 daily boardings. This analysis assumes a completely unconstrained system, meaning passengers are not discouraged from riding the system due to a bottleneck or delay in getting to the system. The ridership forecast relies on the construction of ample parking at each facility, a robust network of pedestrian and bicycle access routes, as well as reconfiguration of an efficient and desirable transit network feeding the monorail.

The more conservative of the ridership forecast range represents approximately 10,000 additional regional transit trips, or a reduction of auto vehicle trips in the region of 10,300, less than 1% of the overall single vehicle trips. The auto vehicle trip reductions are spread throughout the study area, with a small decrease in traffic volume on major roadways. For example, the southbound traffic on I-270 in the AM peak period would decrease by roughly 350 vehicles at the segment north of the Intercounty Connector (ICC) and by approximately 500 vehicles south of Frederick.

Competing transit system ridership would decline, especially the MARC Brunswick Line, commuter bus MT 505/515, MD 355 BRT, and Ride On 100, which would collectively reduce in ridership by nearly 10,000 trips per day. The Corridor Cities Transitway (CCT) and WMATA Metrorail would see a slight increase in daily boardings.

The evaluation of the operations and ridership of monorail on this alignment has found that this system has enough merit to achieve operational viability, however, the ridership is anticipated to predominantly shift from existing transit systems and will have very little impact on existing road networks. Therefore, the ridership has been determined to be a concern due to the decrease in ridership anticipated from the other transit services and the overall lack of reduction of single occupancy vehicle trips from I-270.

Feasibility and Reasonableness

This Feasibility Study evaluated the feasibility and reasonability of utilizing the monorail technology in this study area corridor. This Feasibility Study investigated and evaluated monorail in this corridor and measured the effectiveness of this system using the following metrics:

- Evaluation of monorail technology in general, and if it is appropriate for the study corridor
- Evaluation of the specific design requirements of monorail and the proposed alignment, and the alignment's potential cost, impact, and benefits
- Evaluation of the I-270 corridor for the viability of a transit system

Based on the evaluation completed as part of this Feasibility Study, the construction of monorail within this corridor is physically feasible. This feasibility determination is based on the technology and proposed alignment. Impacts to existing transit ridership and vehicle volume reductions on I-270 were not fully examined. At this point it is recommended that any future study of monorail in this corridor consider the full impact on these two factors. If this system is to be evaluated further, the next step would be a detailed evaluation consistent with the National Environmental Policy Act (NEPA), which which requires federal agencies to assess the benefits and effects of the project, and conduct extensive public outreach. This detailed analysis would likely include the development of an Environmental Impact Statement.

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APPENDIX A

Frederick-Shady Grove Ridership and Revenue Study and Sensitivity Analysis Memo

APPENDIX B

TPB Staff Assessment of Cambridge Systematics Report Prepared for The High Road Foundation

APPENDIX C

MDOT Monorail Global Scan and Assessment, November 2020

APPENDIX D

Monorail Alignment

MARYLAND DEPARTMENT OF TRANSPORTATION