From:	peter
To:	Council Public Hearing
Subject:	Corridor Forward public comment support materials
Date:	Tuesday, February 15, 2022 4:32:24 PM
Attachments:	prt10to1.png ReubenJusterPSPRTasUrbanModeTRR23502013.pdf

[EXTERNAL EMAIL]

Council members,

Personal Rapid Transit by far is the best mode of transportation available.

The planning staff admitted in their briefly report to the Planning Board they did not have the expertise to evaluate PRT modes of transportation. Planning staff said they didn't have a budget to hire a qualified consultant.

From Montgomery County GetOnBoardBRT website:

"Montgomery County first proposed BRT as the most appropriate mode for improving transit in the MD 355 corridor as part of the 1993 Strategic Transit Plan"

The time for BRT was 1993. The world of technology has moved way beyond BRT.

Don't be that Council member that rejected BRT in 1993 when it was the best transit alternative.

PRT has emerged as the correct course for our County don't bury PRT they way BRT was buried in 1993.

We need expertise to evaluate all possible transportation modes as clearly what we have been doing in the past made us one of the most congested areas in the nation.

Why is the County using unqualified personnel to study will have such a huge impact on our lives and livelihoods?

Attached is a UMD study of the cost benefit analysis of BRT, PRT and light rail along the Purple Line alignment.

For a small fraction of the cost of BRT or LRT, both capital and O&M costs, we can build personal rapid transit guideways with 1% of the right of way land requirements. Glydways CEO Mark Seeger presents the economics and benefits of personal rapid transit system.

Any Federal funding for these proposed projects are subject be challenged in court for failing to evaluate all alternatives for the 270 Corridor.

Rather than spending a huge portion of public funds which currently don't exist, I suggest the County implement a online multi-user urban planning simulator, to simulate the actual costs and use of each proposed alternatives.

This would allow citizen to see what's being proposed for them, take test rides between the places they want to go, on all transportation alternatives. The platform would allow citizens to create their own alternatives that could be evaluated by the community.

According to MNCPP report on MD 355 BRT. Rush hour traffic auto transit times will increase by 7 minutes(15%) with MC planning's preferred BRT B alternative.

PRT has:

- Faster - 1/4 the transit time of BRT
- Cheaper - 1/4 the capital costs of BRT
- 1/10 the operating and maintenance costs of BRT - no drivers
- Safer - no interaction between vehicles and pedestrians and road traffic - Morgantown PRT Zero crashes since 1975
- Transit for a Post COVID world - riders don't share air space with other riders
- Quicker implementation - small land footprint, light footbridge and bike lane construction
- All trips are non-stop, point-to-point and require no transfers between corridors. This makes travel during rush hour faster than even cars.
- Lighter roadbeds with lower environmental footprint
- transportation equity - low cost allows build out to all MoCo neighborhoods

I request the Council amend the Corridor Forward study to include of a full design and cost simulation PRTs with and without street drive-able cars along with all other proposed transit modes and alignments under study.

I also ask the Council to eliminate the arbitrary classification between highways and transit. We believe the entire County's population is better server at transportation system that are better than existing modes.

The transportation solution we choose, should have the lowest transit times, highest reliability,be the safest and most sustainable.

Here is a article on pedestrian crash data for buses and light rail per passenger mile compared to cars.

Bus did slightly better then cars. Articulating bus studies, the type used in BRT systems, are involved in 4 times the crashes as standard buses.

PRTs fulfill all of the public's stated desires.

Peter James

Comparative Analysis of Personal Rapid Transit as an Urban Transportation Mode

Article *in* Transportation Research Record Journal of the Transportation Research Board · December 2013

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Comparative Analysis of Personal Rapid Transit as an Urban Transportation Mode

Reuben Juster and Paul Schonfeld

Personal rapid transit (PRT) is a modern form of transportation that moves people directly from origin to destination. PRT commonly consists of four-person driverless pods that travel on grade-separate right-of-way at speeds of around 25 mph. Planned PRT systems, with the exception of a system under construction in Amritsar, India, are relatively simple systems that consist of only a few stations on a short route. The potential of PRT as a substitute for traditional medium or large-scale urban transit such as bus rapid transit, light rail transit, and modern streetcars was examined. The proposed Purple Line light rail project in the Maryland suburbs of Washington, D.C., was modeled as a PRT system with the BeamEd 1.3.2 simulation tool, although the Purple Line route and station locations were not optimized for PRT. PRT, bus rapid transit, and light rail transit versions of the Purple Line were compared with respect to costs, environmental effects, and system performance. Multiple sensitivity analyses were performed to assess the effect of certain simulation inputs on PRT system performance. Comparisons between the three alternative modes of the Purple Line favor PRT in total travel times and capital costs, an indication that PRT could be a viable option as a transportation mode in other urban environments. The risk of failure in the implementation of a new technology on a grand scale is the largest obstacle that hinders wider PRT implementation.

