Ultra-Wideband (UWB) can provide centimeter accuracy location for all the cars in the tunnels with very low cost to deploy. When used with Connected Vehicle (CV) Dedicated Short Range Communications (DSRC) integrated with the signal system it can provide much more accurate and responsive signaling than the conventional Communication Based Train Control (CBTC) systems. They can also be installed for a fraction of the cost of CBTC continuous inductive technology due to the minimal need for outages. It is also a standards-based technology in the surface roadway market that prevents the agency from being gauged by the high cost of the rail signaling system vendors.

Technology Deployment

Existing rail signaling systems rely on track circuits installed in the tracks to locate the trains. The problem with this old technology is that it only tells you that a train is occupying a block which can be miles long in some locations. It also does not communicate speed. Some rail systems have added GPS to trains to provide better location and speed data, but this does not work in areas where satellites are obscured like, urban canyons, tunnels, stations, and mountainous areas. GPS has not been shown as accurate enough to determine what track a train is on when there are parallel tracks without other means to assist in the location. Positive Train Control (PTC) and Communication Based Train Control (CBTC) systems use transponders in the tracks to provide periodic location updates and low bandwidth communications to the train, but have to rely on onboard processing using wheel rotations to maintain a location. UWB provides the high accuracy location (<5cm) in real-time anywhere within the right of way. It also provides a continuous wayside to train communications.

The UWB transmitters would be installed on each car and their wayside units are typically integrated into the lighting every 50 to 100 meters in the tunnel and along the wayside. CV units are installed every 300 to 1000 meters to communicate back to the signaling system. They can easily be installed in yards and other dark territories to light up the areas with very little cost.

Ultra-wideband technology is a chip set that uses ultra-low power pulses to provide centimeter accuracy location through cooperative communications. It has widespread use in defense and mining applications and has begun to take off in the transportation arena. NYC recently demonstrated its use in surface streets do to the poor location quality of GPS in urban canyon environments. The NYC CV Pilot had 4 out of 5 of the CV vendors incorporate the UWB chip set into their product to meet the cities accuracy requirements. (https://youtu.be/ZycoQmnNo18)

Having continuous knowledge of the high accuracy vehicle locations and speed in the tunnels allows more advanced signal control systems such as Positive Train Control (PTC) and Communication Based Train Control (CBTC) to have key information to provide reduced train spacing allowing higher throughput. Existing CBTC systems cannot match the accuracy and ease of installation of this new concept. Also, existing location systems used with CBTC deployments install transponders in the tracks and rely on wheel turn information to maintain a location estimate between transponders. CV/UWB will maintain continuous location of any
equipped object in the area along the right of way allowing it to be used for many more purposes in addition to signaling.

In addition to the signaling system benefits, the system allows precise asset management along the right of way allowing a complete collection of all wayside assets as well as providing real-time locations of all the rolling stock and right of way workers. Consist management of the vehicles and their train ID becomes an immediate process at any point in time. This is a huge benefit to the operations control centers, the yard masters, the wayside and rolling stock maintainers.

This can also be used tracking workers in or near the right of way and alerting the workers when trains are approaching. It allows drones to be dispatched quickly into the tunnels to allow track inspections for maintenance personnel to get eyes in the field very quickly.

The commercial CV devices will be in large scale deployment on all surface street vehicles over the next few years based on accepted IEEE standards. Installing the same technology on the trains will help at railroad crossings in being able to provide warnings to vehicles for approaching trains and for trains in being alerted to obstacles in the railroad crossing.

Many of the DSRC vendors have integrated the UWB technology in their units in addition to Cellular and WiFi capabilities. This will allow a wide range of vendor choices for the technology. It will also allow use of the technology for public communications use onboard the trains.

**Solution Objectives**

There are several areas that using CV & UWB will improve rail operations.

**Train Spacing** – With continuous location and speed spacing knowledge the train operator as well as the signaling system will be able to know the surrounding vehicles and be able to determine what actions to take immediately reducing the spacing requirements. The brick wall spacing can be eased because you know any change in velocity and can incorporate that into your spacing algorithms.

**Safety** – Vision Zero is a USDOT goal to prevent any kind of incident or loss of life. As CV infrastructure is being deployed in New York City, Tampa Florida and Wyoming on the surface streets the application of the technology for rail systems holds just as much importance to improve safety. UWB can also be used as an active radar with LIDAR like resolution. This can pick up other objects obscuring the tracks. The system also provides worker protection by tracking the workers when they are in or near the right of way and can be used for warning the workers of approaching trains and alerting the train operators of fouled tracks ahead.

**Compatibility** – This can be integrated into the existing fixed block or moving block signal system to provide better location and speed data for the train control dispatchers and better cab signaling for the train operators. Alternatively, this can be the backbone of a new CBTC system to replace the existing signaling.

**Cost** – The cost of these devices a much less expensive than traditional track circuits for obtaining location and can do much more. ($500 per UWB device and $1200 per CV/UWB onboard device. They don’t require expensive wiring like other field systems and major track outages. These costs are dropping quickly at the automotive industry are requiring these on all new vehicles by 2021 based on the new NHTSA proposed rulemaking.) As confidence grows in
these devices the track circuits can be replaced. This can save over $2B in deployment costs over the current CBTC systems.

