# 7 Key CBTC Functions Transit Operators Must Understand

## Achieve Operational Efficiency,
## Recover Faster from Service Disruptions &
## Increase Ridership Satisfaction

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# 1. Acknowledgements

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Any errors in this document are my own and should not tarnish the reputation of my colleagues.

# 2. Introduction

Operationally critical functions must be understood when deploying a CBTC solution. These functions define how a railroad operates once the solution is deployed and if neglected the Operator can expect service disruptions, longer recovery times and irate commuters. Laser-focus on the CBTC Solution's operational functions will ensure that the operational requirements of the Operator are satisfied.

Functions that define a CBTC solution are split into two broad categories; core functions and non-core functions (Figure 1). Core functions handle the basic Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functionality such as positioning, train tracking, propulsion & braking control, routing, movement authority, interlocking, regulation, scheduling and communications.

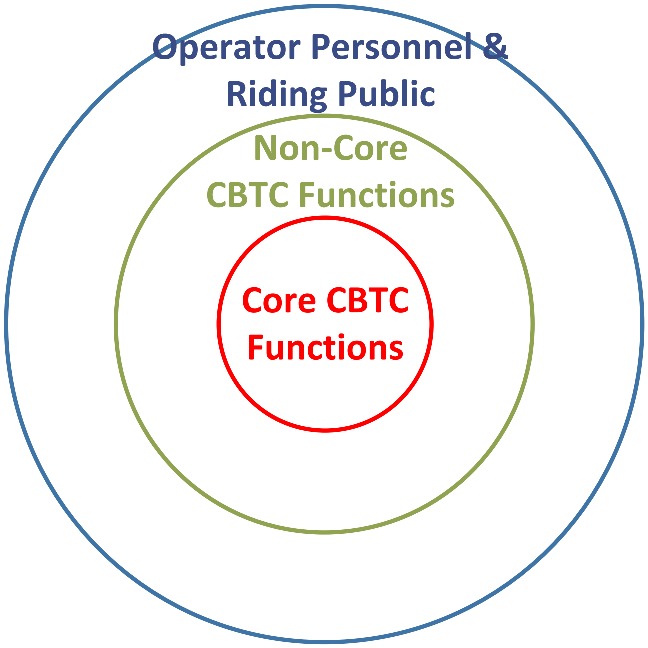


*Figure 1 - CBTC functions split into two groups; core functionality & non-core functionality*

Suppliers generally refuse to change core functions from project to project due to complexity and cost (there are exceptions). Therefore, Operators have no choice but to accept these functions as is, otherwise they should seek another CBTC solution.

However, Operators have influence over the design of non-core functions because the Operator’s personnel and the riding public interact directly with these functions and the Suppliers recognize this. Non-core functions must meet the Operator’s unique operational needs otherwise the inadequate functions will hamper the Operator’s ability to deliver satisfactory Service.

For example, a Supplier developed a work zone protection function on a previous project for Operator A and would like to implement this function with no changes on Operator B’s property. This function may have been applicable to Operator A but due to the unique operating environment of Operator B, this function must be modified to fit. The Supplier will resist but the Operator must push.

Ignoring non-core functions means blindly accepting the Suppliers proposed solution. Understanding the operating environment is crucial to understanding the everyday scenarios encountered when running Service such as Service build up, diagnostics & maintenance, recovery from Service affecting faults or passenger information and announcement systems. Only then can the Operator create a design framework for a CBTC solution that the Supplier must follow.

Of the numerous non-core CBTC functions, seven are key because of the multiple implementation options available or their importance is not appreciated by most Operators. They are as follows:

**Key Function #1: Train recovery** – In a signalling system with no secondary train detection (track circuits or axle counters), this is a critical function when a train is unable to communicate with the wayside (considered the worst-case failure in this paper). Three train recovery options are presented in Section 0, each one increasing in complexity and cost; the Operator must select an option based on their operating environment.

**Key Function #2: Work zone protection** – Creating a safe corridor for workers at track level while maintaining Service level is a critical concern for all Operators. In a CBTC application, the work zone function takes on greater importance because the trains are either driverless or operating in an automated mode. A vital SIL4 (Safety Integrity Level 4) design is required to inform the CBTC system of workers at track level, while maintaining Service. This section presents a SIL4 conceptual design.

**Key Function #3: Equipping Work Cars with CBTC equipment** - Equipping work cars with CBTC equipment is not a function but a decision and operationally, a critical one. Work cars must coexist with passenger carrying trains either by equipping work cars to follow the same rules as passenger carrying trains (consistency) or by applying special rules to unequipped work cars.

Operators with a fleet of 60 or 70 work cars may opt for rule book consistency and equip work cars whereas small Operators may opt for special rules and operate with unequipped work cars. Every railroad property is unique and how they operate their work cars in a CBTC environment is no different.

**Key Function #4: Diagnostics** – Effective diagnostics allow a CBTC system to localize and pinpoint problems, permitting the Operator to quickly recover from Service affecting faults.

A proper diagnostic architecture has three levels and each level increases the resolution of the problem. All suppliers utilize a level 1 architecture, most implement a rudimentary level 2 but no Supplier has successfully implemented a level 3 diagnostics architecture. This section presents the architecture for each diagnostic level.

**Key Function #5: Fallback mode** – Fallback mode is a mechanism to track trains using secondary detection devices such as track circuits or axle counters. It is a legitimate mode of operation, but avoid it when possible. The cost of implementing a fallback mode will outweigh the marginal benefits this function provides. The Operator must take a methodical approach when evaluating the need for fallback because the consequence of making the wrong decision is costly. Three fallback mode options are presented along with the criteria to determine if fallback mode is needed.

**Key Function #6: Launching trains** - Transit authorities planning to transition from conventional to CBTC signaling must treat the depot and mainline as a single entity, otherwise the boundary becomes a barrier for launching trains into service. A CBTC solution is effective only when it has control over all aspects that affect mainline operations; the time it takes to launch trains from the depot is a factor.

**Key Function #7: Cutover strategy** –The Operator must select the right cutover strategy to transition from conventional signalling to CBTC with minimum impact to Service. The Operator must have an approach in mind so the Supplier can design a solution that supports the strategy.

CBTC Suppliers have developed very good core CBTC functionality but the non-core functions are generally lacking. Unfortunately, these functions are critical to operations and therefore the Operator must have an operational focus within a CBTC context when deploying a CBTC solution; the Operator must translate their existing operational philosophy, procedures or methods into a CBTC design framework the Supplier can understand and implement.

The seven key functions described in this paper will give Operators control when deploying a CBTC solution on their property.

## 2.1 Scope & Purpose

Various implementation options or design concepts are presented for the seven key non-core CBTC functions.

## 2.2 Acronyms

| | |
|---|---|
| 2oo3 | Two out of three |
| AI | Artificial Intelligence |
| AREMA | American Railway Engineering and Maintenance-of-Way Association |
| ATC | Automatic Train Control |
| ATO | Automatic Train Operation |
| ATP | Automatic Train Protection |
| ATPM | Automatic Train Protection Manual |
| ATS | Automatic Train Supervision |
| CBI | Computer Based Interlocking |
| CBTC | Communication Based Train Control |
| CENELEC | Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization) |
| CO | Central Operator |
| CV | Communicating Vehicle |
| DMS | Diagnostic Maintenance Server |
| HMI | Human Machine Interface |
| ISA | Independent Safety Assessor |
| IOP | Input/Output Processor |
| LRU | Line Replaceable Unit |
| LLRU | Lowest Line Replaceable Unit |
| MA | Movement Authority |
| MT | Maintenance Terminal |
| NCV | Non-Communicating Vehicle |
| NMS | Network Management System |
| PD | Platform Doors |
| RAM | Reliability, Availability & Maintainability |
| SDD | Secondary Detection Device |
| SIL | Safety Integrity Level |
| SW | Switch/Point |
| TO | Train Operator |
| TPR | Train Protection Reservation |
| VC | Vehicle Controller |
| WL | Warning Light |

## 2.3 Definitions

The following terms used throughout this paper are defined as follows:

| | |
|---|---|
| ATPM | Automatic Train Protection Manual is a train mode that allows the train operator to control the train propulsion and braking but the Vehicle Controller (VC) will monitor to ensure that the train operator does not exceed the permitted limits (speed, direction, target point). |
| CBTC Signalling | Signaling solution that uses two-way train to wayside communication to establish the position of a train instead of traditional relay-based track circuits or other secondary train detection system. |
| Central Operator (CO) | Personnel monitoring the entire CBTC system from a central location. |
| Conventional Signalling | Traditional fixed block (relay or software) based signalling. |
| Operator | Transit agency that owns, operates and maintains the urban transit infrastructure. |
| Service | Passenger carrying trains operating on an urban transit line. |
| SIL4 | CENELEC standard that defines a relative level of risk-reduction provided by a safety function. Four SIL levels are defined with SIL4 the most dependable and SIL1 the least. AREMA has not defined a SIL equivalent concept. |
| Supplier | Company that designs and deploys a CBTC signalling solution. |
| Train Operator (TO) | Personnel driving the trains. |
| Vital | A design that is considered a safety function. |
| Work Cars | Rail vehicles used to perform maintenance activities along the track. Also referred to as Maintenance Vehicles. |

## 2.4 What Is CBTC?

Using the definition from IEEE’s CBTC standard 1474.1, section 4.1 states:

The primary characteristics of a CBTC system include the following:

- High resolution train location determination, independent of track circuits.
- Continuous, high capacity, bi-directional train to wayside data communications.
- Train-borne and wayside processors performing vital functions.

In other words, a CBTC system is able to determine the accurate location of a train, independent of track circuits or axle counters, using a bi-directional communication link while keeping the system safe.

This is a basic definition of a CBTC system but in recent times CBTC has come to mean much more. When the word CBTC is used, it commonly refers to an automated driverless system made up of an ATO, ATP and ATS component as defined in IEEE 1474.1.

- ATO functions include automatic speed regulation, automatic station stopping & alignment, train & platform door control and routing.
- ATP functions include fail safe protection against over speed, collision and avoidance of other hazardous conditions.
- ATS functions include monitoring and control of all train movements in the entire system.

These three components can be implemented in several different architectures but for the purpose of this paper, the generic architecture defined in IEEE 1474.3 is used.

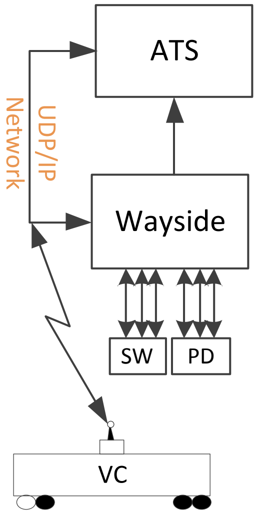


*Figure 2 – Generic CBTC architecture based on IEEE 1474.3*

- ATS is responsible tracking and displaying trains, provide route setting capabilities, and regulating train movements. The ATS is a non-vital device which implements all ATS functions defined in IEEE 1474.1.

- Wayside is responsible for vitally tracking and routing trains and controlling all trackside equipment such as switches and platform doors; in some designs the wayside includes a CBI component using conventional logic. The wayside implements a portion of the ATP functionality.

- Vehicle Controller (VC or train borne equipment according in IEEE1474.3) is responsible for ATP and ATO functions. The ATP logic of the VC must determine the location of the train and enforce the speed and movement authority limits. The ATO logic is responsible for controlling the propulsion, braking and train doors.

# 3. Key Function #1 – Train Recovery

Train recovery is a critical function because it defines how the Operator will recover a failed train under a worst-case failure defined as a VC unable to communicate the train's position to the Wayside (the Wayside cannot track the train). If the CBTC design can handle the worst-case scenario, then all other train recovery scenarios are taken care of automatically.

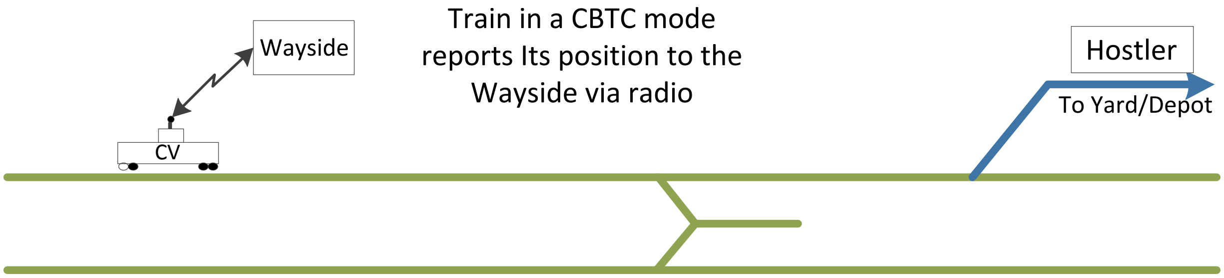
A stranded train due to communication failure is a rare event due to the built-in redundancy all CBTC solutions provide: redundant network design, redundant radios on the trains, overlapping radio coverage and hot standby VCs; nonetheless the CBTC solution must have a design in place to recover from this rare event.

In this scenario, a communicating train (CV) is unable to transmit its position to the Wayside (radio failed). The non-communicating train (NCV) will brake to a stop and Service behind the train will halt (Figure 3). The Operator must decide how to rescue this train from the mainline and allow Service to continue.

***Note:*** *the discussion from this point forward assumes a train operator (TO) walked to the NCV or a TO was already on the train when communication failed (some systems demand a TO be on the train even though it is an automated system).*

CV – Communicating Vehicle
NCV – Non Communicating Vehicle

Note: The Vehicle Controller (VC) controls the train but in the diagrams below CV and NCV is used to indicate a communicating and non communicating train



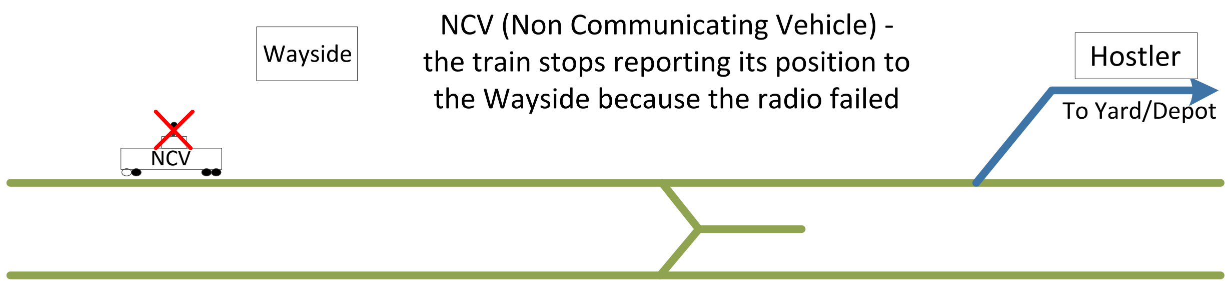


*Figure 3 - Worst case train failure*

If the Train Operator (TO) switches to manual mode and moves the train, it becomes a ghost train (see Figure 4) because it's not reporting its position and the wayside is unaware the train is moving.

This invokes CBTC rule number one, NCV's are not permitted to move without protection.

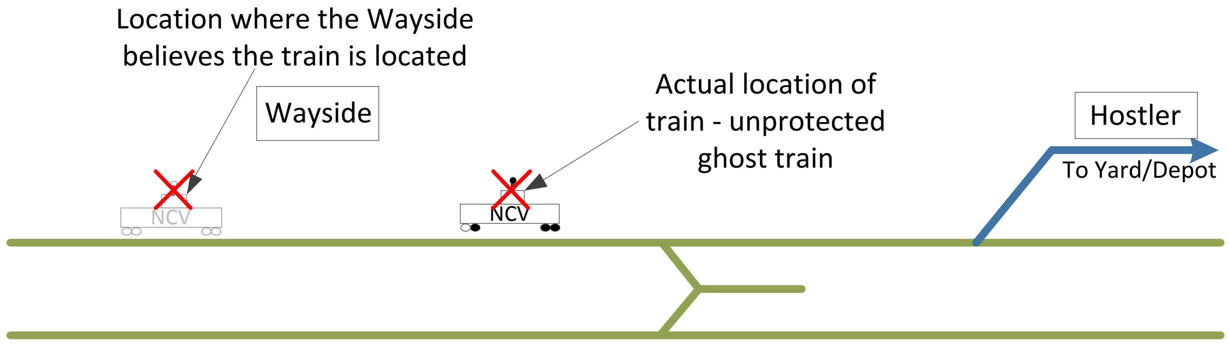


*Figure 4 - Ghost Train*

Challenge for the Operator: a train packed with commuters is not able to re-establish communication with the wayside and cannot move in manual mode. The Operator must decide how the CBTC *design* will recover this failed train.

The Operator has three design options available:

- **Train Protection Reservation (TPR)** – Create a safe corridor between two points on the track to allow a non-communicating vehicle (NCV) to travel safely within.
- **Train coupling** – A communicating vehicle (CV) tows a non-communicating vehicle (NCV).
- **Fallback mode of operation** – Secondary detection devices are utilized to track the non-communicating vehicle.

Each option is more complicated and costly than the last, but the operating environment ultimately determines which option is applicable to the Operator.

## 3.1 TPR – Train Protection Reservation

*Note: This section is based on IEEE 1474.3 section 6.1.4*

The TPR is a basic building block for any CBTC solution. It is created at the request of the CO to isolate a section of track to permit a failed train to travel safely within. The TPR prevents switches from moving and automatic trains from entering and/or operating inside the TPR (Figure 5).

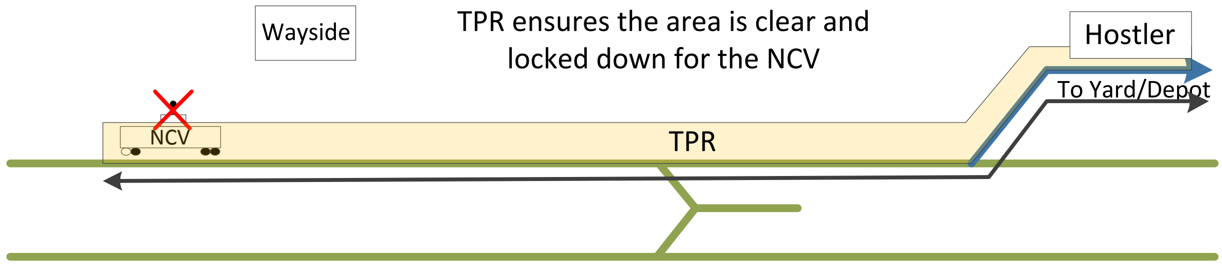


*Figure 5 - TPR*

Once the TPR is locked down, the CO will give the train operator (TO) permission to move the NCV within the TPR. When the train reaches its final destination, the TPR can be removed either by manual procedure or a design that verifies the TPR is cleared of all obstructions.

The advantage of the TPR function is the simplicity of its design. The disadvantage is if the final destination is far off, the TPR will cover a large section of track, which means Service is impacted until the train reaches its destination. To counter this, small TPRs can be set until the train reaches its final destination, such as station to station or station to switch.

The TPR is a basic protection mechanism that allows an NCV to safely travel from its current location to the final destination.

## 3.2 Train Coupling

### What Is Train Coupling?

Two components to coupling CBTC trains include the physical act of coupling and the logical process of coupling. Coupled trains are tracked as single trains and are protected as such. During the act of coupling with an NCV, the VC on the CV train must extend its position envelop to include the extra cars introduced by the NCV (Figure 6).