Personal rapid transit (PRT) is a modern transportation mode that is a hybrid of automated people movers and taxis. PRTs are similar to automated people movers, for they are both grade separated and controlled centrally by computers. PRTs are similar to taxis in having a capacity of about four passengers per vehicle and taking passengers directly and non-stop from origin to destination. This innovative point-to-point transit mode features stations with their own tracks (off-line), enabling vehicles to bypass stations at full speed or decelerate before serving a station without interfering with other vehicles. Since PRT vehicles travel directly from origin to destination, and PRT stations have off-line tracks, PRTs are not limited to networks of fixed routes. PRTs are flexible route systems and can be designed with webbed networks capable of covering an entire metropolitan area.

PRTs use miniature vehicles, allowing for smaller stations and structural components that are less intrusive and less expensive than other rail-based modes. Smaller vehicles may seem to decrease the capacity of the system, but they allow lower headways, theoretically as low as 0.5 s, ensuring that the mode can accommodate many vehicles and passengers. PRTs usually run on electricity from either batteries or an electrified rail. Designing PRT alignments is easier with a minimum turning radius of about 32 ft (9.75 m) and steep gradients. The main drawback of PRTs is their lower vehicle performance compared with that of other modes, reaching speeds of only about 30 mph (48.3 km/h) and accelerations of around 8.2 ft/s^2 [2.5 m/s^2 (*1*)]. PRTs can be implemented in various settings, from an airport circulator to the primary mode in a modern planned city.

Passengers do not require special training to ride PRTs. To ride on PRTs, passengers select their destination at their origin station. Electronic signs at the station then direct passengers to specific platforms to wait for their PRT vehicles (if they have to wait at all). After PRT vehicles arrive at a station and dock into a berth, the doors automatically open and close, and the vehicles transport the passengers directly to their final destinations.

Most PRTs that are planned or in operation do not take advantage of the full PRT capabilities. Current PRT networks cater to limited passenger demands and consist of only a few vehicles. PRT has the potential of becoming an urban transportation system replacing bus rapid transit (BRT), streetcars, and even light rail transit (LRT). A simulation model of the Purple Line, a planned Washington, D.C., area LRT project, recast here as a PRT system, is used to assess the applicability of PRT as an urban transportation mode. The PRT, BRT, and LRT versions of the Purple Line are compared based on their operation, cost, safety, and effect on the physical environment. Different types of sensitivity analyses and a capacity analysis are conducted to explore how various uncertainties might affect performance of the system.

SYSTEM CHARACTERISTICS COMPARED WITH OTHER MODES

Speed

PRTs are currently designed to travel at speeds up to 30 mph (48.3 km/h), far below those of other transit modes. However, their average speed, which takes into account the time required to stop at each station, exceeds that for some other transit modes. Unlike its competitors, PRT stops only at stations when and where it is requested by its passengers, thus saving considerable deceleration, dwell, and acceleration time. APTA estimates that the average speed of PRT is around 23 mph (37.0 km/h), and thus faster than the 20 mph (32.2 km/h) average speed of heavy rail, one of the fastest forms of urban transit (*2*). The total trip time using PRT is lower for additional reasons besides the higher average speed. Many times passengers must wait long periods for their transit vehicle to arrive, and they may have to wait multiple times if they require route transfers. Even if a journey on PRT passes through many different track sections, the PRT vehicle is able to make the required switches without

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requiring passengers to transfer to different vehicles. A theoretical 8-mi (12.9-km) trip with two 4-mi (6.4 km) legs would take about 21.9 min on PRT and about 35 min on heavy rail as a result of higher average speed, lower wait time, and lack of any transfer time (*2*). The theoretical distance to access a PRT is below the access distance for conventional transit. Conventional transit has fixed routes, and if the origin and destination of a trip are not both near the same transit route, passengers have to walk longer distances, use another mode to access transit, or wait for transfers. PRT systems can have many branches to serve major activity centers even if they are not close to a major branch. More PRT stations can be provided at convenient locations owing to their smaller size and cost.

Capacity

PRT capacity in large urban networks is expected to be at most 10,000 passengers per hour per direction (pphpd). The line capacity, the number of passengers that can pass through a certain point, is just below that of BRT and LRT, which have just above 10,000 pphpd, but far below heavy rail's capacity of about 40,000 pphpd. The capacity figures assume sparse networks, rather than the denser weblike networks that PRT can serve. In a dense PRT network with multiple tracks, parallel routes and passing opportunities would increase the capacity (*2*).

Cost

In 2007, before the first few modern PRT systems were completed, the average capital cost was estimated at $30 to $50 million per two-way segment mile (*2*). The estimation assumes moderate system design complexity, climate, and right-of-way costs. New studies and actual practice have shown that the initial cost estimation was too conservative. London Heathrow Airport's PRT cost only about $16.2 million per mile. A recent study estimated the cost of PRT at $10.2 million per mile and $1.05 million per station (*3*). The operating and maintenance costs (in 2005 dollars) are projected to be from 30¢ to 80¢ per passenger mile, with 40¢ on average (*2*). These costs are below the maintenance cost of the Baltimore LRT system, operated by the same transit agency [Maryland Transit Administration (MTA)] that is planning the Purple Line; that cost was $1.26 per passenger mile in 2006 (*4*).

