VUBA PERSONAL RAPID TRANSIT TECHNOLOGY DESCRIPTION

INTRODUCTION

Most aspects of the Vuba personal rapid transit (PRT) technology are presently under development and this document describes how the technology is planned to be developed, assembled and operated. The specific embodiment of PRT described here is based on decades of experience in the industry and is believed by us to be best of breed. Prototyping and testing are bound to uncover even better ways of building a PRT system and some changes to what is presented here are to be expected.

PERSONAL RAPID TRANSIT

The concept of PRT has been in public operation since 1975. The basic idea is that, if a driver is not needed, it makes more sense to use small vehicles rather than large for public transportation. They enable on-demand transport with flexible routing and scheduling. The weight of vehicle needed per passenger is fairly constant regardless of whether the vehicle is large or small. Therefore, the cost of building and operating large and small vehicles is similar on a per-passenger basis. However, small vehicles result in much less off-peak movement of relatively empty vehicles.

Using numerous small vehicles rather than a few large ones has numerous benefits:

- Vehicle weight is less and the loading more distributed, so supporting infrastructure is smaller, cheaper and less obtrusive
- Numerous vehicles result in very short waiting times
- The passenger group in the vehicle can be organized so as to share only a few destinations
- Social distancing is easier

Because the infrastructure is small and inexpensive it becomes viable to raise the guideway above the traffic or even bury it below the ground. Passengers using the PRT are therefore no longer impacting surface traffic and congestion is relieved. At the same time surface traffic is not interfering with guideway traffic and slowdowns, intermediate stops and backups can be eliminated.

A big difference in PRT as compared to rail is that the switching is in the vehicle – the guideway elements do not move. This single factor has significant impacts on operations and capacity:

- Vehicles can travel close together like cars on a freeway as opposed to trains on a track
- Stations can be on sidings so vehicles not needing to pick up or drop off passengers there can bypass them

Organized passenger groups combined with offline stations allows trips to have few to no intermediate stops.

Stations on sidings allow stations to be added without slowing through traffic down. This means numerous small stations can be used rather than a few large ones. This can significantly reduce walking distances and increase ridership.

The original concept of PRT was to emphasize the “personal” aspect and cater to individuals or people already traveling in a group to the same destination. In practice, people have been found to be willing to share rides with strangers – they hold the door open, just like on an elevator. Ridesharing makes sense provided the vehicle is small and there is some organization so that people rideshare only when they have the same destination or when their destination lies along the planned route. In this way each rider has few, if any, intermediate stops.

A vehicle large enough to accommodate a wheelchair and an attendant or a bicycle and its rider will be able to accommodate up to four passengers when those devices are not present. Stretching the vehicle length a little will not increase the frontal area (and the air drag) and will better accommodate luggage, wheelchairs and bikes. It could also accommodate two fold-down seats opposite the doors. This is the configuration Vuba has chosen. Our simulations indicate that accommodating more than six passengers will result in heavier infrastructure and more frequent intermediate stops (or lower occupancy rates).

There are six primary components to a PRT system as follows:

- Vehicles
- Guideways
- Stations
- Control System
- Maintenance/Storage Facility
- Energy System

Each component is addressed in the following sections. While these sections outline our preliminary design requirements it must be noted that we intend to comply with the standards and regulations imposed by the authority having jurisdiction over each project.

VEHICLES

As discussed above, we have determined that the optimal passenger capacity of the vehicle is six passengers. We have also determined that the vehicle should be suspended below the guideway rather than supported above it. The pros of suspended and supported configurations are discussed below.

With a suspended system the wheel/riding surface is protected from weather. The guideway is narrower, yet well-positioned to support solar panels. Suspended systems tend to better facilitate at-grade stations.

Supported systems have shorter columns and, if the vehicles run on rubber tires, facilitate dual-mode where vehicles can operate both on the streets and on the guideway. While dual-mode sounds promising it is very difficult to accomplish and decades away from being practical. Switching arrangements on supported systems tend to be simpler than for suspended systems.

Key Vehicle Design Aspects

The vehicle will be designed to have an iconic shape simultaneously giving an impression of speed and a feeling of safety and security. It must appear well secured to the overhead guideway. It should be stable and not swing side-to-side during movement and when stopped at the station. The vehicle will be stable against tipping under the worst-case combination of loads. Vehicle-vehicle collision at speeds up to 5 Km/hr (3 mph) shall not cause damage to either

Figure 1. Vehicle

vehicle. The exterior shape should accommodate level travel while the guideway tilts up to 30% (17°).

The vehicle body must be light and durable. We plan to build it from composite materials such as glass-fiber reinforced plastic (GFRP) with poly-carbonate windows.

The front and rear of the vehicle should be readily identifiable. The vehicle's designation (number) should be clearly legible on the outside. The exterior shape and details should allow for interchangeable (non-permanent) vinyl graphic wraps including over windows.

Windows will be tinted to reduce radiated heat and to add to privacy. Electronic occlusion of windows may be provided to prevent peeking when passing over private facilities. All windows will be sealed shut except for emergency escape windows that can be pushed outward.

Figure 2. Vehicle front view

The finished exterior surface shall be painted/protected /designed to not sustain corrosion damage during its structural life. It should allow for pressure washing.