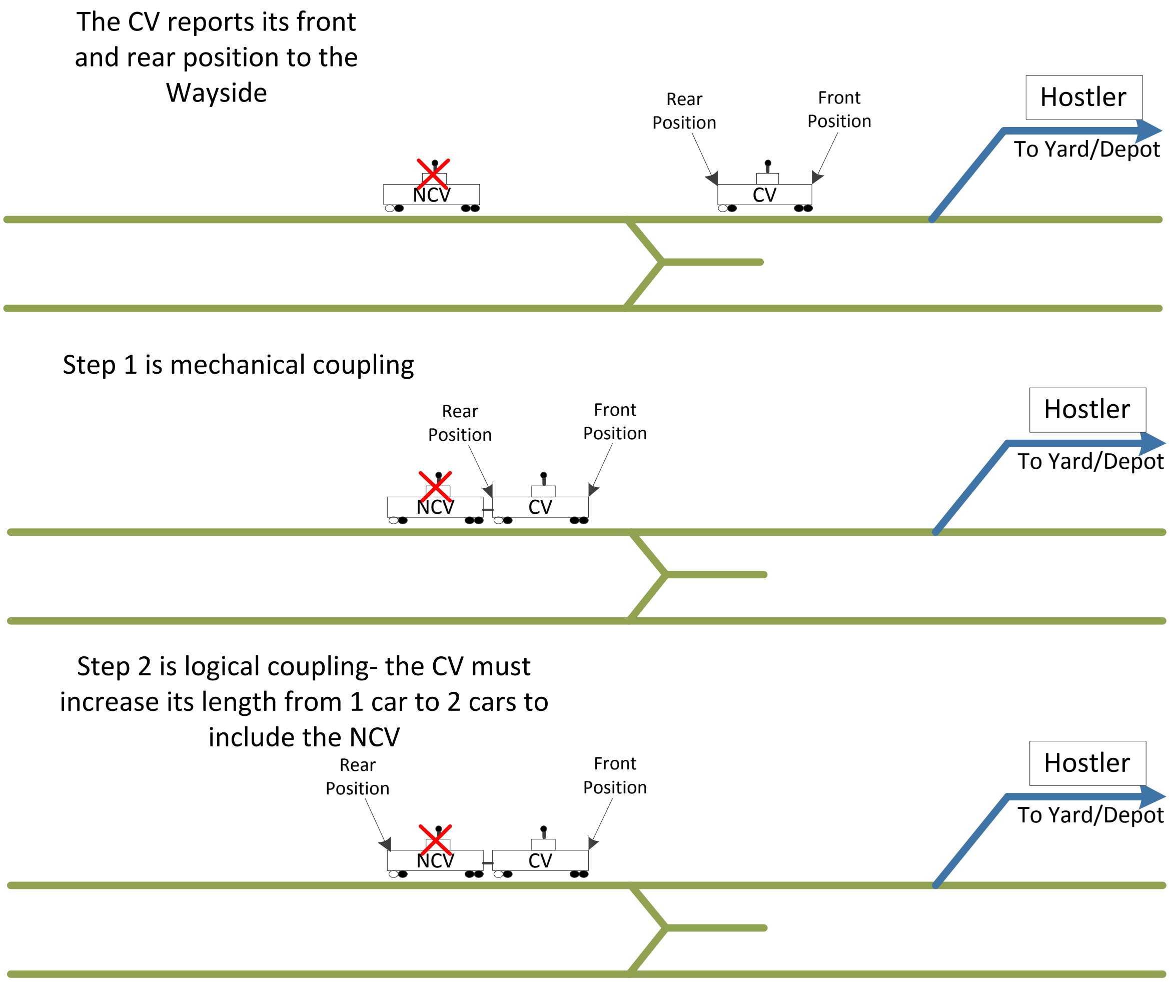
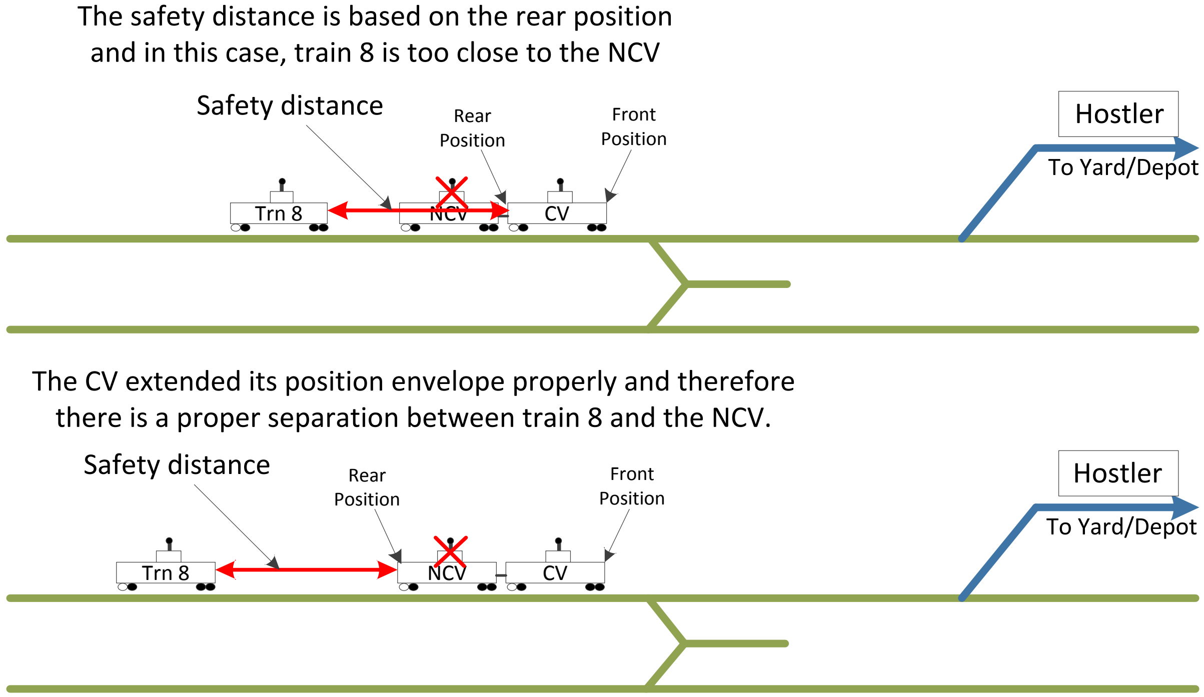


*Figure 6 - Coupling trains*

In the above example, the CV train extended its position envelope by moving the rear reported position a full car length to include the NCV. The wayside will receive the new position report allowing it to protect the train.

The logical coupling process is critical because the safety distance between trains is based on the rear of the CV (Figure 7). If the CV does not extend the rear position to include the NCV, the NCV is not protected.

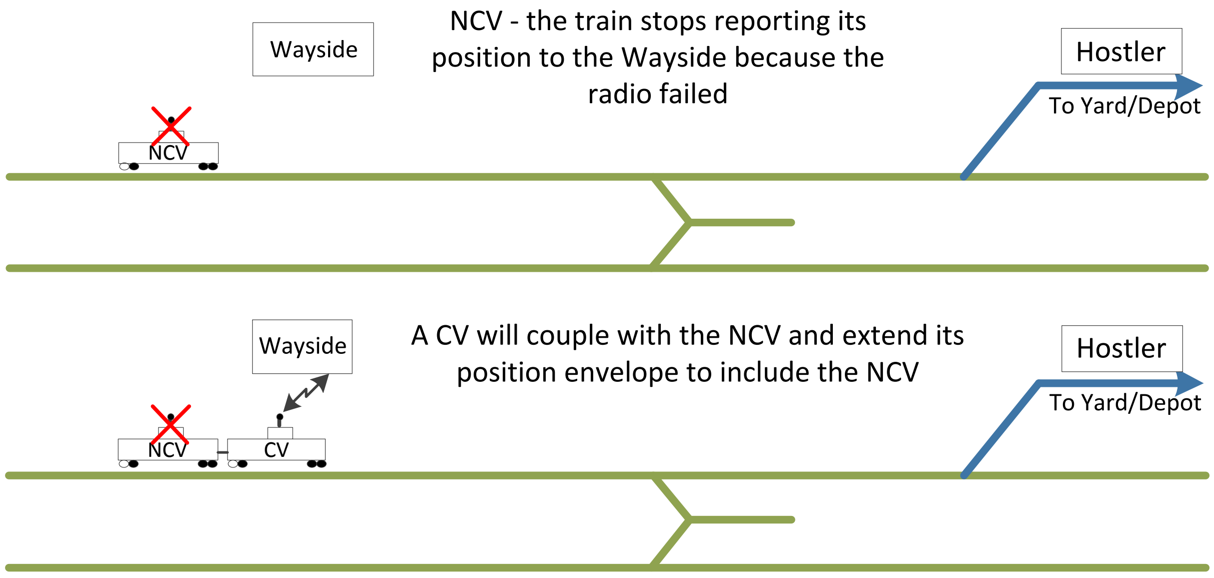

The safety distance is based on the rear position and in this case, train 8 is too close to the NCV

The CV extended its position envelope properly and therefore there is a proper separation between train 8 and the NCV.

*Figure 7 - Extending the CV's position envelope*

## How to Recover Using Train Coupling

Train recovery involves a CV coupling with the NCV and towing it back to the yard under protection of the CV train (Figure 8).


NCV - the train stops reporting its position to the Wayside because the radio failed

A CV will couple with the NCV and extend its position envelope to include the NCV

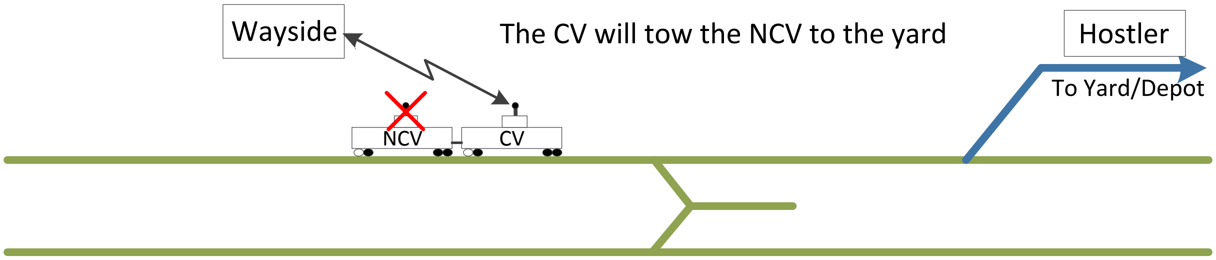


Figure 8 - Using coupling to recover a failed train

The advantage of coupling is that Service can begin immediately after the CV starts to tow the NCV. There is no need to wait for the train to reach its destination as is the case with the TPR.

The disadvantage is the complicated design. The CBTC system must consider characteristics of the new train (e.g., length of the coupled train, Emergency Brake Rate (EB) rate, service brake rate, jerk rate, acceleration) which is not an easy task. Sending a rescue train to recover an NCV during rush hour is also a difficult task. If the number of train types is kept to a bare minimum, preferably one, the number of coupled train combinations the design must consider is reduced; simplifying the solution.

The design may be the purview of the Supplier but complicating the design does not serve the Operator. If the Supplier is not able to produce a stable design, the function may never stabilize or mature and it is the Operator who suffers in the end.

## 3.3 Fallback Mode

Fallback mode of operation is the third and most expensive option. This option allows a failed train to travel, unaided unlike the previous two options, using conventional signalling rules to its final destination.

*Note: section 0 states that architecture 2 is used in this paper which means there is no fallback mode of operation. However, fallback mode can be added if required.*

Under normal operating conditions, all trains will operate under CBTC signalling rules. If a train fails, that train will operate under conventional signalling rules (Figure 9).

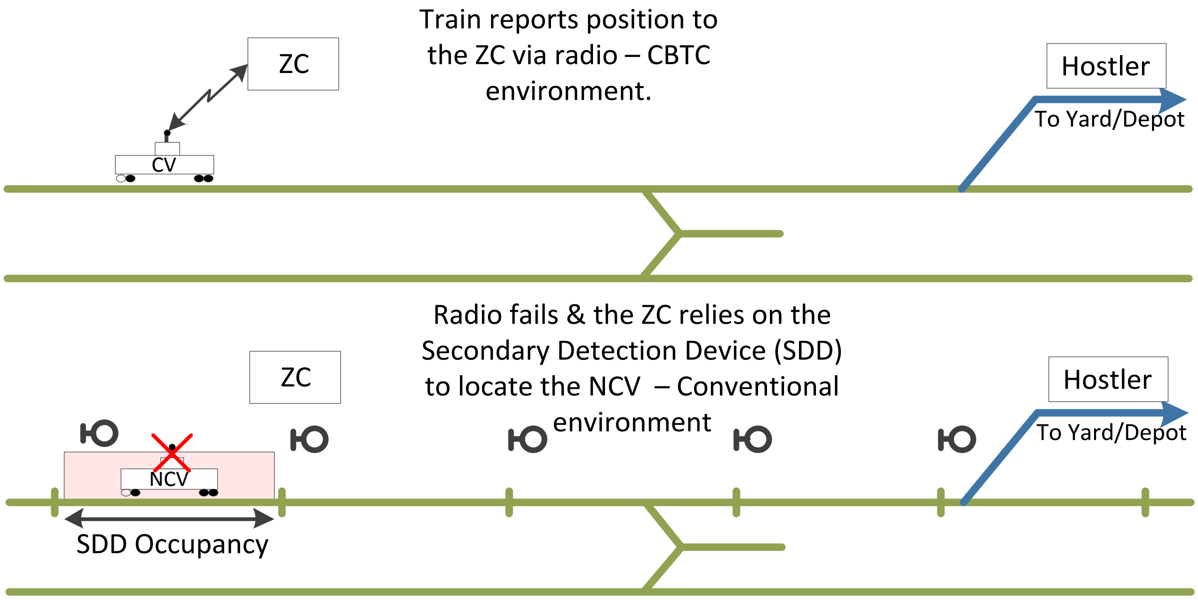


*Figure 9 - Switching to fallback mode under a train failure*

Since the NCV is not communicating its position, the wayside will use secondary detection devices (SDD) to track the NCV. The following CV trains will operate under CBTC signalling rules while maintaining a one block separation from the NCV in front (Figure 10).

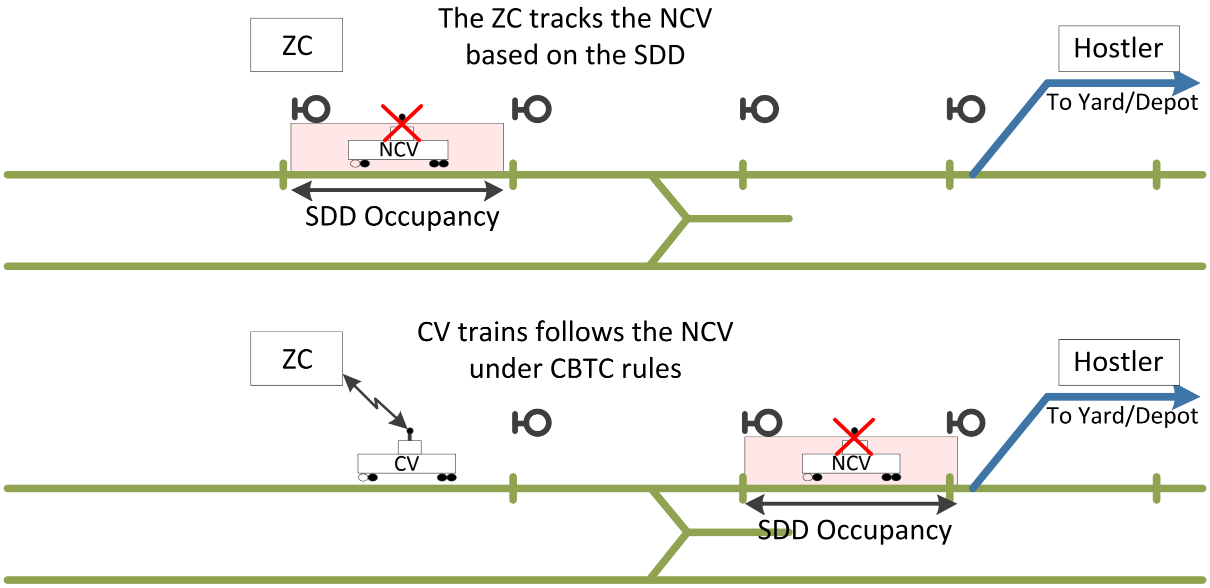


*Figure 10 - Fallback mode to track a NCV train*

The advantage of fallback mode is that Service recovery is faster over the previous two methods. Instead of waiting for a TPR to clear or a rescue train to arrive to couple, the fallback mode allows the train to move as soon as the signal is permissive. The operational impact is limited to:

1. The time it takes to recognize the problem and change to manual mode (non CBTC mode) and start moving.
2. Speed limitations imposed on non CBTC trains by the Operator.
3. Greater separation between trains imposed by the fallback mode (conventional signalling).

Its disadvantage is its complicated design, increased capital cost, greater maintenance requirements and reduced reliability due to extra trackside equipment (signals, track circuits or axle counters, trip stops). The decision to implement a fallback mode must be weighed carefully between the operational requirement and the cost to implement and maintain the solution. The different types of fallback mode are discussed further in section 0.

## 3.4 Conclusion

A stranded train is a rare event due to the built-in redundancy all CBTC solutions provide: redundant network design, redundant radios on the trains, overlapping radio coverage and hot standby VCs. But in the rare instance when a train is stranded, the Operator must have a train recovery strategy otherwise the impact to operations is severe.

The Operator has three options:

The TPR is a basic train recovery tool that will serve the majority of Operators in the event of a failure. The disadvantage is that other trains cannot travel within this area until the NCV reaches its destination.

Train coupling solves the problem of a long one-train-only corridor; however, trying to get a rescue train in the middle of rush hour to a failed train would be a challenge. Coupling requires a limited number of train types and the complicated design costs more to implement.

Fallback mode is operationally the preferred method because the impact to operations is lower when compared to the first two options but from a capital and maintenance cost perspective, it is very expensive and not recommended.

The train recovery requirement must be based on a firm understanding of the operational need; otherwise an over-engineered and expensive solution such as fallback mode will be implemented.

# 4. Key Function #2 – Work Zones

Given that all railroad properties are under constant maintenance, creating a safe corridor for workers at track level, while maintaining service through the work zone is a critical concern for Operators.

In a CBTC application, work zones take on greater importance because the trains are either driverless or operating in an automated mode with a train Operator. If a CBTC train enters an area with workers, the train will not stop; it will continue to move at the same speed. There must be a vital mechanism to inform the CBTC system of workers at track level.

Unfortunately, few Suppliers have a SIL4 work zone implementation. If there is a design, it's either SIL 2 or SIL 3 with a reliance on operating procedures rather than vitally enforced by the CBTC solution. Operators must have a grasp of their work zone requirements when writing their specification to ensure their workers are protected.

This chapter will propose a conceptual framework for a vital SIL4 work zone implementation.

## 4.1 Implementing a Work Zone

Setting and clearing a work zone area is a critical aspect of a work zone design and where most Supplier designs fail the SIL4 test; relying on the ATS to set and clear the work zone area is not a SIL4 design because the ATS itself is not designed to support SIL4 functions.

The Operator is forced to rely on communication between the CO at central control and the work crews at track level to set and remove a work zone. A proper design removes the human element (CO communicating with the work crews) and puts the onus on the CBTC system to vitally set the work zone and ensure that work crews have cleared the area before removing the work zone.

An effective design uses work zone tags (different from position beacons) permanently installed on the track. Work zone tags are passive devices with a unique ID. The tags are either placed at regular intervals, such as every 200 meters, or they are placed strategically so that a work zone does not interfere with operations; for instance around interlocking's (Figure 11).

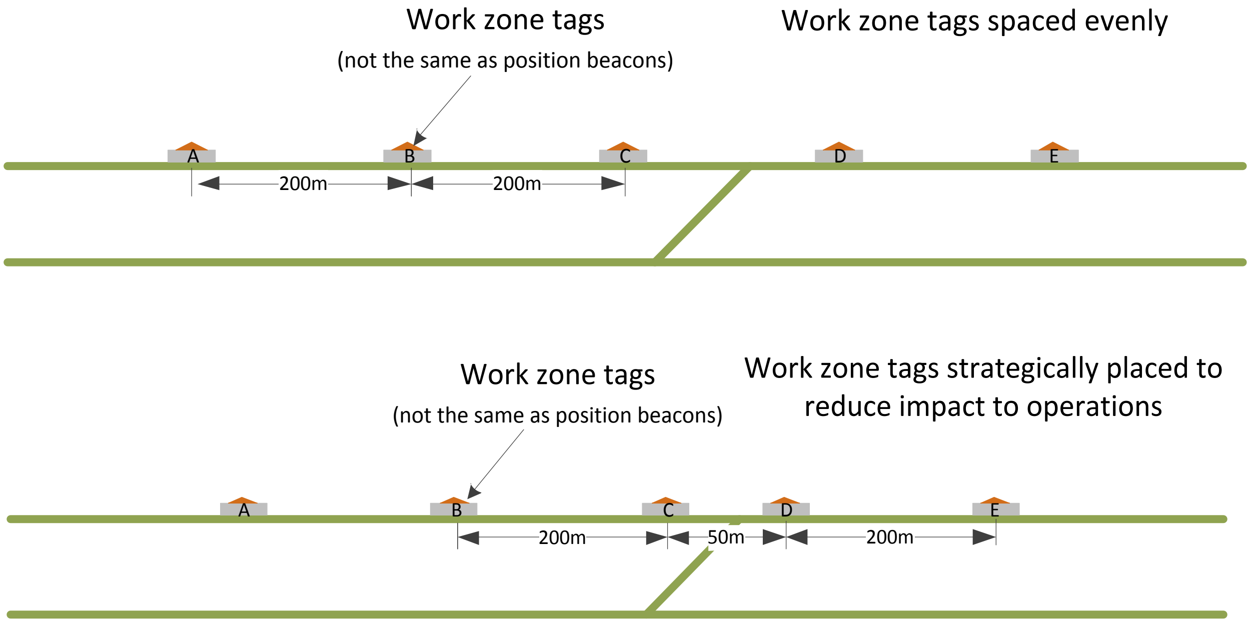


*Figure 11 - Work zone tags*

A work zone area is defined by two Warning Lights (WL - battery powered SIL4 device with software logic) connected to two work zone tags. When maintenance crews are ready to perform their work at track level, they will connect two warning lights to two work zone tags that contain the work area.

The WL reads the ID of the work zone tag to identify where it is located on the track and transmit the work zone tag ID to the wayside after initiating communication (Figure 12). The WL waits for the wayside to confirm the implementation of the work zone before flashing its warning light.