Environmental Impact

For some aspects, including noise and emissions, PRT is better for the environment than are most other transit modes. PRT produces about two-thirds of the noise of heavy rail or bus because PRT takes the quietest components from each mode (*2, 5*). Bus rubber tires are relatively quiet when moving over asphalt, but most buses use gas or diesel motors that operate with many loud explosions per second. Heavy rail uses electric motors that are relatively quiet for their power, but its steel wheels screech on top of steel rails. PRTs use electric motors and rubber tires that provide quieter transportation.

Many government agencies have set goals for clean air and cutting greenhouse gas emissions. PRT could be a great tool to help in reducing emissions, by encouraging more people to use public transit while using less energy than most other public transit modes do, including buses, light rail, and heavy rail. The one significant environmental handicap for PRT is its visual obstruction. While the physical infrastructure is less obtrusive compared with other elevated forms of transit, PRT is mostly elevated, unlike LRT or BRT, which can operate on surface streets with mixed traffic (*2*).

BACKGROUND ON MARYLAND TRANSIT ADMINISTRATION PURPLE LINE

The Purple Line is an MTA light rail project connecting Montgomery and Prince George's Counties, the two suburban Maryland counties adjoining Washington, D.C. The project is in the detailed engineering phase after the federal government approved it in October 2011 (*6*). The projected capital cost of the locally preferred alternative is estimated at $1.6 billion (2011 dollars), including everything from physical infrastructure to professional engineering costs. MTA estimates that 65,000 riders will use the Purple Line in 2030, 43% of whom will connect to Metrorail, Washington's heavy rail system, highlighting the multimodal nature of the project (*7*). Many alternatives were considered, including no-build, traffic system management, BRT, and LRT alternatives. The BRT and LRT alternatives were each divided into low, medium, and high investment alternatives (*8*). For this paper, Purple Line figures for alignment, cost, and ridership represent the medium investment LRT and high investment BRT alternatives, since these are the closest to the locally preferred alternative.

History

Plans for the Purple Line originated in the early 1970s, when Montgomery County considered building a transitway on the Georgetown Branch, an abandoned railroad right-of-way (*9*). Montgomery County purchased the right-of-way between Bethesda and Silver Spring in 1988, but converted it into a recreation trail, rather than a transit corridor, despite the $70 million offered from the governor for a trolley. The Capital Crescent Trail, as it is now called, became a popular recreational facility with many users adamantly protecting the trail from any possible development (*10*). No serious advances for the Purple Line occurred until the project's resurrection in the early 2000s, this time including a previous study's alignment that would extend the transit line into New Carrollton, a city in Prince George's County. The project was renamed the Bi-County Transitway, reflecting the project's extension into Prince George's County and the consideration of additional transit modes, including BRT. From 2003 to 2008, MTA conducted meetings with the public and other government agencies to receive input that would be published in a draft environmental impact statement. During that period, the Bi-County Transitway was renamed the Purple Line (*9*). In October 2009, the National Capital Region Transportation Planning Board approved the Purple Line as a light rail link between Bethesda and New Carrollton (*11*).

Route

The Purple Line is 16.3 mi long and has 21 stations. The alignment starts in the west in Bethesda's central business district near the Bethesda Metro Station. The alignment follows the Capital Crescent Trail through affluent residential neighborhoods before paralleling an existing railroad corridor north of Silver Spring's central business district. The alignment between Bethesda and Silver Spring is mostly grade separated. After a station in the Silver Spring Transit Center, a multimodal transit hub, the alignment runs on surface

