

Internal Circulation Study

Baltimore Washington International Thurgood Marshall Airport

Draft Report by

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0.0 EXECUTIVE SUMMARY

The University of Maryland Civil and Environmental Engineering Department (ENCE) has conducted a study of internal circulation alternatives at the Baltimore Washington International Thurgood Marshall Airport (BWI) for the Maryland Aviation Administration (MAA). The study was especially targeted at the expected 2030 passenger levels. The scope of work for the project included the following:

1. Collect information on BWI's current internal circulation system
 - a. Characterize BWI's current internal circulation travel patterns including bus routes and pedestrian movements
 - b. Acquire passenger counts and service quality measures for different modes
 - c. Obtain travel time, performance, and capacity information for current BWI operated buses
 - d. Review literature on internal airport circulation systems
 - e. Study BWI's Master Plan to understand how future plans affect the demand and configuration of the internal circulation system
 - f. Have preliminary meeting with MAA to discuss:
 - i. The current state of the internal circulation system
 - ii. Possible alternatives for improvement of internal circulation system
 - iii. Measures of effectiveness (MOEs) that will be used for analysis
2. Research the possible alternatives or combination of alternatives to improve internal circulation
 - a. Combine train, parking, and rental car buses
 - b. Create an on-demand system for buses
 - c. Covered walkways and moving sidewalks
 - d. Automated People Mover system (APM) with fixed route
 - i. Include research about different makes and construction options
 - e. Personal Rapid Transit (PRT) system with flexible route
3. Screen out unpromising alternatives with input from MAA
4. Develop simulation models to help evaluate MOE's
 - a. APM and PRT will necessitate the development of a new simulation model that will be capable of:
 - i. Analyzing the effects of different demand levels and patterns
 - ii. Analyzing the effects of various vehicle characteristics (maximum speed, acceleration, etc.) and fleet sizes
 - iii. Estimating travel time and delay for users under various circumstances
 - b. Other alternatives will be analyzed with preexisting models
5. Compare alternatives according to MOE's such as:
 - a. Cost including capital and annual costs
 - b. Environmental effects (GHG, NOx, etc.)
 - c. Customer comfort

- d. Effect on airport operations (traffic flow, security)
 - e. Capacity and passenger delay
- 6. Present analysis of alternatives to MAA and select preferred alternative(s)
- 7. Create a detailed conceptual design of selected alternative (time permitting):
 - a. Upgrades and demolition of existing facilities
 - b. Location of new facilities
 - c. Rendering of alternative
- 8. Present conceptual design to MAA

0.1 RESEARCH

The first part of the report focuses on researching the airport's current condition, technologies for intra-airport transportation, and examples of what other airports have built. The current condition of the airport is examined by reviewing the 2011 BWI Marshall Master Plan. Special attention is given to sections pertaining to internal circulation. The current shuttle bus operations are summarized as a basis for other evaluations. Numerous journals, especially entries from the American Society of Civil Engineers's (ASCE) Automated People Mover Conference proceedings, are reviewed to study different internal circulation technologies. Information on current airport automated guideway transit (AGT) systems is also researched.

0.2 ALTERNATIVES AND MEASURES OF EFFECTIVENESS DESCRIPTIONS

The different alternatives for BWI's internal circulation system are proposed. They include a No Build, Automated People Mover (APM), and Personal Rapid Transit (PRT) alternative. The No Build alternative continues the airport's use of buses, but also includes analysis of different bus engine types. The APM and PRT alternatives each have numerous alignments that are evaluated individually. Lifecycle cost, operational assessment, and air emissions are the measures of effectiveness used to evaluate each alternative. The lifecycle cost includes the capital and the annuitized operating/maintenance. Value of time is examined, but is only integrated with the total cost in a sensitivity analysis. The operational assessment focuses on what the 2030 projected trip time would be for each alternative. The No Build Alternative trip time is estimated using previous studies, while the other alternatives' trip times are estimated with simulation output. When evaluating the air emissions, the No Build Alternative's estimate is dependent on bus miles per year, while the other alternatives use megawatt hours per year.

0.3 ALTERNATIVES EVALUATION

The results of the alternatives evaluation are summarized below in Table 0-3-1.

Table 0-3-1: Summary of Alternatives Evaluation

Alternative	Total Cost (\$ million)	Average Weighted Trip Time (Minutes)	NO _x (kg/year)	SO ₂ (kg/year)	CO ₂ (kg/year)
No Build	120	18	1459		18,754,634
APM	443	8.3	3,977	11,706	10,822,884
	-	-	-	-	-
	1459	13.3	9,803	33,406	11,021,200
PRT	183	3.9	3,624	10,506	10,426,621
	-	-	-	-	-
	491	10.9	9,811	33,434	11,030,414

A range of values is shown for the APM and PRT alternative because multiple alignments are evaluated. No Build is the most economical alternative. PRT is the quickest and in some cases, the least polluting alternative.

0.4 SENSITIVITY ANALYSIS

Much of the output in the alternatives evaluation is based on assumptions which are evaluated in the Sensitivity Analysis section. The capacities of the APM and PRT are tested with larger than projected demand. The fuel price projections are increased and decreased to test how they affect the total cost of different bus types. The discount rate is adjusted to see if it changes the total cost rankings of the alternatives. Lastly, the value of time is adjusted and its effect on the total cost of each alternative is evaluated.

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1.0 STUDY JUSTIFICATION

BWI Marshall has consistently been lauded by the press and several trusted ranking organizations as providing passengers with a high level of service. A recent article praised BWI about the airport's growing number of passengers, low passenger fees, and the lowest average ticket price in the area. The volume of passengers using BWI, which is projected to grow to 18 million passengers per year by 2030, will strain BWI's internal circulation. Travel times between different airport facilities are forecasted to increase significantly and without adequate intervention, the convenience that BWI is known for will be degraded. For BWI to stay competitive with the other area airports, it needs to ensure that passengers and airport employees can navigate the airport with ease, even with the additional traffic expected in the future. Improving the internal circulation system will not only improve the travel times for automobiles around the airports, it will also provide passengers and employees another easy to use option for navigating the airport. This study is necessary to examine the best way of improving BWI's internal circulation system and continue the airport's increase in passengers.

2.0 SUMMARY EXISTING AND FUTURE FACILITIES

A summary of BWI Marshall's current and possible new facilities is necessary to plan for improvements to the internal circulation system and the possible implementation of an automated guideway transit. Most of the information in this section summarizes pertinent topics in the 2011 BWI Marshall Master Plan prepared by Landrum & Brown.

2.1 PASSENGER TERMINAL

As of 2012, BWI Marshall's passenger terminal has five main two level concourses that contain all the facilities necessary for passenger processing. Most passengers and airport employees are expected to use this facility and require some form of transportation to access it. The terminal itself is divided into three areas including the South Terminal (A & B Concourses), Central Terminal (C, D, and Commuter Concourses), and the North Terminal (E Concourse). The master plan indicates that future growth in the terminal area would either occur by expanding Concourses C and D, or by expanding Concourse E and creating Concourse F next to Concourse E.

The changes to the internal circulation system must address the passenger terminal as most passengers are either coming from or to the terminal. Multiple stops maybe planned for the terminal area to facilitate intra-terminal transportation and to minimize the distance passengers or employees have to walk to access the new circulation system. The improvements to the internal circulation system should not interfere with the anticipated growth of the terminal area.

2.2 ROADWAY ACCESS SYSTEM

Several highways and Interstates serve BWI Marshall. I-195 is the primary route into the airport with access to I-95 and the Baltimore-Washington Parkway. Aviation Blvd. and Dorsey Road together circle the airport and provide access to other airport facilities. A two level roadway serves the curbside area, and runs on the inside of the horseshoe shaped passenger terminal and surrounds the hourly parking garage. The lower level serves arrivals and provides 2,600 linear feet of curb space on the side of the road next to the terminal and 2,300 linear feet on the side next to the parking garage. The lower roadway has seven lanes, including in order from next to the terminal to the parking structure:

- Two 13.5 feet "authorized only" lanes used by commercial vehicles (Taxis, shuttle buses, etc.)
- 20 feet wide passenger refuge area where passengers wait to be picked up by personal vehicles
- Four 11 feet wide passenger pick up lanes for personal vehicles
- One 20 feet wide "express" bypass lane designed to allow personal vehicles who already picked up their passenger to bypass the downstream congestion of the passenger pick up lanes

The top roadway serves departures, and is 2,200 and 2,600 linear feet for the part of the roadway adjacent to the parking structure and terminal respectively. The top roadway has six lanes including in order from next to the terminal to the parking structure:

- Two 15 feet "authorized only" lanes
- 20 feet wide passenger refuge area
- Four 12 feet wide passenger pick up lanes

See Appendix 1 for a cross section of the curbside area roads.

I-195, Aviation Blvd, Terminal Rd. and their intersections are expected to be reconfigured to increase their capacity and make room for runway/taxiway improvements. Terminal Rd and Aviation Blvd's relocation will eliminate the at-grade intersections with the light rail. The design of the new circulation system should take into account the roadway reconfiguration.

2.3 PARKING

There is a variety parking facilities for passengers to use, including parking owned by the airport and by private companies. Parking spaces closest to the terminal are more valuable and tend to be more expensive. Table 2-3-1 lists the different parking options around the airport.

Table 2-3-1 Passenger Parking Lots

Public Parking Lot	Number of Spaces	Distance from Terminal A/B	Hourly Rate/Daily Rate
Hourly Garage	5,300	100 feet	\$4/\$22
Daily Garage	8,400	0.8 miles	\$2/\$12 (1 st hr \$6)
Express Lot	1,400	0.8 miles	\$2/\$10 (1 st hr \$4)
Long-term Lots A and B	10,100	2.3 miles	\$1/\$8
Overflow	4,600	4.5 miles	
Rail Station Lot	2,000	1.8 miles	Free for commuters\ \$9
Fast Park Red Lot	1,070	1.2 miles	N/A\ \$9
Fast Park Blue Lot	2,140	1.7 miles	N/A\ \$8.50
Park 'N Fly	1,750	2.3 miles	N/A\ \$8
Econopark BWI	1,200	3 miles	N/A\ \$7.95
Preflight Airport Parking	1,120	2.6 miles	N/A\ \$9.50

**Lots not owned by airport italicized*

Source: MAA, 1/2012; Google Maps, 1/2012; Edwards and Kelcey, 11/2005; MARC, 1/2012; Airport Fast Park, 1/2012; Park 'N Fly, 1/2012; Econopark Express, 1/2012; Preflight Airport Parking, 1/2012

There are 5,710 employee parking spaces in parking lots scattered throughout the airport. The largest lots, West and East Employee Lots, are located about 3.1 miles from Terminal A/B., but have since been abandoned in favor of a large parking lot near the BWI Business Park light rail station.

Passenger parking is expected to expand according to the master plan with three possible alternatives. Each parking alternative will have a substantial amount of parking located far enough away to require some type of shuttle to the passenger terminal. Each passenger parking alternative will expand the Hourly and Daily Garage, although Alternative 2 will expand the Daily Garage further than the other two alternatives. Alternative 1 will combine Long-term Lots A and B, and move employee parking to the Hourly Garage. Alternative 2 would move long term parking to the North Cargo Area and would be partially surrounded by the light rail line. Alternative 3 would move long term parking to where the current Consolidate Rental Car Facility is located. The airport is likely to build out Alternative 1, but the new automated transportation system should be designed to be incorporated in any of the alternatives.

2.4 OTHER FACILITIES

The Consolidated Rental Car Facility (CRCF) contains all the rental car agencies at BWI Marshall and has a capacity of about 7,500 vehicles. The facility is about 2.7 miles from Terminal A/B. Expansion of the CRCF will occur in the same possible locations as the long term parking alternatives including in the expanded Hourly Garage, North Terminal Area, or expansion of the current CRCF.

A light rail station located adjacent to Terminal E transports passengers and employees to Baltimore City, Baltimore County, and Anne Arundel County. There is also the BWI Marshall Amtrak/MARC Station located 2 miles from Terminal A/B. The station is on the electrified Northeast Corridor, which has train service to destinations all over the Eastern Seaboard. MARC, a commuter rail service, has frequent weekday train service from the station to locations as far south as Washington DC and as far north as Harford County, Maryland.

2.5 APM/PRT SYSTEM AS PROPOSED IN THE MASTER PLAN

The master plan proposed three mutually exclusive automated shuttle systems that would shuttle passengers and possibly employees to the Hourly and Daily Parking Garages.

Alternative 1 would have two cable propelled APMs, one on the east side of the garages and one on the west side. Since there are two independent APMs, one shuttle would still be operating in case another needs maintenance or repair. This alternative would be the most economical because cable-propelled technology is the least expensive type of APM system to build. Additional capacity can be provided by adding more cars to the trains, but the route could not easily be extended and usually there is only one train per track in airport applications. Users of the system would have to cross their parking structure if their terminal is on the other side of their location in the parking structure. Maintenance on the vehicles would have to be performed at the stations.

Alternative 2 consists of a loop around the parking structures and could have either single or twin guideways. A twin guideway system would allow users to reach any station using the shortest path, provide redundancy in case of problems, but would increase construction and maintenance costs. A single guideway system would be more economical, but it would decrease the level of service for passengers as they are forced in one direction around the loop and any problem in the system could shut down the trains. The alternative consists of self-propelled vehicles that could be added to the system as needed. A maintenance facility would be located north of the light rail tracks parallel to Aviation Blvd for both a single or twin guideway system. This alternative could be an APM or PRT system.

Alternative 3 is similar to Alternative 2 as they utilize self-propelled vehicles, are expandable/extendable, and have a remote maintenance facility. Unlike Alternative 2, Alternative 3 utilizes a reverse J shaped network instead of a loop network. The reversed J shaped network would require the alternative to have twin guideways. Alternative 3 would be cheaper and provide a similar level of service compared to the twin guideway Alternative 2, but users on the east side of the daily garage would have to cross to the west to access a station. Alternative 3 could be an APM or PRT system.

2.6 CURRENT SHUTTLE BUS OPERATIONS

BWI operates six shuttle routes around the property including services from the terminal area to multiple outlying facilities. Table 2-6-1 lists all the BWI Shuttle Operations.

Table 2-6-1: BWI Shuttle Operations

Route	Roundtrip distance (miles)	Round trip time (minutes)	Bus Hours/Day	Bus Type
Long Term Parking Lot A	7.1	70	155	40' Diesel
Long Term Parking Lot B	7.7	70	155	40' Diesel
Daily Parking Garage	4	40	164	40' Diesel
Express Parking Lot	4.1	40	171	Cut-away Diesel
Employee Parking Lot	4.8	40	116	40' Diesel
BWI Rail Station Garage	6.3	40	104	40' Diesel
Consolidated Rental Car Facility	8.1	51.3	120	40' CNG

The current operation's level of service is shown below in table 2-6-2. The peak period is 4am-7pm. The off peak period covers all other times. The Express Parking Lot shuttle is not shown because it will be eliminated by 2030.

Table 2-6-2: Current Shuttle Operations Level of Service

Shuttle Route	Passenger Trip Time (Minutes)		Headway (Minutes)		Average Waitime (Minutes)	Average Travel Time (Minutes)	Average Trip Time (Minutes)
	Peak	off peak	Peak	off peak			
Longterm Parking Lots	20.0	15.0	10.0	15.0	5.5	19.0	24.5
Daily Parking Garage	5.0	5.0	5.5	15.0	3.7	5.0	8.7
Employee Parking Lot	5.0	5.0	10.0	20.0	6.1	5.0	11.1
BWI Rail Station Garage	10.0	9.0	8.0	25.0	5.8	9.8	15.6
Consolidated Rental Car Facility	17.0	13.0	10.0	10.0	5.0	16.2	21.2

Source: (BWI, 2012; URS/RK&K/ Booz, Allen & Hamilton, 2006)

BWI Marshall contracts out all shuttle routes, except for the Consolidated Rental Car Facility route, which is managed by the rental car consortium. The contracted shuttle route buses are powered by ultra-low sulfur diesel fuel and the rental car buses use Compressed Natural Gas (CNG). Together, the shuttle routes use 49 diesel buses, 14 cut-away buses, and 25 CNG buses. All the shuttle bus operations including fuel, labor, maintenance, and facility costs are estimated in this study at \$20,403,274 a year. The cost is similar at other similarly sized transit agencies.

The shuttle operation is a large source of air pollution at the airport as shown in table 2-6-3.

Table 2-6-3: Shuttle Bus Emissions

Air Pollutant Type	Emission Amount / Year	Note
Carbon Dioxide Equivalents	7,220,280 kg	Incorporates all greenhouse gases and adjusted them for their global warming potential Greenhouse gases are responsible for climate change
Carbon Monoxide	32357 kg	A poisonous gas
Nitrogen Oxides	474 kg	Responsible for smog
Particulate Matter	19 kg	Causes cardiovascular issues and other negative health effects
Hydrocarbons	2495 kg	Responsible for smog

Source: EPA (2012)

Changes to the shuttle bus operation could have a significant positive impact on BWI's emissions. The map of the shuttle routes and other details for analysis appear in Appendix 2.

3.0 CURRENT TECHNOLOGIES FOR INTRA-AIRPORT TRANSPORT

Airport transport includes two main categories: buses and automated guideway transit. Buses in airport travel a portion of their journey with the rest of traffic. Buses also vary in size and engine type.

Guideway transit uses some kind of rail or concrete guideway to control the motion of a vehicle or a group of vehicles and usually operate on its own right-of-way. Airport guideway transit vehicles are usually automated (controlled centrally by a computer). This section discusses the different types of buses and automated guideway transit that the BWI airport can choose from.