*Note: prior to workers connecting the WL at track level (to implement a work zone), the CO closes the tracks leading to the work zone area. This is done by procedure, which is a separate discussion outside the scope of this paper.*

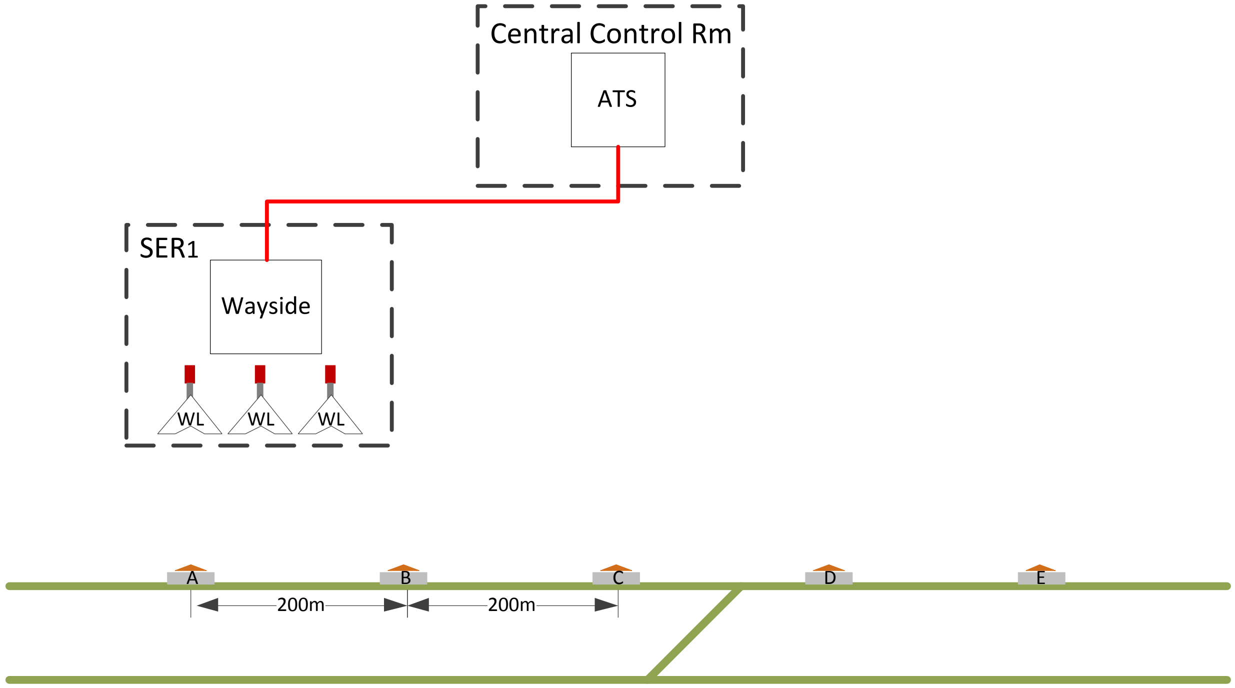
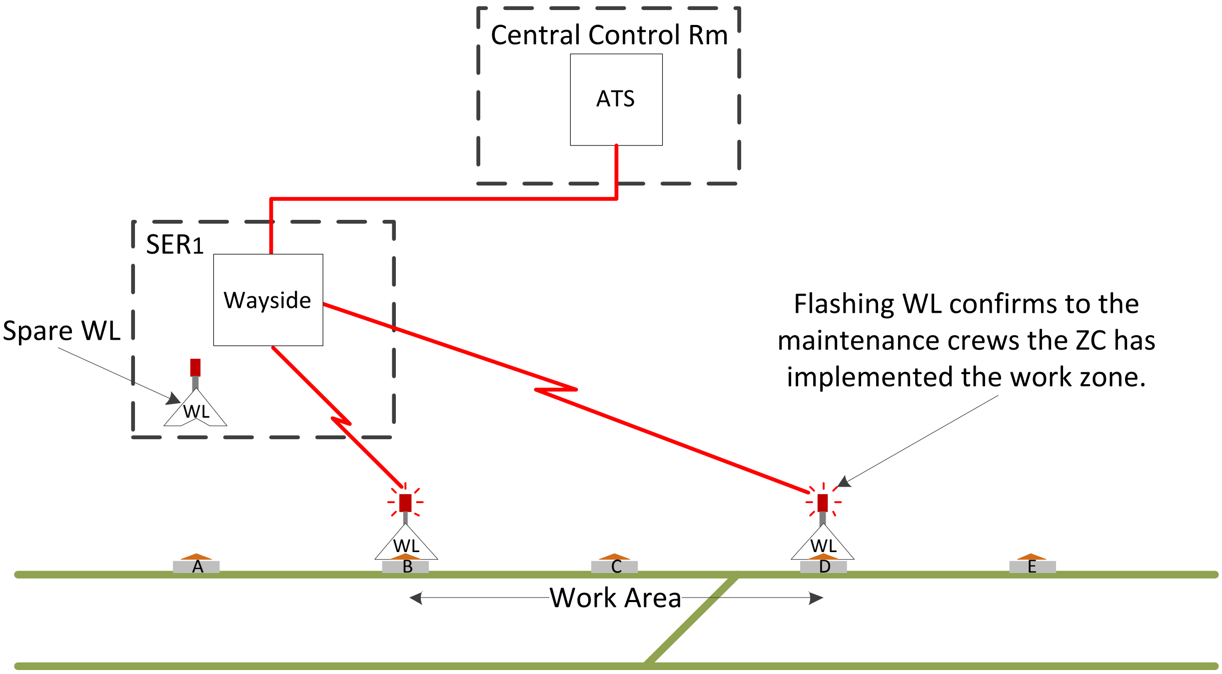


*Figure 12 - Implementing a work zone using warning lights*

The wayside will not implement a work zone if only one WL is installed; it expects to see two WLs connected to two different work zone tags. Once the second WL is connected and transmitting, the wayside will implement the work zone and send a confirmation to both WLs that will start flashing confirming to the maintenance crews that the work zone is implemented vitally (Figure 13). The wayside will also send the work zone status to the ATS to inform the CO.



Flashing WL confirms to the maintenance crews the ZC has implemented the work zone.

*Figure 13 - Flashing WL indicates the work zone has been implemented by the wayside*

Once the work zone is implemented, it's locked. If either or both WLs are removed or fail, the work zone remains in effect. This is to prevent an inadvertent or accidental removal of a work zone, leaving the crew unprotected.

Removal of a work zone requires the maintenance crew to push a work zone release button at one of the two WLs which will cause:

- Wayside to release the work zone;
- WL to stop flashing and
- WL to sound a warning tone indicating the work zone is released

In the remote chance that both WLs fail, the work zone will not be released until a spare WL replaces one of the failed WLs and the work zone release button is pushed.

## 4.2 Work Zone Operations

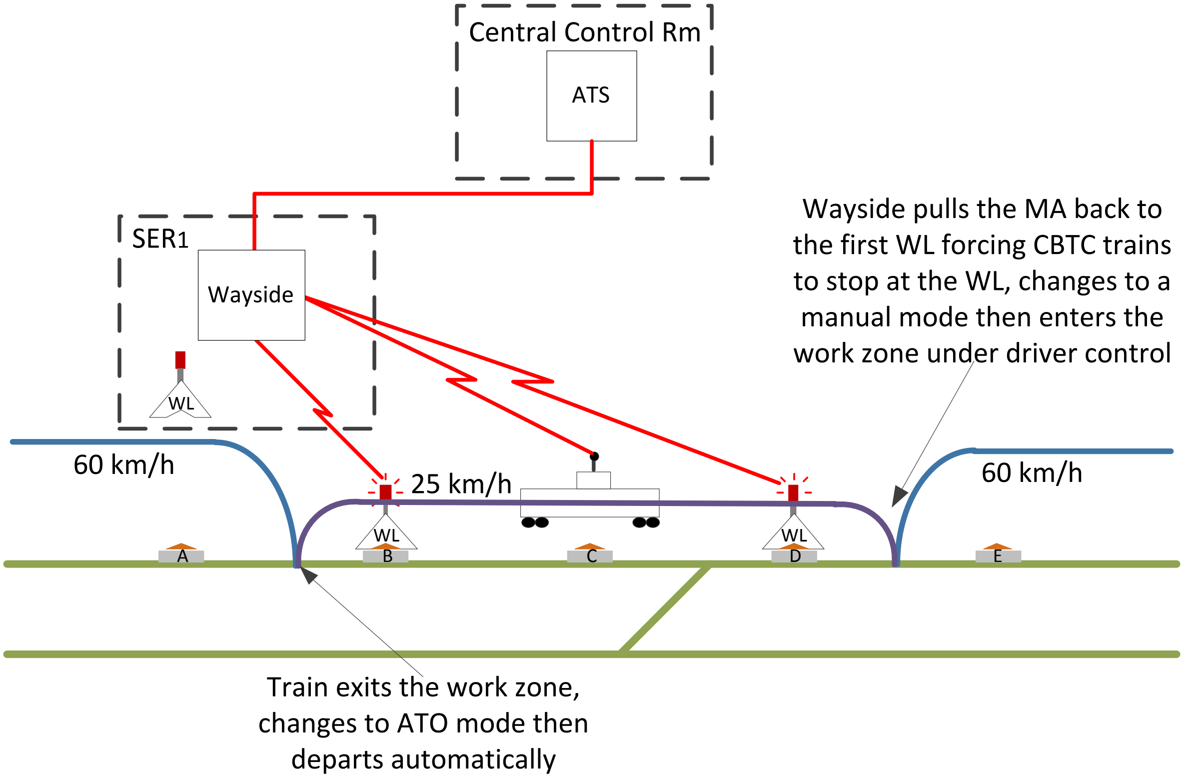
The purpose of implementing a vital work zone function is to protect workers from a CBTC train and to allow a CBTC train to pass, keeping Service disruption to a minimum. This is accomplished by one of two methods:

1. Trains arrive at the WL, stop and enter in a non-automated mode; or
2. Trains enter the work zone at a reduced speed in an automated mode

*Note: The Operator must have procedures in place so the work crews and TO are both aware of how a CBTC train will pass through the area. These procedures are outside the scope if this chapter.*

In option 1, the wayside will restrict the movement authority (MA) up to the WL. Once the train arrives at the WL and stops, the train operator (if there is a driver) changes to a manual mode with ATP protection and enters the WL under driver control (Figure 14).

The advantage of this option is that the train operator is alert to the activity in front of the train, such as a worker falling onto the track that the VC equipment on the train would not detect.



Wayside pulls the MA back to the first WL forcing CBTC trains to stop at the WL, changes to a manual mode then enters the work zone under driver control

Train exits the work zone, changes to ATO mode then departs automatically

*Figure 14 - CBTC Train entering a work zone in manual mode*

When the train exits the work zone, the driver places the train in ATO mode and departs automatically.

Under option 2, the wayside will set a speed restriction at the WL and when an automated train arrives it will reduce its speed and enter the work zone. When the train exits, the train resumes normal line speed (Figure 15).

The advantage of option 2 is that a driverless train can enter the work zone at reduced speed; but this option requires the maintenance crew to be extra vigilant because there is no driver to stop the train if a worker inadvertently falls in front of the train.

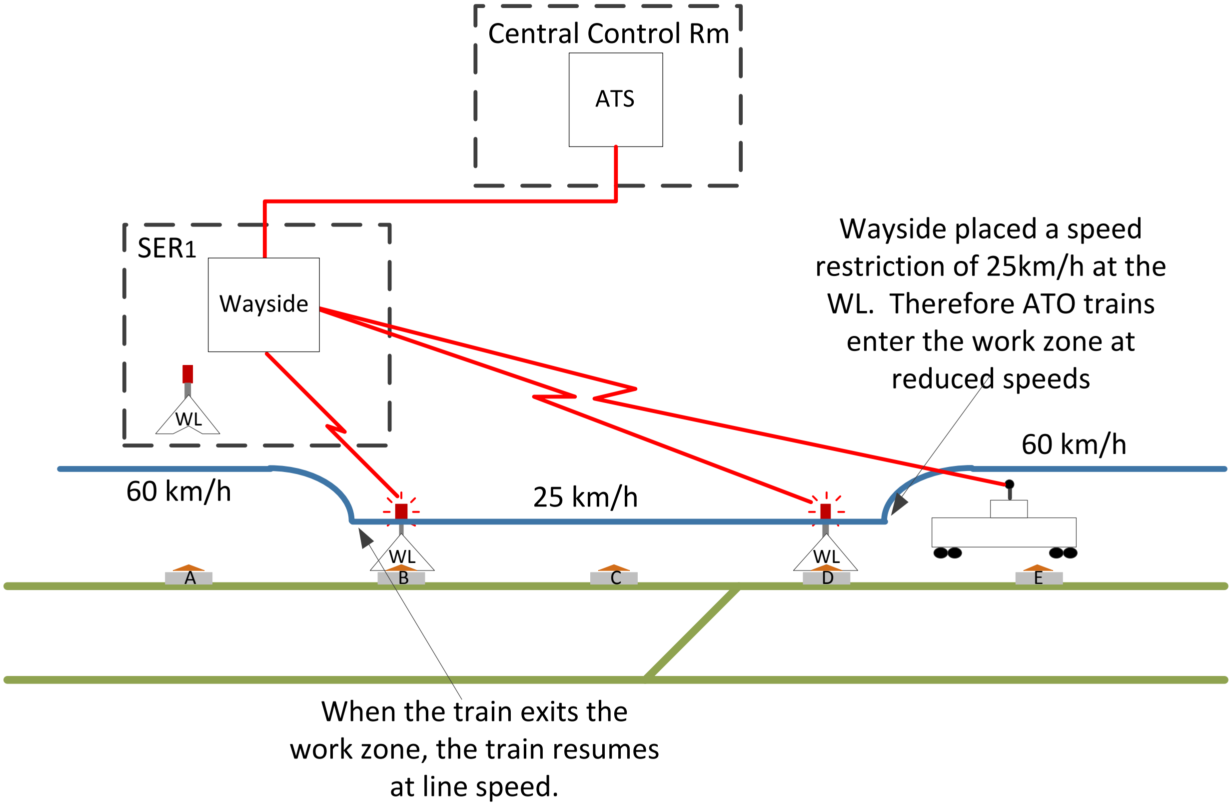


*Figure 15 - CBTC train entering a work zone at reduced speed in ATO mode*

## 4.3 Conclusion

A vital SIL4 work zone function is essential for railroads implementing a CBTC solution; because trackside maintenance is a regular routine of a running railroad. Unfortunately, work zone functions offered by most Suppliers demand the Operator to use operating procedures to implement and remove safely.

Two critical aspects of a SIL4 work zone function are:

- The ability to determine where the work zone starts and ends; and,
- Confirmation that the work crews have cleared the work zone area before removing the work zone.

The concept proposed here accomplishes this by developing a SIL4 WL and installing work zone tags along the track. The cost of implementing this function is high and therefore Operators must establish the requirements for a work zone function upfront so Suppliers can include the cost of developing this function as part of their overall cost.

Worker safety demands that Operators have a clear picture of their work zone requirements rather than relying on Suppliers to propose a solution dependent on operating procedure.

# 5. Key Function #3 Equipping Work Cars (Maintenance Vehicles)

Equipping work cars with a VC is not a function but a decision; and operationally a critical one because, to perform maintenance activities along the track, work cars must coexist with passenger carrying trains.

In a CBTC environment, a train is tracked and protected if it is equipped with CBTC equipment (only equipped trains can report their position to the wayside); otherwise operational procedures are used to protect unequipped trains.

Therefore, work cars are either equipped to allow them to follow the same rules as passenger carrying trains (consistency) or unequipped and operational procedures are applied to protect the work car (special rules).

Operators with a fleet of 60 or 70 work cars may opt for rule book consistency and equip work cars, whereas small Operators may opt for special rules and live with unequipped work cars. Consistency across an operating environment is an important aspect for safety and operational efficiency but every railroad property is unique and how they choose to operate their work cars is no different.

## 5.1 Unequipped Work Cars – Special Rules

An unequipped work car is no different than a non-communicating vehicle (NCV - see section 3. Key Function #1 – Train Recovery), it cannot report its position and therefore the wayside cannot protect it. For an unequipped work car to enter the mainline, special rules must apply.

The Operator has two options; implement a Train Route Reservation (see section 3.1 TPR – Train Protection Reservation) or implement a fallback mode of operation (see section 7. Key Function #5 – Fallback Mode of Operations).

## TPR

A TPR is a simple but intrusive instrument because of the operational impact. A TPR creates a safe corridor for a work car to travel within while denying permission to other trains.

A TPR is not a viable option for operating work cars during Service because of the delays it would create for the riding public. During non-Service hours, TPRs may be sufficient for an Operator if:

- Service does not run 24 hours a day
- Operator has a small track network
- Operator has a small work car fleet

Las Vegas monorail is an example of a system that Operates work cars with TPRs. It has 7km of track, the system operates less than 24 hours a day, and the small work car fleet does not enter the mainline during revenue Service hours.

The advantages of using TPRs include:

- Simple low cost solution.

The disadvantages of using TPRs include:

- Intensive procedure.
- Large swaths of track locked down due to the TPR.
- Lack of operational consistency: CBTC rule for passenger trains and TPR rules for work cars.

## Fallback Mode of Operation

Fallback is a more complicated and costly alternative but an operationally less intrusive tool to manage work cars.

Fallback implements a conventional signalling system superimposed on the CBTC system to track trains along the transit network. This means that passenger trains will operate under CBTC rules and work cars will operate under conventional signalling rules.

Fallback allows an Operator with a large fleet to track, route and insert work cars on the mainline during Service with minimal impact to operations (see hybrid and mixed mode fallback operation in section 0). Fallback is a viable option for larger Operators but the capital and running maintenance costs are high.

The advantages of fallback include:

- Track each work car in the system.
- Work cars can enter the mainline during Service with minimal impact to Operations.

The disadvantages of fallback include:

- Complicated design.
- High capital cost to implement.
- High running maintenance costs.
- Reduced reliability.
- Lack of operational consistency; CBTC rules for passenger trains and conventional rules for work cars.

## 5.2 Equipping Work Cars – Consistency Across The Operating Environment

Equipping work cars with a VC offers consistency across the operating environment; CBTC rules apply to passenger trains and work cars. But equipping work cars is not the same as equipping passenger trains. Work cars have their own unique set of problems that don’t apply to passenger trains.

Each passenger train is identical to the next such as the number of cars, type of cars, propulsion characteristics, braking characteristics and physical characteristics. Therefore, the VC hardware and software are generic and the entire fleet has the same equipment and firmware; equipment and firmware can be installed from one train to another.

This does not apply to work cars because a 60 work car fleet can have up to 30 different types of work cars. To complicate matters further, they can all interchange to create a different consist (a consist is a series of individual cars coupled together) depending on the maintenance activity planned for that day. The VC must take into consideration all possible work car combinations to determine the train consist and each consist will have different characteristics such as size, type, braking and propulsion characteristics.

The Operator must incorporate these variables to create a design that allows the work cars to operate under the same rules as passenger trains. This must be the objective for any design or concept.

## Concept

The VC resides on the locomotive (powered work car) only. When the locomotive is not coupled to another work car, the position envelope (front and rear position of the train) will match the length of the locomotive (Figure 16).

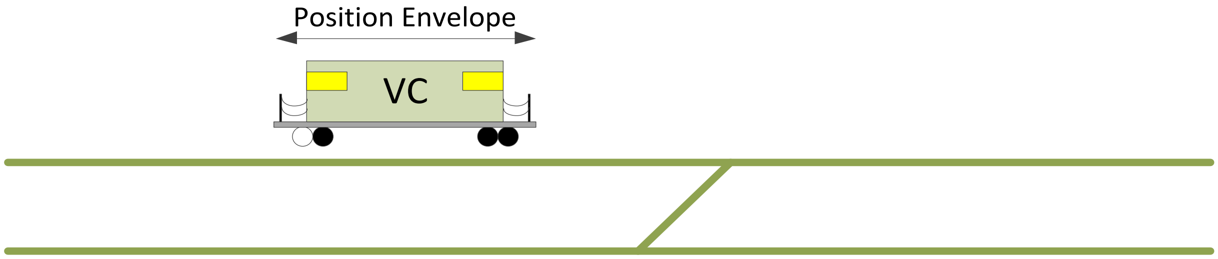
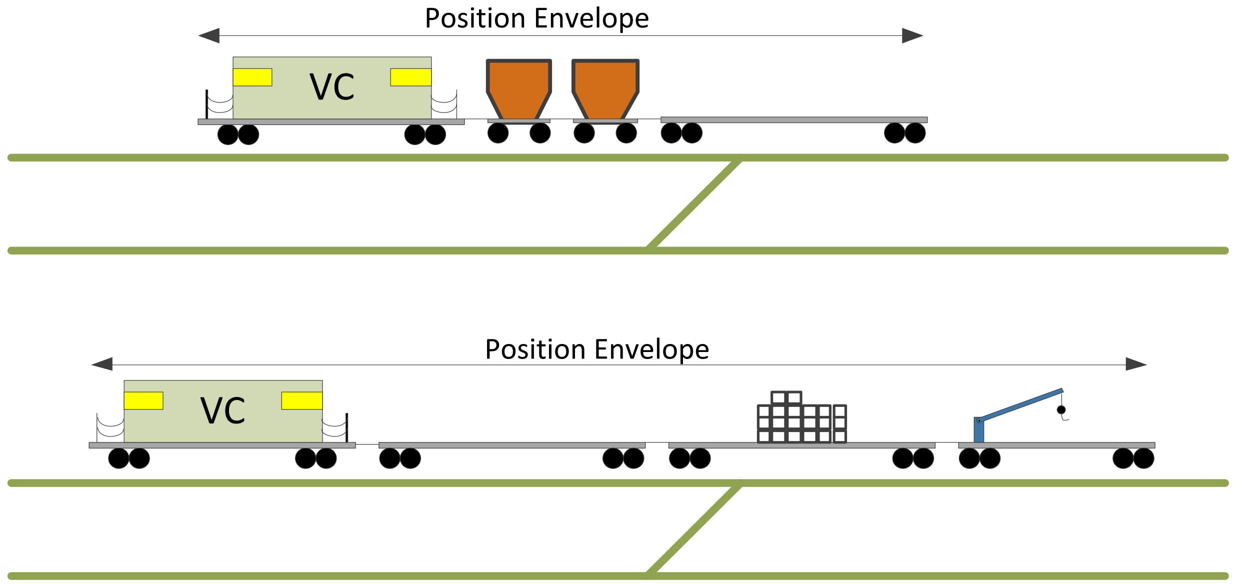


*Figure 16 - Single locomotive (powered work car)*

The VC will extend the position envelope if the locomotive is coupled to other types of work cars (Figure 17) and this is accomplished if each coupled work car sends its car type ID via the train lines.