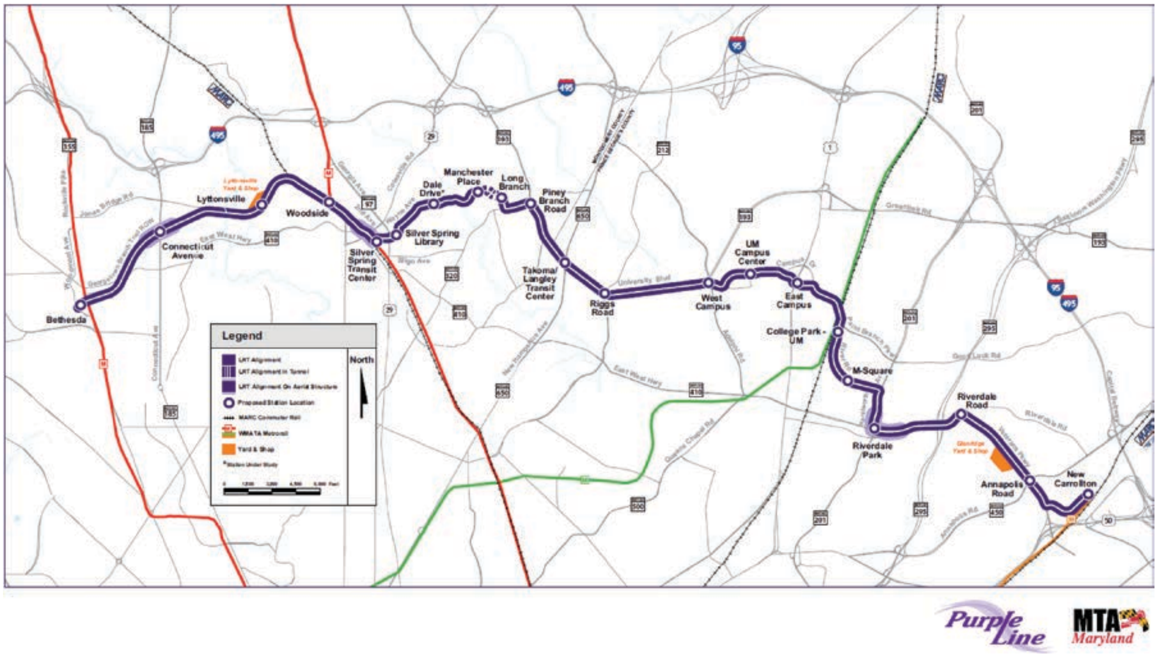

FIGURE 1 Locally preferred alternative route [(7) UM = University of Maryland].

streets. Next, the light rail line goes through a tunnel to navigate a steep grade and runs on dedicated centerlines on two major streets near the border of Montgomery and Prince George's Counties. The Purple Line passes through the University of Maryland College Park campus at grade and then crosses another rail–metro corridor at the College Park Metro Station. East of the College Park Metro Station, the light rail runs on a surface street through many federal government research centers and the city of Riverdale Park. In Riverdale Park, the tracks are partly elevated over streets to mitigate potential impacts to a busy intersection. After Riverdale Park, the alignment runs on dedicated lanes before reaching its terminus at New Carrollton, which includes a Metro Station, a bus hub, and a train station on the Northeast Corridor. One of the important aspects of the project is how the Purple Line links many other transportation modes with stations collocated at four Metro stations, three of which also have commuter–intercity rail stations (*7*). The current locally preferred alternative is shown in Figure 1.

BeamED SIMULATION

BeamED, developed by Beamways AB, is the simulation tool used here to model the Purple Line as though it were a PRT system. BeamED allows the user to draw PRT networks out of different elements by simply clicking on a graphical user interface. The elements include one- and two-way tracks, stations, vehicle depots, and junctions. Some of these elements can be seen in Figure 2. There are several ways to input ridership demand. The easiest method involves inputting the population near the PRT and setting the percentage of population that use the PRT. The simulation then automatically divides the population proportionally based on the number of berths at each station. Another way is to input a demand matrix with the number of riders between each station. Geographic information system data can be employed to estimate ridership based on the magnitudes of different population types (residential, work, shopping) in each geographic information system polygon. Vehicle size and kinematics can be specified to reflect different design vehicles.

During the simulation, stations have an ideal number of empty vehicles stored, based on the demand anticipated at each station. The simulation commands empty vehicles to redistribute themselves to reach the stations' ideal dwelled vehicle count. The simulator uses a pseudodynamic traffic assignment technique for vehicle route assignment, with each vehicle following the shortest path to its destination, recalculated every virtual 5 min for each origin–destination (O-D) pair. The horizontal alignment of the track affects vehicle performance, but vertical alignment cannot be input in the simulation and does not affect vehicle performance. The program records statistics throughout the simulation, except during the first part of the run, when the system is stabilizing.

FIGURE 2 BeamEd sample [(*12*) dr = drive; rd = road; ave = avenue].

The simulation operates in a way similar to group rapid transit, with passengers having the same O-D pair sharing a vehicle if they arrive at the same time, though this occurrence is uncommon because passengers do not usually wait. For 1 h of PRT operation to be modeled, the simulation runs in only a few seconds. The output includes a plethora of information, ranging from a trip timetable to average delay and mean vehicle use (*12*).

METHODOLOGY

Multiple Google Maps images are uploaded and scaled for each model to provide an appropriate background to aid in creation of the virtual PRT network. Virtual stations are placed where the transit project's stations are located and have 5 to 30 berths depending on the station's demand on the O-D matrix. A 30-berth station may be too long to fit above ground in some urban settings, but for a high demand PRT station, multiple parallel station platforms may be used to reduce the station length. Large depots are scattered through the system. The Purple Line's PRT alignment follows the LRT alignment exactly with two-way tracks connecting each of the planned stations.

The simulation uses an O-D matrix as the demand input. A travel demand forecasting technical report provided the 2030 daily O-D matrix for the Purple Line. The daily O-D matrix is multiplied by 0.2, the average peak factor for the Washington Metro system, to convert daily volumes into peak hour volumes (*13*). The peak factor is the ratio of the peak hour passenger count over the daily passenger count.

Most of the vehicle specifications are kept at default levels recommended by the BeamEd user manual, which sets the velocity (33.5 mph) and acceleration (5.37 mph/s) at levels that passengers can tolerate. The headway is set at 3 s, and vehicle capacity at four passengers, both of which are normal for current PRT technology (*12*).