3.1 BUSES

Most airports, including BWI Marshall, have at least one shuttle bus route to circulate passengers and employees around the airport grounds. Compared to other forms of intra-airport transport, buses have the lowest capital costs and are the most flexible in terms of changing routes. The only substantial capital cost for bus systems are the buses themselves, which many different manufacturers produce. Shuttle bus routes can be changed at will, not requiring any construction beside minor sign and waiting area relocation. Buses operate independently and if one fails, the other buses can usually bypass the disabled vehicle. Shuttle bus routes usually only serve one origin destination pair and in some cases the routes overlap. Shuttles buses usually share the right-of-way with other airport traffic and subjected to the same congestion that other airport vehicles experience. At BWI, the buses have exclusive uses of the two lanes adjacent to the terminal, but are still forced to share the road with other traffic outside the terminal area. Buses are more labor-intensive than automated vehicles, requiring a driver for each bus. Bus engines have recently gotten cleaner, but (with the exception of electric buses) are still a point pollution source and may be an obstacle in air quality goals. Extensive bus operations also tend to damage roads, which is estimated to cost about \$1.09 per passenger trip (Tegnér & Angelov, 2009). Most airport buses are 40' long and use either diesel, compressed natural gas (CNG), or hybrid-electric engines.



Figure 3-1-1: BWI Shuttle Bus
Source: Virtual Tourist (2012)

3.1.1 DIESEL

The majority of buses operating in the US use diesel engines. Most diesel engines use fuel obtained from refining crude oil. Bus operators are usually experienced operating diesel buses, and do not require

special facilities or training. Diesel is not very volatile and has a high flash point, making it safe to use. Capital costs for diesel buses are among the lowest. Although diesel engines appear to have lower capital costs, many bus agencies are switching to different engine types. Diesel fuel tends to be more expensive than other fuel types and produces more toxins. Petroleum-derived diesel fuel previously contained large amounts of sulfur, but new processing techniques takes out much of the sulfur.

Biodiesel, derived from plant oil or animal fat, can be used instead of petroleum diesel to reduce certain emissions, receive federal alternative fuel credits and use less imported crude oil. No alterations to traditional diesel engines are necessary unless the engine will be operating in cold temperatures. There are two different types of biodiesel, a 20% biodiesel 80% petroleum diesel blend (B20) and 100% Biodiesel (B100). Biodiesel emits less carbon monoxide, particulate matter, and carbon dioxide, but emits more nitrogen oxides. Both types of biodiesels are more expensive than petroleum diesel, but certain government incentives make biodiesel prices more comparable to petroleum diesel (TCRP 146, 2010).

3.1.2 COMPRESSED NATURAL GAS

Compressed natural gas (CNG) for buses is the next most popular fuel type and has recently become more popular. CNG buses are becoming more prevalent because natural gas is cheaper than diesel and produce less pollution. Natural gas normally has much lower energy density than petroleum-based fuels, but when it is compressed, the energy density increases to a usable level. Most natural gas is domestically produced and there is enough available for decades to come. CNG buses produce less emissions than diesel buses with the exception of Carbon Monoxide.

Natural gas is not the perfect energy source. CNG buses require massive storage tanks because of the low energy density of natural gas. The additional weight and low energy density reduces the fuel economy. Capital costs are higher with slightly costlier buses and expensive refueling facilities that require large amounts of electricity to power compressors. CNG buses also have higher maintenance costs and lower vehicle performance when compared to diesel buses (TCRP 146, 2010).

3.1.3 HYBRID-ELECTRIC

The fastest growing bus type is hybrid-electric buses. This type of bus uses fuel in addition to electricity. The electricity comes from the energy recovered when the buses decelerate. Hybrid buses have better vehicle performance, fuel economy, reliability, and emission production compared to diesel buses. The main drawbacks included higher capital costs, special training for mechanics, and the necessity of minor facility upgrades (TCRP 146, 2010).

Table 3-1-1: Bus Type Comparison

Engine Type	Diesel	Biodiesel (B20)	CNG	Hybrid
Vehicle Cost (\$1000)	350	350	375	445, expected to decline
O & M Cost (\$/mile)	0.32	0.32	0.41	0.35
Fuel Economy	3.2 MPG	3.2 DGE	2.7 DGE	4.01 MPG
National Fuel Price	\$4.12/gallon	\$4.18/gallon	\$2.08 /GGE	\$4.12/gallon
GHG Emissions Compared to Diesel	N/A	-10%	-4%	Between -12% & -32%
Other Emissions Compared to Diesel	N/A	All emission lower except slightly higher NOx	All emission lower except it emits more CO than new Diesel	At least 25% less
Reliability Compared to Diesel	N/A	Same	Unknown	Mixed results, additional engine components complicate repairs, but lessen the burden on other parts
Performance Compared to Diesel	N/A	Same (worse with B100)	Slight reduction with acceleration and hill climbing ability	Better acceleration at low speeds
Facility Upgrades	None	\$400	\$1,000,000 +	\$5000/50 buses
Special Training	None	None, but staff should be aware of cold weather effects	Fuel dispensing, maintenance, and safety training needed	Additional training for maintenance workers required for handling batteries
Safety	Fuel is toxic and needs to be properly stored	Fuel less toxic than diesel	Natural gas itself not toxic, but leaks can be dangerous	Lithium Ion Batteries can explode

Note: Values based on US average, not BWI specific

Source: TCRP 146- Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements (2011) & Clean Cities Alternative Fuel Price Report (2012)

3.2 AUTOMATED GUIDEWAY TRANSIT

Automated guideway transit (AGT) includes a wide spectrum of technologies ranging from the typical traditional automated people movers seen at most airports to the upcoming personal rapid transit that has recently been introduced to London Heathrow Airport. Traditional automated people movers, monorail, and light rail can also be grouped together as automated people movers.

3.2.1 TRADITIONAL AUTOMATED PEOPLE MOVERS

APMs are fully automated driverless vehicles that operate on fixed guideways on exclusive right-of-way. The vehicles operate with rubber tires on a concrete guideway or steel wheels on rail. The capacity of the system ranges from 5000-20,000 people per hour per direction (pphpd) with vehicles acting in single units, married pairs, or trains. Most APMs have platform screen doors at each station acting as an intermediate door between the APM doors and the stations. APM services have fixed schedules, but during off-peak periods, vehicles can remain at stations until they are called by passengers to their stations. Most APM's in North America are built in airports for intra-airport circulation or inter-terminal service. APMs' advantages include automation, small headways, and liberal grading/curvature requirements. With automation, small headways, and shorter train sizes; station platform lengths can be shorter. APMs can be self-propelled via electricity on a third rail or propelled with a cable system, which is more economical. The main disadvantages are their slow speeds of usually 30 mph (though they have been known to be faster), high construction cost, and the high cost of extending system since mostly the same manufacturers must be used again, thus decreasing bidding competition. Cable-propelled APMs have the added disadvantage of not being easily expandable (Moore & Little, 1998).



Figure 3-2-1: DFW Skylink APM

3.2.2 LIGHT RAIL

Light rail systems, which have seen a surge in popularity in urban areas, can also be utilized for airport circulation. Light rail are usually powered by overhead catenary wires, but can also receive electricity via an electrified third rail. They commonly have steel wheels that run on steel tracks, but can also use rubber tires that run on a concrete guideway. Unlike traditional APMs, they are flexible in terms of whether they are grade separated and automated, or at grade and manual. Light rail advantages include their operating speeds (up to 70 mph), can run with other modes of traffic, high train capacity, standardized technology that increases bidding completion, and shorter platform length requirements. The main disadvantage is light rail's heavier vehicles, which require more structural support (Moore & Little, 1998).



Figure 3-2-2: AirTrain JFK
Source: NYC MTA (2012)

3.2.3 MONORAIL

Monorails are self-propelled vehicles that are supported below or above a single rail or guideway. There are large and small capacity systems that also vary in speed. Large capacity monorails can handle 500-2000 pphpd (people per hour per direction), while small capacity monorails support 500-3000 pphpd. They are less common at airports, but Newark Liberty Airport has a monorail system to transport passengers from terminal to terminal and to the airport's Northeast Corridor rail station. Monorail benefits include less expensive and less intrusive support structures, and fast speeds of up to 55 mph. The drawbacks include larger minimum headway, longer trains, narrowness of the vehicle and the unusable space in the front and back of the trains (Moore & Little, 1998).



Figure 3-1-3: AirTrain Newark
Source: PANYNJ (2012)

3.2.4 PERSONAL/GROUP RAPID TRANSIT

Personal rapid transit (PRT) is similar to APM as they are both automated guideway transit, except PRT provides on-demand service where passengers select their destination and the PRT transports them directly to their destination bypassing intermediate stations. The passengers' vehicles are only occupied by the passengers' travel party, making the vehicle more personal and comfortable. The capacities of PRT vehicles vary depending on the manufacturer, but usually fit around four people, including their luggage. Vehicles are powered via electrified rail or onboard batteries, and are usually supported by rubber tires on concrete guideways. In areas with uncomfortable weather, it is recommended to use an electrified rail as the power source to support the demands of heaters or air conditioners. PRT vehicles are much lighter than other automated guideway transit vehicles, thereby decreasing the size and cost of structural components. Designing the PRT alignment is easier with a minimum turning radius of about 32 feet and liberal gradients restrictions (though vehicle propulsion may limit the extreme gradients). The main drawback of PRTs is their vehicle performance, which is slower than light rail or monorail reaching speeds only up to 30 mph and acceleration of around 8.2 ft/sec^2 . The system at BWI may need higher vehicle capacity and speeds than PRTs can provide, but the technology exists with group rapid transit (GRT). GRT features larger vehicles than PRT and requires passengers with the same or similar origin destination pairs to share the same vehicle. GRT systems can operate with a single vehicle serving a group of nearby stations instead of just a pair of stations to decrease the number of vehicles needed. The group of stations cannot be too large because as the number of stations served increases, the GRT starts to resemble APMs. GRTs' larger vehicle size also requires larger and more expensive infrastructural components (Vectus Transit, 2011).



Figure 3-2-4: Heathrow Ultra PRT
Source: Ultra PRT, 2012

4.0 AUTOMATED GUIDEWAY TRANSIT AT OTHER AIRPORTS

Many other airports have already built different kinds of automated guideway transit to shuttle people from the terminal area to other sites including other terminals, parking, transit stations, or rental car facilities. This section will include summaries of automated guideway transit built at other major airports that are not exclusively in the terminal area.

4.1 TAMPA INTERNATIONAL AIRPORT MONORAIL

Tampa International Airport, which is known as the first airport to utilize APMs, also has a functioning pinched loop monorail. The Bombardier built monorail opened in 1991 and connects the passenger terminal to the four sides of the long term parking garage. The 3,200 feet system has eight stations and operates with five single-car trains during peak periods. The vehicles look like PRT vehicles, rather than typically long monorail trains. The system operates with 84 second headways, thus providing low waiting times. Monorails can reach speeds of 50 mph, but in Tampa's case, the short length of the system only necessitated a design speed of 20 mph. Tampa's monorail is very dependable, operating 99.4% of the time. This type of monorail system would work well for the small scale APM alternatives mentioned in the BWI Master Plan (Lindsey 1998).

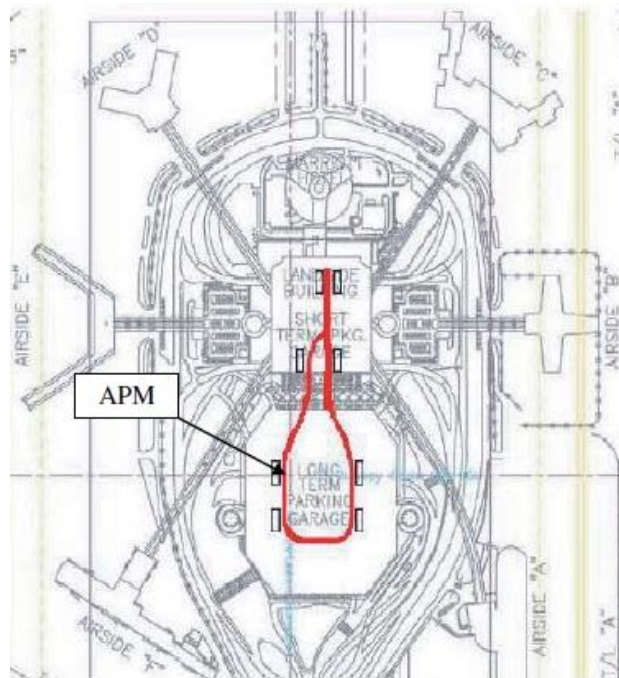


Figure 4-1-1: Tampa Airport Monorail
Source: ACRP 37 (2010)

4.2 LONDON HEATHROW'S ULTRA PRT

One of the newest PRT systems in the world opened in September 2011 at London Heathrow Airport, connecting Terminal 5 with the business car park. It was built by Ultra, a UK based company specializing in building PRT systems. The system cost about £25m (\$38.2m) and consists of 21 vehicles operating between three stations connected by 2.36 miles of guideway. The vehicles are called Ultra pods, which

have a capacity of up to four people including their luggage. These rubber-tired vehicle have a 16 foot turn radius and weight only 1870 pound, which minimizes the guideway infrastructure's structural requirements. The vehicles are battery-powered and charged whenever they are at a station. They can also reach speeds up to 25 mph. Each PRT station can handle 100-120 vehicles per hour with minimal waiting time. At Heathrow, the waiting time is only 30 seconds. All pods are monitored from a central location and an independent Automatic Vehicle Protection system was implemented to ensure passenger safety. The system is compliant with all US safety regulations. A system similar to Ultra's PRT system including everything from vehicles, infrastructure and control systems can cost approximately 11-24 million dollars per mile. (Ultra Global PRT, 2011).



Figure 4-2-1: Heathrow T5 PRT
Source: Google Maps (2012)

4.3 AIRTRAIN JFK

AirTrain JFK is an automated light rail system at John F. Kennedy International Airport (JFK). The 8.4 mile AirTrain JFK is longer than typical airport APMs consisting of a 2 mile loop connecting the terminals in the Central Terminal Area, a branch that connects to the Howard Beach subway station 3 miles away, and a branch that connects to the busy Jamaica subway and train station 4.5 miles away. AirTrain has a maximum operating speed of 62 mph to move passengers through the long system quickly. There are ten stations built of pre-cast concrete. This APM utilizes steel wheel on steel rail technology; that is rare for airport APMs, which usually use rubber tires on concrete guideways. The airport authority chose steel on steel technology to allow it to use quick and high capacity vehicles that may one day be able to travel all the way to Manhattan. The airport needed AirTrain JFK for many reasons, including providing transportation to: all passenger terminals, multiple MTA subway and commuter rail lines near JFK, rental car and hotel shuttle bus depot, long term/employee parking, and alternate pick up/ drop off locations. The \$1.9 billion system was built under a Design-Build-Operate-Maintain contract by a consortium consisting of Slattery/Skanska, Bombardier, and STV Inc. AirTrain JFK was completed in December of 2003 and by September of 2004, it carried about 30,000 passengers perday. The system is free for those

traveling around the airport, but if someone enter or exits the system at one of the stations connecting to an MTA station, a fee must be paid with a metro card. Service headways range from every 7 minutes during peak periods to every 15 minutes (PANYNJ 2011). When the system first opened to the public, it was plagued with service problems, especially with trains failing to communicate with the centralized vital computer, but has since been made more reliable (Plate, 2005).

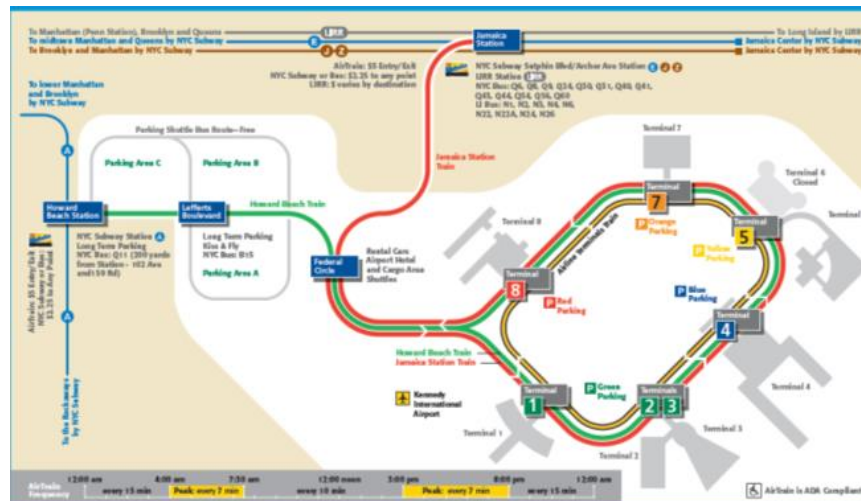


Figure 4-3-1: AirTrain JFK
Source: PANYNJ (2011)

4.4 AIRTRAIN SFO

AirTrain SFO is a traditional automated people mover that is five miles long with nine stations. The network consists of a loop that connects all the terminals with the central parking garage, the SFO BART station, and a segment that comes out of the loop to the maintenance building and the rental car facility. The system opened in 2003 at a cost of \$430 million and uses Bombardier-based technology. The trains have a top speed of 30 mph and are supported on rubber tires that move on a concrete guideway. The vehicles are powered by a third rail that is placed in the middle of the guideway (Cabanatuan 2003).