The VC database will contain the vehicle characteristics (length, braking and propulsion) of all work cars to dynamically calculate the new position envelope and braking & propulsion characteristics. The VC must take into account that some cars will carry cargo; braking and propulsion characteristics must be based on the maximum loading of those cars.



As cars are hitched or removed from the locomotive, the position envelope and braking and propulsion characteristics will change

*Figure 17 - Locomotive coupled to other cars*

A VC able to determine the number of work cars and work car types it’s coupled to, will operate like a passenger train. Equipped locomotives will enter the mainline at any time and reach their destination without disrupting Service.

This is the standard for which all Operators must strive.

## Other Issues

The Supplier is responsible for implementing the concept but the Operator is responsible for delivering work cars that are “CBTC ready.” For most Operators, this is the difficult part of the equation.

The concept relies on the coupled work car sending the work type to the VC but this assumes that the work car is “CBTC ready” defined as:

- Space to install CBTC equipment (VC)
- Train lines and/or Ethernet/MVB line available to transmit information to the VC

Operators with an older fleet will probably have no space to install VCs and/or no train lines to send information; some work cars are modified passenger cars which add to the complication.

With such an assortment of vehicles, the Operator must assess whether part of the fleet should be decommissioned and replaced with modern work cars or retrofitted and upgraded to support CBTC operations before the decision to equip work cars is made.

## 5.3 Conclusion

Equipping work cars has major implications on the final CBTC solution and how the Operator will use their work cars.

Equipping work cars permits a consistent operating environment where CBTC rules apply to passenger trains and work cars. But it may mean retrofitting a portion of the fleet and replacing a portion to support CBTC. Depending on the age and size of the fleet, capital costs could be large.

Not equipping work cars creates two operational environments; one for passenger trains operating under CBTC rules and another for work cars operating under conventional or TPR rules. Further, the capital and running maintenance costs (over the life of the system) are large if the decision to implement a fallback mode of operation is taken; TPR is a simple low cost solution if the operating environment is conducive to it.

Both options can be costly and the Operator must take careful stock of their operating environment and the state of their assets (work cars) before deciding on equipping or not equipping work cars. The Operator must strive to create a consistent operational environment where all trains operate under the same rules.

# 6. Key Function #4 – Diagnostics

The time it takes for the Operator to identify a problem, localize the problem and fix it is determined by the diagnostics capabilities of the CBTC solution. Sophisticated diagnostics will keep this time to a bare minimum and pinpoint the exact cause of the problem; rudimentary diagnostic will waste critical time by providing only basic information while the rest of the investigation left to the Operator's maintenance personnel.

Diagnostics capabilities are key to a running railroad and the capability is defined by the diagnostic architecture. A proper architecture has three levels and each level increases the resolution of the problem:

- **Level 1** – Service Affecting Diagnostics - CO alarms indicating problems that affect passenger service.
- **Level 2** – Corrective Maintenance Diagnostics - alarms indicating LLRU's that need to be replaced.
- **Level 3** – Predictive Maintenance Diagnostics - predicting an LLRU failure before it fails.

For example, Level 1 diagnostics will report that a train lost communication; level 2 will indicate why the train lost communication (such as a communication board failure); and level 3 should predict the communication board failure before it happens.

At a time when the industry is moving towards more sophisticated software-based signalling systems, diagnostics capabilities must keep pace. The Operators must dictate a diagnostic framework that the Supplier must follow or accept the solution the Supplier provides.

## 6.1 Level 1 Diagnostics – Service Affecting Diagnostics

Level 1 diagnostics are geared towards first responders (CO). It provides the first indication of a problem affecting passenger service; such as a train EB, platform doors failed to open, a switch lost correspondence or a train lost communication. Level 1 diagnostics provide the CO with information to help the CO decide how to keep the trains moving based on the nature of the problem; their purpose is not to fix the problem.

Figure 18 defines a level 1 architecture based on the generic CBTC architecture (illustrated in Figure 2).

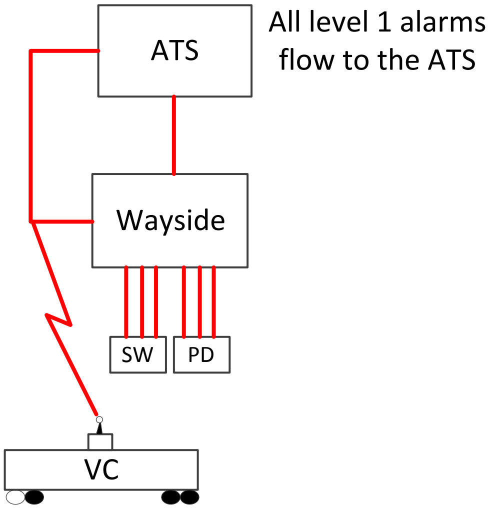


*Figure 18- Level 1 diagnostic architecture – red path*

The alarms generated at this level are called level 1 alarms and they travel on the red path. Each subsystem sends its level 1 alarms to the ATS (repository of all level 1 alarms) for any Service-affecting fault.

For example:

- If a train applies the emergency brakes, the VC will send a level 1 alarm to the ATS.
- If the platform doors  fail to close, the wayside will send a level 1 alarm to the ATS.

The key to this architecture is that all subsystems must be connected to the red path and the alarms should fall within the category of a level 1 alarm. The Operator must ensure all level 1 alarms are captured because missing alarms prevent the CO from recovering from a Service-affecting fault whereas trivial and non-alarms create clutter and distract the CO from priority alarms that need immediate attention.

The diagnostic architecture is as important as the alarms it generates. The architecture provides a path for the alarms to reach the ATS and the generated alarms allow the CO to make an informed decision. If either one is missing, the CO will either miss a fault or make the wrong decision, delaying recovery from a Service affecting fault.

## 6.2 Level 2 Diagnostics – Corrective Maintenance Diagnostics

Level 2 diagnostics are geared towards maintenance personnel whose primary purpose is to monitor, analyze and pinpoint faults in the system such as a microprocessor board has halted on the wayside or the speed sensor has failed on train 5. Unlike the CO, maintenance personnel are not concerned with keeping the trains moving; they are focused on keeping the system fault free and level 2 diagnostics serve this purpose.

Level 2 diagnostics are conducted at the LLRU (Lowest Line Replaceable Unit) level, resulting in greater demand for data than level 1. Telemetry from every LLRU on every subsystem is required to notify the maintenance personnel of the exact LLRU that needs to be replaced.

The data required to support level 2 diagnostics requires a more sophisticated architecture as shown in Figure 19.

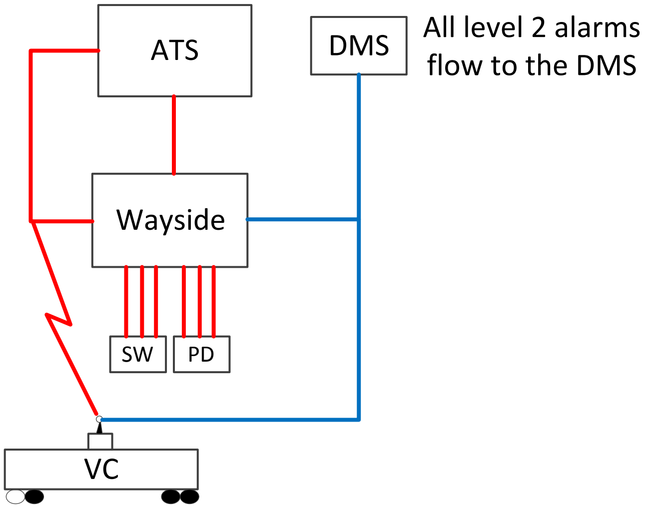


*Figure 19 - Level 2 diagnostics architecture – blue path*

The individual subsystems (Wayside, VC, IOP) collect the health status of each LLRU in their area and transmit the data to the Diagnostic Maintenance Server (DMS) via the blue path. The DMS stores the health status and processes it for each LLRU in the system. For maintenance personnel, the DMS is a window into the health of the system that pinpoints the exact LLRU that requires attention.

The blue path feeds level 2 (LLRU health status) alarms to the DMS and the red path feeds level 1 alarms to the ATS.

## 6.3 Level 3 Diagnostics – Predictive Maintenance Diagnostics (Big Data)

Predicting a failure before it occurs is the Holy Grail for maintenance personnel and predictive maintenance is the purpose of level 3. Relying on the actual condition of the LLRU to predict when maintenance is required enables maintenance personnel to proactively plan corrective maintenance activities versus the reactive approach of the previous two diagnostic levels.

However, prediction demands data because the prediction algorithm creates a normal operating baseline based on historical data for each LLRU. The algorithm devours data for each LLRU and the architecture must feed this appetite.

The prediction algorithm resides on the DMS but the key element of a level 3 architecture is its ability to store large volumes of data for an extended period of time to feed the prediction algorithm.

Therefore, the CBTC system must have a built in long term storage capacity to allow the DMS and the prediction algorithm to see trends and predict failures; referred to as level 3 alarms.

Unlike level 1 and level 2 alarms, where the information has a direct impact to Service and therefore must be transmitted immediately, level 3 faults are not immediate threats (predicting failures in the future) but if not addressed, they will become Service-affecting faults.

For example, if the pulses of a speed sensor drift outside the normal pattern, the sensor is flagged as an LLRU needing corrective maintenance; if the voltage fluctuation of a power supply falls outside of its normal range, it is flagged as an LLRU needing corrective maintenance.

Predictive maintenance is the gold standard for any maintenance program but no Supplier has this capability; at the same time Operators are demanding prediction without understanding the infrastructure required for such a function.

Once a level 3 diagnostic architecture is implemented, predictive maintenance becomes a possibility; even if the Supplier can’t provide a predictive maintenance algorithm, the Operator can develop one on their own.

### Capturing Telemetry

Capturing telemetry is a side benefit of a level 3 diagnostic architecture. It enables key data to be recorded, assisting with incident investigation such as an accident or a near miss. Data such as speed of the train, when brakes were applied, position of the switch or how accurately trains align at the station can be recorded.

## 6.4 Conclusion

Diagnostic capability is a critical function in a CBTC signalled system because the complexity is an order of magnitude higher than a traditional relay-based conventional signaled system. The high demand for diagnostic data requires a diagnostic architecture that supports the easy flow of information from the source of the problem to a central location where the maintenance personnel make decisions.

An effective diagnostic architecture will alert the maintenance personnel about the cause of the problem before they arrive at the equipment room or train; whereas an ineffective diagnostic architecture forces the maintenance personnel to investigate the cause of the problem at the equipment room or train.

The Operator must understand the three diagnostic levels before defining their requirements:

- **Level 1 Diagnostics** – Captures Service-affecting faults that prevent passenger trains from maintaining Service. Every supplier has level 1 diagnostics in some form but the Operator must scrutinize the alarms to ensure all possible service-affecting problems are covered.
- **Level 2 Diagnostics** – Maintenance server that flags failed LLRUs requiring corrective maintenance. The Operator must ensure the server is the nerve centre for all diagnostic data, scrutinize the alarms, ensure all LLRU are covered including trackside equipment and ensure the alarms are displayed in a user-friendly format.
- **Level 3 Diagnostics** – Predictive maintenance – Flags LLRUs that need to be replaced before they fail. No Supplier has this capability and it is not possible until the basic level 3 architecture is in place.

If the Operator understands these three basic diagnostic levels, they will be better equipped to demand a diagnostic infrastructure that suits their needs. Unfortunately, most Operators give little consideration to this critical function when developing their CBTC specification; usually a small section is mentioned in the technical specification. Unless the Operator exactly defines the type of diagnostics they need, the Supplier will provide minimum diagnostics that will receive the Operator’s approval.

# 7. Key Function #5 – Fallback Mode of Operations

Fallback mode, in a CBTC application, is a legitimate mode of operation; but avoid it when possible. The cost of implementing a fallback mode will outweigh the marginal benefits that fallback provide: increased complexity; increased maintenance cost; and up to 30% increase in capital costs. Yet some operators handcuff their solution by imposing a fallback mode requirement without understanding the need.

The operating environment ultimately determines if fallback mode is required and which of the multiple options is selected. The Operator must take a methodical approach when evaluating the need for fallback because the consequence of making the wrong decision is costly.

## 7.1 What Is Fallback Mode Of Operations

Fallback mode is an auxiliary method of detecting trains using conventional means.

Dr. Alan Rumsey defines fallback (secondary train control system) as follows:

*"… a secondary train control system is defined as signaling equipment that, when integrated with the primary CBTC system, provides a level of automatic train protection (ATP) functionality for trains either:*

- Not equipped with train-borne CBTC equipment, and/or
- Operating with partially or totally inoperative train-borne CBTC equipment, and/or
- Operating within an area of track with partially or totally inoperative wayside CBTC equipment.

*A secondary train control system is not a complete/stand-alone signaling/train control system, but rather auxiliary equipment to provide partial ATP functionality for the movement of non-CBTC-equipped trains and/or the movement of CBTC-equipped trains in the event of certain CBTC system failures."*

In other words, fallback mode of operation is the ability to track trains with track circuits or axle counters if the primary CBTC signaling system is inoperable, not available or non-CBTC equipped trains (NCV) enter the system.

## 7.2 How Does Fallback Work

Of the different types of fallback mode, the favoured option is mixed mode of operation (option 3 below) because of its robustness to handle the needs of any transit Operator. But other methods such as fallback mode and hybrid fallback mode are also used and described below.

## 7.3 Option 1 – Fallback Mode (Conventional Signalling)

This mode runs in isolation of the CBTC system (Figure 20). When the CBTC system is operating, the fallback mode is not. If there is a CBTC system failure (such as a radio network problem), the entire system is switched to fallback mode and the trains move according to conventional signaling rules. Once the problem is fixed, the system switches back to CBTC mode. This mode is useful during the initial deployment and transition from conventional signalling to a CBTC solution.

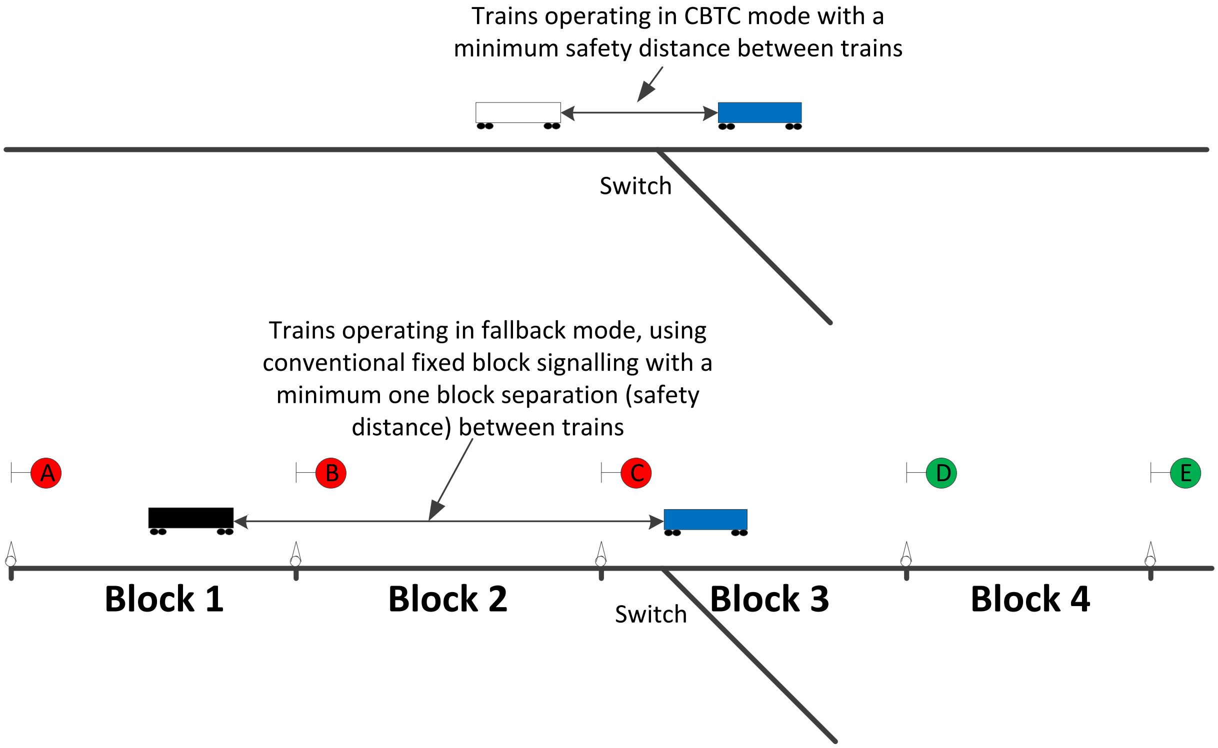


*Figure 20- Fallback Mode Option 1 - Fallback Mode*

## 7.4 Option 2 – Hybrid Fallback Mode

This mode confines fallback mode to a small section of track (Figure 21). If a localized radio network fails, preventing CBTC operations in that area, fallback mode would be applied only to this section of track.

A train approaches in CBTC mode and stops just short of the fallback area, switch to manual mode and proceed using conventional signaling rules. Once the train clears the fallback area, it switches back to CBTC mode and continues to its destination.

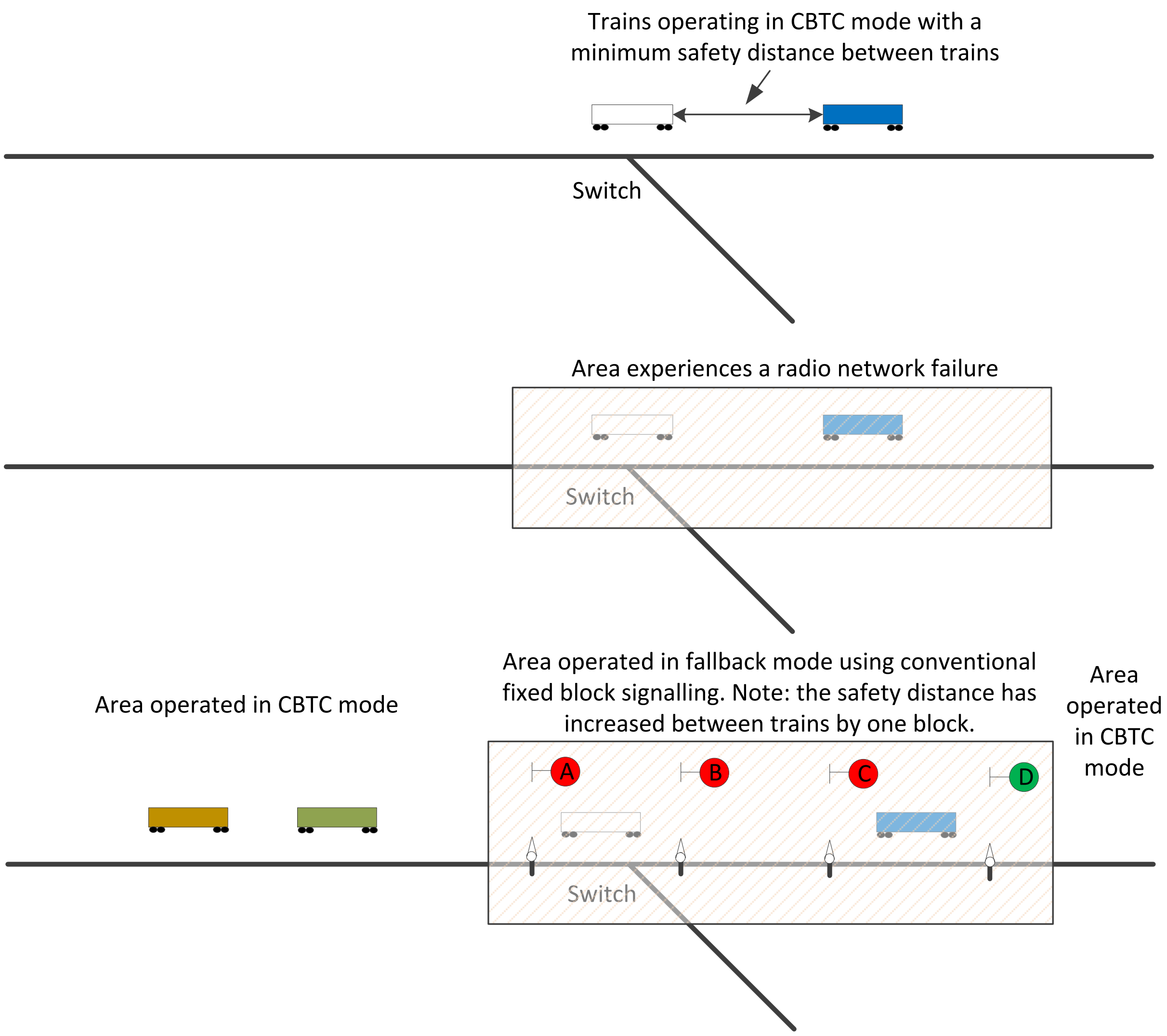


*Figure 21- Fallback Mode Option 2 – Hybrid*

## 7.5 Option 3 – Mixed Mode of Operation

In this mode CBTC equipped and non-equipped trains operate on the same track at the same time during revenue Service operations; CBTC trains operate under CBTC rules and conventional trains operate under conventional rules.