Reliability & Resiliency – UWB was designed to military specs due to the origins in the defense industry. Their cooperative communication also allows them to self-monitor and report any loss of signals. They will be deployed redundantly so that that they can still operate with individual failures.

Power and Space Constraints – Power of the UWB devices are 2 Watts and are a very small form factor. That is why it is so easy to integrate into existing tunnel lighting systems or power with solar panels and batteries outside tunnels. CV units are only 5 Watts and are only located in the signal locations.

Installation Time – NYC maintenance crew with very little training installed 25 units in the street lights of 10 blocks on 6th Ave in 2 hours. The UWB vendor has worked with several tunnel lighting companies to integrate their transponders into the lighting system. These can be installed as part of the normal lighting maintenance schedule. This makes it the most efficient way to address the major project delay item of getting outages for installation. There is no need to have long track outages required for continuous CBTC crossover loops or other CBTC technology.

Technical Overview

1. Solution Technical Components and Specifications –

The basic concept of the technical solution is to use roadway based communications standards and technology to provide the key communications and location technology for the subway trains. The USDOT has adopted the Dedicated Short Range Communication (DSRC) IEEE 802.11p standard for vehicle to vehicle and vehicle to infrastructure Connected Vehicle (CV) communications. There are a dozen separate DSRC vendors and most of the auto manufacturers plan to include the technology in their new vehicles. There are dozens of applications identified by the USDOT for use of the technology and they are funding many different CV related projects around the country including the 3 CV Pilots in New York City, Tampa, FL and Wyoming and the Columbus Smart Cities project.

The Basic Safety Message (BSM) transmitted 10 times a second will be used to obtain the train location and speed data and other relevant communications data. There are also standard signaling data messages that can be adapted for Rail use in communicating Cab Signaling and eventually train control.

The Wayside equipment will include DSRC Radios connected to the signal huts and Ultra-wideband (UWB) transponders integrated with the tunnel lighting and other location opportunities. The UWB transponders are used improve the accuracy in the tunnels where GPS is not available. It has been widely used in mines and indoor factory locations where other location means are not available. They provide under 5-centimeter location accuracy at the 0.1 sec update rate. It will also provide very accurate speed values. The UWB also has the capability to pass low bandwidth
(200kbps) data between the units that could pass train and object location data up and down stream.

**CV/UWB Deployment**

**On-board Systems**

On-board the cab trains we will install one or two CV/UWB units to provide the train to train and train to wayside communications. These can be connected to an onboard display to provide an advanced cab signaling guidance to a train operator or to provide direct CBTC-type train control of braking and/or throttle. Other non-cab cars can have just the UWB unit installed so that they can be located from the cab cars and from the infrastructure to allow precision location in the yards and maintenance facilities and precision docking operations.

**CV On-board Unit (OBU)** – This is a typical DSRC Onboard Unit. It normally has interfaces for antennas for DSRC, WiFi, Cellular, and UWB. It has ports for network, displays, and serial buses. The serial buses can be used to connect to the door controller and maintenance bus for better information to be incorporated into Advance Cab Signaling and CBTC functionality. Devices are very low power ~5Watts.

**Advanced Cab Signaling** - Cab signaling is something provided to assist the train operators in receiving advanced notice of upcoming signal indications on displays inside the train cab. It is considered a non-vital operation that provides the train operator information to assist in the train operation. Advanced Cab Signaling can be achieved with the highly accurate and frequent situational awareness provided by the CV/UWB technology. Train operators can be shown multiple signals ahead with much more detailed information. The Door and maintenance data from preceding vehicles and the
signal and switch indications ahead can be used to generate recommended speeds or countdown for the train operators to proactively maintain much smoother flows. This will allow a much higher throughput of trains, especially in lines limited by station stop times. It also greatly improves the energy efficiency of the system.

**Control Interfaces (Optional)** – The DSRC devices can have a direct interface to the Vehicle On-board Controller (VOBC) to allow the vehicle to maintain complete vital Communication Based Train Control (CBTC). This would allow the braking and throttle to be directly controlled from the robust situational available with these systems. Given the more detailed leading vehicle information such as automated/manual control, train consist, actual braking dynamic data, and train type data the moving blocks can create a much more accurate braking solution that takes into account the relative train dynamics that will allow the trains to follow closer than the brick wall situation. In other words, knowledge of the leading vehicle’s expected braking can be used to calculate the moving block internal to the following vehicle. This is more similar to how roadway vehicles behave. Also, knowledge of the door status on the leading vehicle will let the following vehicle know if a stopped vehicle at a station is more likely to be moving out of the station. The following vehicle will also be aware of leading vehicle’s maintenance data that can be used to determine potential behavior.
**Dedicated Short Range Communication (DSRC) Wayside Equipment** – The DSRC wayside radios consist a combined unit that provides the infrastructure link to the trains to provide two-way communications. The IEEE 802.11p and IEEE 1609 standards provide a low latency highly secure method of communications that allows vehicles to talk to each other and to the infrastructure.