The vehicle will accommodate six seated passengers (no adult standees allowed) ranging in size from 5th percentile female to 95th percentile male. It will allow one bicycle or a wheelchair with attendant in addition to 2 – 5 other passengers. The door must have a minimum clear opening width of 76 cm (30") and height of 150 cm (59"). The vehicle floor must be level with the platform to facilitate roll-on, roll-off of bags, pushchairs and wheelchairs. Fresh appropriately conditioned (heated or cooled) air shall be provided at more than 15 m^3/h (9 ft^3/min) per passenger.

Figure 3. Vehicle top view

The interior surfaces must be easy to clean and disinfect without causing surface wear and must accommodate all weather conditions. They should allow for non-permanent and easily changeable printed and digital advertising. Flooring should have non-slip surface with no tripping hazards. Interior materials shall be fireproof and the vehicles shall be fitted with fire extinguishers and smoke detectors.

Passengers should feel safe and secure in a seated position when the vehicle is moving. Maximum sustained accelerations shall be 0.25g lateral and vertical; 0.35g longitudinal. Maximum jerk rates shall be 0.25g/s lateral, vertical and longitudinal. Handrails/handholds should be placed in strategic locations to allow passengers to steady themselves as they take and leave their seats, enter and exit the vehicle.

Seating should be designed to be comfortable for the duration of the longest trip. Passengers should be seated facing each other (except for the side jump seats). Interior noise levels should be less than 74 dBA stationary, doors shut; 76 dBA moving up to 48 Km/hr (30 mph); 79 dBA moving above 48 Km/hr (30 mph). Vehicles should be equipped with Wi-Fi and charging outlets.

Emergency exit from a vehicle that is stuck high above the ground will be provided by a flexible evacuation tube (used for skyscrapers) mounted in the floor. Opening a floor panel will expose the tube. Passengers will simply enter the tube and slide slowly to the ground. The speed of the decent will be controllable by flexing the arms outwards to slow down.

Figure 4. Emergency exit tube

Bogeys

The bogey is the part of the vehicle that contains the wheels, propulsion battery and motor and runs inside the guideway. The vehicle hangs from the bogey on two bars that extend down through a narrow gap in the guideway. The bogey design is a trade secret and this description is just a general outline. Basically, the bogey is supported by four wheels that run on riding surfaces located on each side of the narrow slot.

The bogey is constrained within the guideway and must go wherever the guideway goes. In effect, the guideway steers the bogey. When the guideway goes around a curve, so does the bogey. When the guideway is superelevated (banked like a road) around a curve, the bogey leans over towards the inside of the curve. This causes the vehicle to also lean over. This reduces the side force on passengers helping to keep them feeling comfortable. We restrict the amount of superelevation to be similar to that found on roads – we are building a transportation system, not an amusement park ride. We want our passengers to be comfortable, not scared or suffering from motion sickness.

When the guideway splits apart at a diverge, the bogey goes either left or right depending on the instructions it has received from the control system. The switch that selects the direction is simple yet very reliable and failsafe (meaning nobody gets hurt if it fails).

An important aspect of the vehicle-bogey connection is that, while we do want to restrict relative movement laterally, we want to allow some relative tilt movement. When the guideway slopes down or up, we want the vehicle to remain horizontal. In this way we can keep the passengers comfortable while traversing steep slopes.

Figure 5. Vehicle stays level while guideway slopes

GUIDEWAYS

The guideway is comprised of three basic elements – foundations, columns and beams.

Foundations

Extensive geotechnical investigations will be undertaken for each project in order to determine the soil conditions, depth to water table and bedrock, etc. Only once these factors and many others, such as wind loading, earthquake propensity, etc., are known can the foundations be designed. Foundations will typically be made of poured-in-place reinforced concrete. The foundation will be capped with a short length of column with built-in bolts to which the actual column will be attached.

Foundations will need to be carefully positioned to support the columns and ultimately the guideway in exactly the right place. However, the reality is that underground utilities are often irregularly placed and may prove difficult to avoid. Sometimes relocation of utilities will be required but we plan to minimize this by first trying to avoid them in the location of the guideway and second implementing a special column design that can accommodate the footing being up to a meter on either side of directly under the guideway. In reasonably good soil conditions drilling and constructing a column foundation should only take a few hours.

Figure 6. Double-curved column

Columns

Columns can be built of steel, concrete or composites such as GFRP. GFRP is expected to cost less overall and to have a longer life as well as supporting curved shapes better. Figures 6 and 7 show two different curved column shapes.

Columns will typically be spaced 20 to 30 m apart. Their base diameters will vary based on local factors such as wind and earthquake loading in addition to spacing. These diameters will typically be 0.6 m to 1.0 m – similar to, or a bit larger than, light poles.

Column height will vary according to what the guideway is going over. Clearance beneath the vehicles will typically be greater than 2.5 m for pedestrians and 4 m for roadways, depending on local requirements.

Figure 7. Single-curved column

Beams

Beams between the columns are also depicted in Figures 6 and 7. Straight (tangent) sections of beams will be connected by curved sections as necessary to follow the desired alignment. These curves will be both horizontal and vertical. In some situations, horizontal and vertical curves will be combined. While this is a bit more difficult to construct it provides a much more sinuous and good-looking guideway.