RESULTS

Operations

The PRT Purple Line simulation is rerun approximately six times, until adding more vehicles does not further improve average travel or wait times. This occurs with 1,100 vehicles. The Purple Line's PRT equivalent has better travel times and wait times than its original LRT version. Travel time refers to the time spent moving in transit vehicles, and waiting time is the time spent waiting for a transit vehicle. The average travel time and wait time for the LRT version of the Purple Line are 11.2 and 3 min, respectively. The BRT average travel time and waiting time are 13.6 and 3 min, respectively. The PRT version's travel time and wait time are 9.06 and 0.12 min, respectively. The average travel time is calculated by multiplying each element of the O-D demand matrix by the O-D travel time matrix and dividing the product by the total demand. The wait time for LRT-BRT is estimated as half the headway, assuming uniform passenger arrivals over time, equal headways, and no leftover passengers. PRT average wait time is a simulation result. When one takes into account average waiting time and travel time, implementing the Purple Line as PRT could save commuters 3,570 person hours per day during the busiest hour of travel.

The section of the Purple Line near Riverdale Park and New Carrollton receives the greatest travel time benefit from becoming a PRT. One travel time comparison anomaly is that the BRT-LRT version of the Purple Line is faster for the segment between Bethesda and Silver Spring, a segment with the exclusive right-of-way of the Capital Crescent Trail and no signalized intersections. The waiting time for the PRT version is far less than for the LRT version, and the difference is greater during off-peak periods. The LRT trains have lower scheduled frequencies during periods with lower demand, but most PRT vehicles would still be available to users, keeping waiting time miniscule. In fact, only 27.3% of Purple Line riders would have to wait at all during the peak hour if the system is built as a PRT.

Cost

The capital cost estimation of the PRT system, seen in Table 1, uses Carnegie and Hoffman's approximation of $44 million per mile of bidirectional guideway (*2*). The right-of-way and site work costs for the PRT use the figures from the Purple Line's medium investment light rail alternative. Those costs are originally $154.20 million dollars combined, but they are multiplied by 0.75 to account for the narrower PRT right-of-way, which is less than half as wide as LRT (*8*). The estimated total cost for the PRT Purple Line is $835.49 million compared with the $1.6 billion for the LRT version (locally preferred alignment) and $1.2 billion for the BRT version [high investment alignment (*7, 8*)]. On the basis of such estimates, the Purple Line project could greatly decrease its capital costs if built as a PRT. Cost estimation can be a difficult component of transit projects, owing to the variability in land, labor, and component costs. The limited number of completed PRT projects amplifies the difficulty of approximating cost. Using the capital cost figures of currently operating PRTs may be inaccurate, for they are small in scale compared with those of the PRT version of the Purple Line. The latter requires large stations capable of handling large loads.

The foregoing cost estimation does not include travel time savings. Daily demand and average travel time for the Purple Line are not available, but if the average peak hour time savings per person is conservatively assumed for the average daily travel time savings, the PRT Purple Line saves riders 17,851 h/day. That estimate is conservative because off-peak LRT and BRT wait times would increase far more than PRT wait times. Thus, using the Federal TIGER Grant value of time of $12.50 per passenger hour, the PRT version of the Purple Line would save more than $81 million per year in transit riders' time over that of the MTA-chosen LRT alignment (*14*).

Theoretical studies estimate PRT annual costs to be lower than those of LRT or BRT, but operating and maintenance costs for actual PRT systems are scarce (*2*). It is conceivable that, without needing drivers, PRT would have lower annual costs, but the number of mechanics needed to maintain hundreds vehicles could dent its annual cost savings. Another troubling aspect for annual expenses is the cost of replacement parts. PRT technology is not standardized, and the first supplier could take advantage of its monopoly on replacement parts.

TABLE 1 Project Costs

Item	Quantity of Item	Unit Cost ($ million per mile)	Total ($ million)
Miles of bidirectional guideway	16.36	44	719.84
Right-of-way and site work	0.75	154.20	115.65
PRT grand total	na	na	835.49

NOTE: na = not applicable.

Safety

PRTs have the potential to be the safest form of urban transportation for users and bystanders. Many light rail and streetcar lines in the United States run in streets with the rest of traffic and risk causing severe collisions with cars, pedestrians, or bikes. There were 382 fatalities and 3,665 collisions involving pedestrians, cars, or bikers and rail transit (heavy rail and light rail) between 2003 and 2008. Almost half the fatalities were people trespassing into the rail right-of-way and committing suicide (*15*). These statistics may argue against building the LRT Purple Line, but rail transit is still a safer mode compared with personal automobile travel. One problem with any collision involving a transit vehicle is that it attracts more attention than an automobile-only accident and makes the public more wary of new transit, thus creating a not-in-my-backyard effect. A light rail project in Los Angeles, California, was opposed by local community members who were concerned that people would be hit by trains because a nearby light rail line and commuter rail system were constantly in the media for causing multiple pedestrian and vehicular fatalities (*16*). The PRT Purple Line would be completely grade separated, and the vehicles would weigh between 1,000 and 2,000 lb compared with 97,900 lb for a light rail train car and 69,420 lb for a 60-ft articulated bus (*2, 17, 18*). Since the proposed PRT system would be separate from the rest of traffic, trespassing would be more difficult; even if collisions occur, PRT vehicles weigh less than most cars and are slower than rail vehicles. The public is less likely to worry about safety issues and to hinder project development.