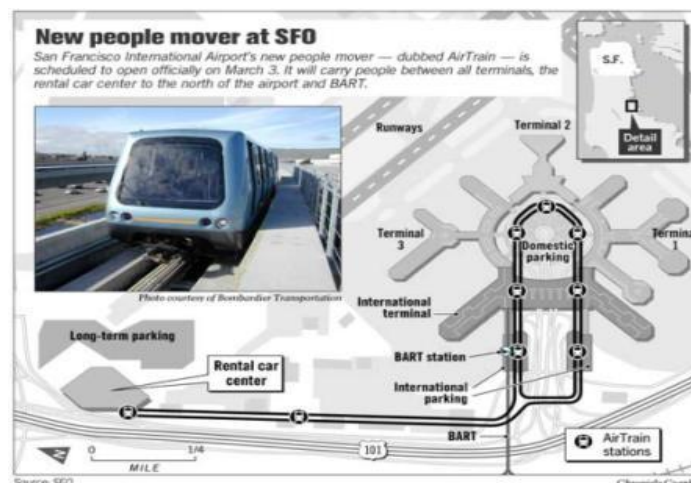


Figure 4-4-1: AirTrain SFO
Source: SFO (2003), Bombardier Transportation (2003) , and SF Chronicle (2003)

4.5 MORGANTOWN PRT

While the Morgantown PRT is not located at an airport, it has one of the first forms of GRT transport, though it is informally referred to as a PRT. The GRT in Morgantown was originally funded as a pilot project by what is now the Federal Transit Administration in the beginning of the 1970's. It was built in two phases. The first phase had 3 stations and 45 automated vehicles. The second phase increased the size of the system to 5 stations and 71 vehicles. The GRT system officially opened in 1979.

The system in 1996 consists of 71 vehicles capable of moving up to 30 mph along guideways that span 3.6 miles connecting all five of the stations. The vehicles are powered by electrified rail fed into the system from 11 substations. The GRT even includes pipes embedded in the guideway that circulate hot water to melt snow that is common in the area. The system features two computer networks with one being a backup network in case the primary network fails. This was done for reliability rather than safety. The software that oversees the GRT has about 75,000 lines of code. To ensure there are no crashes in the system, a redundant collision avoidance system is used to prevent vehicles from colliding into a stopped vehicle ahead of itself. The guideway network is divided into many blocks that each have an antenna that broadcasts a safe-to proceed tone to oncoming vehicles. If a vehicle does not detect a "safetone", the emergency brakes are applied. When a vehicle proceeds into a block, it activates its presence detector, a magnet fastened to its guide axles, which causes the computer to deactivate the safetone in the vehicle's block, thus preventing a collision. The computer system also virtually calculates which safetones should be on and off, and if the real and virtual systems disagree, all vehicles in that particular zone are stopped. The speed of the vehicles and the guideway switches are also controlled by tones. The switches on the guideway are passive with the vehicles controlling the switches. The minimum headway for the system is set as 15 seconds.

There are three operating modes including demand mode, operating mode, and schedule mode. In demand mode, a passenger selects a destination and then waits for a vehicle to be assigned. The vehicle assignment is determined by wait time or number of passengers demanding the same station. If the waiting time exceeds 5 minutes or more than 15 passengers demand the same station, a vehicle will be assigned. This mode is used during school days with heavy and unpredictable demand. In operating mode, predetermined routes are used similar to shuttle buses. This mode is used during heavy demand periods with predictable movements. The circulation mode uses a few vehicles that stop at each station. This mode is used during off peak periods.

Between the start of Phase II and 1996, the reliability was 98.7%, which was above the design goal of 95.5%. Only a few minor injuries were caused by the GRT system out of the 45 million passengers it carried. It typically carried 15,000 passengers during regular school days in 1996. It costs a little above \$3 million/year to operate (Kangas & Bates, 1998).

Jon Bell © 1999

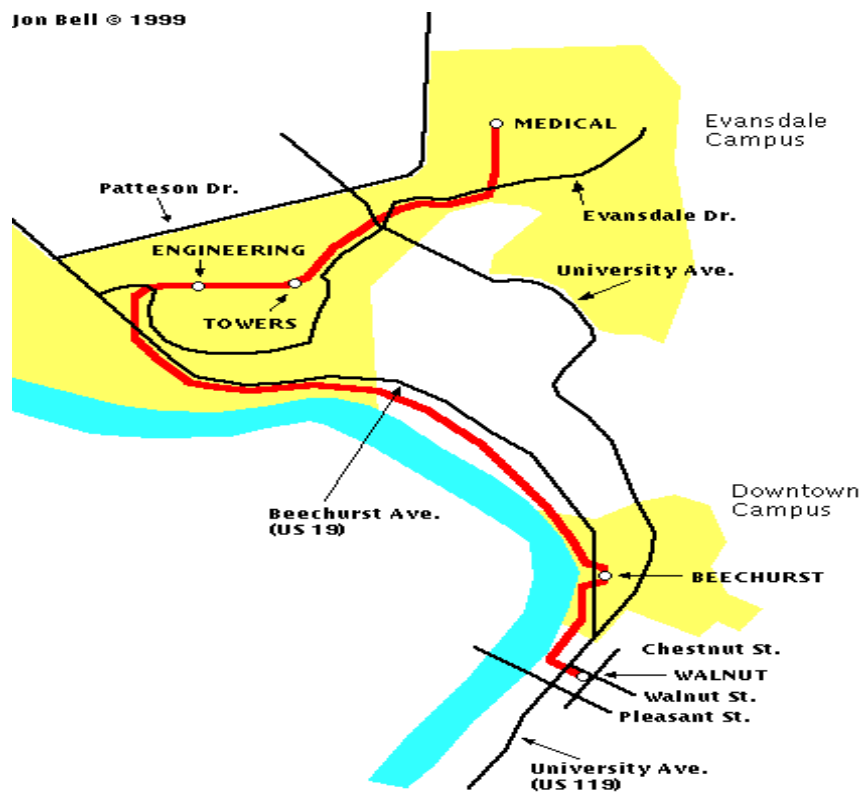


Figure 4-5-1: Morgantown PRT
Source: Jon Bell (1999)

5.0 ALTERNATIVES

The alternatives reflect the different technologies available for the new circulation system. The no build and transportation system management (TSM) alternatives are required by NEPA and even if an EIS is not required, a no build and TSM alternative gives flexibility to the decision makers (FHWA, 2006).

5.1 NO BUILD

The no build alternative will keep the current shuttle bus system with more frequent service to keep up with the airport's growth. By 2030, 125 40' buses will be in operation at BWI compared to the 74 40' operating in 2012. The no build alternative will analyze the bus operation with different bus technologies. Possible service improvements or reductions may be recommended based on the bus service study in conjunction with the expected changes to BWI Marshall's road network.

5.2 AUTOMATED PEOPLE MOVER

The automated people mover alternative could use monorail, traditional APM, or light rail based technology. The APM system at BWI Marshall could have different routes as many other airport APMs have multiple branches. Walking distances to parking spaces, especially in the long term lots, will be longer because an APM alternative would only have a limit number of stations to serve large parking lots and structures.

5.3 PERSONAL RAPID TRANSIT/ GROUP RAPID TRANSIT

This alternative could utilize a personal rapid transit type system where a smaller four person vehicle take passengers directly from origin to destination, or group rapid transit system where a larger vehicle would take a group of passengers from multiple origins to multiple destinations. PRT and GRT would both bypass intermediate stations and have smaller stations that would better serve large parking lots and structures with multiple stops.

6.0 AUTOMATED GUIDEWAY TRANSIT ALIGNMENTS

The automated guideway transit alternatives will each have several different optional segments covering different parts of the airport. Some destinations may be neglected in the final alignment if it is too expensive to build there. In that case, shuttle bus service will continue to provide access to the destination. The overview of the options can be seen in Appendix 3. The figures in the Options section utilized symbols as shown in figure 6-0-1. The required alignment and station must be built if a new transportation system is built and is not dependent on which options are chosen. The required/optional alignment and stations are specific to the terminal and are discussed in the required segment section. The optional stations and alignments are sections of the network that are dependent on the options chosen. There are two main optional branches on the network, the West Leg to the employee parking lot and the East Leg to the Long Term Parking Lots. Not every station in a leg needs to be built and could be skipped if the expected ridership to the station does not justify the cost. The phase dependent stations are optional stations serving facilities that do not exist yet, but are envisioned in the master plan. The PRT/GRT stations and alignments are a part of the network that is optional, but can only be built if PRT/GRT technology is selected. Those stations and alignments are limited to PRT/GRT due to the short distances between the stations, which are not feasible for APM technology. It should be noted that if cable propulsion is used for the APM, only one side of the required optional alignment loop could be built.

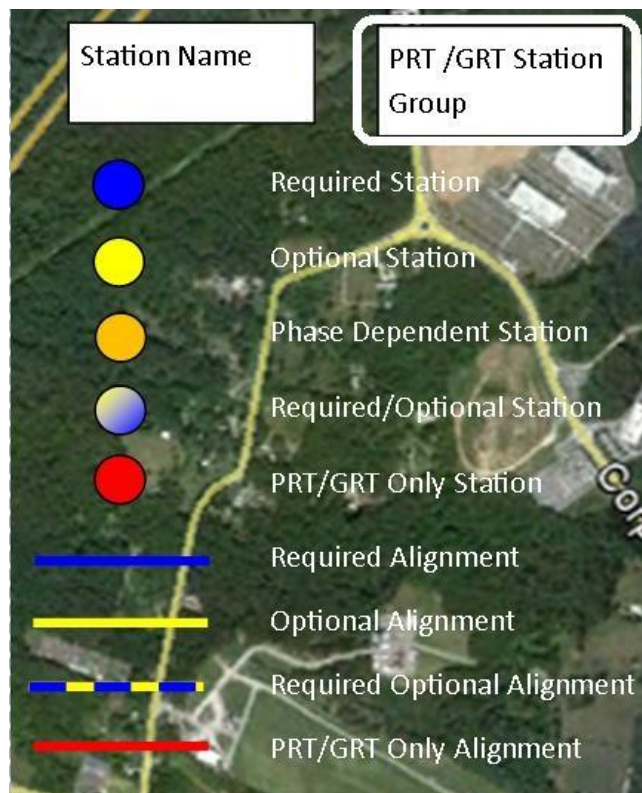


Figure 6-0-1: Alignment Diagram Key

6.1 REQUIRED SEGMENT

The required segment itself has options in terms of which side of the garages it will go, thus forming the required optional alignment. It could curve around the South Terminal and run on the southwest edge

of the garages, curve up the North Terminal and the northeast edges of the parking garages. The required segment could even form a complete loop around the garges using both of the previously discussed options. The advantage of the segment running on the southwest sides of the garages is that it will be closer to Southwest Airlines operations, the largest air carrier at BWI Marshall, and the Daily Garage station is closer to the Four Points Hotel. The disadvantage is that if Terminal F is built, it will be far away from automated guideway transit system. If the other segment is selected, the system would have better access to other terminals, but at the expense of the busiset terminal. Both of the previously mentioned segments can be joined together to form a loop and provide a high level of access to the terminal area, but at a considerable expense. All three of the potential alignment for the required segment has track going to a maintenance facility to the north of ElkrIDGE Landing Road. The maintenance facility would be unnecessary if a cable propelled technology is used. The BWI Business Park and Consolidated Shuttle Depot Station (CSD) is an optional station that would be designated as the only place that non-airport shuttles would be allowed to pickup and drop off passengers. The MTA lightrail tracks and station will be reconstructed according to the master plan to make way for Terminal F and the reconstruction of the roadways around the airport. The MTA could relocate the BWI Business Park station to the Consolidate Shuttle Depot and forgo a new alignment into the terminal core.

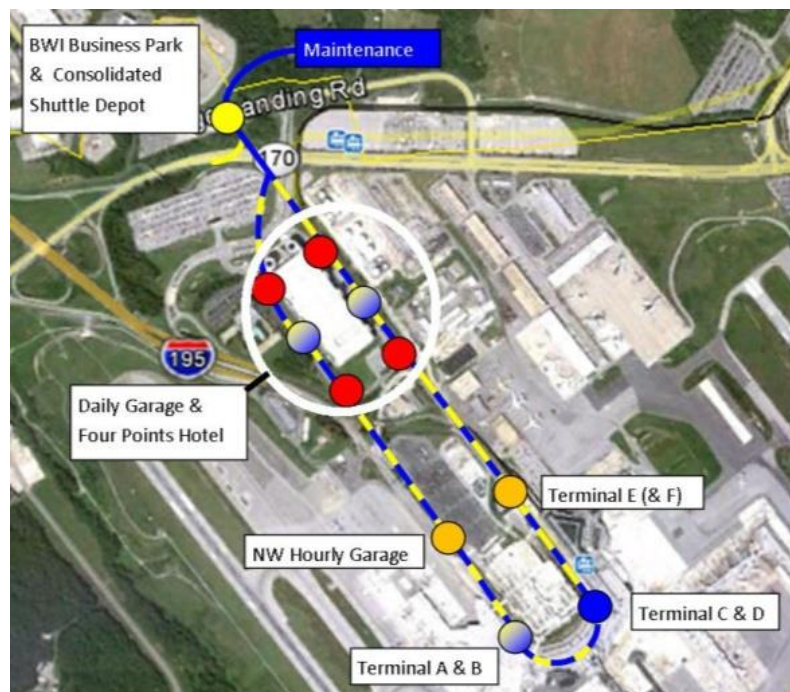


Figure 6-1-1: Required Segment Diagram

6.2 WEST LEG

The West Leg diverges from main alignment and goes toward the employee parking lot via the CRCF and BWI Rail Station. Building the West Leg would result in constructing a tunnel under I-195 to prevent the new transportation system from interfering with Runway 15R's operations. If a station needs to be built at the BWI Rail Station, the alignment must deviate to the north of the rail station to avoid the Higgins Site, an ancient archeological site south of the rail station.

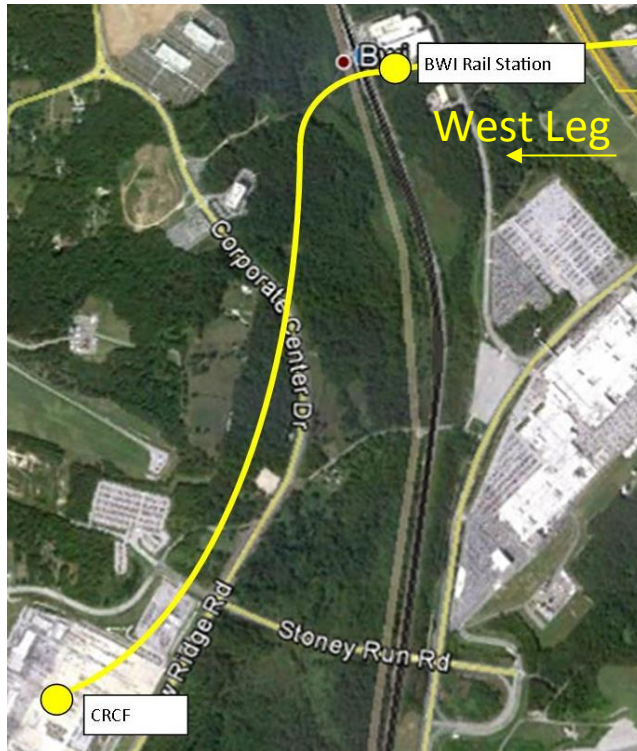


Figure 6-2-1: West Leg

6.3 EAST LEG

The East Leg will serve the long term parking lots. If APM technology is used, a few stations would be placed at the middle of each lot area. If PRT or GRT technology is used, many stations would be built around the edge of the parking lots.

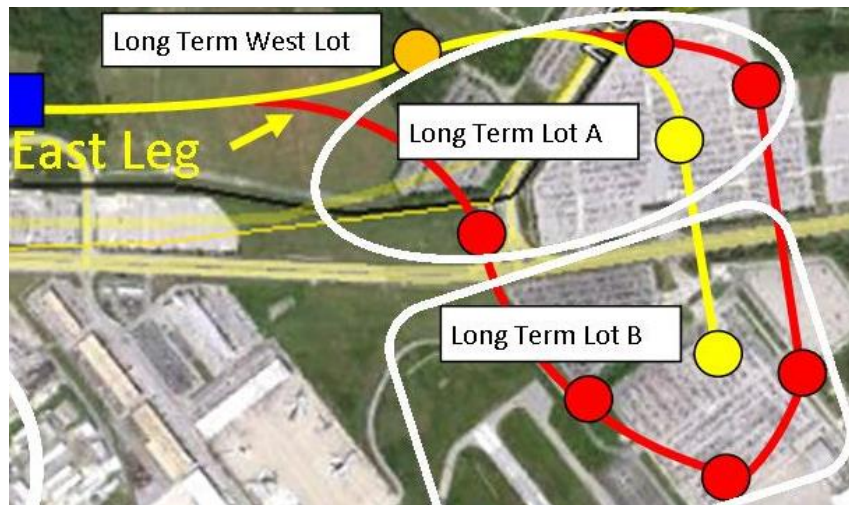


Figure 6-3-1: East Leg

7.0 MEASURES OF EFFECTIVENESS

7.1 LIFE CYCLE COST

The cost of each alternative is estimated in terms of its construction/capital costs and operation/maintenance costs. A value time analysis is included, but not combined with the life cycle cost.