The artificial intelligence behind the CBTC system is aware of the conventional fixed block occupancies and treats them as an obstruction; when a CBTC train approaches, it stops a safety distance away.

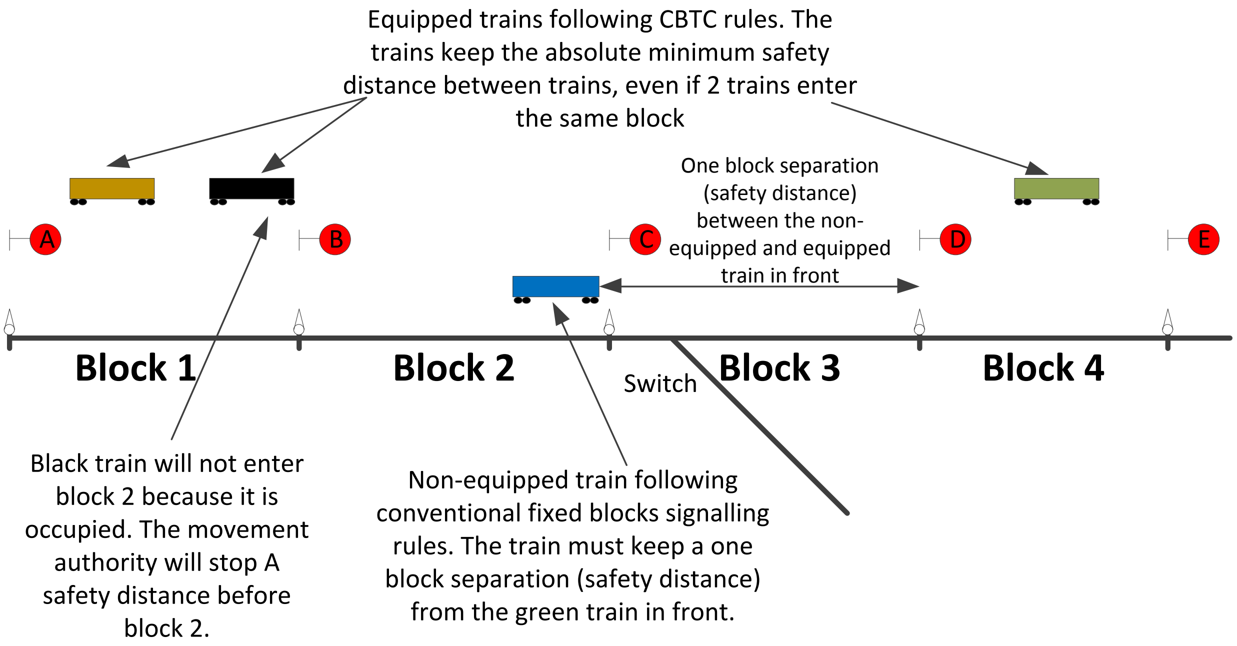


*Figure 22 – Fallback Mode Option 3 - Mixed Mode of Operation*

In the above example, all trains (except blue) follow CBTC rules, which keep a minimum safety distance with the train or obstruction in front. The blue train is not CBTC equipped, therefore it is tracked by the conventional signaling system and keeps a minimum one block separation from the train in front.

Each train behaves as follows:

- The mustard train maintains the absolute minimum safety distance from the black train in the same block (CBTC rules).
- Block 3 is occupied by an unequipped train (blue train), therefore the entire block is treated as an obstruction and one block separation is maintained in front and behind

the train. The black train stops a minimum safety distance from signal B. Although, the black train could travel up to signal C, the CBTC system is not be able to determine if block 2 is occupied by the black or blue train.

- The blue train stops at signal D because it must maintain a one block separation from block 5, which is occupied (conventional rules), even though the green train in block 5 is a CBTC train.

The conventional signalling component is fully integrated into the CBTC solution allowing both modes to coexist. This means:

- If there is a system-wide radio failure, trains can operate using conventional signaling rules.
- If there is a localized radio problem, the trains can move through the affected area using conventional rules and CBTC rules when outside the affect area.
- If an unequipped work car must enter the system, the work car would follow conventional signalling rules and all other trains will use CBTC rules.

Mixed mode of operation is the most flexible option because of its ability to handle all scenarios.

## 7.6 Is Fallback Mode for Everyone

The benefits of CBTC operation have been proven in revenue service operation but the perception remains that a CBTC system must be supplemented by a fallback mode of operation. To determine if fallback mode is needed, the operating environment must be tested against established criteria.

### Criterion 1 – Is The Railroad Property An Open Or Closed System?

In an open system, CBTC equipped trains coexist with unequipped trains. This occurs on shared tracks where CBTC equipped commuter trains operate with unequipped freight trains on the same section of track. The commuter train will operate using CBTC rules and the freight train will operate under conventional rules.

The two signaling methodologies must coexist; the CBTC and non CBTC train must be able to detect each other and maintain the appropriate safety distance according to their signaling methodology.

In a closed system, only CBTC equipped trains operate and unequipped trains never enter the system.

## Criterion 2 - Are Work Cars Equipped Or Unequipped?

Operators may decide not to equip their work cars (see section 5. Key Function #3 Equipping Work Cars (Maintenance Vehicles)) due to the cost of the fitment program or other technical problems. In this scenario the Operator has two options, either implement fallback mode or operate work cars using a TPR (see section 3.1 TPR – Train Protection Reservation).

TPRs are a viable option but this depends on the operating environment. If the transit property has 50 to 60 work cars operating every night, TPRs will be difficult to implement and fallback mode may be preferable. But for a small Operator with 2 or 3 work cars TPRs may be adequate.

## Criterion 3 – What Kind Of Train Recovery Is Required?

If the Operator has a closed system and the work cars are CBTC equipped, the Operator must decide on a train recovery strategy in the event of a worst-case failure; defined in Section 0 as a train unable to communicate its position with the wayside.

In that rare instance when a train is stranded, the Operator has three options:

- TPR or
- Train Coupling or
- Fallback Mode

Each option has its advantages and disadvantages and section 0 discusses this in further detail; if the TPR or coupling options are not acceptable then fallback mode becomes the default choice.

## 7.7 Conclusion

Unless there is an operational requirement, based on the criteria described above, fallback mode should be avoided. The cost of implementing a CBTC solution with fallback outweighs the marginal benefits that fallback provides:

- Extra equipment reduces reliability.
- Extra equipment increases the running maintenance costs.
- An order of magnitude complexity is added to the overall solution.

A thorough analysis must be conducted to determine if fallback mode is absolutely needed because the consequences of a wrong decision are costly and will remain with the Operator for the life of the CBTC solution.

# 8. Key Function #6 - Launching Trains

Transit authorities planning to transition from conventional to CBTC signaling must treat the depot and mainline as a single entity; otherwise the boundary becomes a barrier for launching trains into service. The barrier results from CBTC and conventional signalling speaking different languages; a simplified interface will lose something in translation, preventing a seamless handover of a train from depot to mainline.

Transit agencies planning to deploy a CBTC solution must be mindful that a CBTC solution is effective only when it has control over all aspects that affect mainline operations. The time it takes to launch trains from the depot is a factor because it compromises the throughput on the mainline. Non-CBTC actors, such as a conventionally signalled depot, hinder a CBTC solution's ability to control the flow of trains on the mainline, reducing the advantages CBTC was meant to introduce.

Implementing a CBTC solution on the mainline and leaving the depot conventionally signalled is a mistake. This chapter presents two design options: Option 1 is a compromise; and Option 2 is the gold standard.

Before describing the two options, the impact of ignoring this rule is discussed first.

## 8.1 CBTC Mainline & Conventional Depot

Figure 23 shows a typical mainline/depot alignment with the hashed lined depicting the boundary that transit agencies define to separate their operations; the depot Operator has authority over the depot control area and the mainline Operator has authority over the mainline control area.

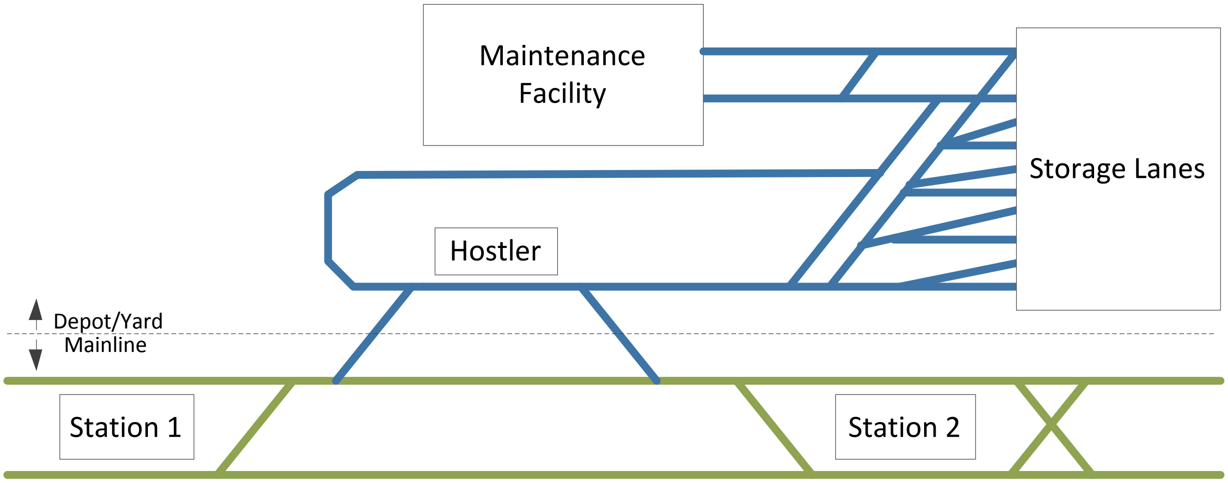


*Figure 23- Typical Depot*

Due to cost or other reasons transit planners may decide to implement CBTC on the mainline only (depot remains conventional) and will typically use the mainline/depot boundary to separate the CBTC control area from the conventional control area (Figure 24).

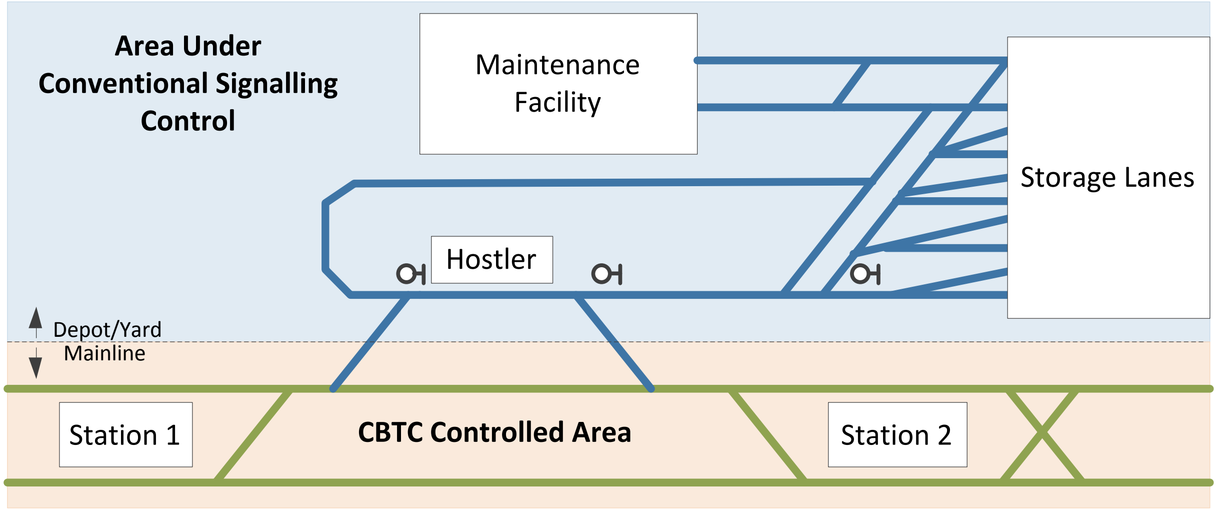


*Figure 24- Option 1 CBTC/Conventional Control Area*

At first glance, this is a simple and elegant arrangement; straight line down the mainline/depot boundary separating CBTC area from the conventional signalled area. However, this is based on a lack of understanding of the characteristics of a CBTC solution and generates problems when launching trains into service.

Initializing the vehicle controller (VC) is a prerequisite for launching a train. Several initialization steps are performed; however, the critical step is localizing the train by crossing two beacons to gain position (Figure 25). This enables the CBTC system to "see" the train. These beacons must be placed within the CBTC territory and since the territory is confined to the mainline, it creates an operational nightmare.

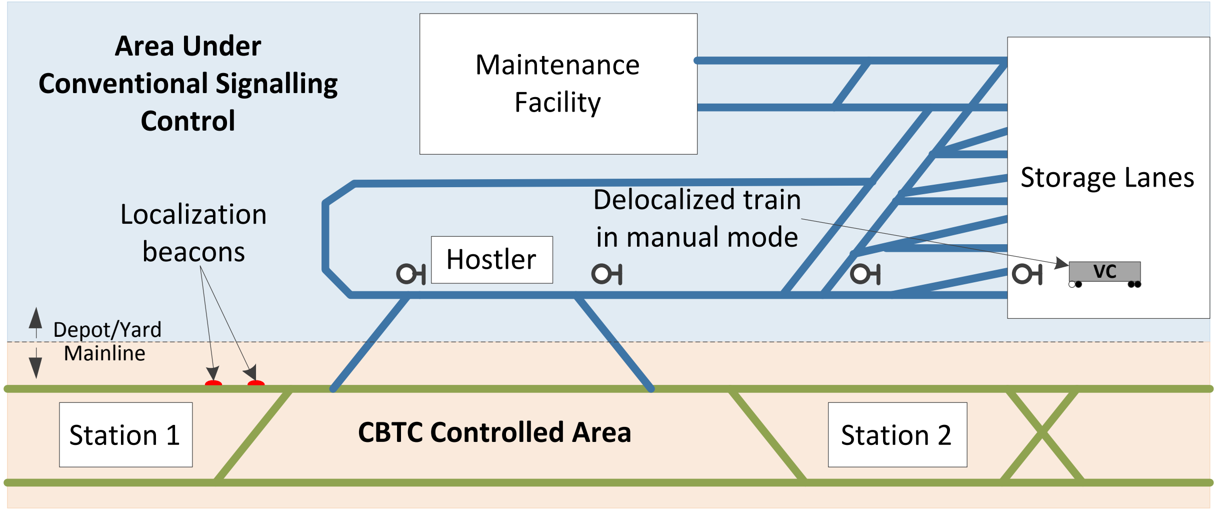


*Figure 25- Location of localization beacons for Option 1*

Launching trains requires the train to move from the storage lane to the hostler in manual mode following conventional signalling rules (Figure 26). Since the VC's are not localized (beacons are located on the mainline), the CBTC system cannot see the train. Therefore, before the train can enter the mainline, the CBTC system imposes draconian measures to protect the train by implementing a TPR from the hostler to Station 1. Other trains operating on the mainline are denied entry into the TPR (Figure 27).

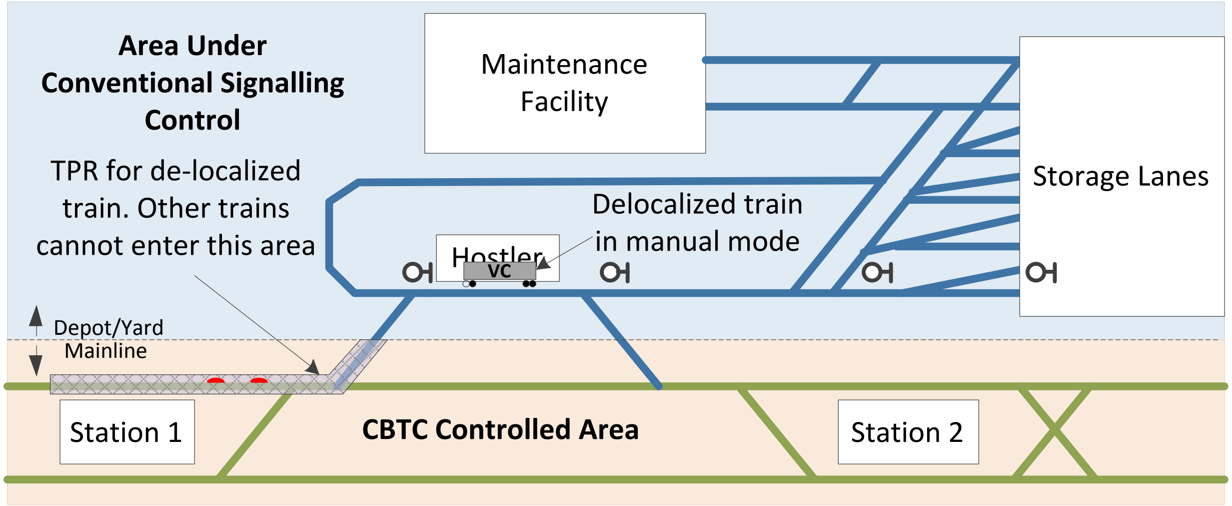


*Figure 26 - Delocalized train traveling from the storage lane to the hostler*

The train establishes position as it crosses the beacons and localizes (Figure 28). Only at Station 1 can the train enter a CBTC mode and depart. By this time, trains are bunching behind Station 1, slowing Service.

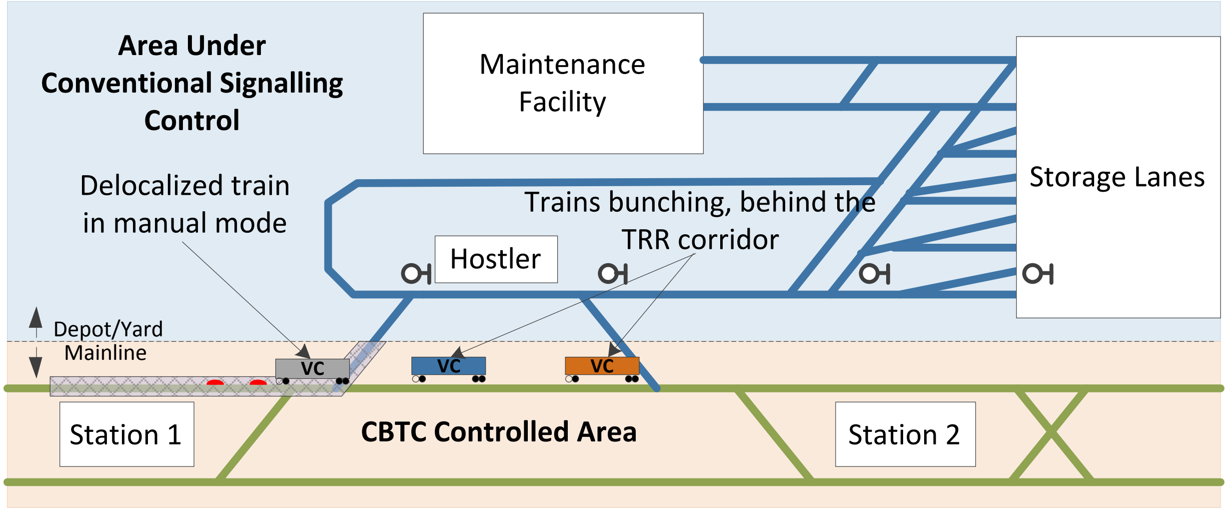


*Figure 27 - Delocalized train entering CBTC control area after the TPR is created*

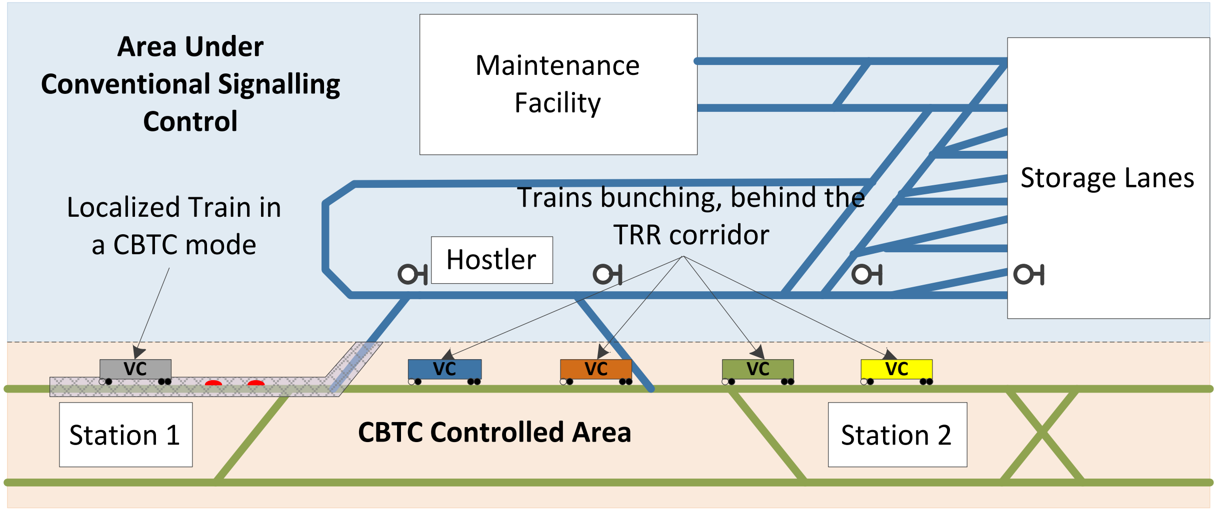


*Figure 28 - Train localized after crossing the localization beacons*

If the train does not localize (beacon antenna failed for example), the train cannot reverse direction back to the yard because the hostler is occupied by the next train waiting to depart for Station 1. The TPR must be extended past Station 1 to the nearest crossover and circled back to the yard on the bottom track. This is a large swath of track to take out of service during passenger carrying hours.