In addition to supporting the bogeys, the guideway must provide them with running and guidance surfaces. These must be smooth with no sudden changes in horizontal or vertical direction or in superelevation. This will be ensured by designing the guideway plan, profile and superelevation in accordance with highway and automated people mover standards.

Figure 8. PRT in an existing road reserve

Figure 8 depicts an urban guideway with vehicles, columns and beams. It shows how these features can fit within an existing road reserve, can form a matching unit and can add an exciting element to the urban infrastructure. When you imagine the vehicles quietly flowing along the guideway you can start to get a feel for what strives to be a modern mobile art form.

STATIONS

Stations can be of many shapes and sizes. Most stations will be small with only two or three vehicle berths. Larger stations will usually be associated with intermodal facilities where passengers can transfer to and from other modes such as buses, motos and taxis. These stations could have up to about twelve vehicle berths. Larger stations will typically not be needed since it is usually better to build a few smaller stations rather than one large one. This is not only easier to fit into existing infrastructure, it also reduces walking distances. PRT is the only mode that can efficiently do this because of the small vehicle size and the fact that the stations are offline, so adding more stations does not slow through traffic.

Stations can be elevated or at grade. Elevated stations require stairs and elevators to access the platform. This can be inconvenient and expensive to maintain. On the other hand, elevated stations are easily seen from a distance, so people quickly figure out where to go.

At-grade stations are more convenient to use and cost less because they require less infrastructure. At-grade stations are enabled by the station guideway sloping down steeply to bring the vehicles down to grade. They take up more room because pedestrian access must be prevented in any areas where the vehicles pass at less than 2.5 m clearance.

Figure 9. Small at-grade station

The preference is for at-grade stations wherever space is available. Figure 9 shows a typical small at-grade station.

Figure 10 shows more details for a small at-grade station.

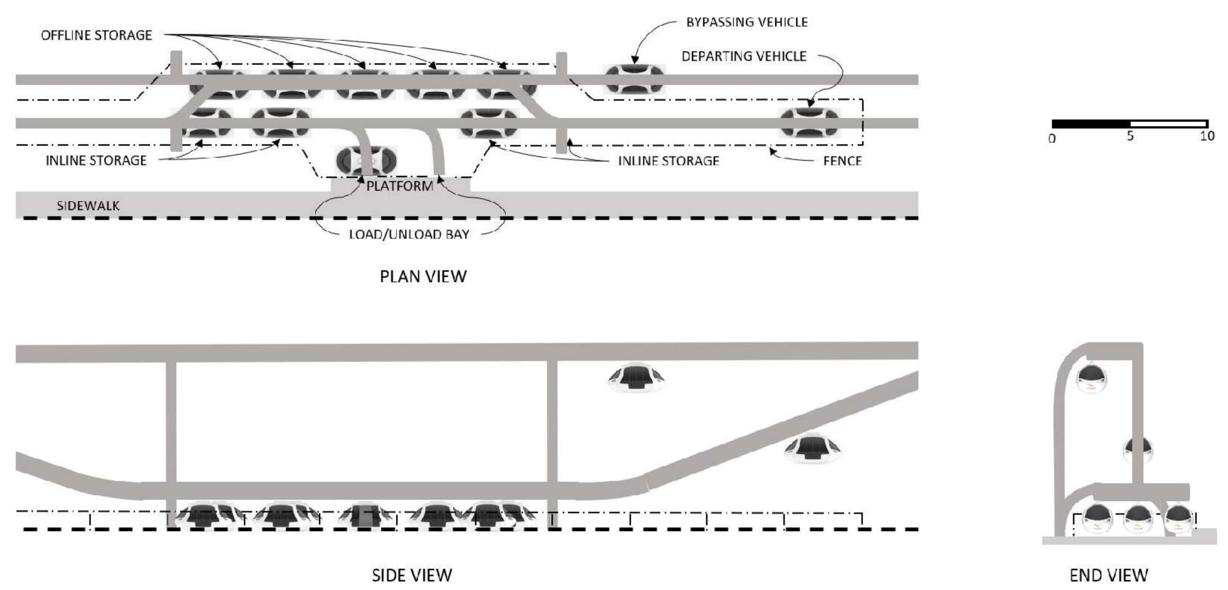

Figure 10. Small at-grade station details

Figure 10. Station attached to building

Another station alternative involves attaching a station to an upper floor of a large building (see Figure 10). Automatic sliding doors would be built into the building and would only open in the presence of a vehicle. Passengers would step out of a vehicle entering directly into the building after passing through the sliding doors. The station platform would thus be inside the building and should be located near the building's vertical circulation features (stairs and elevators). The vehicles would never enter the building and the sliding doors (plus a small canopy) would keep the weather out of the building and the occupants safely inside except when boarding a vehicle.

Station operations are a vital aspect that enables PRT systems to run efficiently. Both vehicle and passenger operations must be handled correctly.