7.2 OPERATIONAL ASSESSMENT

The alternatives and sub-alternatives are be inputted into simulations programs to predict average passenger trip times and capacity utilization. The average trip time is the total time it takes a passenger to get from their origin to destination. The average trip time includes the average travel time, average wait time, and walking time. The trip time is the time spent moving in transit. The wait time is the time spent waiting for the transit vehicle to arrive and is half the headway. A walking time could be added to the average travel time if passengers must walk an extra distance to their destination. Passenger, employee, and transit service levels are not consistent over the whole day. The inconsistency is reflected in the average trip time by incorporating different travel and wait times throughout the day, and weighting the times based on how many people are expected to encounter those travel and wait times.

The outputs from the simulation will further be separate by service route in order to combine certain alternatives (e.g. shuttle bus for outlying facilities and APM for terminal area parking structures). VISSIM 5.30, a traffic microsimulation package, evaluates the congestion of the roadway system. A Java-based APM simulation specifically created for this project analyzes the APM alternatives. TrackEdit, Taxi 2000's proprietary PRT control system, simulates the proposed PRT system. The internal circulation modes are evaluated during a peak hour period to see if they have the capacity to handle BWI's passengers and employees. The passenger loads used as input in the simulations are based on existing shuttle bus usage. It is assumed that all people using airport buses currently will use the new form of transportation. A growth factor is applied to account for an increase in demand due to the growth of the airport.

7.3 EMISSIONS

Most modes of transportations directly or indirectly produce air pollutants including carbon dioxide, nitrous oxides, ozone, hydrocarbons, carbon dioxide, and particulate matter. Maryland SB 278, the Greenhouse Gas Reduction Act of 2009, dictates that Maryland must reduce its greenhouse gas emissions by 25% based off the 2006 levels. Other types of air pollutants almost reach or already violate the US Clean Air Act ambient levels.

Table 7-3-1: Ambient Air Quality in Anne Arundel County

Pollutant	Classification
8-Hr Ozone (1997 standard)	Serious
2.5 micrometers particulate matter (1997 standard)	Nonattainment
8-Hr Ozone (2008 standard)	Moderate

Source: EPA (2012)

Nonattainment of the Clean Air Act regulation results in financial penalties. BWI Marshall's shuttle bus operations are a major contributor of the above pollutants. The diesel engines emit particulate matter and nitrogen oxide. The nitrogen oxide reacts with other volatile organic compounds to form lung-

damaging ozone (EPA, 2012). To help Anne Arundel County get attainment on the ambient particulate matter levels and prevent ozone levels from getting worse, the internal circulation system should emit less of those pollutants. The bus pollution levels will be estimated directly from how much each bus emits. The electrified modes (APM/PRT) will be evaluated based on how much power plants emit to supply the alternatives' electricity.

8.0 RIDERSHIP ESTIMATION

The future ridership bus alternative can simply be estimated by taking into account the growth of the airport, but the automated guideway transit alternatives need an origin destination (OD) matrix as an input for the simulation program. Figure 8-0-1 gives an overview of the process.

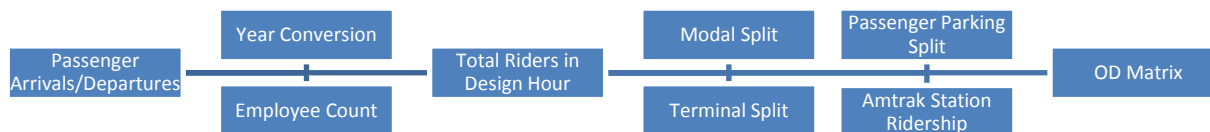


Figure 8-0-1: Ridership Estimation Diagram

8.1 PASSENGER ARRIVALS/DEPARTURES

The base numbers for each of the alternatives' ridership estimations utilizes the 2005 "Originating and Terminating Passenger at Curbside" curves performed by Ricondo & Associates for the Master Plan. The curves display BWI's passengers per hour arrival and departures patterns over a typical day. The passengers were limited to those whose origin or final destination is BWI Marshall. The Ricondo & Associates estimation summed all the available plane seats in 15 minutes increments and multiplied them by a load factor and percentage of passengers originating/terminating at BWI Marshall. The plane seats are further distributed to reflect the arrival/departure patterns of passengers to/from their planes. Figure 8-1-1 shows the arrival and departure curves at BWI on a typical day.

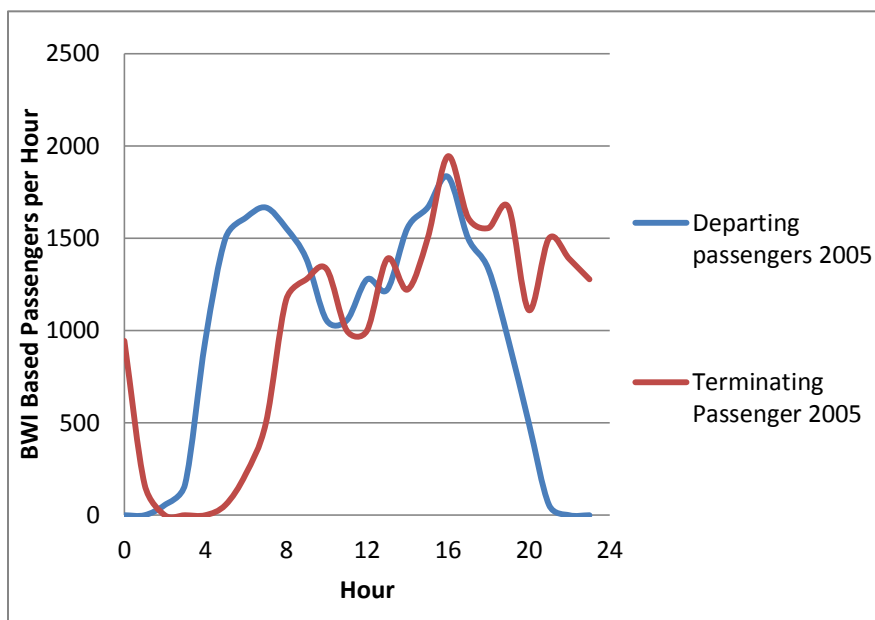


Figure 8-1-1: Arrival/Departure Curve for a Typical Day at BWI Marshall

8.2 YEAR CONVERSION

The Ricondo & Associates study projects the originating and terminating patterns for 2005 and requires conversion for future or current ridership projections. A ratio with future or current annual passengers over the 2005 annual passenger count converts the hourly passenger count to another year. The actual annual passenger count figures are from the Bureau of Transportation Statistics and the projected annual passenger count figures are from the master plan.

8.3 EMPLOYEE COUNT

An arrival or departure curve for employees is not available. Instead the total daily employees who require shuttle service are taken from Table 8 in Appendix E of the 2006 APM study. To convert total employment to an employee per hour curve similar to the passenger arrival/ departure curve, the daily employment number is distributed proportionally to the passenger curve, assuming that the number of employees is proportional to passengers. For example, if 12% of the daily passengers depart during the hour between 12 pm and 1 pm, 12% of the daily employees depart between 12pm and 1pm as well.

8.4 TOTAL RIDERS PER DESIGN HOUR

The curves for passengers and employees are converted to represent the arrival/departure patterns for years 2010 and 2030. 2010 is selected as the present year because 2010 is the most recent year that the Bureau of Transportation Statistics has full records. 2030 is selected as the future year because many airport improvements are scheduled to be completed by 2030 and availability of a passenger forecast for that year. After converting the curves to a design year, the hour with the most potential riders is selected as the design hour. 4 pm is selected as it has 8.4% of the daily volume. It is assumed that all passengers and employees will use the new system to circulate around the airport.

8.5 TERMINAL AND MODAL SPLIT

Each of the potential automated guideway transit riders trip has an end at the terminal area and another end dependent on which mode they used to travel to/from the airport.

The terminal trip end first depends on how many terminal area stations are built. Alternatives for the automated guideway transit system include cases with one, two, or three terminal area stations. All of the terminal area trip ends are assigned to one terminal area station in the case in which only one station is built. If two stations are built in the terminal area (South and East Terminal Stations), the passengers are split proportionally to the number of passengers that use each terminal as shown in Table 3.3-28 of the Master Plan, "O&D Passenger Activity" performed by Ricondo & Associates. Potential passengers going to Terminals A, B, or C are assigned to the South Terminal Station and passengers going to Terminals D or E are assigned the East Terminal Station. The third possible terminal station would be built if future Terminal F is built. The third terminal ridership would be proportional to how many gates Terminal F contains compared to the gates at the entire airport. Figure 8-5-1 shows the projected passenger split between the terminals.

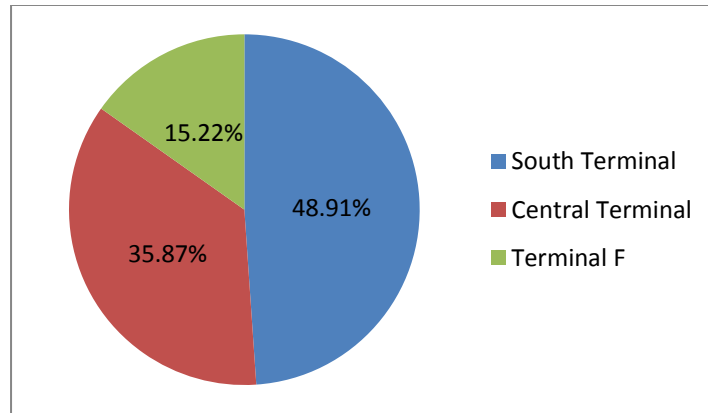


Figure 8-5-1: Terminal Split

The other end of each passenger's/employee's automated guideway transit system journey is based on the mode they used to get to or leave the airport. The mode split for passengers is taken from Table 3.3-18 of the master plan, "Estimated Mode Choice and Vehicle Occupancies by Originating and Terminating Passengers" estimated by Ricondo & Associates. The employee mode split is taken from Table 3.2 of the 2006 APM study, "Employee Access/ Egress Mode" performed by Booz Allen. Both of the mode split estimations neglected how many passengers and employees use MARC or Amtrak and the passenger modal split neglected public transit in general. Since each alternative has a consolidated shuttle depot, it is assumed that public transit riders for airport passengers is included in the figures for private transit modes (door to door shuttle, taxi, hotel shuttle, etc.), which will all use the consolidated shuttle depot (CSD). The Amtrak/MARC ridership is estimated by multiplying the CSD design hour total passenger count by the ratio of estimated Amtrak/MARC trips over all transit trips (10%) estimated from the 2006 APM study. The estimated Amtrak/MARC ridership is subtracted from this study's CSD ridership. Passenger parking is distributed between the Daily Garage and the Long Term Parking proportional to daily shuttle ridership as shown in Table 3.7 of the APM study. Each of the parking areas contain multiple stations and riders are divided evenly among stations within a parking area. The express parking lot is neglected because it will likely be eliminated. The Hourly Garage is currently accessed via skyways and does not need service from the automated guideway transit system. The employee and passenger modal split is shown in figures 8-5-2 and 8-5-3 respectively.

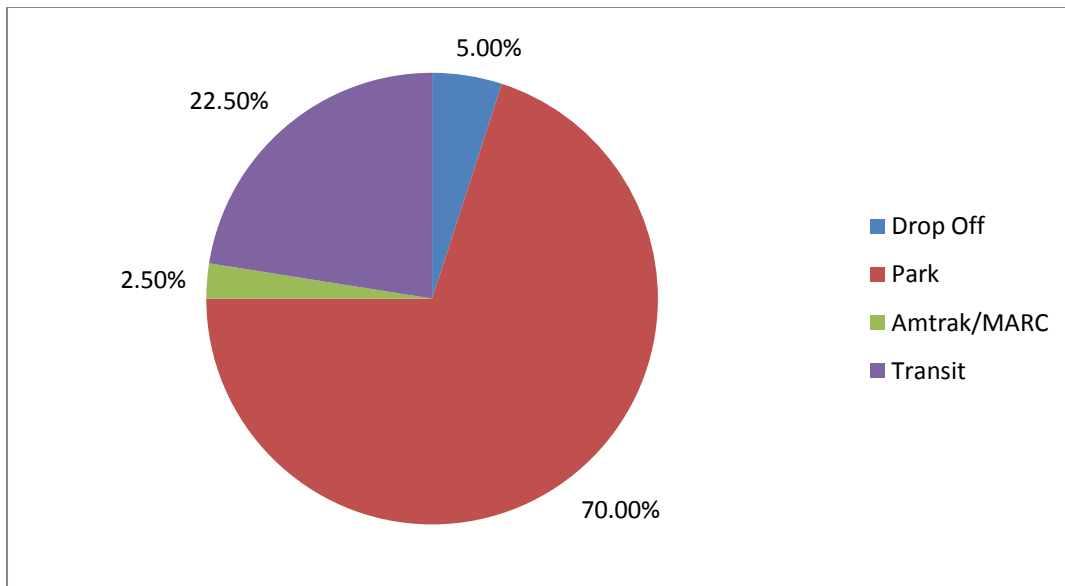


Figure 8-5-2: Employee Modal Split

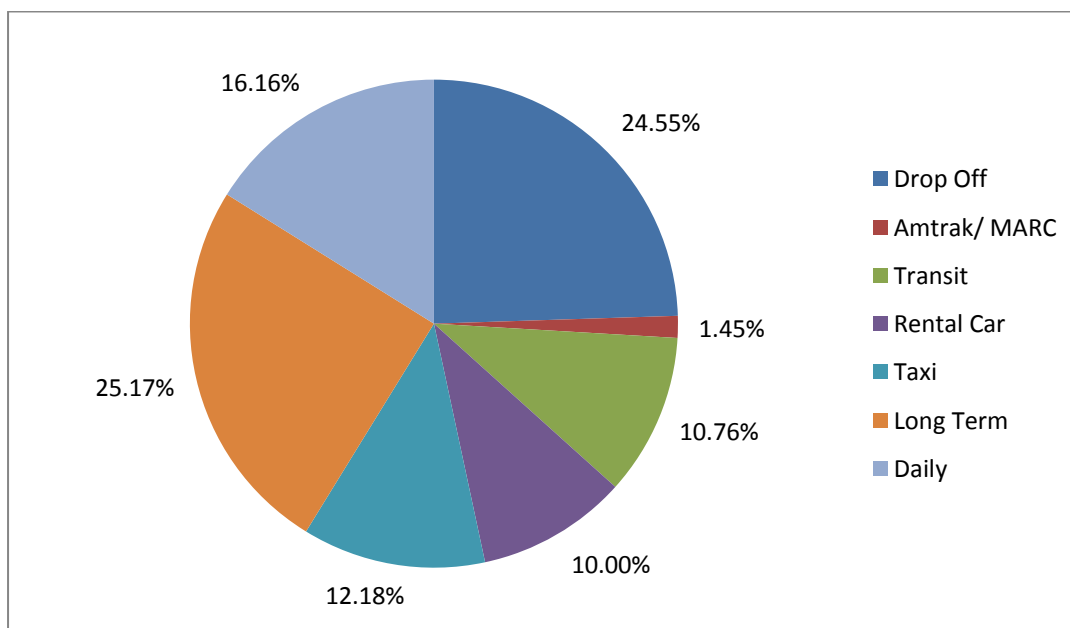


Figure 8-5-3: Passenger Modal Split

8.6 ORIGIN DESTINATION MATRIX CREATION

With the terminal and modal split known for each potential rider, the Origin Destination Matrix is created. Below is sample calculation of the potential 2010 peak hour ridership from Terminal A, B, and C to the CSD. In this alternative, the APM goes all the way to the employee and long term parking lots. There are also two terminal stations.

$$\begin{aligned}
601 \frac{'10 \text{ PT Pass}}{PHR} &\approx \left(\frac{10770973 '10 \text{ Pass}}{9742195 '05 \text{ Pass}} \right) \left(1944 \frac{'05 \text{ Pass}}{PHR} \right) \left(0.28 \frac{PT \text{ Pass}}{Pass} \right) \\
146 \frac{'10 \text{ Emp}}{PHR} &\approx \left(6700 \frac{'04 \text{ Emp}}{Day} \right) \left(\frac{1944 \frac{'05 \text{ Pass}}{PHR}}{23833 \frac{'05 \text{ Pass}}{Day}} \right) \left(\frac{10770973 '10 \text{ Pass}}{9947636 '04 \text{ Pass}} \right) \left(0.25 \frac{PT \text{ Emp}}{Emp} \right) \\
466 \frac{'10 \text{ CSD Riders}}{PHR} &\approx \left(0.674 \frac{Terminal \text{ ABC Riders}}{Total \text{ Riders}} \right) \left(0.9 \frac{CSD \text{ Riders}}{Transit \text{ Riders}} \right) \left(601 \frac{'10 \text{ PT Pass}}{PHR} + 146 \frac{'10 \text{ Emp}}{PHR} \right)
\end{aligned}$$

Pass=Passengers Emp=Employees PT= Public Transit PHR=Peak Hour

8.7 FINAL ORIGIN DESTATION TABLES

The OD tables are shown in Appendix 4. In 2030, there would be about 66,988 passengers and employees using the new automated guideway transit system of 112,572 total passengers and employees that come in and out of the airport.