Effect on Physical Environment

Another concern for the communities around the Purple Line is its effects on the physical environment, including air quality, noise, destruction of land, and traffic. PRT and LRT may be nearly equivalent in regard to energy use per passenger, but PRT is quieter and takes less space than LRT or streetcars do. Most PRTs run on rubber tires on concrete guideways, which are quieter than the steel wheels on steel rails of light rail and streetcars. Whistles are required for light rail to warn nearby people of their presence. As a result of PRT grade separation, they have the ability to avoid using such whistles, which are known for irritating the surrounding community: a not-in-my-back-yard effect.

Most infrastructure projects built in developed areas require alteration of the landscape, whether in moving property lines or condemning buildings. A major issue with the Purple Line is the destruction of the Capital Crescent Trail to accommodate the light rail. Many trees in the parkland section of the trail will need to be cleared to make room for train tracks. A tunnel carrying the trail in central Bethesda would be diverted onto surface streets to allow the light rail to use the tunnel, disrupting the continuity of the trail. The current tunnel is 32 ft wide, enough for either a recreation trail or a light rail line, but not both. The tunnel would have to be widened to 57 ft to accommodate both, but there is currently a building above the tunnel, and any work on the tunnel requires expensive precautionary methods to support the tunnel during renovation. One alternative being considered is elevating the recreation trail above the LRT, but that is also an expensive option (*19*). A double-tracked PRT right-of-way is 13 ft wide and could easily fit in the tunnel without sacrificing the recreation trail or requiring expensive tunnel renovation. The smaller right-of-way requirements and structural components would also decrease the number of cleared trees (*3*). Another land issue for the Purple Line is that about 500 properties will be affected by the project, including 170 that will be temporarily condemned and 31 that will be permanently condemned (*20*). Fewer properties would have to be taken if a narrow PRT system were built instead. A negative attribute of PRTs is the necessity of building viaducts above current streets to keep the PRT separate from traffic. The overhead catenary wires for light rail may be considered an eyesore, but PRT viaducts are even more intrusive.

The Purple Line in both forms will decrease travel time and increase level of service (LOS) for transit riders, but many light rail projects can cause major disruptions for the rest of traffic. The Purple Line is an exception, causing only minor disruptions and, in some cases, improving the LOS (*8*). PRT in the transit corridor would further improve the LOS compared with at-grade transit modes, by removing transit vehicles from streets.

SENSITIVITY ANALYSIS

The BeamEd simulation effectively models PRT, but it is limited by the accuracy of inputs. A sensitivity analysis is performed to observe the effect of changing important variables, including the minimum allowable headway, number of vehicles, maximum velocity, and vehicle size. Figures 3 and 4 show how changing the system characteristics can affect the average travel time and waiting time. The *x*-axis for both graphs represent the percentage of the original values of the Purple Line, as specified at the end of the section on methodology and start of section on results.

Headway

The minimum allowable headway in a traffic stream refers to the smallest headway allowed between two vehicles. Headways between PRT vehicles will greatly vary depending on demand, but they must be above the minimum headway. A minimum headway of 3 s is the standard for modern PRT, but certain suppliers have technology that allows PRT vehicles to operate with minimum allowable headways below 1 s. To check how headway affects the Purple Line, the minimum allowable headway is varied from 1 to 10 s, while keeping all other parameters at the default value. The number of vehicles is set at the values of the original simulation trials. The Purple Line shows no performance improvement with a decrease in minimum allowable headway. Increasing the minimum headway substantially increases waiting time and travel time. If the headway has to be set above 3 s, capacity can be recovered with additional vehicles.

Number of Vehicles

The 1,100 PRT vehicles that the Purple Line would initially need might not be available owing to cost or supply issues. Alternatively, more vehicles might be used to entice additional ridership through better service. The simulation is run with 500 to 2,500 vehicles. Additional vehicles marginally decrease the waiting time but also increase the travel time resulting from system congestion. Decreasing the number of vehicles greatly increases waiting time and marginally decreases travel time.