Vehicle operations

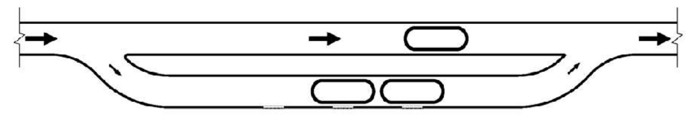

Figure 11. Station with inline berths

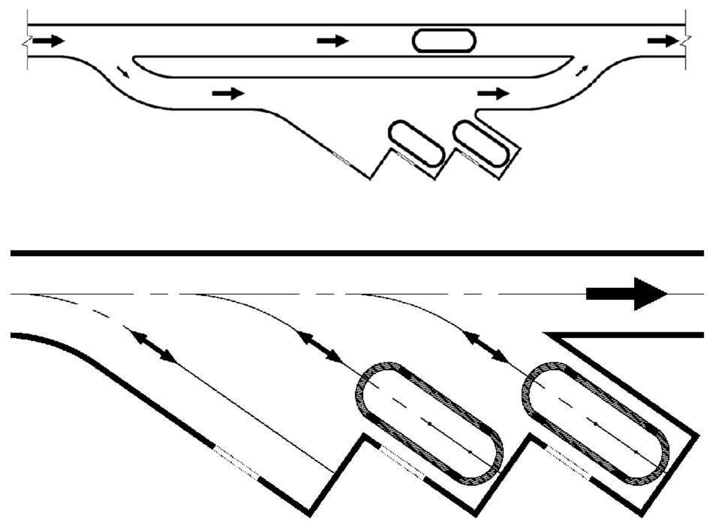

Figure 12. Station with offline berths

The way vehicles move into and out of stations depends largely on the station configuration of which there are two basic types – inline (series) station berths and offline (parallel) station berths. Figure 11 shows the basic layout of a station with inline (series) berths. In this configuration a following vehicle cannot pass a preceding vehicle. The station functions most efficiently if all the vehicles are cleared out of it before letting a following vehicle in. This means the first vehicle in always occupies the front bay (the furthest to the right in Figure 11). In off-peak periods this rule can be relaxed and vehicles can advance between offloading and loading to avoid unnecessarily ejecting empty vehicles to let a full vehicle unload.

Figure 12 shows a station with offline berths. In this configuration vehicles enter any empty berth. They can occupy the berth as long as necessary without blocking other vehicles. If necessary, a vehicle entering this station could leave without ever entering a berth. This flexibility turns out to be very important when dealing with two potential problems. The first is a vehicle stuck in a station due to mechanical or passenger-related issues. The second is more complicated and is discussed below

A vehicle arriving at station when all bays are full can cause significant problems. Some systems deny such vehicles entry into the station guideway and force them to loop around and try again (this is called a wave-off). We think this is a bad idea potentially causing its own problems. We prefer a multi-faceted solution:

1. Provide additional inline storage on the station entry guideway
2. Provide additional offline berths for vehicle storage only
    a. This also reduces the size of the empty vehicle storage facility
    b. This helps keep ready vehicles close by and reduces wait times
3. Have the control system meter the vehicles destined to a station to a rate slightly less than the station capacity
4. As an absolute last resort, make the next vehicle in line for a station berth bypass the berths and either go to the next station or circle around to try again. This should never happen but, if it does, the passengers must be compensated in some way for the inconvenience. This is effectively a waveoff but, unlike the one previously described, the act of the vehicle passing through the station allows time for its diverted trip to be pre-planned.

With the above solution, the station with offline berths is preferable even though it likely has slightly less hourly throughput and requires vehicles to be able to back up.

Passenger Operations

Passengers arriving at a small (two-berth) station will select a destination on the smart-phone app or at the station kiosk. They will also select and pay for either a premium or a standard fare. If they are sufficiently economically disadvantaged, they can choose to document this and receive a discount off the standard fare.

Upon paying their fare a premium passenger group (up to six people) will be assigned the next available empty vehicle and told the planned departure time. They will be directed to the berth their vehicle is in, or will arrive at, and will be informed of their vehicle number. When their vehicle is ready for them, the display above the berth will flash their vehicle number and destination. They will then board (usually within about a one-minute total waiting time) and travel nonstop to their destination.

Standard passengers will pay their fare and then be informed of their planned departure time. This departure time is approximate and may be updated before their vehicle arrives. Within about a minute of their departure time they will be informed of their vehicle number and which berth to wait at. When their vehicle has arrived and is ready for them, the display above the berth will flash their vehicle number and destination. They will then board (usually within about five minutes total waiting time) and travel to their destination with one or two intermediate stops. Note that the vehicle picking up standard-fare passengers will likely not be empty when it arrives. Some of those already in the vehicle may alight while others may stay on board since this is only an intermediate stop for them. When they board, they will likely do so along with others who have been waiting for the same vehicle. During the five-minute waiting time the control system will be working to:

- Match this rider with a vehicle going to the same destination and planning to pass this station
- Match this rider with a vehicle planning to pass this station and heading in the direction of this passenger's destination
- The above process will automatically match this rider with a preceding or following passenger(s) at this station traveling to the same destination or along the same route.

The purpose of all this matching is to increase average vehicle occupancies as much as possible without unduly adding to each passenger's intermediate stops. The impact of ridesharing on operational costs can be seen if one understands that the difference in operating costs for a vehicle carrying 5 passengers compared to three is very small while the difference in fare revenue is 67%.