9.0 ALTERNATIVES EVALUATION

9.1 NO BUILD

Three different types of 40' buses including CNG, Hybrid Diesel, and Diesel buses are being considered to replace and grow BWI's bus fleet. Even though the rental car consortium manages its own shuttle bus system, its buses are included because the other alternatives would possibly replace bus service for the CRCF and therefore the cost of the shuttle bus to the CRCF must be included. Table 9-1-1 breaks down all the costs for the no-build alternative with different types of buses. A green, yellow, and red cell indicates that the bus type is superior, moderate, or inferior respectively for a particular category. The no build alternative assumes constant shuttle demand growth and existing fleet replacement,

Table 9-1-1: Net Present Value of Bus Only Alternatives

Bus Type	Capital Cost	Operating Cost	Fuel Cost	Facility Cost	Total Cost
Diesel	\$43,131,640	\$20,083,421	\$70,464,045.81	\$0.00	\$133,679,107
CNG	\$46,212,472	\$24,144,294	\$47,401,080.68	\$2,000,020	\$119,757,866
Hybrid	\$56,071,132	\$21,437,046	\$58,220,128.45	\$8,760.96	\$135,737,067

Capital cost refers to the cost of purchasing buses. Operating cost includes labor, facility maintenance, and bus maintenance costs. Facility cost is the capital cost of adding special bus facilities (CNG fuel depot/ battery facility). The costs are accumulated between years 2012 to 2030 and a discount rate of 5% is used to convert the expenses into a lump sum in year 2012. It is assumed that the current 49 diesel buses will be retired at the rate of 7 buses a year, from 2012 until 2020. All 25 current CNG buses will be retired in 2018. Buses purchased after 2012 will be retired 12 years after purchase, as recommended by the Federal Transit Administration's *Useful Life of Transit Buses and Vans*. Most cost figures are taken from Appendix 2, but the projected fuel costs was obtained from US Energy Information Administration's 2012 Outlook for the Mid-Atlantic Region. A more detailed financial analysis can be found in Appendix 5.

The bus trip times, shown in table 9-1-2, are calculated from the previous APM study and interpolation.

Table 9-1-2: 2030 Shuttle Operation's Level of Service

Shuttle Route	Travel Time (Minutes)		Headway (Minutes)		Average Wait Time (Minutes)	Average Travel Time (Minutes)	Average Trip Time (Minutes)	% Difference From Current Conditions
	Peak	Off Peak	Peak	Off Peak				
Long Term Parking Lots	30.0	19.0	3.0	10.0	2.2	27.7	29.9	22.3%
Daily Parking Garage	7.1	5.5	3.0	25.0	3.8	6.7	10.5	20.4%
Employee Parking Lot*	7.1	5.5	3.0	20.0	3.3	6.7	10.0	-9.4%
BWI Rail Station Garage	14.1	9.9	5.0	20.0	4.1	13.2	17.3	11.0%
Consolidated Rental Car Facility	27.8	14.3	5.0	15.0	3.6	24.9	28.5	34.6%

Source: BWI,2012; URS/RK&K/ Booz, Allen & Hamilton, 2006

*The passengers that use off-airport shuttles are added the employee parking lot shuttle

The bus operations will significantly slow down in 2030 due to congestion around the airport, though wait time will decrease because additional buses will run to increase capacity. The employee parking lot trip time is the only route to decrease due to the lower wait time. For analyzing the average trip time and cost of congestion, passengers using off-airport shuttles are considered employee parking shuttle users since their shuttle exits the airport near the employee parking lot. The current average trip time is 15.4 minutes and is forecast to increase to 18 minutes. There would be an additional 3000 passenger hours/day endured by the users of the shuttle bus. Using the FAA “Economic Values for FAA Investment and Regulatory Decisions” value of time of \$38.26 (\$28.60 in the year 2000), the increase congestion would result in \$42 million in wasted time per year (FAA, 2004).

Table 9-1-3: 2030 Shuttle Emissions

Bus Type	# of Buses	Mileage	Emissions (kg/year)				
			CO2 eq	CO	Nox	pm	HC
40' Diesel	125	3.6 MPG	19,500,000	0	4,300	0	70
40' CNG	125	2.7 MDGE	18,800,000	145,000	1,500	0	130
40' Hybrid	125	4.01 MPG	16,800,000	0	3,300	0	70

Table 9-1-3 shows the emissions of the shuttle bus operations in 2030 with the different types of propulsion technology. Hybrid electric buses are superior in every category except for Nitrogen Oxides which CNG buses are superior. These emission reflect current bus technology and not of that of 2030. Emissions from future buses will likely decrease and may affect the environmental ranking of the fuel types.

Based on the cost and the emissions information, it is recommended that BWI use CNG buses if the airport decides to expand its bus fleet.

9.2 AUTOMATED PEOPLE MOVER

The automated people mover alternative has different possible alignments, as shown in Appendix 6. In this study, the alignments differ in extent of the system, not the specific route the APM will take. The Minimum Build alignment goes from Terminal A/B to the new Consolidated Shuttle Facility via the southwestern side of the loop. The Loop alignment includes the loop and the segment that goes to the loop to the Consolidated Shuttle Facility. The West Leg alignment includes the loop alignment and the segment that goes to the consolidated rental car facility. The East Leg alignment includes loop alignment and the segment going to the long term parking area. The Full Build alignment includes both the east and West Leg alignment. A schematic of the Full Build alignment can be seen in Appendix 7. The initial phase of the automated people mover would not include all the stations listed in Appendix 6. The Terminal F and West Long Term Parking stations will not be initially built since they won't be built until after the APM construction. Those two stations will be built as infill stations after the areas near the stations are built. The following analysis uses the 2030 ridership projection and includes the Terminal F and West Long Term Parking stations.

Table 2-2-1: Automated People Mover Costs

Alignment	Number of Stations	Length (miles)	Capital Cost (\$million)	Annual Cost for 18 years (\$million)	Bus Costs (\$million)	Total Cost (\$million)
Minimum Build	3	1.12	283	100	60	443
Loop	6	2.05	476	112	60	648
West Leg	8	4.34	907	285	32	1224
East Leg	9	3	623	243	49	915
Full Build	11	5.36	1118	341	0	1459

The capital costs, shown in Table 9-2-1, are based on figures from Miami International Airport's MIA Mover APM and includes a 20% contingency. The annual costs utilize an estimated operation and maintenance cost of \$0.53/passenger mile (adjusted for inflation) along with passenger mile output from the APM simulation (Carnegie, Voorhees, & Hoffman). The annual costs until 2030 are summed to a net present value with a discount rate of 5%. The bus costs are the estimated with the same figures as the no-build alternative with the shorter travel distances taken in account. The bus service is necessary to serve areas where the APM does not serve.

The travel times for the automated people mover alternative is calculated with a Java-based simulation created for this project. A virtual network is created to scale of the different APM alignments proposed at BWI. The APM trains are programed to have:

- Maximum speed of 55 km/hr, though it is decreased on curves
- Capacity of 300 (3 car trains)
- Acceleration and brake rate of 1.32 m/sec^2
- Runtime of 1 virtual hour after a 1000 second period before to get simulation into equilibrium

The average trip time for the automated people mover alternative is broken up into two tables. Table 9-2-2 displays the travel time for each destination if it receives direct APM service in an alignment. Table 9-2-3 displays the travel times for destinations if they do not receive direct APM service in an alignment and requires a transfer at the Consolidated Shuttle Depot.

Table 3: Direct APM Trip Times

Destination	Passenger Trip Time (min)	Headway (min)		Average Wait Time (min)	Average Trip Time (min)	% Difference From Current Conditions
	Peak/ Off peak	Peak	off peak			
Long Term Parking Lots*	7.7	5.0	10.0	3.0	12.7	-48%
Daily Parking Garage	3.0	3.8	7.5	2.3	5.3	-40%
Consolidated Shuttle Depot	4.0	2.5	5.0	1.5	5.5	-50%
BWI Rail Station	6.7	5.0	10.0	3.0	9.7	-38%
Consolidated Rental Car Facility	9.6	5.0	10.0	3.0	12.6	-40%

*An additional 2 minute penalty is assigned to account for the longer distances between parked cars and APM stations.

Table 4: Indirect APM Trip Times

Destination	Passenger Trip Time (Minutes)		Headway (Minutes)				Walk time (Minutes)	Average Wait Time (Minutes)*	Average Trip Time (Minutes)	% Difference From Current Conditions
	Mode	APM	Bus	APM	Bus	APM				
Long Term Parking Lots	4.0	13.5	2.5	2.2	5.0	5.0	5.0	2.9	25.4	4%
Daily Parking Garage	3	N/A	4.0	N/A	8.0	N/A	2.0	2.4	7.4	-15%
BWI Rail Station	4.0	4.4	2.5	5.7	5.0	13.0	5.0	5.1	18.5	19%
Consolidated Rental Car Facility	4.0	8.8	2.5	1.3	5.0	2.9	5.0	2.3	20.1	-5%

*A walk time for the Daily Parking Garage is only applied for the Minimum Build Alternative to incorporate the walking time half the passengers will encounter from walking from the station side of the parking garage to the other side of the garage

The APM trip time is generated from an APM simulation produced for this project and the headways are assumed. In the case where the APM passenger must transfer to a bus, a 5 minutes penalty is assumed to take into account walking from the APM to the shuttle stop. The direct APM trip times are considerably lower than current trip times and would be unaffected by future projected roadway congestion. The indirect APM trip times are usually slower than the current shuttle buses, but faster than the projected future trip times of the shuttle buses. Table 9-2-4 shows the average trip time and monetized time savings/cost for each APM alignment. The travel time savings uses the average travel time for the APM alternative and the average travel time for the No Build Alternative.

Table 9-2-4: APM Trip Time Savings

APM Alignment	Average Trip Time (min)	Travel Time Savings (\$ million/year)
Minimum Build	14.1	\$ 63
Loop	13.5	\$ 72
West Leg	11.6	\$ 104
East Leg	10.3	\$ 124
Full Build	8.3	\$ 156

APMs are not a point source of pollution since they run on electricity, but the electricity they use is generated from sources that produce air emissions. The air pollution created from the electricity consumed by the APM is displayed in Table 9-2-5.

Table 9-2-5: APM emissions

APM Alignment	Mwh/year	Nox(kg/year)	SO2(kg/year)	CO2(kg/year)
Minimum Build	7,000	4,000	12,000	10,800,000
Loop	7,000	4,000	11,000	10,600,000
West Leg	15,000	7,000	25,000	10,100,000
East Leg	12,000	6,000	19,000	11,400,000
Full Build	21,000	10,000	33,000	11,000,000

Source: BGE, 2012

Baltimore Gas and Electric, the electricity provider of BWI, provided the emission rate for the electricity used by the APM. The emissions from the supplementary buses are also included and are based off the same figures used for the No-Build Alternative. The APM will greatly reduce the airports emissions and if the airport finds an zero-emissions electricity source, the emissions are further reduced.

9.3 PERSONAL RAPID TRANSIT

Taxi 2000, a high capacity personal rapid transit (PRT) developer, provided the analysis for the PRT alternative. This company is equipped with echo™, its self-developed proprietary software technology that controls the Skyweb Express PRT system. echo™ has been verified by independent third party studies on its ability to safely control thousands of vehicles simultaneously. Taxi 2000 used its TrakEdit software, echo™, and the same input information from the APM alternative. It designed the PRT alternative similarly to the APM alternative, except for some PRT specific alterations. These alterations include using two parallel one-way tracks instead of a single two-way track and providing bypasses for vehicles to turn back to the terminal area. Skyweb Express's infrastructure and control system is adaptable to complex routing and facilitates a phased project approach. Taxi 2000's PRT alternative is shown in Appendix 9. Similarly to the APM alternative, the alignments include different parts of the alternative as displayed in Appendix 8. TrakEdit assumed:

- The minimum headway between vehicles is 1.5 seconds (Within the Automated People Mover Standard's requirements)
- Vehicles travel at a velocity up to 27 mph
- Occupancy of each vehicle is 1.25

The cost of each PRT alignment is shown below in Table 9-3-1.

Table 9-3-1: PRT Alignment Costs

Alignment	Number of Stations	Length (miles)	Capital Cost (\$million)	Annual Cost for 18 years (\$million)	Bus Costs (\$million)	Total Cost (\$million)
Minimum Build	3	1.12	76	47	60	183
Loop	6	2.05	135	53	60	248
West Leg	8	4.34	269	134	32	395
East Leg	9	3.00	192	115	49	356
Full Build	11	5.36	330	161	0	491

Source: (Taxi 2000, 2012)

The capital costs are based on the high end of the cost estimate for a system meeting the 2030 ridership projections. The capital costs include a 20% contingency. The annual costs utilize an estimated operation and maintenance cost of \$0.25 per passenger mile (adjusted for inflation), based on extensive research and financial modeling, along with passenger mile output from the simulations of the BWI system. Costs reflect the manufacturer specifications of Skyweb Express's off the shelf components. The annual costs until 2030 are summed to a net present value with a discount rate of 5%. The bus costs are estimated with the same figures as the APM alternative. The bus service is necessary to serve areas where the PRT does not serve.

The average trip time for the Skyweb Express PRT alternative is presented in Tables 9-3-2 and 9-3-3 for the direct and indirect travel times respectively.

Table 9-3-2: Direct PRT Trip Times

Destination	Passenger Trip Time (Minutes)	Headway (Minutes)		Average Waitime (Minutes)	Average Trip Time (Minutes)	% Difference From Current Conditions
	Peak/ Off peak	Peak	off peak			
Long Term Parking Lots*	5.0	0.02	0.02	0.01	6.0	-75%
Daily Parking Garage	1.5	0.02	0.02	0.01	1.5	-83%
Consolidated Shuttle Depot	2.6	0.02	0.02	0.01	2.6	-76%
BWI Rail Station	5.0	0.02	0.02	0.01	5.0	-68%
Consolidated Rental Car Facility	7.0	0.02	0.02	0.01	7.0	-67%

Source: (Taxi 2000, 2012)

*An additional 1 minute penalty is assigned to account for the longer distances between parked cars and PRT stations. The penalty is smaller than APM because the PRT stations have better coverage of the parking area.

Table 5: Indirect PRT Trip Times

Destination	Passenger Trip Time (Minutes)		Headway (Minutes)				Walk time(minutes)	Average Wait Time (Minutes)*	Average Trip Time (Minutes)	% Difference From Current Conditions
	Peak/Off Peak		Peak		Off Peak					
	Mode	PRT	Bus	PRT	Bus	PRT				
Long Term Parking Lots	2.6	14	0.02	2	0.02	5	5	1	23	-8%
Daily Parking Garage	1.5	N/A	0.02	N/A	0.02	N/A	2	0	4	-60%
BWI Rail Station	2.6	4	0.02	6	0.02	13	5	4	16	0%
Consolidated Rental Car Facility	2.6	9	0.02	1	0.02	3	5	1	17	-19%

Source: (Taxi 2000, 2012)

*A walk time for the Daily Parking Garage is only applied for the Minimum Build Alternative to incorporate the walking time half the passengers will encounter from walking from the station side of the parking garage to the other side of the garage

All trip times, with the exception of the in-direct BWI Rail Station, are lower than current trip times. Table 9-3-4 shows the average trip time and monetized savings for all the alignments (Taxi 2000, 2012).

Table 6: PRT Trip Time Savings

PRT Alignment	Average Trip Time (min)	Travel Time Savings (\$ million/year)
Minimum Build	10.9	\$ 114.14
Loop	10.4	\$ 123.08
West Leg	7.9	\$ 162.16
East Leg	6.3	\$ 188.07
Full Build	3.9	\$ 227.15

Similarly to APMs, PRTs are not a point source of pollution since they run on electricity. Taxi 2000's energy output and Baltimore Gas and Electric's figures of emissions per Megawatt hour are used to evaluate PRT's environmental impact. The air pollution created from the electricity consumed by the PRT is displayed in table 9-3-5.

Table 9-3-5: PRT emissions

APM Alignment	Mwh/year	Nox(kg/year)	SO2(kg/year)	CO2(kg/year)
Minimum Build	6,600	3,624	10,506	10,426,621
Loop	5,920	3,307	9,426	10,070,128
West Leg	13,747	6,573	21,885	9,162,091
East Leg	10,615	5,362	16,899	10,755,618
Full Build	21,000	9,811	33,434	11,030,414

Source: BGE, 2012

10.0 SENSITIVITY ANALYSIS

The results of the alternative evaluation section are based off multiple assumptions. A series of sensitivity analyses show the influence of some of the assumptions.

10.1 DEMAND

The sensitivity of the alternatives' ability to handle different levels of demand is evaluated. For buses, it is assumed that additional buses maybe purchased to handle an increase in demand, as is therefore neglected in this evaluation.

10.1.1 APM

The travel demand for each alternative analysis is based on the BWI Master Plan's 2030 projected passenger levels. Passenger demand tends to be very unpredictable, even with the best forecasting techniques. Using the APM simulation, each of the APM routes' headways are decreased to increase the capacity of the system. The change in headway is coordinated in conjunction with the demand multiplier, a factor multiplied with the peak hour origin destination demand matrix from the alternatives analysis. The simulation starts with a demand multiplier of 0.25 and increases the multiplier by 0.25 if both routes' trains are not over capacity. If any train is over capacity, their route's headways are decreased by 30 seconds. Figure 10-1-1 shows the summary of the simulation results. This analysis is done with two car trains (200 passengers per train) and three car trains (300 people per train). The Consolidated Rental Car Facility (CRCF) and Long Term Parking (Long) routes operate concurrently during the simulation.