Velocity

The maximum velocity for PRTs is generally set around 30 mph for passenger comfort, but new features could allow PRTs to travel faster without sacrificing passenger comfort. The velocity is varied from

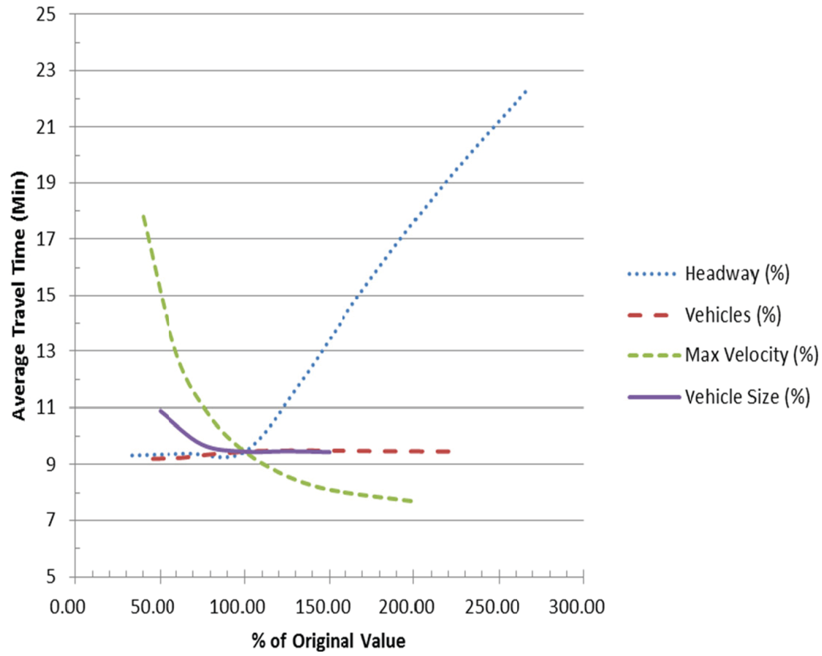

FIGURE 3 Effect of vehicle characteristics on average travel time.

6 to 30 m/s (13.4 to 67.1 mph). As expected, increasing maximum velocity decreases travel time and wait time.

Vehicle Size

One reason that PRTs tend to be inexpensive is that the small vehicle size allows a smaller and less expensive infrastructure. If vehicles were even smaller, it is conceivable that the infrastructure cost could be even lower. Larger vehicles could decrease the number of vehicles needed and would let larger groups travel together. The simulation is run with vehicle sizes from two to six (passengers per vehicle). Increasing the vehicle size from four passengers has little effect on travel or waiting times, but decreasing the vehicle size substantially increases waiting time.

CAPACITY ANALYSIS

The Purple Line PRT system has plenty of capacity to handle the demand predicted for the year 2030, but those figures do not reflect the possible induced development and demand near stations. At

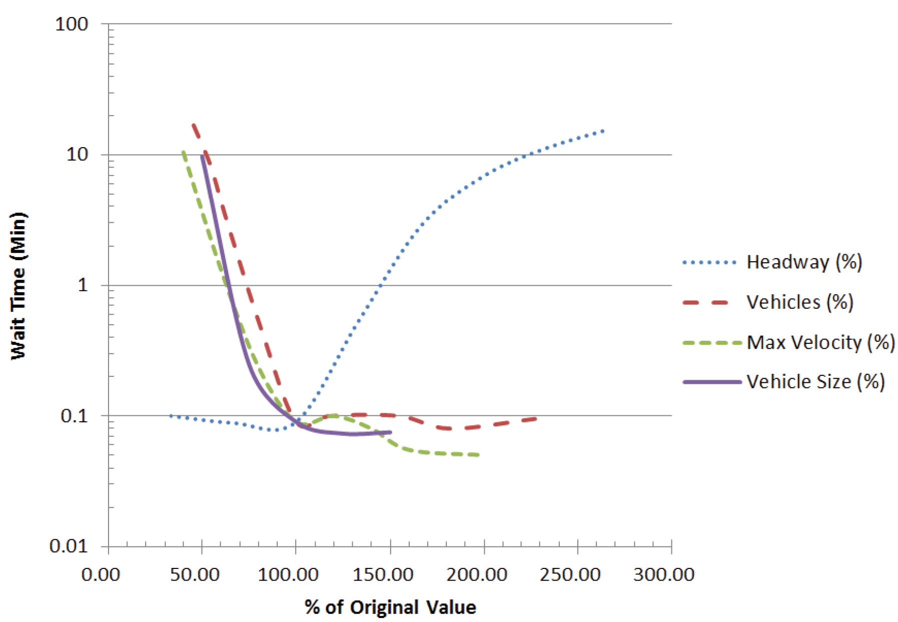

FIGURE 4 Effect of vehicle characteristics on wait time.