Empty vehicle trips are a problem for most transit systems. With our ridesharing program, we believe we will have a very low percentage of trips that are completely empty. Even with an 80/20 split in directional traffic, if the peak direction vehicles average five riders, the other direction vehicles will average one.

Stations with three or more berths will require more platform organization. Figure 13 shows a potential station configuration with four berths.

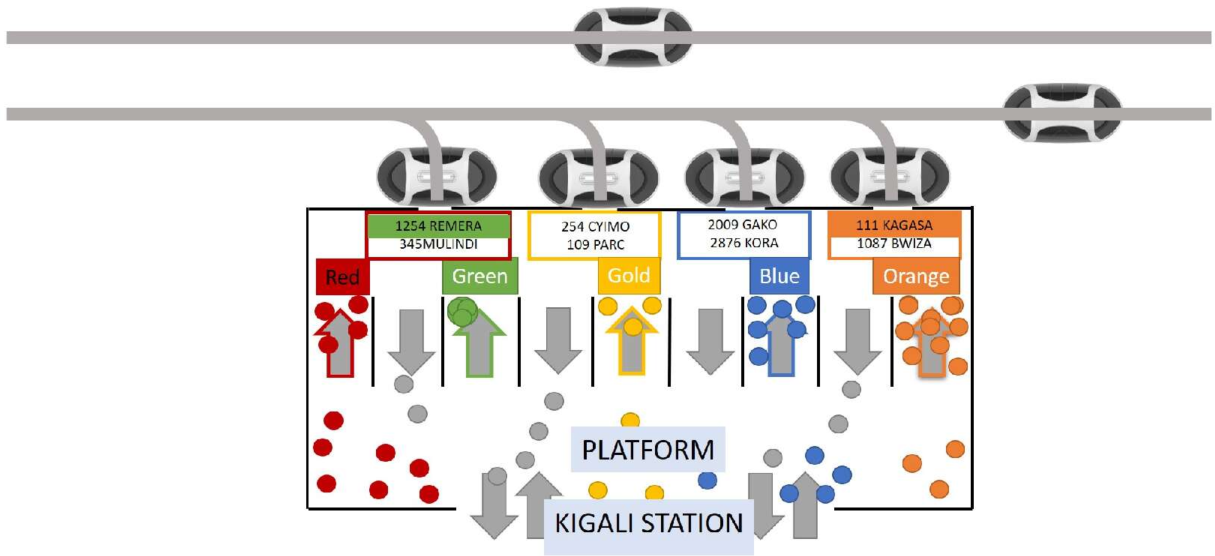

Figure 13. Four-bay station platform layout and operations

Passengers may only enter the platform after they have requested a destination and purchased their ticket on an app or at a kiosk. If they have purchased a premium ticket they are instructed to proceed directly to the green boarding area. Other passengers are told to wait in the back of the platform area and, once informed of their assigned color (red, gold, blue or orange), to wait in the vicinity of their assigned boarding area, but not to enter the boarding area. When their destination and assigned pod number appears above their assigned bay, they can enter their boarding gate. When their destination and assigned pod number start flashing (as for Pod 111 going to Kagasa) they must quickly board their pod. An animation of station operations can be viewed here.

Note that pre-booking a trip is unnecessary and not permitted. A pre-booked trip will be too likely to have the vehicle arrive on time but not the passengers. Passengers must be at the station before they can request a ride. Since their ride will arrive in minutes, pre-booking is not necessary.

Platform Safety

Platform edges must be surrounded by railings at least 1.2 m high to prevent passengers from falling off the edge of elevated platforms. Railings are needed adjacent to at-grade platforms to prevent passengers from wandering under a guideway and being struck by a vehicle. Protected areas not intended for public access can be used for landscaping or a pond to obviate the need for railings.

On elevated platforms the opening in the railing opposite the vehicle door position will be protected by sliding gates synchronized to operate simultaneously with the vehicle doors. Sliding gates are expensive and not considered necessary on at-grade platforms. Here the opening can be protected by signs and markings supplemented with CCTV monitored by an intelligent video interpretation system that issues public address warnings if passengers enter the opening when no vehicle is present.

Intermodal Facilities

The 4-bay station operations described above will be effective for larger stations with up to six or seven berths. Some stations serving other modes such as large bus depots may need to be larger. In this event the best solution will be to either collocate two stations (i.e. have two station platforms in one station) or have a number of stations located around the depot. Stations at a bus depot will undoubtedly also serve moto passengers as well and possibly taxi passengers in addition. These stations will become true intermodal facilities.

PRT stations acting as intermodal facilities could be as simple as one or more stations located above an area serving other modes (such as a bus depot). Passengers changing mode would then simply walk to or from the PRT station and use its stairs or elevators to change levels. On the other hand, they could be far more complex facilities.

Many communities take advantage of passengers having to wait for transit to turn the intermodal facility into a retail hub with coffee shops, restaurants, etc. Vuba's goal is to get its customers to their destinations as quickly as possible and avoid waylaying them in the middle of their travels. Therefore, we prefer to focus on efficient transportation. This is not to say that there is not an opportunity in commercial development and a need for it in relation to intermodal facilities. Vuba is certainly open to facilitating such services where delays due to legacy transit systems provide an opportunity and a need.