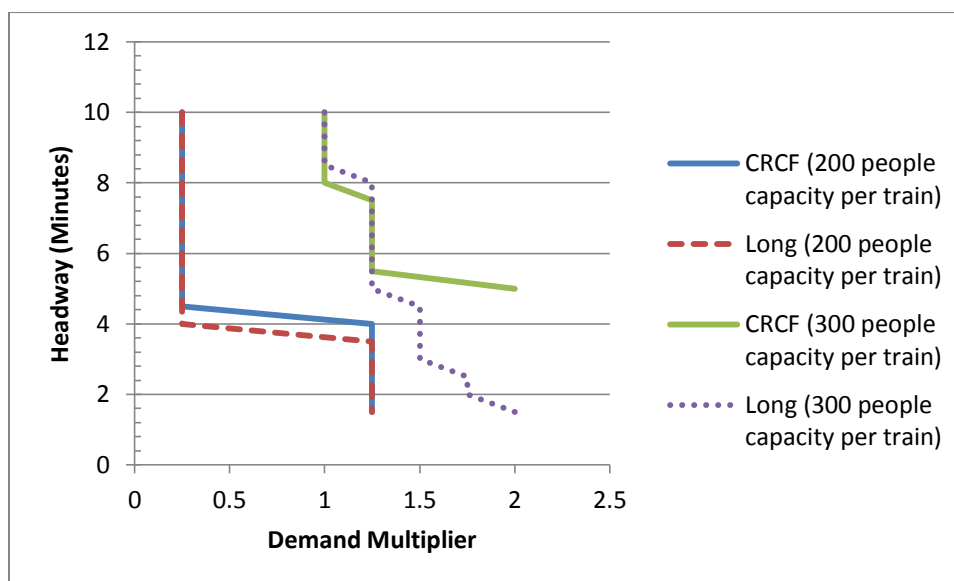


Figure 10-1-1: APM Headway Sensitivity

The headway requirement to prevent the system from operating above capacity is very dependent on individual train capacity. Two car trains must run with a headway of about 3.5 minutes to handle 2030 peak demands. Three car trains can handle the 2030 peak demand with headways of about 8 minutes. Two car trains could still be operated between 12:00 am and 5:00 am without capacity problems. The

CRCF route could function with a greater headway than the long term parking route, especially with three car trains.

10.1.2 PRT

PRT's ability to handle demand is a function of the capacity of a single-track section and stations. The capacity of a single-track section is calculated theoretically with the below equation:

$$Capacity \left(\frac{Passengers}{Hour} \right) = \frac{Average \text{ Occupancy} \left(\frac{Passengers}{Vehicle} \right) * 3600 \left(\frac{Seconds}{Hour} \right)}{Headway \left(\frac{Seconds}{Vehicle} \right)}$$

3 second headways are what current PRT systems are using. Skyweb Express's system would run with 1.5 second headways, but is seeking to run with 0.5 second headways. Taxi 2000 assumes vehicle occupancy of 1.25 passengers per vehicle. The sensitivity analysis varies vehicle occupancy between 1 and 8 passengers per vehicle. One person per vehicle implies there is absolutely no ride sharing. An average occupancy greater than 1 and less than or equal to 4 involves some to absolute ridesharing respectively. Average occupancy greater than 4 would require extensive ridesharing and larger than typical PRT vehicles. Figure 10-1-2 shows the capacity with varying occupancy and headway.

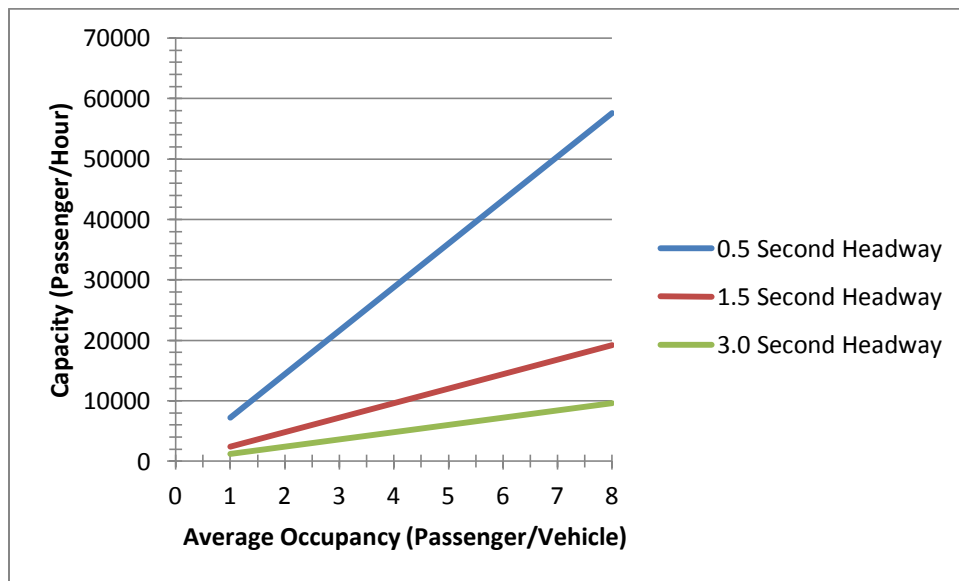


Figure 10-1-2: PRT Track Capacity

A headway of 1.5 second per vehicle and average occupancy of 1.25 passengers per vehicle yields a single track capacity of 3000 passengers per hour. This would be a challenge for PRT with the forecasted 2030 ridership, but could be accommodated with double tracking. If the average occupancy is unchanged, but the headway is decreased to 0.5 seconds per vehicle, the capacity triples to 9000 passengers per track section. If 0.5 second headways are still not possible in 2030, ridesharing would increase the capacity of the system. If each vehicle has 4 passengers, the capacity of a single track is 9600 passengers per hour with a headway of 1.5 seconds. Larger vehicles would enable a higher capacity (19,200 passengers per hour), but the track sections would need to be built larger to handle the increased weight of the vehicle and additional passengers. Conversion from PRT to GRT would help increase the rate of ridesharing.

PRT stations are offline or off the main traveled path. This allows vehicles to stop without blocking other vehicles. PRT stations do have capacity limits and if too many vehicles try to use the same station, there could be a major blockage. Skyweb recommends stations with 12 berths . A group of 12 berths is accessed by a platform and has a capacity of 1,150 vehicle trips per hour. Additional platforms can be added for 1000 additional trips per hour. Figure 10-1-3 shows how the average occupancy and number of platforms affect station capacity.

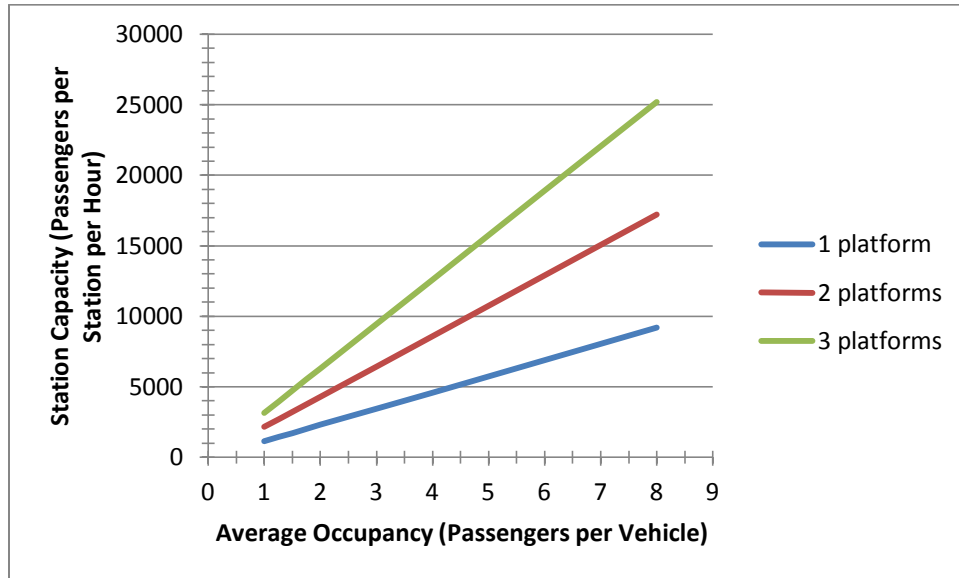


Figure 10-1-3: Station Capacity Analysis

The busiest station under the Full Build scenario, Terminal West, would need to handle 2000 passengers per hour during the peak period. 2000 passengers would be difficult to accommodate with only 1 berth and average occupancy of 1.25 passengers per vehicle. Only 1 platform would be needed if the average occupancy was above 2 passengers per vehicle. If 2 platforms are used, the average occupancy would not matter. Another way to possibly overcome station capacity issues is to create more stations in the terminal area.

10.2 FUEL PRICE

Fuel costs fluctuated widely in the early 21st century and while there are projections available for fuel costs, the projection values are not certain. Fuel is the largest cost of operating bus fleets and is the determining factor when selecting the most economical engine type. Figure 10-2-1 shows the total cost of operating the BWI bus fleet for 18 years under the No Build alternative with respect to the difference in fuel cost projection.

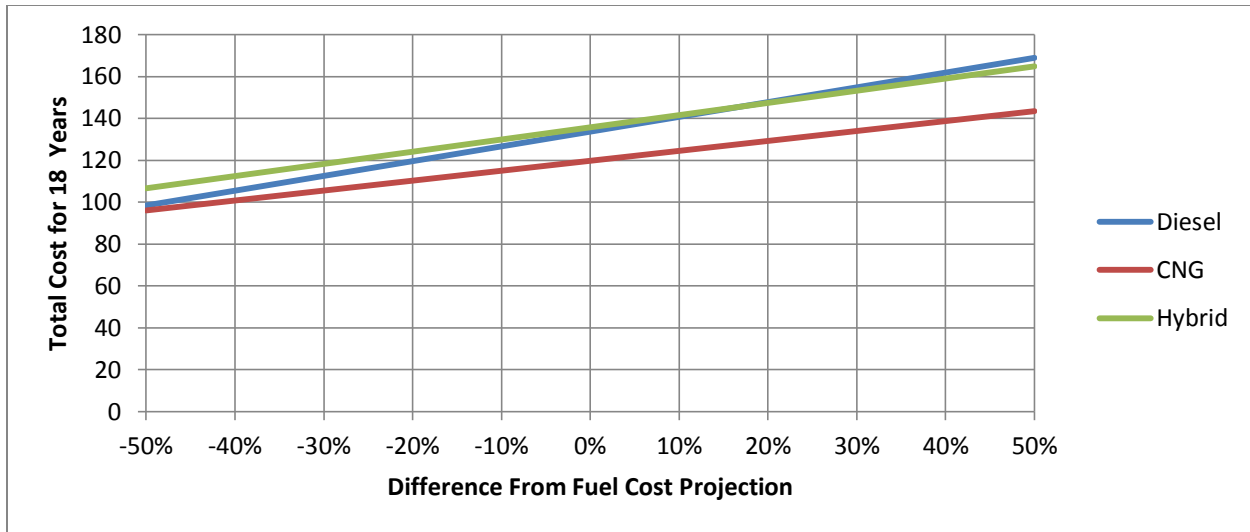


Figure 10-2-1: Fuel Cost's Effect on Total Cost

Compressed Natural Gas (CNG) buses would still be the most economical option if natural gas prices increased 30% over projections with unchanged diesel price projections. Hybrid buses become cheaper than traditional diesel buses if diesel fuel prices are about 20% over projections. With such unpredictable fuel prices, the airport must take into account fuel prices when purchasing new buses as fuel costs have such a large role in determining the total cost.

10.3 DISCOUNT RATE

A discount rate of 5% is assumed for all alternatives to convert annuities to present value. The higher the discount rate, the less future money is worth in present time. A discount rate of 0% defines a dollar a year from now equivalent to a dollar now. A discount rate of 10% assumes a dollar a year from now is worth only 90 cents now. A sensitivity analysis of the total cost to the discount rate is shown in Figure 10-3-1. Note that the APM and PRT alternative use the full build alignment.

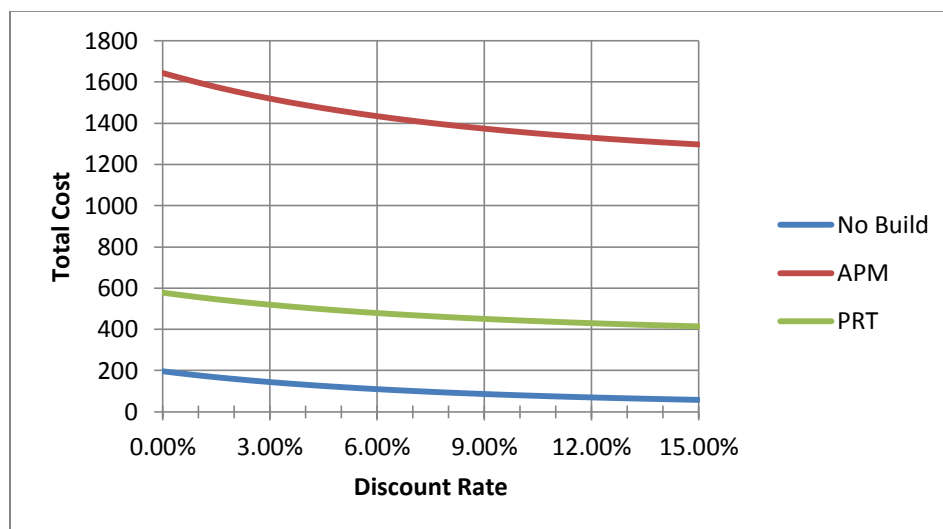


Figure 10-3-1: Discount Rate's Effect on Total Cost

The discount rate has no effect on the ranking of the alternatives' total cost. The large capital cost for automated guideway transit forms the majority of the total cost. Even if the annuities shrink in value with a larger discount rate, the initial capital cost will maintain the total cost ranking.

10.4 VALUE OF TIME

The value of time refers to how much money a passenger would pay to save an hour of their time. The analysis of alternatives uses a value of time of \$38.26, which may seem extravagant, but reflects the time sensitivity of airplane travel. A sensitivity analysis is performed on value of time not only to find how the net cost of the alternatives is sensitive to value of time, but what the value of time needs to be to get a positive return on the project. Figures 10-4-1 and 10-4-2 show how the value of time effects the net present value of each alignment for the APM and PRT alternatives respectively. The net present value is the total cost subtracted by the annuitized time savings. The time saving compare the weighted average travel time of the APM/PRT alternatives to the no build alternative.

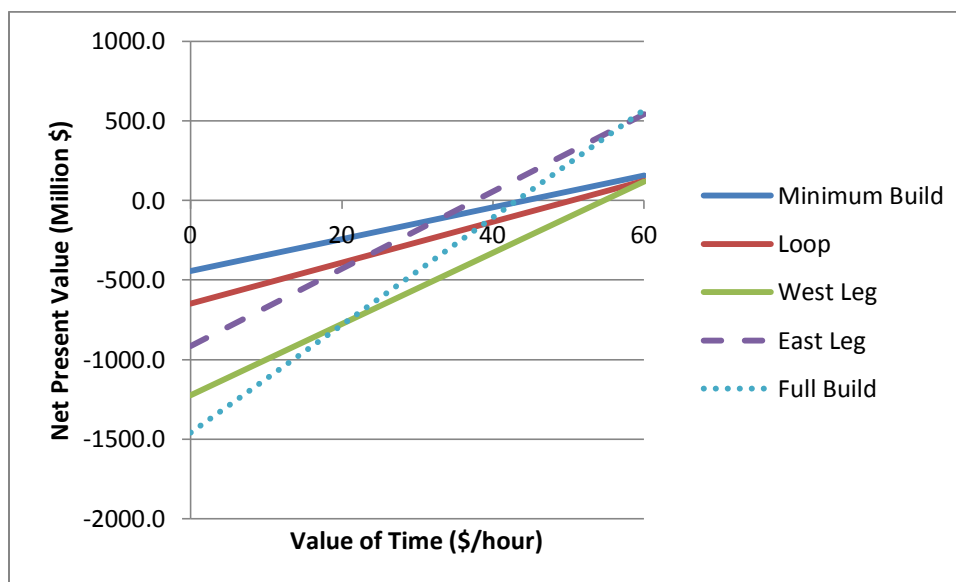


Figure 2-4-1: APM's Value of Time Analysis

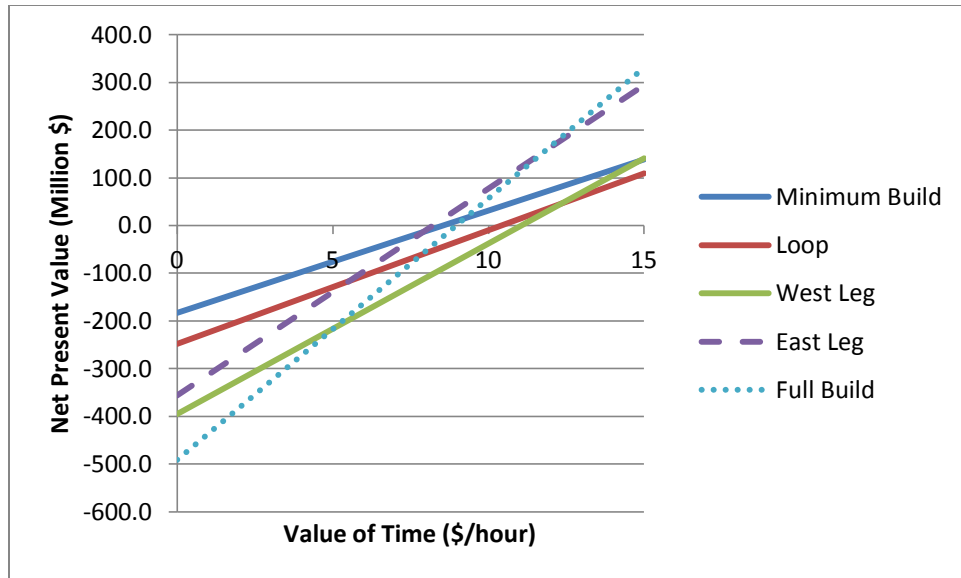


Figure 3: PRT's Value of Time Analysis

All the automated people mover alternatives, except for the East Leg alignment, require a value of time greater than the FAA's recommendation. All the personal rapid transit alternatives require a value time below the FAA's recommendation. The PRT's Minimum Build, East Leg, and Full Build alternative all need a value of time between \$7 and \$8 to get a positive net present value. The PRT alignments require a lower value of time for a positive net present value compared to APM because the PRT alignments are cheaper and have a lower simulated trip time.