Under this arrangement the Operator is not aware the train is unfit for service until it reaches Station 1, which is too late. The Operator is left with no options to remove the train from the mainline other than to continue to the nearest crossover, causing further disruption to service.

One alternative is to implement fallback mode of operation but this is a costly capital expense and an over-engineered solution to a simple problem.

## 8.2 Option 1 – Hybrid Configuration

Under the hybrid option, the CBTC boundary is extended to include the hostler, permitting the localization beacons to be placed inside the depot (Figure 29). The train follows conventional signalling rules as it leaves the storage lane (Figure 30) and establishes position when crossing the beacons (Figure 31). The advantage is that by the time an ATC ready train arrives at the hostler, it can depart with no disruption to mainline operations (Figure 32). Further, if the train is not able to localize, the Operator can route the train from the hostler back to the storage lane without ever entering the mainline.

The hybrid option enables the Operator to:

- Launch trains in ATC mode from the hostler.
- Identify failed trains before they enter the mainline.
- Route failed trains from the hostler to the storage lane.

The problem that arises out of this option is who controls the hostler: the yard operator or the mainline operator? During Service launch, the mainline operator will need to control the trains entering the mainline but in between rush hour Service, the yard operator may need the hostler to move trains around within the yard.

It is possible for both the yard and mainline operator to control the hostler but this is frowned upon and control of the hostler can become an organizational turf war.

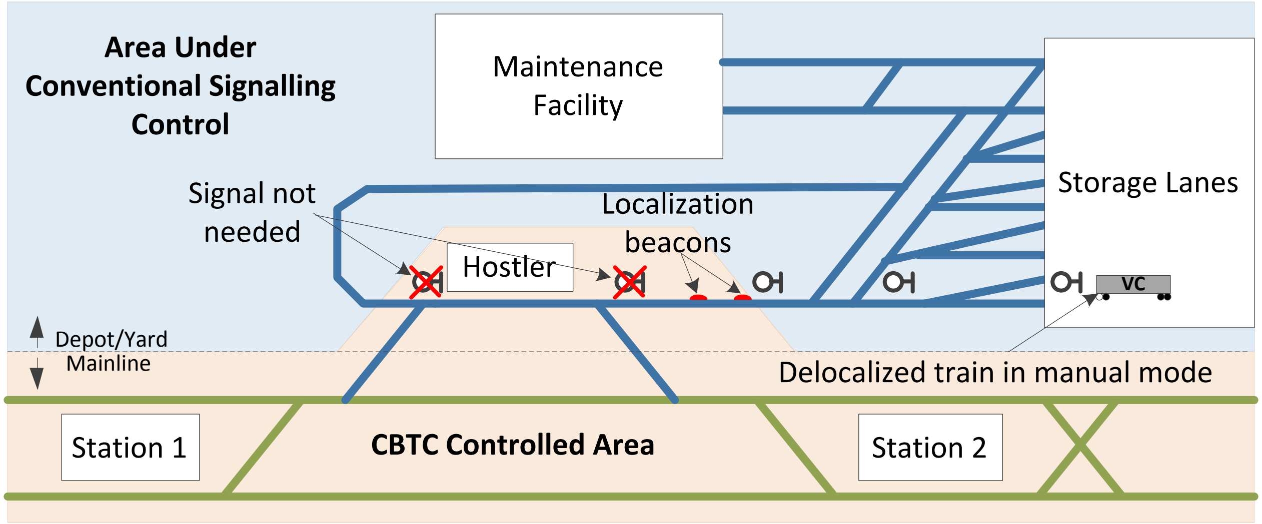


*Figure 29 - Location of localization beacons for Option 2*

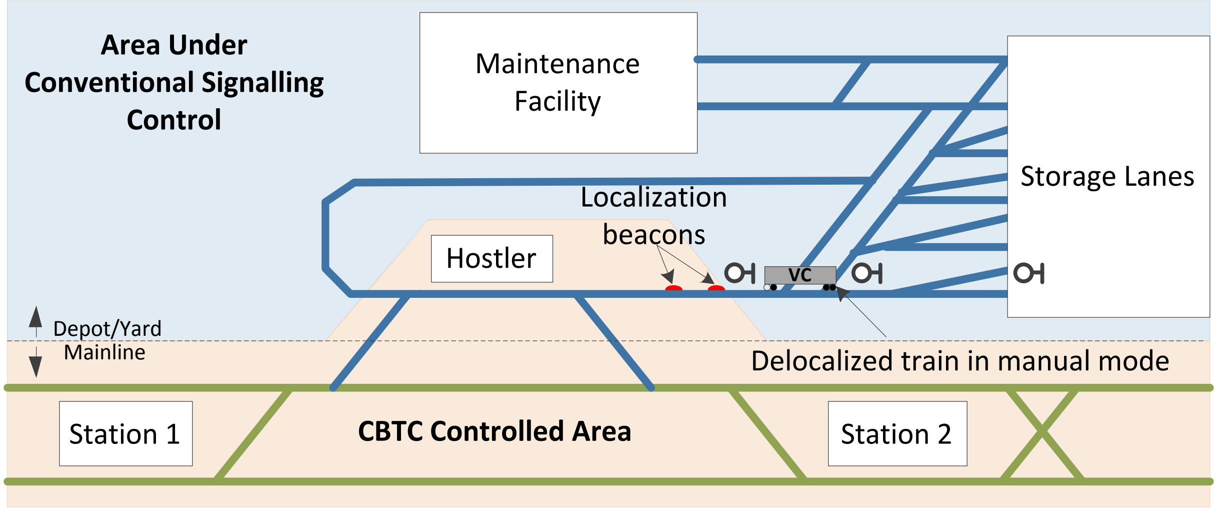


*Figure 30 - Delocalized train travelling from the storage lane to the hostler*

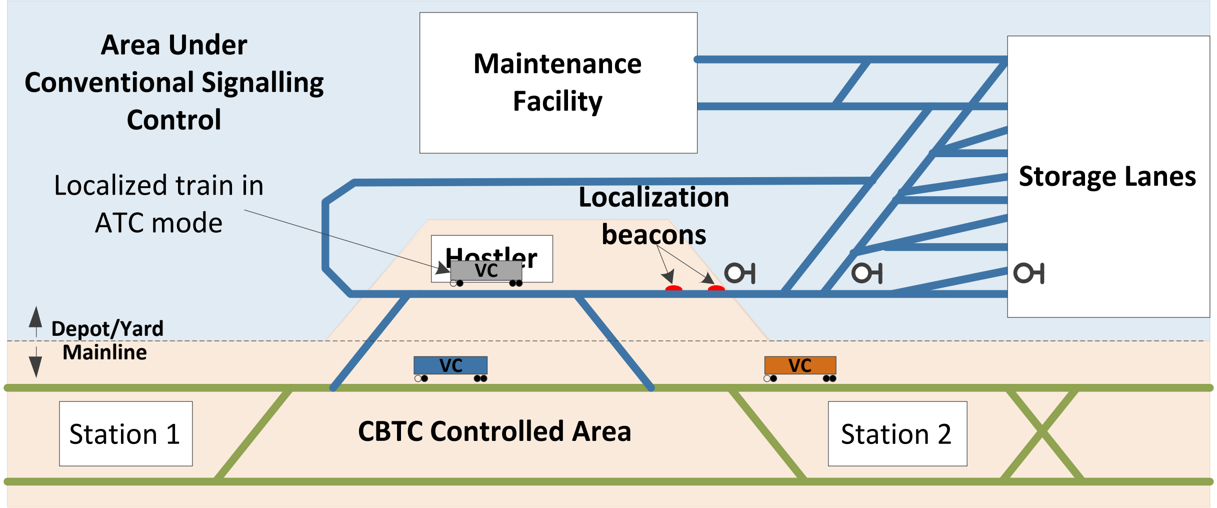


*Figure 31 - Localized train arriving at the hostler*

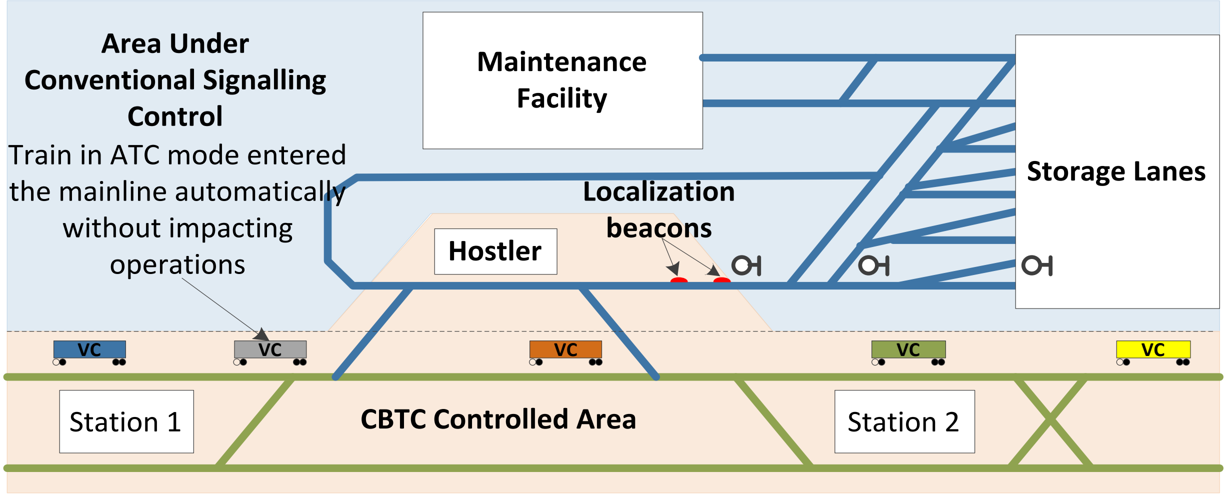


*Figure 32 - Localized train entering the mainline in ATC mode*

## 8.3 Option 2 – Gold Standard

The ideal configuration is full CBTC control of the depot (Figure 33). The trains are ATC ready in the storage lanes and localization is not required. At the appointed time, the train will depart the storage lane for the hostler and injected into the mainline when the schedule calls for it. It is a fully automated launch utilizing the full capability of the CBTC solution.

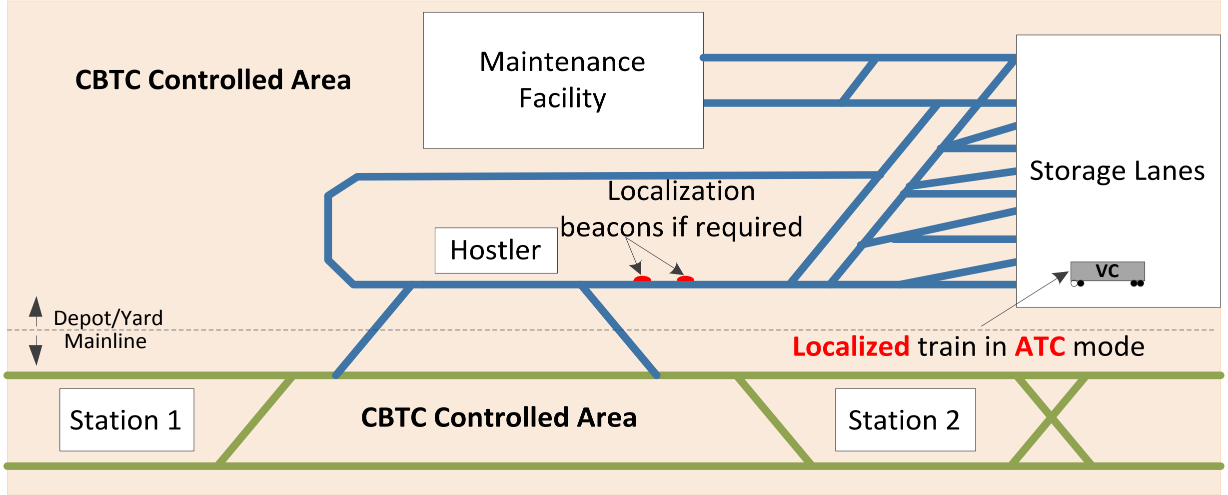


*Figure 33 – Gold Standard*

The advantages of Option 1 are included but with the added benefit of launching trains in ATC mode from the storage lane; the delay of changing modes from manual to ATC at the hostler is removed, allowing for a faster launch.

## 8.4 Conclusion

To utilize the full functionality of a CBTC solution, the hostler must fall under CBTC control; otherwise:

- The operational advantages of CBTC are lost.
- The Operator’s ability to flag a failed train is compromised.
- Trains cannot be placed in ATC mode until the first station.
- Throughput on the mainline is compromised.

Transit agencies planning to deploy a CBTC solution must understand that a CBTC solution is effective only if it has control over all aspects that affect mainline operations. Therefore, every inch of track should be under CBTC control because a patchwork approach is the main ingredient for operational inefficiency.

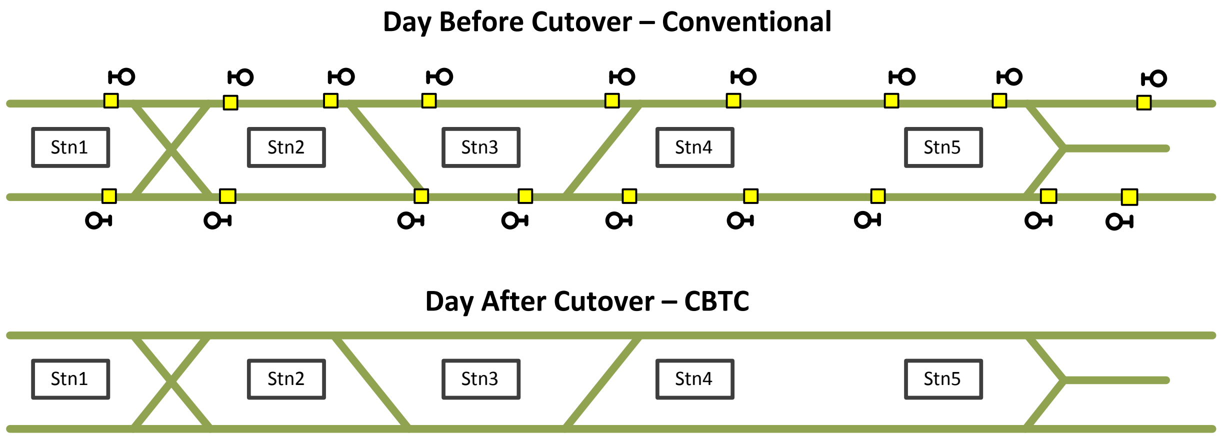
# 9. Key Function #7 – Cutover Strategy

A cutover strategy defines how the Operator will switch from their current signaling system (usually conventional) to CBTC. The cutover strategy has no impact on operations once the system is fully cutover but if the cutover strategy is not well thought out, the roll out of CBTC will be painful to the Operator and the riding public.

There are several strategies that can be utilized to cut the system over and each one requires a design up front.

## 9.1 Big Bang

As the name implies, on a Friday before the cutover weekend, the line is running under conventional signalling and on Monday, the day after cutover weekend, the line is running under CBTC signalling.


Day Before Cutover – Conventional

Day After Cutover – CBTC

*Figure 34 – Big bang cutover*

The big bang approach requires a high degree of confidence the solution will perform almost flawlessly once deployed but, as is the case with any beta software, bugs always surface. Nevertheless, this is a valid approach and it has its advantages if the Operator can tolerate the disadvantages.

## Cutover

When the big bang approach is utilized, the legacy signalling equipment is taken offline (decommissioned) and the CBTC equipment is brought online, except for the switch machines.

During the cutover, the switch machines transition from the legacy system to the CBTC system; therefore, a cutover cubicle is required to make this transition smooth (Figure 35). The cutover cubicle allows the legacy system to control the switch machine then switchover to allow the CBTC system to control the switch machine. Any other legacy equipment required by the CBTC system will require a similar cutover cubicle.

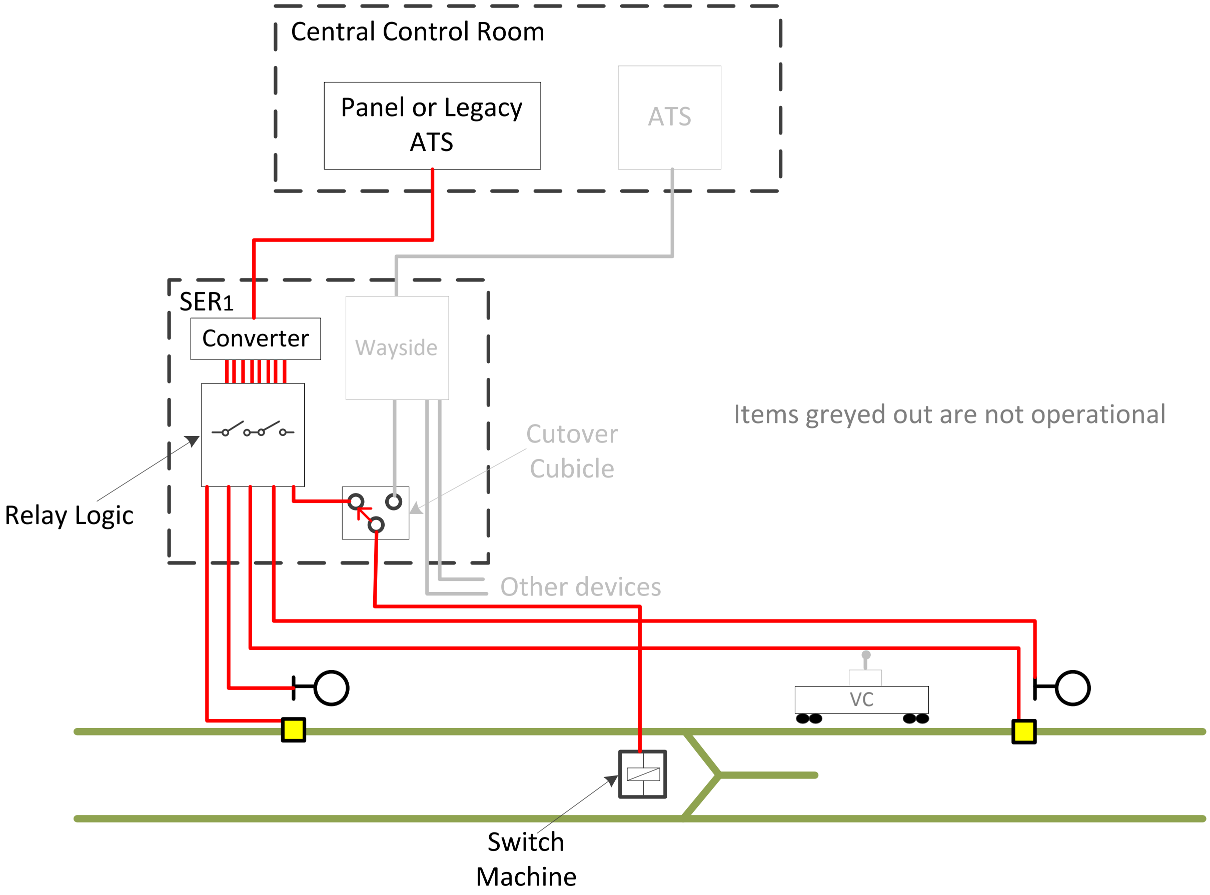


*Figure 35 - Big bang cutover approach before the cutover occurs*

After the cutover:

- The ATS bypasses the panel,
- The wayside bypasses the relay racks,
- The VC takes control of the trains,
- The data communication system (DCS) connects all subsystems together.

By the end of the weekend, the CBTC system would take control of Service for the start of Monday rush hour.

The legacy equipment would remain until a good time is found for it to be removed.