Station Access and Parking

Our intent is to provide close station spacing so that anyone living or working in our PRT service area is within about a five-minute walk of a station. We wish to promote the small amount of exercise involved in using our system and discourage people from using motorized transport to get to our stations (except intermodal facilities located mostly on the boundaries of our service area). For this reason, we prefer not to provide parking facilities at our stations (except at intermodal facilities).

Even in a big city, walking to our stations may not be easy. Roads are not always paved and paved roads do not always have sidewalks. In some locations our stations may be located mid-block and access from the adjoining streets may require a long walk around the block. We plan to work with the communities receiving our systems to have them join us in upgrading sidewalks and facilitating pedestrian shortcuts wherever needed.

CONTROL SYSTEM

Often called the "heart" of the system, the computer control system is more like the brains. It is out of sight and mind to most users and even some system owners. There are three distinct aspects to the control system – vehicle control, passenger interface/ticketing and manual oversight.

Vehicle Control System

Besides the vehicle-based switching system, control is the key aspect of a PRT system that is unique. While automated people movers have similar control systems, they do not typically allow vehicles to operate at less than one-minute headway (time between vehicles) much less the two- or three-second headways we need for our initial deployment. Driverless cars do, however, operate at headways down to or below one second. Nonetheless, they are not centrally controlled or bound to any kind of synchronized behavior. In addition, they operate in a vastly more complex environment and their control systems have to deal with many more uncertainties, making them far too complex for our needs and rendering them presently incapable of meeting the high safety standards we will be held to.

PRT control systems typically take three or more years to develop and cost millions of dollars. In addition, they face a rigorous independent safety certification process that itself can take six months or so. Control system development is therefore an expensive, time-consuming and difficult task that Vuba has been seeking to avoid.

We have recently located and obtained the rights to use the Anteeo control system. This is the second generation of a control system that has been proven in use in public service since 2014. The PRT system has speeds up to 70 km/hr and theoretical maximum line capacity up to 7,000 passengers per hour (video). Our license for this software includes services by the developer to upgrade it to meet all our needs and integrate it with our vehicles, stations and guideways as well as to assist with the independent safety certification process.

Ultimately our goals for the control system include speeds of 100 km/hr and headways down to one second (providing a theoretical maximum capacity of 21,600 passengers per hour per direction with six-passenger vehicles). In addition, the control system should be infinitely scalable and use low-cost hardware in the vehicles. Fortunately, we do not expect to have to meet these goals for about five years. This gives us ample opportunity to consider whether we should plan to upgrade the Anteeo system or develop a new system from scratch.

The vehicle control system is comprised of three parts:

1. Automatic vehicle operation (AVO): This subsystem performs any or all of the functions of speed regulation, steering, programmed stopping, door and dwell time control and other functions normally assigned to a driver.
2. Automatic vehicle protection (AVP): This subsystem provides the primary protection for vehicles, passengers, personnel, and equipment against the hazards of operation under automatic control. It constantly checks that safety protocols are not being violated and triggers responses (such as emergency stopping) if they are.
3. Automatic vehicle supervision (AVS): This subsystem monitors and manages the overall operation of the PRT system and provides the interface between the system and the central control operator.

Fundamentally, when asked to move a vehicle from station A to station B, the control system must do so quickly and safely, while keeping the operator informed of what is happening. Although they must meet rigorous safety and reliability requirements, vehicle operations are relatively simple and reliable because, once the door is closed, the vehicles do not interact with people or extraneous objects, only with each other. The controlled environment provided by the guideway is what enables this. The fact that the vehicles are suspended below the guideways further controls the environment because the guideways encase the bogey and protect it from the weather and because the shape of the guideways makes it almost impossible for humans or animals to access the guideways in a way that interferes with the vehicles.

Protection against accidents is an AVP function worthy of additional explanation. Because of the controlled environment provided by the guideway, the most probable accident is a rear-end collision between two vehicles. The second most probable accident is a side-on collision between two vehicles where two guideways merge together. Traditionally, these accidents have been prevented through the use of a fixed-block control system.

In a fixed-block control system, the track is subdivided into blocks that are longer than the longest train (or vehicle in our case). Thus, we could use fixed blocks 100 m long. Each block could be defined by a wire loop imbedded in the guideway. When a vehicle enters the loop (block) it would induce an electric current in the loop (through electro-magnetic induction). This would inform the control system that a vehicle is in the loop. If a second vehicle enters an occupied loop, the control system will know and can stop the second vehicle. In practice, the second vehicle must not be allowed to enter the block behind the one the first vehicle is in. This is due to the situation where the first vehicle is still in the first portion (back) of its block and could be immediately impinged upon should a following vehicle enter the block. Thus, in a fixed-block system the separation between vehicles must be more than two blocks.

In a moving block system, the vehicles use other means to sense their separation. The imaginary block is attached to the lead vehicle and moves with it. Thus, the lead vehicle is always in the front of its block and the second vehicle must remain at least one block length behind the first vehicle.