11.0 CONCLUSIONS

2030 will bring new challenges and opportunities to BWI Marshall. Three possible alternatives including No Build, automated people mover, and personal rapid transit are evaluated in this study. Total cost, average trip time, and air emissions are used as measures of effectiveness for the evaluation.

Table 7-0-1: Alternative Comparison

Alternative	Alignment	Total Cost (\$ million)	Average Weighted Trip Time (Minutes)	NO _x (kg/year)	SO ₂ (kg/year)	CO ₂ (kg/year)
No Build		120	18	1459		18,754,634
APM	Minimum Build	443	13.3	3,977	11,706	10,822,884
	Loop	648	12.7	3,737	10,890	10,553,710
	West Leg	1224	10.7	7,384	24,647	10,073,912
	East Leg	915	10.3	5,976	18,992	11,446,047
	Full Build	1459	8.3	9,803	33,406	11,021,200
PRT	Minimum Build	183	10.9	3,624	10,506	10,426,621
	Loop	248	10.4	3,307	9,426	10,070,128
	West Leg	395	7.9	6,573	21,885	9,162,091
	East Leg	356	6.3	5,362	16,899	10,755,618
	Full Build	491	3.9	9,811	33,434	11,030,414

The No Build bus alternative is the cheapest alternative costing \$120 million over 18 years. Most, if not all, airports have some sort of shuttle bus service and when considering the low capital investment, there is little to no risk implementing the No Build alternative. The CO₂ emissions and the average trip time are areas of concern. The terminal road areas are projected to become more crowded in the coming years and additional buses could exasperate the congestion problem. If BWI wants to improve circulation around the airport and add more auxiliary facilities such as a hotel, it should consider another alternative that decreases the airport's reliance on shuttle buses.

The APM alternative may be the most expensive alternative considered here, ranging from \$ 443 million to \$ 1459 million, but it would cut down travel times between 4.7 minutes to almost 10 minutes compared to the No Build alternative. In addition, any alignment of APM would greatly decrease CO₂ emissions though other pollutants could increase depending on the APM's energy source. There is risk involved with any large capital projects, but automated people movers have been successfully implemented at many other airports. If the airport selects the APM alternative, the airport should develop methods to decrease the price of APMs to make the alternative more economical.

PRTs would be the quickest alternative with average trip times ranging from 10.9 to 3.9 minutes per passenger. PRT is projected to be less expensive than APMs, but more expensive than the No Build alternative at \$183 million to \$491 million for 18 years of operation. PRT emissions are less than APM for the less extensive alignments, but greater than APM for a more extensive system. PRT infrastructure is smaller and less complex to construct, leading to a shorter and less intrusive construction process. The biggest issue with PRTs is the risk of implementing the technology. PRT has been successful at a small scale at London Heathrow Airport and the new Amritsar PRT could be the pilot project that confirms complex PRT systems can be successful. If BWI chooses to build a PRT system, the airport could build it in phases and only start later phases if the early phases are successful.

12.0 FUTURE STEPS

The airport can pursue three paths: Study additional alternatives or current alternatives further, pursue a no build alternative, or pursue an automated guideway transit alternative.

12.1 ADDITIONAL STUDIES

The airport may explore some additional alternatives or additional measures of effectiveness before dedicating resources to a specific alternative. In that case, the airport should undertake a similar study to this report, focusing on developing a wide spectrum of alternatives and evaluating the alternatives with a comprehensive set of measures of effectiveness.

Other supplementary studies could also be pursued, including a bus needs assessment, passenger perception survey, tenant perception survey, and/or risk assessment study. The shuttle buses around the airport should be replaced about every 12 years and grow with shuttle service demand. A specific bus needs assessment focusing on fleet renewal and expansion would ensure that there are enough buses running at BWI. The Airport Circulation Study did not focus on how passengers would react to changes in the internal circulation system. A study focusing on the passenger perception would reveal if an improved circulation system would increase the likelihood of passengers selecting BWI over other airports and how much they would be willing to pay in airport fees for a new system. Similar to a passenger perception survey, a tenant perception survey would quantify how much tenants would pay for decrease travel time and increase reliability of a new internal circulation system. No matter how many studies are prepared about a large capital project, there are significant risks associated with using a large amount of resources. Cost overruns and delays occur frequently. A risk assessment study would bring up any issues the airport might face in pursuing a time and capital-intensive project.

12.2 NO BUILD

If the airport chooses to continue using buses for shuttle service under the No Build alternative, BWI should evaluate bus engine types and roadway improvements. The new study could obtain specific quotes on the capital and operating costs of different buses. New bus-only infrastructure projects can be proposed along with the cost and payoff each project.

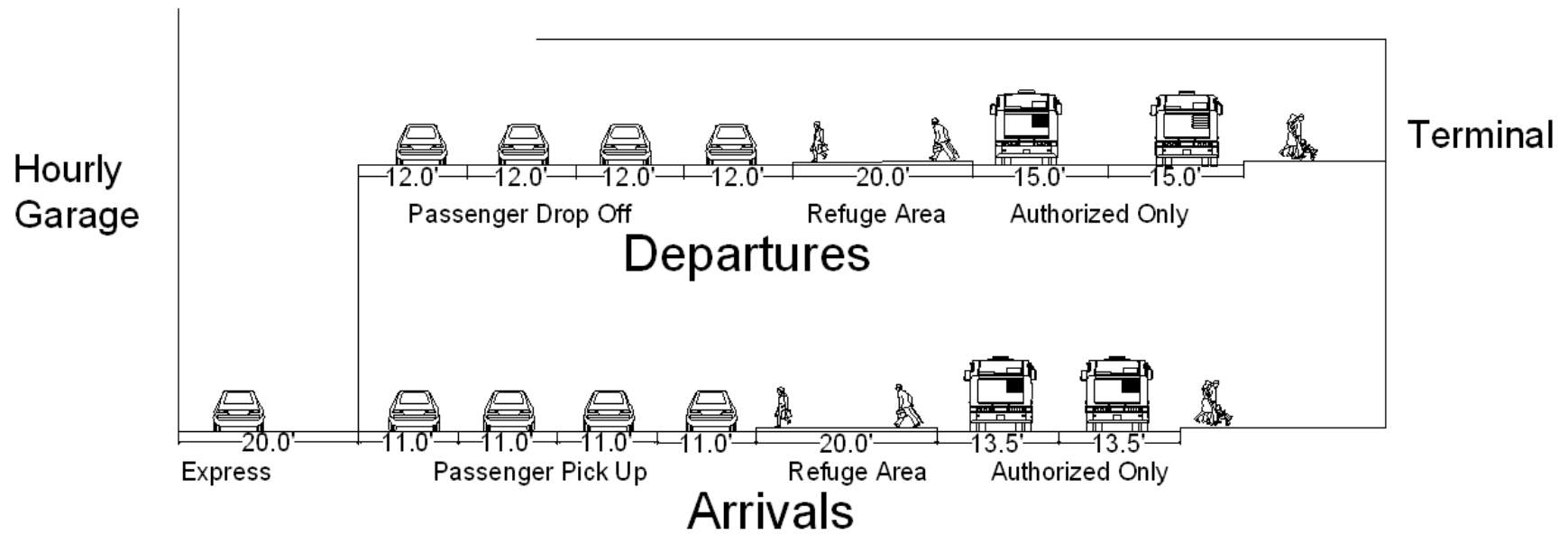
12.3 AUTOMATED GUIDEWAY TRANSIT

Any type of automated guideway transit would be a significant investment by the airport, but the systems proposed still cost less than the \$1.4 billion (not including operating and maintenance costs & not adjusted for inflation) AeroTrain APM at Washington Dulles International Airport (Weiss, 2008). The airport should cultivate an initial design of the new system, selecting which areas of the airport are worth connecting with automated guideway transit. The airport should also determine which type of automated guideway transit would best meet the needs of the airport. After a preliminary design is developed, the airport should release a request for detailed proposals.

13.0 REFERENCES

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APPENDIX 1: CURBSIDE AREA ROAD CROSS SECTION



APPENDIX 2: SHUTTLE BUS COST ESTIMATION

CURRENT SHUTTLE INFORMATION

Route Specifics				Cost Parameters				Emission (kg/year)				
Route	Bus Type	Bus Hours/Day	Miles / Year	Labor (\$/year)	Fuel Cost (\$/year)	Maintenance/Facility Cost (\$/year)	Total \$	CO2 eq	CO	Nox	pm	HC
Long Term Parking Lot A	40' Diesel	155	578423	2696138	602524	196664	3495326	1635651	8966	116	6	752
Long Term Parking Lot B	40' Diesel	155	627304	2696138	653441	213283	3562863	1773875	9723	125	6	815
Daily Parking Garage	40' Diesel	164	1436640	2852688	1496500	488458	4837646	4062499	22268	287	14	1868
Employee Parking Lot	40' Diesel	116	1219392	2017755	1270200	414593	3702548	3448170	18901	244	12	1585
BWI Rail Station Garage	40' Diesel	104	782666	1809022	815277	266107	2890406	2213206	12131	157	8	1017
Consolidated Rental Car Facility	40' CNG	120	778785	2087333	778785	264787	3130905	2202405	5085	171	0	16
Total	N/A	814	5423210	14159074	5616728	1843891	21619693	15335806	77074	1100	46	6053

FUEL INFORMATION

Fuel Type	Fuel Price	Source
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Ultra-Low Sulfur Diesel	\$3.75/ gallon	BWI
CNG	\$2.54/ DGE	Clean Cities

COST INFORMATION

Cost type	Cost	Source
Labor	\$47.656 /bus hour	BWI
Maintenance	\$0.16 / mile	TCRP 146
Facility	\$0.18 / mile	TCRP 146

EMISSIONS INFORMATION

Fuel Economy			Emissions (g/mile)						
Bus Type	# of Buses	Mileage	Source	CO2 eq	CO	Nox	pm	HC	Source
40' Diesel	49	3.6 MPG	BWI	2942	0	0.65	0.0	0.01	TCRP 146
40' CNG	25	2.7 MDGE	Clean Cities	2828	21.9	0.22	0.0	0.02	TCRP 146
40' Hybrid	0	4.01 MPG	TCRP 146	2538.6534	0	.49		0.01	TCRP 146

SHUTTLE ROUTE MAPS*



Daily Parking Garage



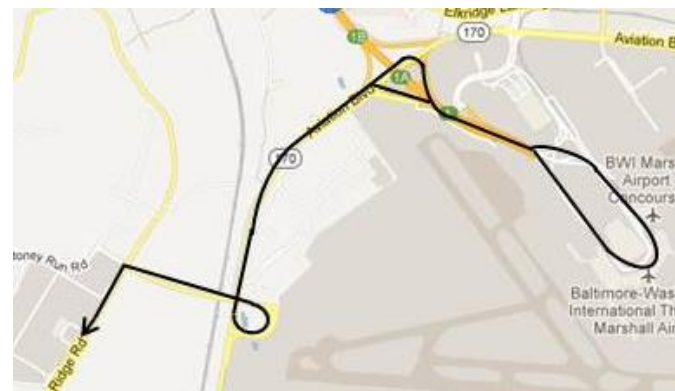
Employee Parking



Long Term Lots A and B (Separate Routes)



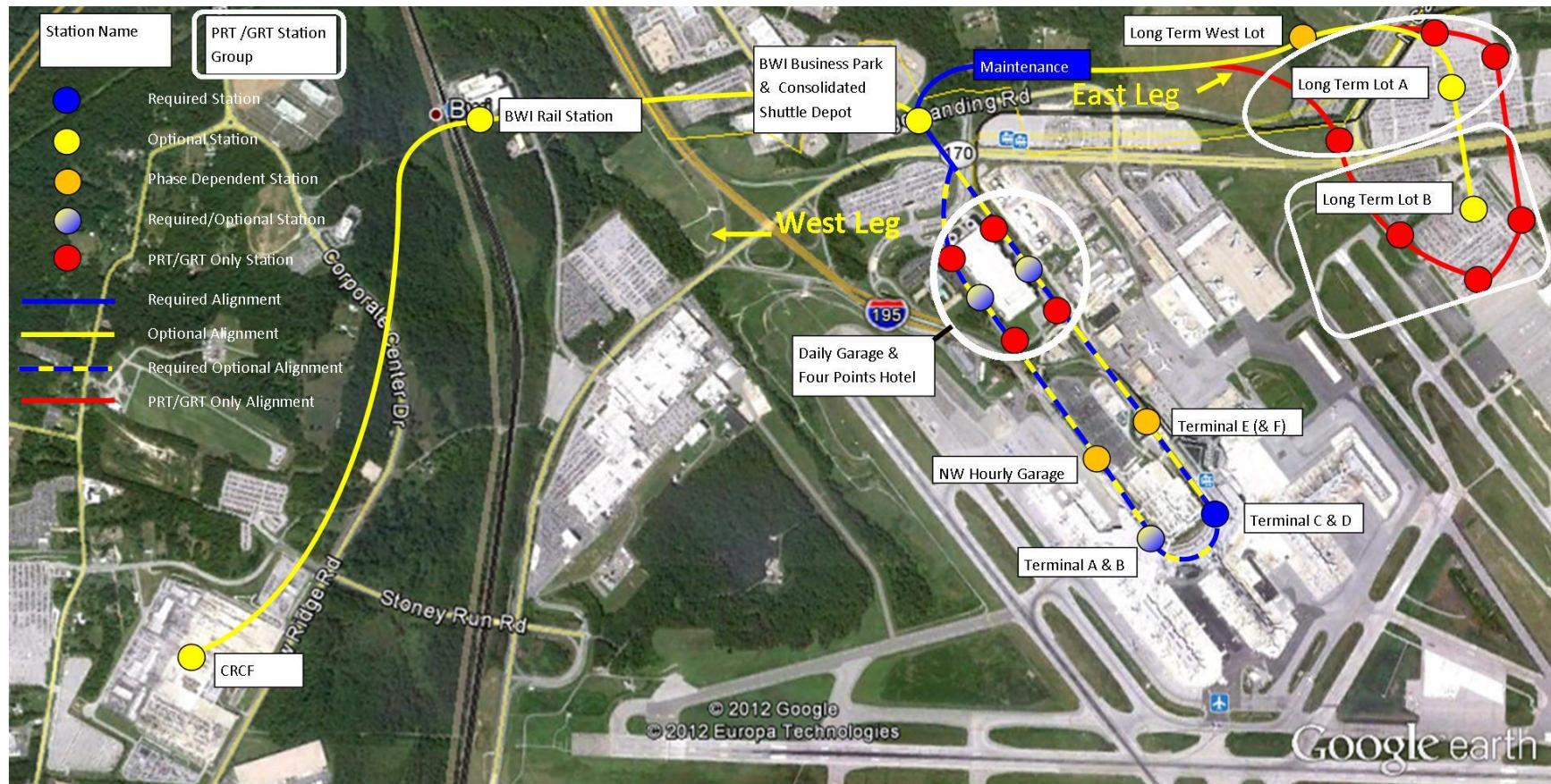
BWI Amtrak/MARC Station



Consolidated Rental Car Depot

*All routes are approximate

APPENDIX 3: APM/PRT OVERVIEW



APPENDIX 4: ORIGIN DESTINATION MATRICES

APM 2030 Full Build		Destination										
		Terminal West	Terminal East	Terminal F	Daily South	Daily North	CSD	South Long	East Long	North Long	Amtrak	CRCF
Origin	Terminal West	0	0	0	193	193	842	114	114	114	165	214
	Terminal East	0	0	0	141	141	618	84	84	84	121	157
	Terminal F	0	0	0	60	60	262	35	35	35	51	67
	Daily South	181	133	56	0	0	0	0	0	0	0	0
	Daily North	181	133	56	0	0	0	0	0	0	0	0
	CSD	808	592	251	0	0	0	0	0	0	0	0
	South Long	107	78	33	0	0	0	0	0	0	0	0
	East Long	107	78	33	0	0	0	0	0	0	0	0
	North Long	107	78	33	0	0	0	0	0	0	0	0
	Amtrak	160	117	50	0	0	0	0	0	0	0	0
	CRCF	202	148	63	0	0	0	0	0	0	0	0

APM 2030 Min Build		Destination		
		Terminal West	Daily South	CSD
Origin	Terminal West	0	788	2060
	Daily South	740	0	0
	CSD	1977	0	0

APM 2030 Min Build with Loop		Destination					
		Terminal West	Terminal East	Terminal F	Daily South	Daily North	CSD
Origin	Terminal West	0	0	0	193	193	1008
	Terminal East	0	0	0	141	141	739
	Terminal F	0	0	0	60	60	313
	Daily South	181	133	56	0	0	0
	Daily North	181	133	56	0	0	0
	CSD	967	709	301	0	0	0