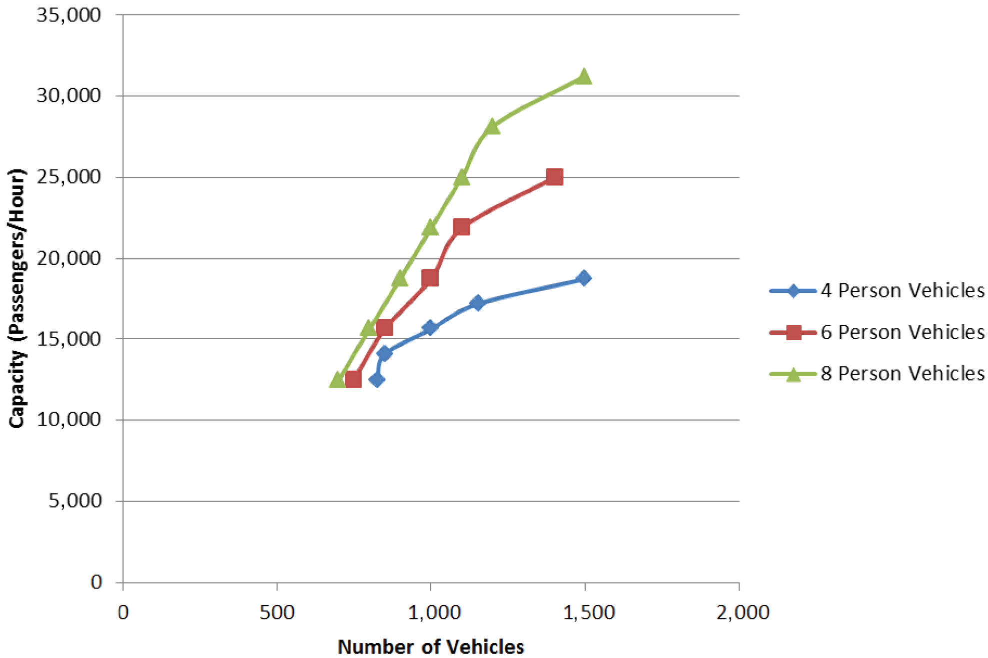

FIGURE 5 System capacity.

the time of writing, 2030 is only 18 years away, and even without induced demand, capacity of the system might not suffice for the near term. A capacity analysis is performed to ensure that the system would be able to handle higher demand levels. The number of vehicles for each demand level is set so the average wait time is just under 1 min. Vehicles can be added to the system until the system is at capacity, occurring when there are too many vehicles operating in a certain amount of space. This is defined as network usage, the maximum number of actual operating vehicles divided by the theoretical maximum number of operating vehicles based on allowable headway, which cannot exceed 35%, according to the simulation guidelines (*12*). Vehicle capacity is also varied from four to eight passengers to examine how it affects system capacity. Results of the capacity analysis can be seen in Figure 5.

The PRT Purple Line can handle up to 18,746 passengers per hour with 1,500 four-person vehicles, 50% above the 2030 peak demand. Larger vehicles could accommodate larger loads, up to 31,244 with eight-person vehicles, but the larger vehicles would require larger and more expensive guideway components. After the system reaches capacity, it is conceivable that additional capacity can be obtained by decreasing headways.

LIMITATIONS

Throughout the paper, many figures are based on projections of PRT operation, rather than actual results. There are no large-scale PRT projects in operation to supply actual capital cost, maintenance cost, safety, or public perception figures. The only PRT systems completed are small in scale and do not provide insight on unanticipated problems that may arise with large-scale projects Another assumption made is that the ridership numbers for the planned transit system would be the same if they were implemented as PRT. The lower wait and travel times would likely increase the number of passengers using the system, though that increase would have to reach 50% to cause capacity problems. The abovementioned travel time comparison is biased against PRT. The Purple Line case study simplifies the origin and destination of each passenger to the stations of the Purple Line. In reality, many of the Purple Line's passengers live or work away from light rail and use multiple bus routes or Metro to connect to light rail. In this case, passengers would save even more time on PRT since they may travel on shorter (more direct) routes, would not wait to transfer to other routes, and with a denser PRT network would have lower access time. If the Purple Line is built as PRT, then MTA could add extra branches and loops to create redundancy and mitigate congestion problems from crowded stations and bottlenecks.

CONCLUSIONS

Overall, PRT seems to be a worthy alternative to LRT or BRT for the Purple Line Project. This analysis is conservatively biased against PRT, since the Purple Line is designed for LRT rather than PRT. If the Purple Line alignment and its stations were designed for PRT, there would be more branches, stations and, possibly, parallel tracks. Passengers of the new system would get to their destination faster, and for most of them, wait time would be negligible. The transit agency and taxpayers would save millions of dollars from low construction and annual costs. Potential collisions with non-PRT vehicles would be eliminated because PRT vehicles would be completely separated from the rest of traffic. The view around PRT infrastructure would be more obstructed, but fewer private properties and trees would be taken to make room for it. The technology to implement PRT has been around for years, but transit providers still hesitate to construct this transit mode. The foregoing analysis indicates that PRT can be quite competitive with other public transit modes in service quality and environmental impacts, as well as costs to transit agencies, and it should be seriously considered when new public transit systems are planned. Additional research should be conducted when better cost-estimating information becomes available on the effectiveness thresholds between PRT and alternative modes.

No government or private organization has ever completed PRT on a scale comparable with that of the Purple Line. Simulations show that PRT can function at a large scale, but there are no physical examples. The actual cost, safety, and operational integrity are all estimates. LRT and BRT have all been successfully implemented all over the world. Cost overruns, transit crashes, and capacity issues are all problems that traditional transit faces. Engineers know to what degree these events can occur for traditional transit, but not for PRT. Transit agencies are risk averse about implementing this new technology. The new PRT in Amritsar, India, may resolve some remaining questions about larger-scale PRT systems and lead to other large PRT projects.

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