The length of a block must be such that, should the first vehicle stop suddenly, the second one can sense (or be warned of) the situation and stop in time to not contact the first vehicle. Thus, the block length typically gets longer with increased speed. The control system we are using has a dynamic moving block system wherein not only does the block move with the vehicle, it also changes in length based on vehicle speeds. This ensures the highest possible safe capacity.

Passenger Interface/Ticketing

The passenger interface/ticketing (PIT) system tells the vehicle control system when to move vehicles and along which route to which destination. In addition to sending passengers where they want to go, the PIT system must also decide where to position empty vehicles. This involves predicting where empty vehicles will be needed and moving them to nearby storage locations. As previously noted, empty vehicles will be stored in stations to the extent reasonably possible. Human controllers will have the ability to influence empty vehicle storage to help meet demand caused by infrequent events such as a large concert or ball game.

The interface between this system and passengers will be a smartphone app or a kiosk at each station. Once passengers arrive at a station, they will use either method to select their destination, choose between premium, standard or economy fare and pay for their ride. Payment through the app will be by credit card or prearranged account. Payment through the kiosk will be by cash or credit card. Either device will be used to verify qualification for economy fares.

Many communities have automated/card-based public transit payment systems such a Tap & Go in Kigali. The PRT fare payment system will be integrated into such systems.

The subsection <u>Passenger operations</u> describes how the PIT system will help guide passengers through the boarding process. On-board screens and/or the PIT app will keep passengers informed of the progress of their trip and expected arrival time.

The PIT system will be responsible for optimizing the ridesharing process in such a way that vehicle occupancies are maximized while passengers are provided with quick, convenient transportation. The PIT system will keep passengers waiting in stations until others arrive that can share rides. Waiting times will be adjustable based on the station and the time of day. Typically, the maximum wait time will be about five minutes.

Vehicles not transporting premium passengers will make intermediate stops to pick up and drop off passengers. The PIT system will ensure no passenger makes too many intermediate stops (probably not more than two).

The PIT system will thus decide which vehicles go where at what time. In addition, it will decide which station berth a vehicle enters. The vehicle control system will be responsible for moving a vehicle safely from defined point to defined point. In plain English, the control sequence could be as follows:

11:05:45. PIT System: Vehicle 123 will be ready to depart Station 23, Bay2 at time 11:05:55 AM bound for Station 35. (Message sent after last passenger enters. Allows time for doors to close.)

11:05:46. Vehicle Control System: Vehicle 123 will depart Station 23, Bay 2 at 11:06:02 AM bound for Station 35.

11:06:15. Vehicle Control System: Vehicle 123 will arrive at Station 35 at 11:15:40 AM. (The vehicle control system estimates time of arrival).

11:15:10. Vehicle Control System: Vehicle 123 will arrive at Station 35 at 11:15:35. (The vehicle control system updates time of arrival).

11:15:20. PIT System: Park Vehicle 123 in Bay 1 at Station 35.

11:15:21. Vehicle Control System: Vehicle 123 will arrive at Station 35, Bay 1 at 11:15:58 AM (implies a brief hold on the entrance guideway).

11:15:58. Vehicle Control System: Vehicle 123 is at Station 35, Bay 1. Doors are opening.

In this way the Vehicle Control System is only responsible for moving the vehicle from one station/bay to the next. It has no need to know where the vehicle is to go after the immediate trip. Similarly, the PIT System has no need to know the specific route being used by the Vehicle Control System. If the Vehicle Control System determines a route is becoming overloaded, it can divert the vehicle to use an alternative route.

Manual Oversight

One or more central control facilities will be manned with controllers. They will have the ability to monitor vehicles as they move about the network. However, the need for controllers to do anything related to normal operations will be minimal. Vehicles will monitor their own health (including battery charge) and pull themselves out of service at the first indication of a problem. The controllers will mainly be occupied with dealing with passengers, unusual circumstances and being prepared to deal with emergencies.

Stations, guideways and vehicle interiors will be well lit and under CCTV monitoring. CCTV will be subject to intelligent video interpretation so that controllers will not have to be continually watching monitors. When the video interpretation determines something unusual is happening it will follow predetermined protocols to deal with the situation. An example may be a passenger stepping through the vehicle entry at a station. This situation is described below.

At-grade station platforms will be surrounded by railings to prevent passengers stepping off the edge and exposing themselves to being hit by an approaching vehicle. The opening will be demarcated by a yellow pad (textured to allow blind people to feel it) with a sign indicating no entry until a vehicle is present. If a CCTV camera sees a passenger stepping on a pad when no vehicle is present it will automatically trigger a public address announcement asking the passenger to step back. If the passenger does not immediately step back, the video interpretation system will notify a controller to intervene.

The controller will evaluate the situation and decide whether or not to halt station operations. The station attendant should immediately correct the situation upon hearing the PA announcement and/or being contacted by the controller. Indications from other automated systems are that passengers are well-behaved when they believe their movements are being monitored.

Vehicles will contain call buttons whereby passengers may speak to controllers. Controllers will be multi-lingual and able to talk most of the languages typically used by riders.

VEHICLE MAINTENANCE/STORAGE FACILITY

Each PRT deployment will include one or more vehicle maintenance/storage facilities. These facilities will typically be centrally located within the PRT service area but could also be on the periphery if not too far away. Central location will facilitate quickly moving vehicles in and out and will help reduce empty vehicle movement and passenger waiting times. Further reductions in these aspects can be obtained by providing some empty vehicle storage in most stations. In most instances the central control facility will be collocated with the maintenance/storage facility.