**DSRC Connected Vehicle Details**
- Need to license the 5.9GHz Transportation frequency band for each wayside location.
- On-board units can have one part 15 license for all mobile units.
- FCC Public Notice DA 04-31658 provides the details of the DSRC RSU licensing process.
- Low latency position/speed updates 10 times per second.
- 300m to 1000m range depending on directional antenna gain.
- Units usually contain WiFi and Cellular capabilities as well that can be used for passenger communications and back-up communications. One CV vendor (Venium) also has a mesh network capability to provide longer range multi-hop backhaul capability as well.
The DSRC units can communicate with existing CBTC zone controllers. They can communicate with the fixed block field end points (FEPS) to get the signal and switch indications in the other lines. Optionally, they could communicate directly back to the RCC non-vital systems to provide better centralized control.

**Dedicated Short Range Communications (DSRC) Wayside Units**

![DSRC Wayside Unit Diagram]

**Ultra-wideband (UWB) Transponders** - Typically, DSRC units rely on GPS for location of the vehicles. However, in tunnel and urban environments there is no effective way to maintain an accurate position location without some other technology. Even using deadreckoning (wheel rotations) and inertial navigation techniques the accuracy decreases over time. That is why many of the DSRC vendors have integrated the UWB chip set into their products to fill in these holes. Imbedded transponders in the track are hard to install and maintain and are subject to damage. They also don’t provide the robust situational awareness of all nearby devices to provide high accuracy location to any device within range in a real-time basis.
UWB Benefits
- Provides 5-centimeter accuracies to location data 10 times a second
- Provides accurate speed data
- Low latency response times
- Can be used to build consists in the yard or worn on right-of-way worker vests
- Can locate in tunnels and in city areas with poor GPS accuracy
- Very easy to install
- No FCC license required

UWB Deployment
- Small low-power unlicensed device
  - Can be integrated with lighting or battery/solar powered (2W power)
  - No interference or FCC licensing
  - Rapid installation
- 200m range (50m-100m transponder spacing) in right of way
- Chipset integrated into existing tunnel lighting systems
- Already integrated with top DSRC Vendors

NYC 6th Ave Deployment of UWB in Urban Canyon

Existing CBTC Systems shown below is limited by its poor location accuracy from fixed tags. Even using the crossing inductive loops can’t provide sufficient location accuracies for optimized moving blocks and they especially suffer at stations from interference and conflicting data and bleed over from adjacent tracks. The track installations and required closures make the deployment much longer timeframe than the proposed solution. The UWB units can easily be
2. Solution Interface to Existing Systems –

The system can be designed to interface to the existing fixed block signaling through the non-vital field end points or with existing CBTC systems through the zone controllers. Optionally, it can be designed for a new deployment from end to end. There can be a phased implementation that will involve some interfaces to existing systems. To the extent that existing system interfaces are required could significantly expand the cost of the project as the agency would require sole sourcing extremely expensive rail signaling vendors.

CBTC systems will have an easier interface in that they can take in the improved location information provided with the CV/UWB solution. Modifications should be made to the CBTC system to take advantage of the new communications capabilities and location tracking of the solution.

The fixed block systems can be interfaced to the non-vital field end points at the signal huts to provide the signal and switch indications. The trains can benefit greatly by having a more adaptive cab signaling system to provide the operator with countdowns until signal changed based on the real-time knowledge of the leading vehicles movements. At some point these fixed block systems can be replaced with a new moving block system to control the vehicles.

Optionally, a new system can be built to fully utilize the new communications and location technology to provide a truly adaptive moving block system that can break the brick wall spacing limitation.

3. Non-Proprietary Technologies –
There are no technologies proposed that are only available from one vendor. The solution is standards based and has the advantage of already being deployed widely on street vehicles. This will significantly lower the per unit costs going forward.

4. Key Benefits of Solution –
   - Low equipment cost
   - Low installation cost
   - Rapid installation
   - Standards based technology
   - Real-time high accuracy equipment tracking
   - Other uses for:
     - Asset Management
     - Passenger WiFi
     - Worker Protection
     - Obstacle Detection
     - Railroad Crossings
     - Drone Maintenance
     - Passenger Communications

**Current deployments**

- The Metrom Rail AURA System unifies PTC, Collision Avoidance, and Worker Protection under a single solution. Reportedly being deployed for MBTA in Boston and some freight rail systems.
- Port Authority of NY/NJ Exclusive Bus Lane (XBL) Automated Bus Project - I am managing a PANYNJ project to automate buses in the Lincoln Tunnel increase current capacity/improve safety. The CV/UWB technology is a key component of this project.
- NYCDOT CV Pilot project showed centimeter accuracy w/ key enabling Ultra-wideband technology.
- NYC MTA tested the technology for deployment on the subway trains and right of way.

**Conclusions**

The CV/UWB solution for rail deployments can provide a significant improvement in rail operations at a relatively low implementation cost. It offers the advantage of using standards based technologies instead of proprietary solutions. It offers many benefits to rail signaling, passenger communications, and right of way safety. It will also offer a much lower implementation cost than existing signaling systems.