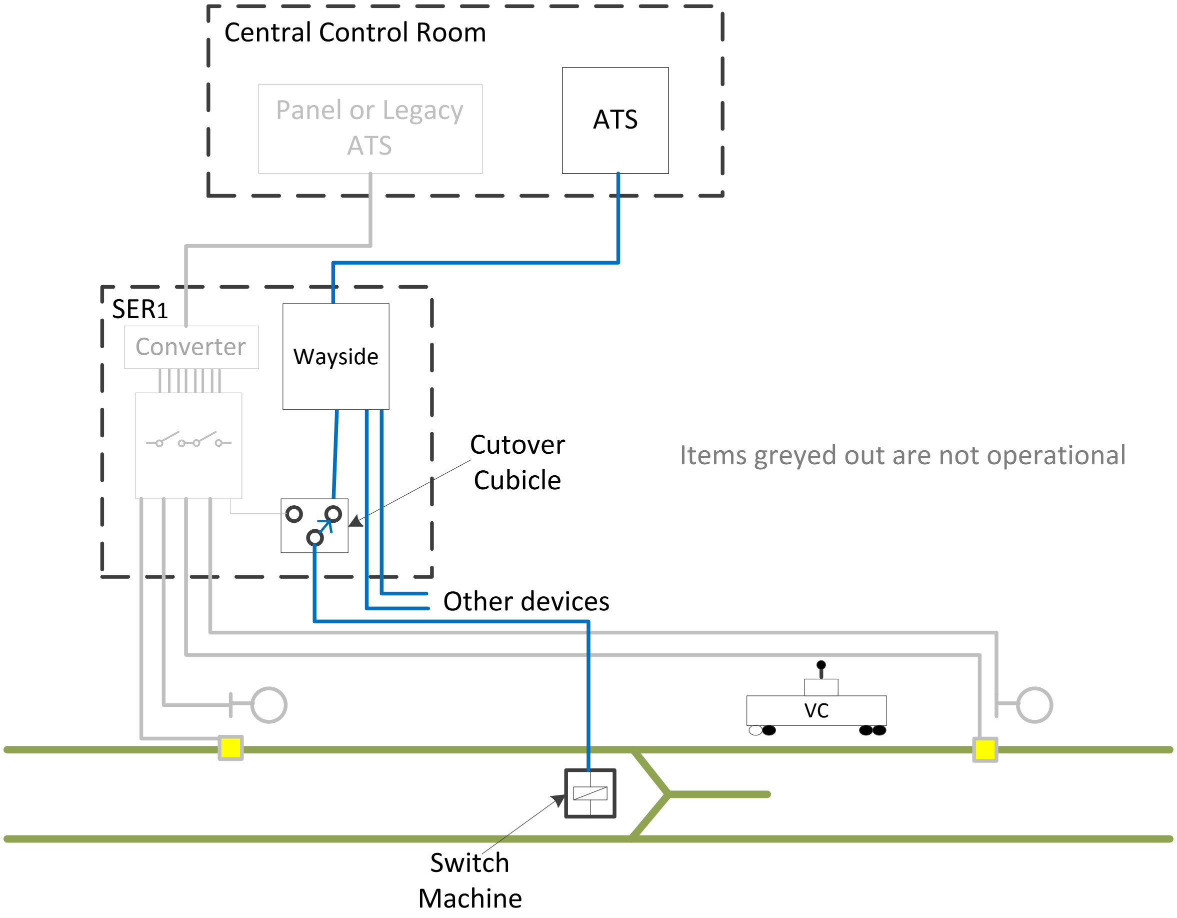


*Figure 36 - Big bang approach after the cutover*

## Advantages

- This cutover approach works on small lines 5km to 10km where is there is little equipment to cutover.
- Temporary designs for the cutover are kept to a bare minimum such as the cutover cubicle.
- Logistically the cutover is simple in the sense that the signals are bagged, trip stops are tied down and the switch machine is cutover.

## Disadvantages

- If there are problems with the software logic, the entire line may be affected.
- Workforce needed for this cutover is large depending on the size of the track.

## 9.2 Phased Cutover

The phased cutover approach breaks the track into small pieces and each piece is cutover one section at a time.

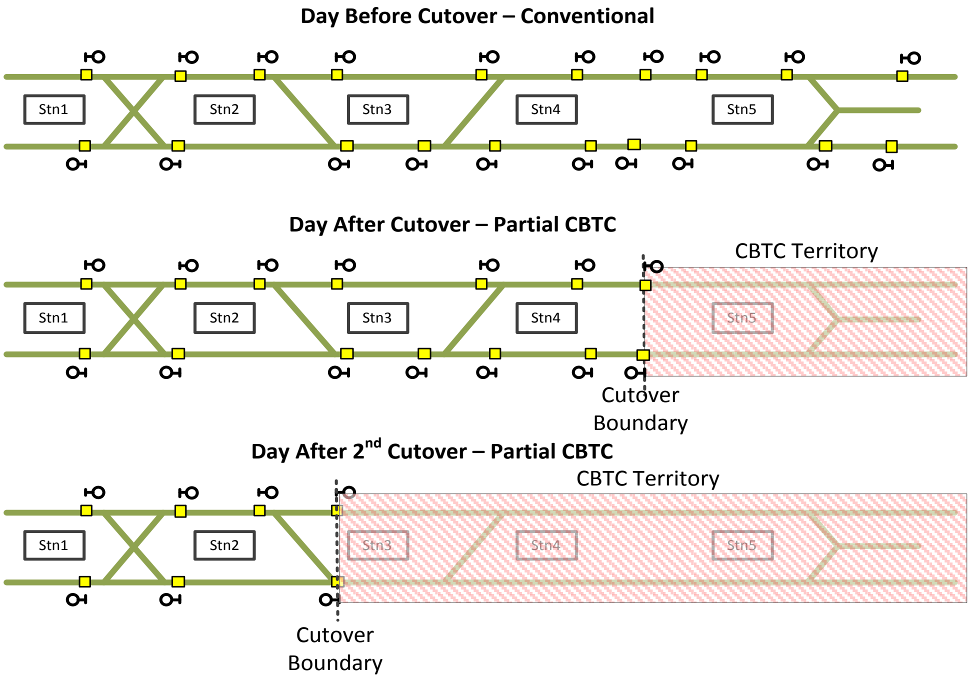


*Figure 37 – Phased Cutover*

Small manageable pieces allow the CBTC solution to mature over time. When the first phase is placed into service, the Operator has a chance to observe the CBTC solution in action for the first time under passenger carrying service.

Passenger Service presents its own unique set of problems that simulated testing will not uncover. A phased approach allows bugs to surface which gives the Supplier time to fix for the next phase and the ridership is not affected along the entire line. When phase 2 is cutover, the solution has greater stability and with each passing phase, the maturity level of the CBTC solution increases.

## Transition Zone

A phased approach requires a transition between the legacy conventional and CBTC system to hand a train off.

When the cutover boundary is magnified, it's not a hard line but a buffer called the transaction zone where the conventional and CBTC worlds overlap (Figure 38). The purpose is to allow a train to enter under conventional rules and exit in CBTC mode or enter in CBTC mode and exit in conventional mode.

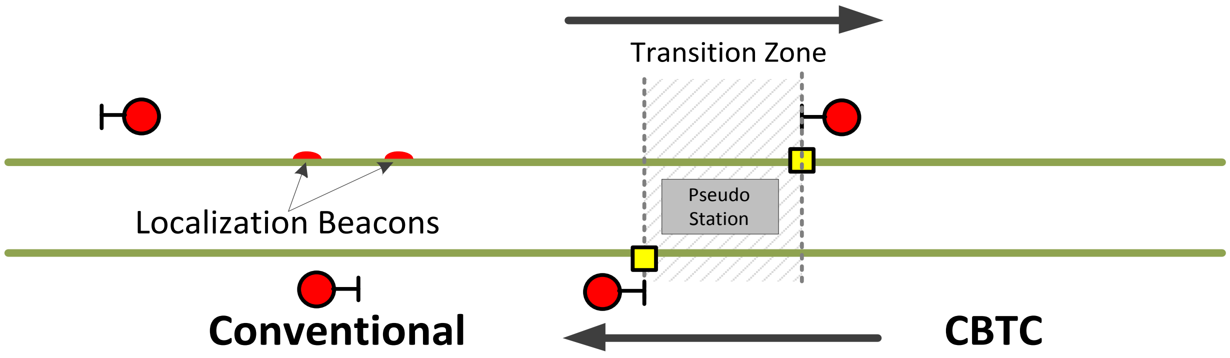


*Figure 38 - Transition zone in a phased cutover approach*

## Entering The CBTC Territory

A train approaching the transition zone from the conventional side will be travelling under conventional rules. To enter the CBTC territory, the train must cross two localization beacons for the VC to gain position and determine where it is located (Figure 39).

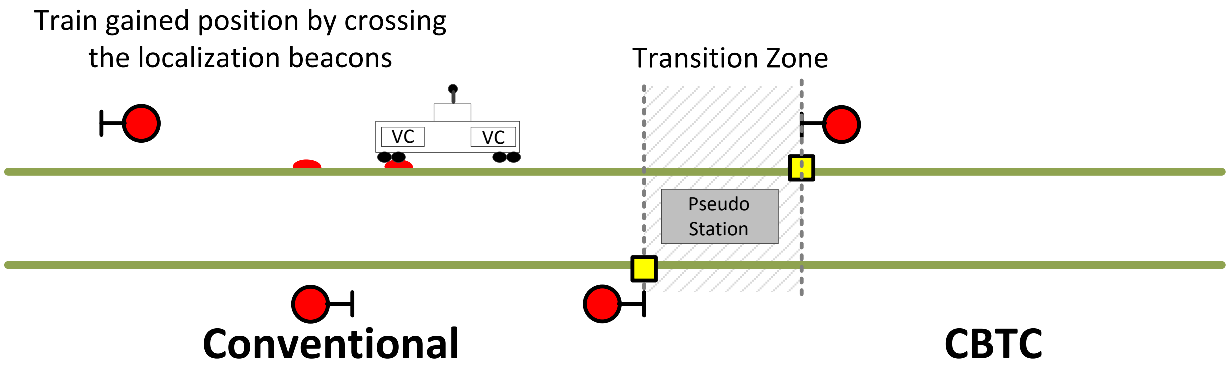
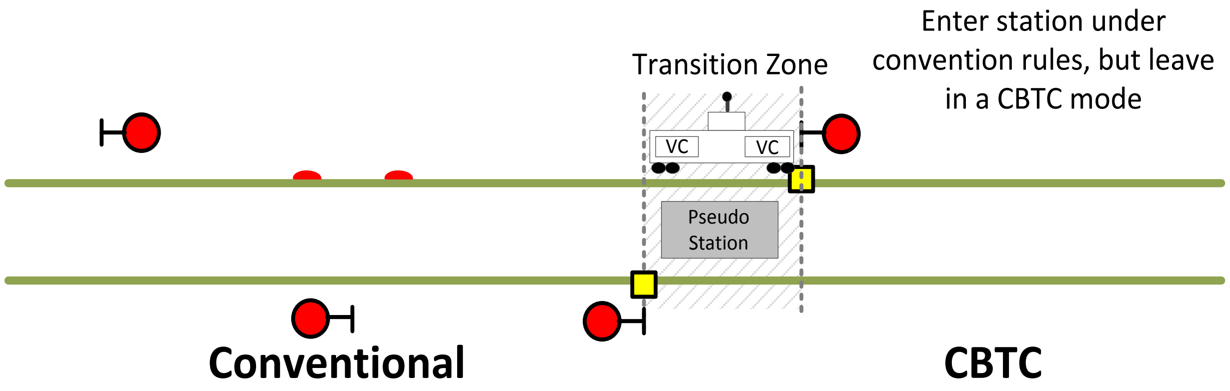


*Figure 39 - Train entering the transition zone from the conventional side*

The train will continue to the transition zone and stop just prior to the red signal (Figure 40). The signal indicates to the driver where to stop the train so the full length of the train is inside the transition zone; otherwise the VC will not allow the train to leave in a CBTC mode.

In the transition zone, the driver will change to a CBTC mode either ATO or ATPM. The CO will set the route from the pseudo station and the train will depart under CBTC control.

Although the signal aspect is not relevant for CBTC, the conventional side will receive the CBTC side guideway status through tie-in circuits and set the signal to a permissive aspect.



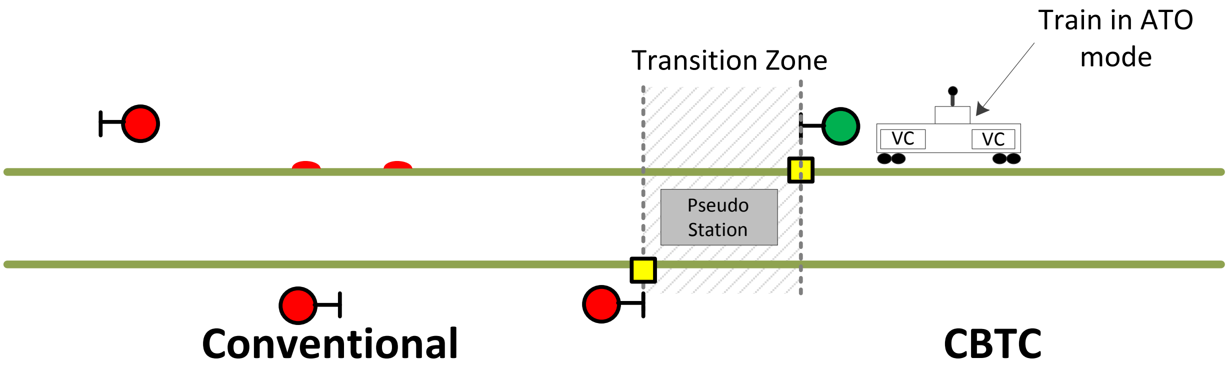


*Figure 40 - Train entering and exiting the transition zone in a CBTC mode*

## Exiting The CBTC Territory

A similar process is followed when exiting the CBTC territory (Figure 41).

- A train operating under ATO mode is routed to the pseudo station.
- The train stops when it reaches the signal in the transition zone.
- The train operator will change from ATO to manual mode.
- The CO will call the signal and aspect will change to a permissive aspect.
- The train operator will depart the pseudo station and follow convention rules
- The tie in circuits will feed conventional track status information to the CBTC side allowing the train to exit the CBTC territory gracefully; the CBTC system does not leave an occupancy when the train exits the CBTC territory.

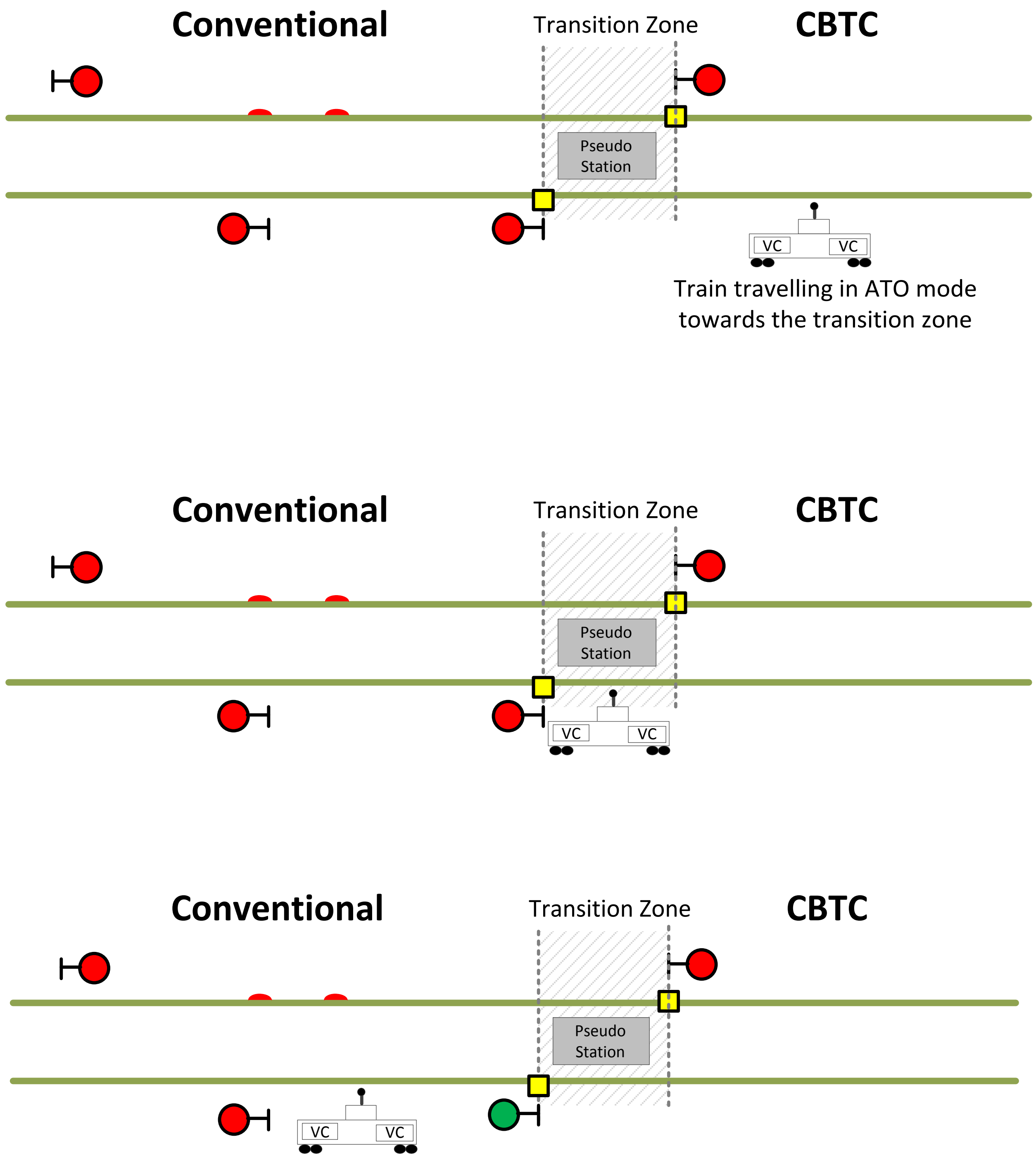


*Figure 41 - CBTC train exiting the CBTC territory & entering the conventional territory*

## Cutover

Prior to the cutover, temporary hardware and software would be designed and installed to support the cutover (Figure 42).

- Cutover cubicle for switch machines.
- Tie-in circuit design to allow a train to travel from the conventional area to the CBTC area and back.
- Temporary wayside, VC and ATS software that defines the pseudo station location and routes leading to the pseudo station.

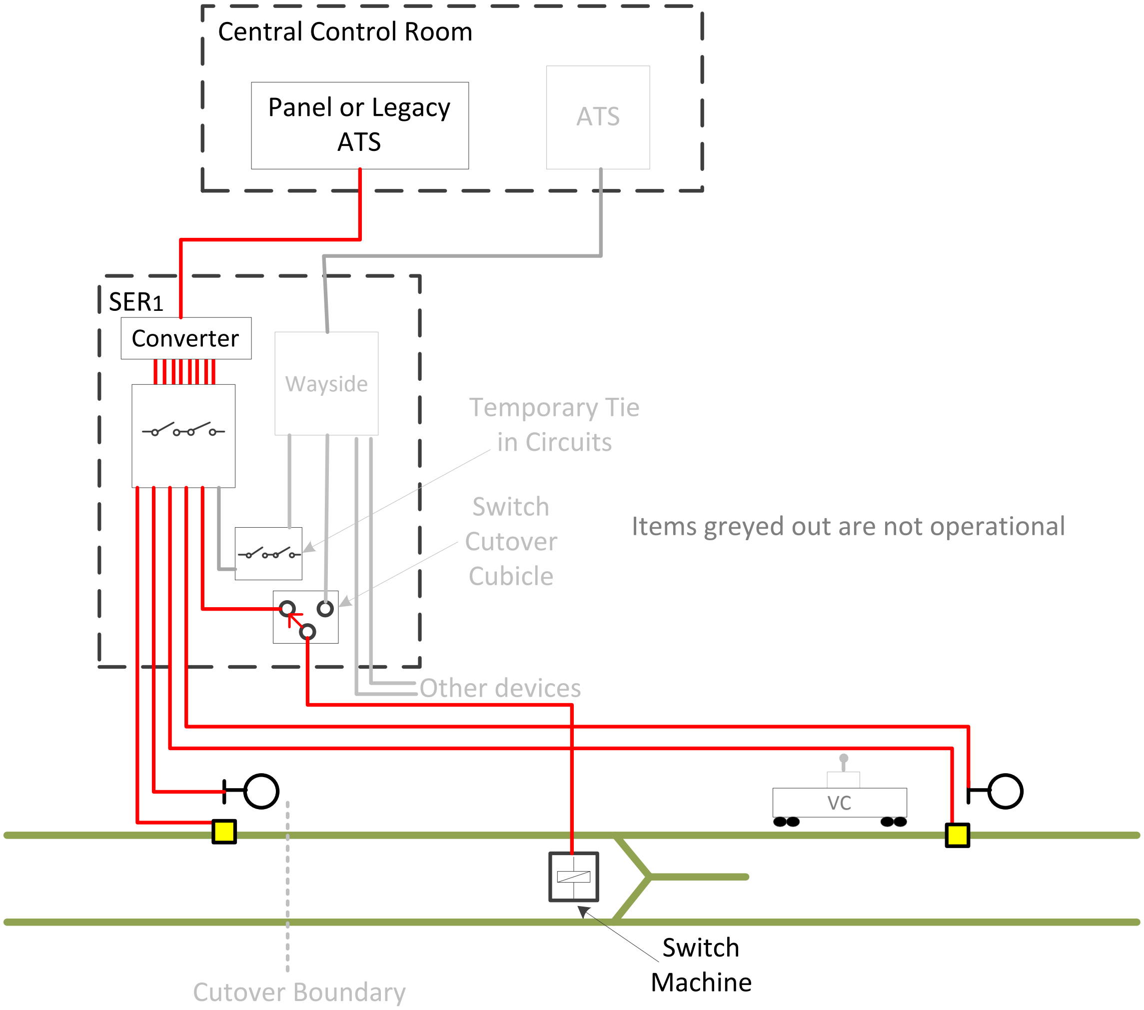


*Figure 42 – Phase cutover - the day before*

After the cutover the CBTC system would take over phase 1 territory:

- The ATS would control the CBTC area and the panel would control the legacy area.
- The wayside would bypass the relay racks in the CBTC territory and the relay logic would continue to operate in the conventional territory.
- The VC would take control of the trains in the CBTC territory but in the conventional territory, the VC would be bypassed.
- The data communication system (DCS) would connect the subsystems together.