Maintenance

Vehicles and bogies will be designed and manufactured to be easy to clean and maintain. Most of this work will take place in the maintenance facility but some will happen in stations.

It is planned for each station to be staffed with an attendant whose primary function will be to facilitate passenger processing through the stations and during the boarding and alighting phases. During off-peak periods these attendants will be less busy while there will simultaneously be a number of empty vehicles in each station. This will provide ideal opportunities for attendants to undertake simple wipe-downs of the vehicle interiors.

More extensive interior and exterior cleaning will take place at the maintenance facility. Vehicles not needed for carrying passengers will be routed through the maintenance facility every few days for a thorough cleaning.

Vehicles will be scheduled for various maintenance activities on a regular basis. In addition, vehicles will monitor their own health and they will be pulled out of service and sent to maintenance whenever a problem is sensed. Most maintenance will be plug and play - comprising removing bad components and replacing them with good ones so the vehicle can go back into service while the component is repaired.

Despite requiring highly reliable and redundant components, the possibility of a vehicle breaking down on a guideway must be dealt with. Unless the vehicle is on fire (in which case the emergency escape chute will be used) the passengers will be required to stay on board. There will be adequate air heating/cooling or ventilation powered by the vehicle battery backed up by the propulsion battery. Two alternate rescue methods are planned:

1. The vehicle behind the stuck vehicle will approach from behind and its bogey with push the front vehicle's bogey until both vehicles arrive in the next station
2. A manned rescue vehicle will back down the guideway and tow the failed vehicle into the next station. In the event the failed vehicle cannot be moved, the passengers will be offloaded by means of a bucket truck (cherry picker).

Storage

Empty vehicle storage must be provided since many/most vehicles will be idle in off-peak periods and all vehicles will be idle during any hours the system is not operational at night. The requirements for empty vehicle storage are primarily to have a place to keep vehicles out of the way when they are not in use. Beyond this consideration must be given to the need for stored vehicles to recharge their batteries and to be protected from the elements and vandalism.

Protection of empty vehicles from the elements is not an important consideration since most vehicles will be out operating in the elements at all times of day and night. Furthermore, most empty vehicles will be standing around at night when there is no sunlight to protect them from. That said, shaded spaces will likely be needed for empty vehicles parked during off-peak periods of the daytime to reduce heat gain. In some locations protection from hailstorms will be required.

Empties parked in the maintenance/storage facility will be protected by the security measures provided at the facility. Empties parked at stations will be in a well-lit area surveilled by CCTV.

Since we plan to use offline station bays, most bays can be occupied by an empty vehicle during off-peak periods and all bays can be so occupied during shut-down periods. In addition, each station will likely have additional holding positions on the incoming and outgoing station guideways that can be used for storage during shut-down periods but not during off-peak periods since these positions will be inline. Where space allows, we plan to provide additional sidings at stations to accommodate additional empty vehicle storage. This has the added advantage of providing temporary storage should station throughput be compromised by an unforeseen event.

Office/General

The maintenance/storage facility will typically be an ideal location for offices, meeting rooms, cafeteria and restrooms for operational and maintenance staff. The facility should therefore be collocated with a station to facilitate access and reduce the need for parking facilities.

ENERGY SYSTEM

Vehicles will be battery powered. The primary propulsion battery will be mounted on the bogie. Vehicles will have their own secondary battery for conditioning the air, for lighting and for operating the doors. Interconnection of the two systems will provide resilience against the unexpected failure of either one.

Electrical power will be generated from solar panels mounted on the guideways, on station roofs and, potentially, on solar farms adjacent to the system. It is anticipated that most of the power needed by the system will be generated in this way.

While vehicle batteries will store power to be used at times solar generation is not feasible, we anticipate additional energy storage will be required. Additional energy storage devices will likely be collocated with stations.

The guideway-based electrical distribution system will be connected to the city's electrical grid at a number of points. This will allow power to flow in either direction so that the two systems can help smooth out each other's demands and supply.

The guideway-based micro-grid should be a valuable asset for the city. Power distribution lines not related to the PRT system can also be run inside the guideway – effectively hiding an eyesore inside a work of art. In locations where existing power lines run along a proposed guideway route, relocating the lines into the guideway can help free up the space needed while improving the appearance of the road reserve.

Key aspects of the PRT system will be backed up by emergency generators so the system can keep functioning during a power outage. It should be noted that the battery-powered vehicles will always have sufficient reserves to reach their destination and then proceed to storage in the event of a power outage.

Vehicle battery charging will happen every time the vehicle is stopped in a storage or station bay. During the peak-of-the-peak (probably about a twenty-minute period) almost all vehicles will be serving passengers. They will be able to boost their battery charge for the 30 or so seconds they are in a station but, for the most part, will need to rely on the charge already in their batteries. As soon as the peak-of-the-peak begins to subside, some vehicles can be sent to storage for longer charging. This implies that battery power must last at least 20 minutes. We plan on at least two hours of vehicle battery power assuming six 30-second boosts during the two hours.