APM 2030 West Leg Build		Destination							
		Terminal West	Terminal East	Terminal F	Daily South	Daily North	CSD	Amtrak	CRCF
Origin	Terminal West	0	0	0	193	193	842	165	214
	Terminal East	0	0	0	141	141	618	121	157
	Terminal F	0	0	0	60	60	262	51	67
	Daily South	181	133	56	0	0	0	0	0
	Daily North	181	133	56	0	0	0	0	0
	CSD	808	592	251	0	0	0	0	0
	Amtrak	160	117	50	0	0	0	0	0
	CRCF	202	148	63	0	0	0	0	0

APM 2030 East Leg		Destination								
		Terminal West	Terminal East	Terminal F	Daily South	Daily North	CSD	South Long	East Long	North Long
Origin	Terminal West	0	0	0	193	193	1008	114	114	114
	Terminal East	0	0	0	141	141	739	84	84	84
	Terminal F	0	0	0	60	60	313	35	35	35
	Daily South	181	133	56	0	0	0	0	0	0
	Daily North	181	133	56	0	0	0	0	0	0
	CSD	967	709	301	0	0	0	0	0	0
	South Long	142	104	44	0	0	0	0	0	0
	East Long	142	104	44	0	0	0	0	0	0
	North Long	142	104	44	0	0	0	0	0	0

PRT 2030 Full Build		Destination													
		Terminal West	Terminal East	Terminal F	Daily West	Daily South	Daily North	Daily East	CS D	West Long	South Long	East Long	North Long	Amtrak	CRC F
Origin	Terminal West	0	0	0	96	96	96	96	842	85	85	85	85	165	214
	Terminal East	0	0	0	71	71	71	71	618	63	63	63	63	121	157
	Terminal F	0	0	0	30	30	30	30	262	27	27	27	27	51	67
	Daily West	90	66	28	0	0	0	0	0	0	0	0	0	0	0
	Daily South	90	66	28	0	0	0	0	0	0	0	0	0	0	0
	Daily North	90	66	28	0	0	0	0	0	0	0	0	0	0	0
	Daily East	90	66	28	0	0	0	0	0	0	0	0	0	0	0
	CSD	808	592	251	0	0	0	0	0	0	0	0	0	0	0
	West Long	80	59	25	0	0	0	0	0	0	0	0	0	0	0
	South Long	80	59	25	0	0	0	0	0	0	0	0	0	0	0
	East Long	80	59	25	0	0	0	0	0	0	0	0	0	0	0
	North Long	80	59	25	0	0	0	0	0	0	0	0	0	0	0
	Amtrak	160	117	50	0	0	0	0	0	0	0	0	0	0	0
	CRCF	202	148	63	0	0	0	0	0	0	0	0	0	0	0

PRT 2030 Min Build		Destination			
		Terminal West	Daily South	Daily West	CSD
Origin	Terminal West	0	394	394	2060
	Daily South	370	0	0	0
	Daily West	370	0	0	0
	CSD	1977	0	0	0

PRT 2030 Min Build with Loop		Destination							
		Terminal West	Terminal East	Terminal F	Daily West	Daily South	Daily North	Daily East	CSD
Origin	Terminal West	0	0	0	96	96	96	96	1008
	Terminal East	0	0	0	71	71	71	71	739
	Terminal F	0	0	0	30	30	30	30	313
	Daily West	90	66	28	0	0	0	0	0
	Daily South	90	66	28	0	0	0	0	0
	Daily North	90	66	28	0	0	0	0	0
	Daily East	90	66	28	0	0	0	0	0
	CSD	967	709	301	0	0	0	0	0

PRT 2030 West Leg Build		Destination									
		Terminal West	Terminal East	Terminal F	Daily West	Daily South	Daily North	Daily East	CSD	Amtrak	CRCF
Origin	Terminal West	0	0	0	96	96	96	96	842	165	214
	Terminal East	0	0	0	71	71	71	71	618	121	157
	Terminal F	0	0	0	30	30	30	30	262	51	67
	Daily West	90	66	28	0	0	0	0	0	0	0
	Daily South	90	66	28	0	0	0	0	0	0	0
	Daily North	90	66	28	0	0	0	0	0	0	0
	Daily East	90	66	28	0	0	0	0	0	0	0
	CSD	808	592	251	0	0	0	0	0	0	0
	Amtrak	160	117	50	0	0	0	0	0	0	0
	CRCF	202	148	63	0	0	0	0	0	0	0

PRT 2030 East Leg		Destination											
		Terminal West	Terminal East	Terminal F	Daily West	Daily South	Daily North	Daily East	CSD	West Long	South Long	East Long	North Long
Origin	Terminal West	0	0	0	96	96	96	96	1008	85	85	85	85
	Terminal East	0	0	0	71	71	71	71	739	63	63	63	63
	Terminal F	0	0	0	30	30	30	30	313	27	27	27	27
	Daily West	90	66	28	0	0	0	0	0	0	0	0	0
	Daily South	90	66	28	0	0	0	0	0	0	0	0	0
	Daily North	90	66	28	0	0	0	0	0	0	0	0	0
	Daily East	90	66	28	0	0	0	0	0	0	0	0	0
	CSD	967	709	301	0	0	0	0	0	0	0	0	0
	West Long	80	59	25	0	0	0	0	0	0	0	0	0
	South Long	80	59	25	0	0	0	0	0	0	0	0	0
	East Long	80	59	25	0	0	0	0	0	0	0	0	0
	North Long	80	59	25	0	0	0	0	0	0	0	0	0

APPENDIX 5: BUS COST

Future 2030 Bus Costs with Diesel Replacements																			
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
# of new CNG buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of new diesel buses	0	10	10	10	10	10	32	10	3	3	3	3	3	13	13	13	13	13	35
# of new hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of retired CNG buses	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0
# of retired diesel buses	0	7	7	7	7	7	7	7	0	0	0	0	0	10	10	10	10	10	32
# of retired hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of CNG buses	25	25	25	25	25	25	0	0	0	0	0	0	0	0	0	0	0	0	0
# of diesel buses	49	52	55	58	61	64	89	92	95	98	101	104	107	110	113	116	119	122	125
# of hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total buses	74	77	80	83	86	89	89	92	95	98	101	104	107	110	113	116	119	122	125
Diesel Cost/ gallon	3.48	3.34	3.56	3.68	3.72	3.78	3.82	3.84	3.88	3.91	3.94	3.97	4	4.07	4.11	4.09	4.12	4.16	4.21
CNG Cost/ gallon	1.872749 667	1.886 213	1.89 833	1.905 062	1.89025 2	1.882 174	1.886 213	1.894 291	1.906 408	1.927 949	1.952 183	1.968 339	1.976 417	1.993 92	2.006 037	2.018 154	2.024 885	2.032 963	2.046 427
Operating Costs	1375693. 548	1426 626	1477 557	1528 489	157942 1.4	1630 353	1510 982	1561 914	1612 846	1663 777	1714 709	1765 641	1816 573	1867 505	1918 437	1969 369	2020 301	2071 233	2122 165
Capital Cost	0	3500 000	3500 000	3500 000	350000 0	3500 000	1120 0000	3500 000	1050 000	1050 000	1050 000	1050 000	1050 000	4550 000	4550 000	4550 000	4550 000	4550 000	1225 0000
Fuel Costs	3747095. 022	3806 100	4178 789	4474 557	469077 1.914	4935 495	5636 670	5857 176	6111 172	6352 900	6597 612	6845 309	7095 990	7422 604	7699 978	7865 938	8128 556	8414 385	8724 917
Facility Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Cost	5122788. 57	8732 725	9156 346	9503 046	977019 3.315	1006 5848	1834 7651	1091 9089	8774 018	9066 678	9362 322	9660 950	9962 563	1384 0109	1416 8415	1438 5307	1469 8857	1503 5618	2309 7082
Miles per year per bus	53054.12 833																		
IRR	0.05																		
NPR	\$133,679, 107.31																		

Future 2030 Bus Costs with CNG Replacements																			
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
# of new CNG buses	0	10	10	10	10	10	32	10	3	3	3	3	3	13	13	13	13	13	35
# of new diesel buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of new hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of retired CNG buses	0	0	0	0	0	0	25	0	0	0	0	0	0	10	10	10	10	10	32
# of retired diesel buses	0	7	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0	0	0
# of retired hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of CNG buses	25	35	45	55	65	75	82	92	95	98	101	104	107	110	113	116	119	122	125
# of diesel buses	49	42	35	28	21	14	7	0	0	0	0	0	0	0	0	0	0	0	0
# of hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total buses	74	77	80	83	86	89	89	92	95	98	101	104	107	110	113	116	119	122	125
Diesel Cost/ gallon	3.48	3.34	3.56	3.68	3.72	3.78	3.82	3.84	3.88	3.91	3.94	3.97	4	4.07	4.11	4.09	4.12	4.16	4.21
CNG Cost/ gallon	1.872749 667	1.886 213	1.89 833	1.905 062	1.89025 2	1.882 174	1.886 213	1.894 291	1.906 408	1.927 949	1.952 183	1.968 339	1.976 417	1.993 92	2.006 037	2.018 154	2.024 885	2.032 963	2.046 427
Operating Costs	1375693. 548	1474 374	1573 055	1671 736	177041 6.262	1869 097	19025 21	2001 202	2066 458	2131 715	2196 971	2262 228	2327 485	23927 41	24579 98	25232 54	25885 11	26537 67	27190 24
Capital Cost	0	3750 000	3750 000	3750 000	375000 0	3750 000	12000 000	3750 000	1125 000	1125 000	1125 000	1125 000	1125 000	48750 00	48750 00	48750 00	48750 00	48750 00	13125 000
Fuel Costs	3747095. 022	3622 982	3744 366	3767 205	370946 8.609	3651 191	34825 39	3424 443	3558 729	3712 591	3874 337	4022 432	4155 448	43097 87	44542 31	46001 04	47348 13	48735 43	50264 53
Facility Cost	1000000	1500 00	1500 00	1500 00	150000	1500 00	10500 0	1500 00	4500 0	4500 0	4500 0	4500 0	4500 0	45000	45000	45000	45000	45000	45000
Total Cost	6122788. 57	8997 356	9217 421	9338 940	937988 4.871	9420 288	17490 060	9325 645	6795 187	7014 306	7241 308	7454 660	7652 933	11622 528	11832 229	12043 358	12243 324	12447 310	20915 477
Miles per year per bus	53054.12 833																		
IRR	0.05																		
NPR	\$119,757, 866.00																		

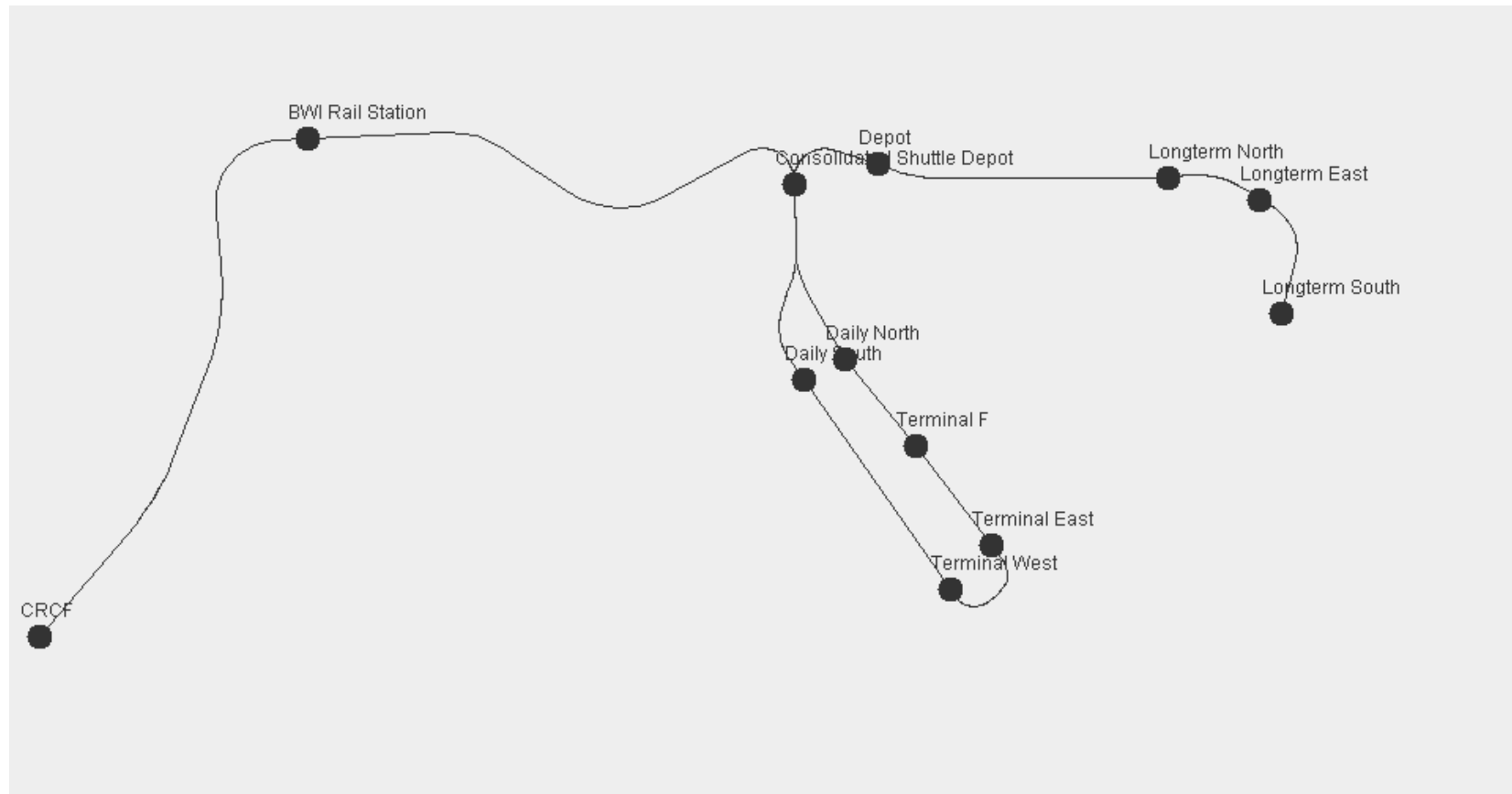
Future 2030 Bus Costs with Hybrid Replacements																			
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
# of new CNG buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of new diesel buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# of new hybrid buses	0	10	10	10	10	10	32	10	3	3	3	3	3	13	13	13	13	13	35
# of retired CNG buses	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0
# of retired diesel buses	0	7	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0	0	0
# of retired hybrid buses	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	10	32
# of CNG buses	25	25	25	25	25	25	0	0	0	0	0	0	0	0	0	0	0	0	0
# of diesel buses	49	42	35	28	21	14	7	0	0	0	0	0	0	0	0	0	0	0	0
# of hybrid buses	0	10	20	30	40	50	82	92	95	98	101	104	107	110	113	116	119	122	125
Total buses	74	77	80	83	86	89	89	92	95	98	101	104	107	110	113	116	119	122	125
Diesel Cost/ gallon	3.48	3.34	3.56	3.68	3.72	3.78	3.82	3.84	3.88	3.91	3.94	3.97	4	4.07	4.11	4.09	4.12	4.16	4.21
CNG Cost/ gallon	1.872749 667	1.886 213	1.89 833	1.905 062	1.89025 2	1.882 174	1.886 213	1.894 291	1.906 408	1.927 949	1.952 183	1.968 339	1.976 417	1.993 92	2.006 037	2.018 154	2.024 885	2.032 963	2.046 427
Operating Costs	1375693. 548	1442 542	1509 390	1576 238	164308 6.354	1709 935	1641 495	1708 343	1764 050	1819 757	1875 463	1931 170	1986 877	2042 584	2098 291	2153 998	2209 704	2265 411	2321 118
Capital Cost	0	4550 000	4550 000	4550 000	455000 0	4550 000	1456 0000	4550 000	1365 000	1365 000	1365 000	1365 000	1365 000	5915 000	5915 000	5915 000	5915 000	5915 000	1592 5000
Fuel Costs	3747095. 022	3684 544	3919 665	4072 769	414923 1.604	4247 651	4496 669	4571 454	4769 696	4958 361	5149 356	5342 680	5538 333	5793 252	6009 739	6139 268	6344 239	6567 325	6809 691
Facility Cost	0	1000	1000	1000	1000	1000	3200	1000	300	300	300	300	300	300	300	300	300	300	300
Total Cost	5122788. 57	9678 086	9980 055	1020 0007	103433 17.96	1050 8586	2070 1364	1083 0797	7899 045	8143 418	8390 119	8639 150	8890 511	1375 1136	1402 3330	1420 8566	1446 9243	1474 8036	2505 6110
Miles per year per bus	53054.12 833																		
IRR	0.05																		
NPR	\$135,737, 067.09																		

APPENDIX 6: APM ALIGNMENTS

Contains station	Does not contain station
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Name of Alternative	Terminal West	Terminal East	Terminal F	Daily South	Daily North	CSD	South Long	East Long	North Long	Rail Station	CRCF
2030 Full Buildout											
2030 Min Buildout											
2030 Min W/ Loop											
2030 West Leg											
2030 East Leg											

APPENDIX 7: APM SCHEMATIC



APPENDIX 8: PRT ALIGNMENTS

Contains station	Does not contain station
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Name of Alternative	Terminal West	Terminal East	Terminal F	Daily West	Daily South	Daily North	Daily East	CSD	West Long	South Long	East Long	North Long	Amtrak	CRCF
2030 Full Buildout														
2030 Min Buildout														
2030 Min W/ Loop														
2030 West Leg														
2030 East Leg														

APPENDIX 9: PRT SCHEMATIC