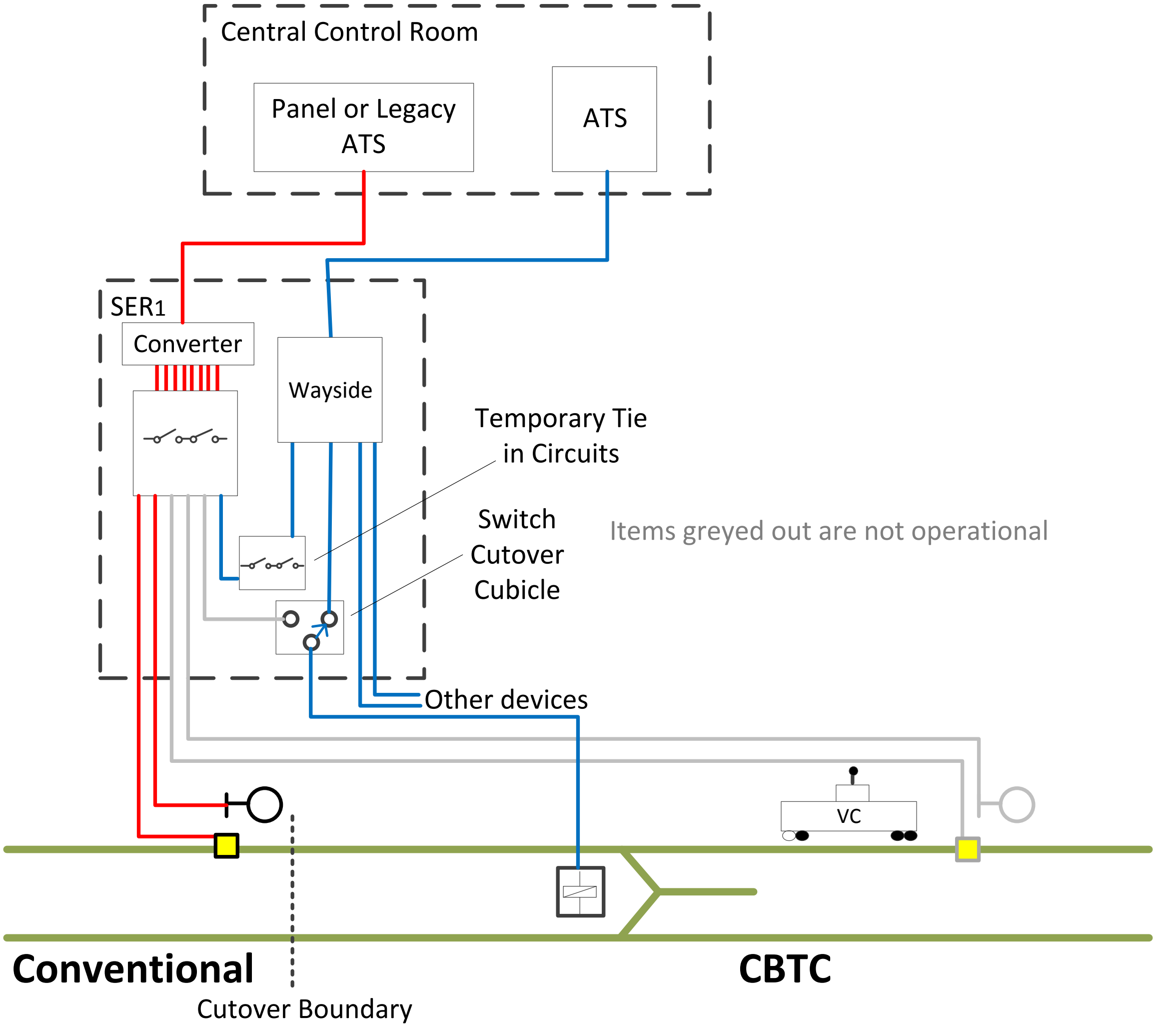


*Figure 43 - Phased cutover - the day after*

### Advantages

- Small manageable areas make for an easier cutover.
- Any problems that surface during passenger carrying service with the new system will affect only the small area that was cutover.
- The supplier can address bugs that surface and the CBTC solution matures with each cutover phase.

### Disadvantages

- Temporary hardware (tie-in circuits) is required to support the transition zone.
- Temporary AC, ATS and VC software (pseudo station, routes, interface with tie-in circuits) is required to support the transition zone.
- Two COs, one for the legacy panel and one for the ATS, must work in close coordination to handover a train from the conventional to the CBTC side and vice versa.

## 9.3 Fallback Mode Leading To CBTC

This approach is applicable if the Operator has decided to implement fallback mode of operation and the fallback block design is as operationally efficient as their current block design.

This approach will apply two cutover stages before the full CBTC solution is deployed. The first cutover will switch from the legacy conventional system to the conventional system controlled by CBTC (fallback mode). The second cutover would deploy the full CBTC solution (Figure 44).

Once the CBTC solution is deployed, the fallback mode becomes dormant and can be used in the event of a CBTC failure.

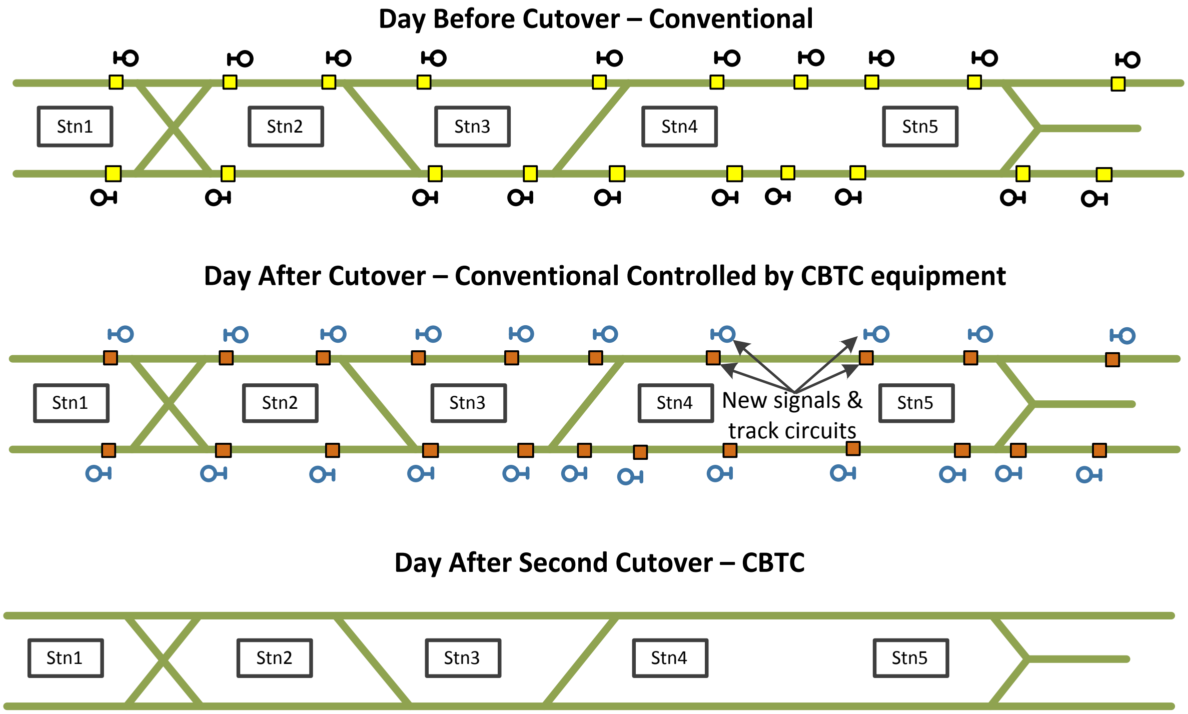


*Figure 44 - Fallback mode leading to CBTC cutover*

## Cutover

The purpose of the first cutover is to activate the fallback mode of operation on the CBTC equipment only. The ATS will replace the panel used by the CO, the wayside will mimic the relay logic of the legacy conventional system (the CBTC portion of the wayside software will be dormant) and the VC will be powered off.

From the driver perspective, the system still operates under conventional signalling rules, the only difference being that new signals are installed at different locations along the track (Figure 45).

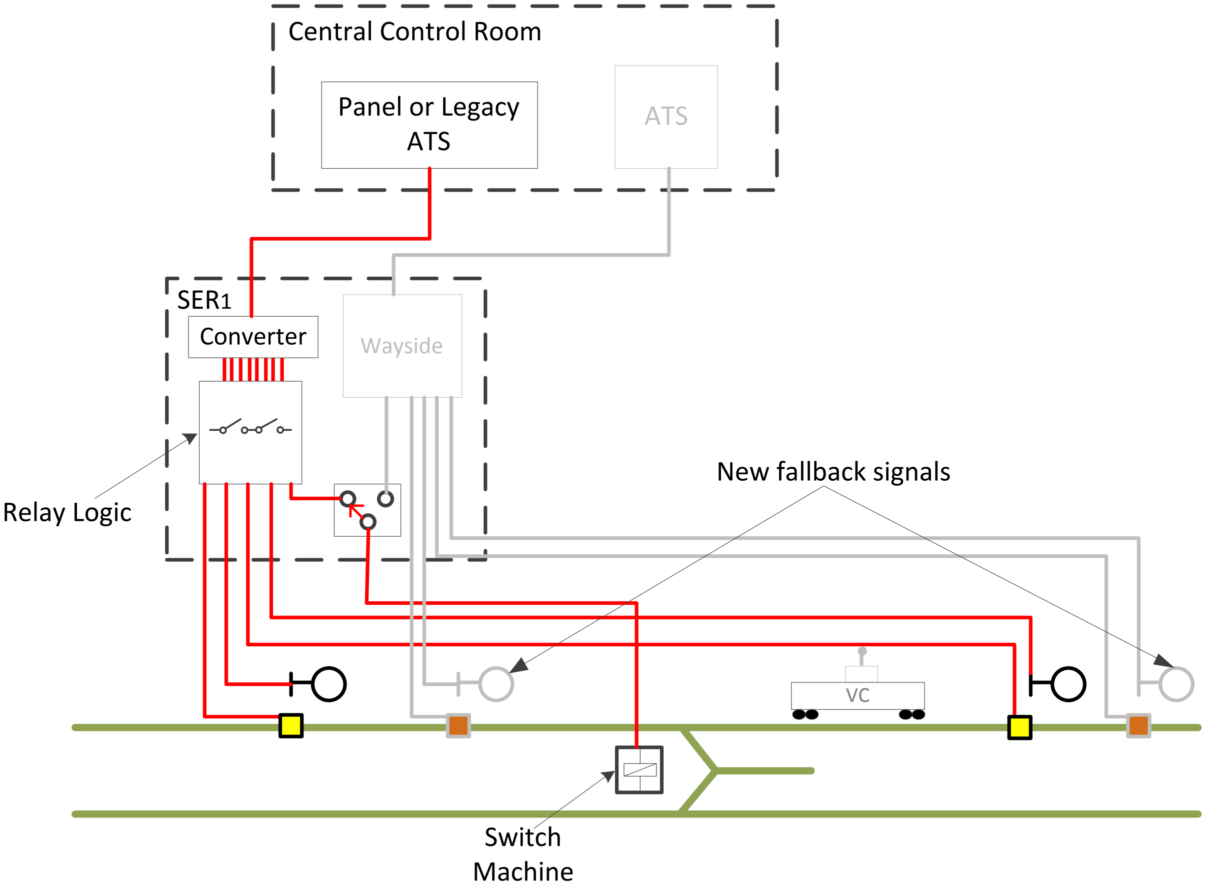


*Figure 45 - Setup before the cutover for fallback leading to CBTC approach*

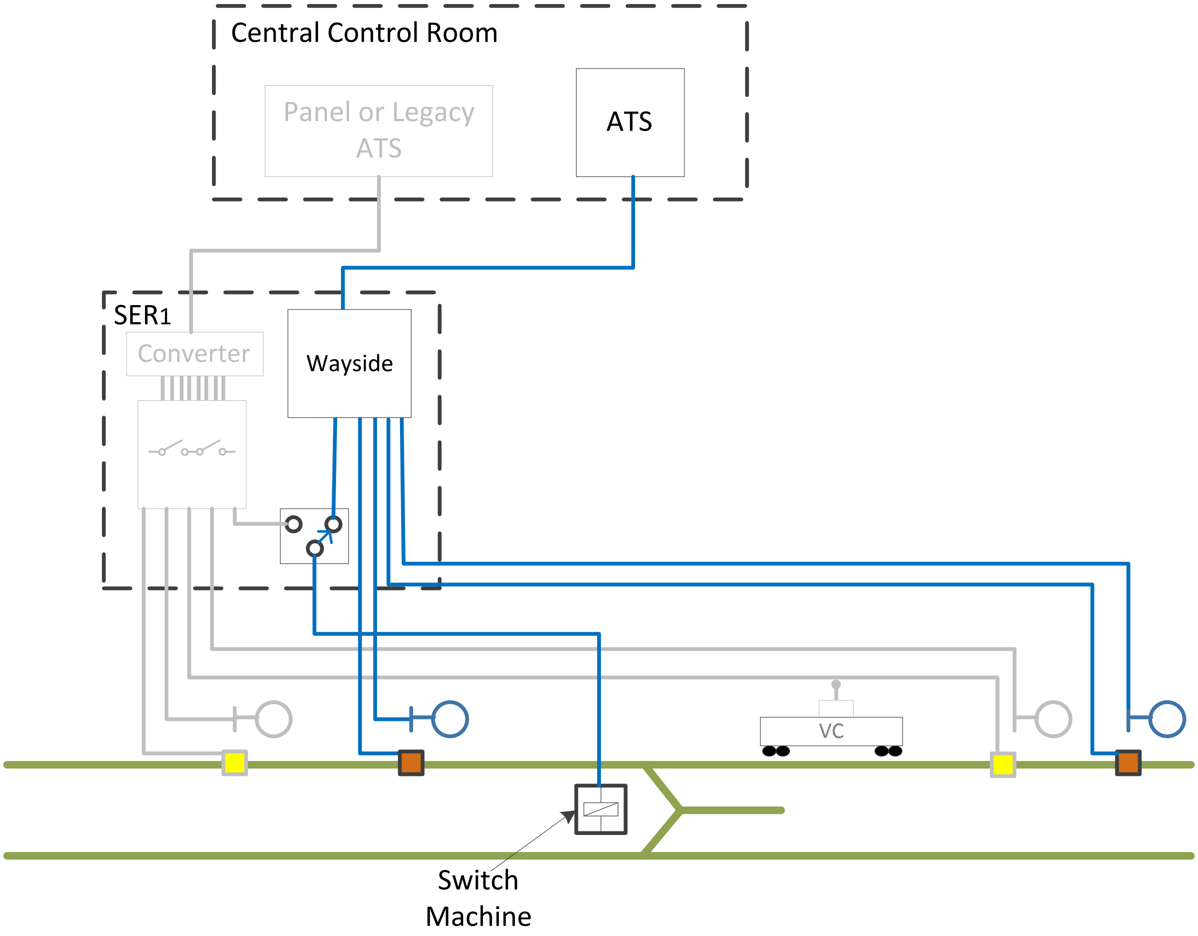


*Figure 46 - Day after the first cutover for the fallback leading to CBTC approach*

The second cutover involves installing the new ATS, wayside and VC software and any other equipment required for CBTC operation. After the cutover, the VC is powered on and the CBTC functions on the wayside are enabled.

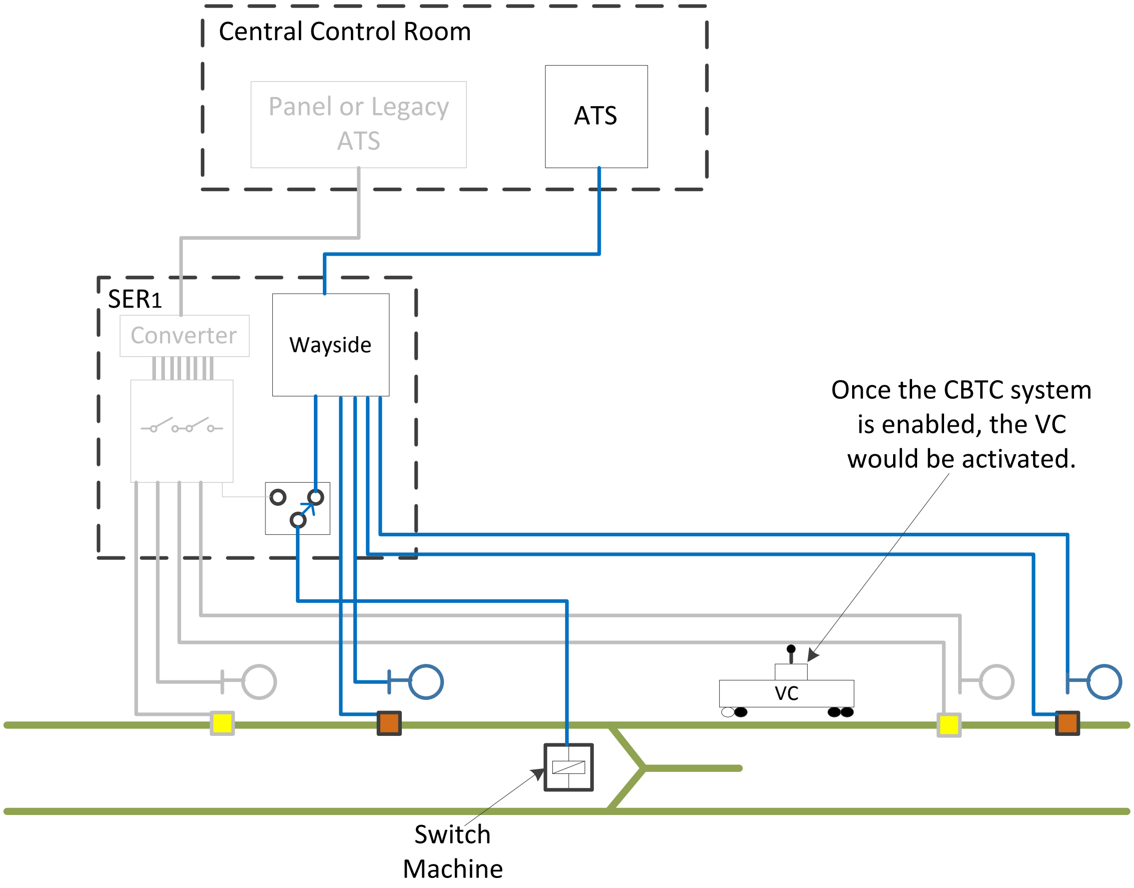


*Figure 47 - Day after the second cutover for the fallback mode leading to CBTC approach*

This cutover approach can also be deployed in phases (similar to the phase cutover approach) which means implementing a transition zone.

## Advantages

- If the Operator has an aggressive schedule, the Supplier can deliver the first cutover quickly followed by the CBTC solution at a future date.
- CBTC equipment is installed and partially operating.
- Operator personnel can adapt to the new equipment while operating under a conventional environment.

## Disadvantages

- This approach is only possible if the CBTC fallback mode block layout is as efficient as the legacy block layout.

## 9.4 Conclusion

There is no right way or wrong way to cutover a CBTC solution. It all depends on the unique operating environment of the railroad property.

If the Operator has a small 7 km track, the big bang approach will serve their needs while minimizing the disadvantages; a 30 km track would require a phased approach with a design up front for the transition zone.

The Operator must determine the cutover approach they plan to take and feed this requirement into their CBTC specification so the Supplier can cost out the cutover strategy.

# 10. Conclusion

Operationally critical functions must be understood when deploying a CBTC solution. These functions define how a railroad operates once the solution is deployed; operators who neglect these functions will live with the impact for the life of the CBTC solutions.

CBTC functions are divided into core and non-core functionality. Core functions do not change from project to project but Suppliers adapt non-core functions to the unique operating environment of the Operator. If the Operators do not have a firm understanding of their operational environment within a CBTC context, they will blindly accept the Supplier's solution which may not be what they need.

Operators must have a firm grasp of the seven key functions outlined in this paper. Decisions made regarding these functions significantly alter how the system operates from one option to the next; a well thought out diagnostic architecture will permit a faster recovery from a Service-affecting fault than a poorly thought out diagnostic architecture.

Other functions can be added to this list such as passenger information and announcement systems (PIS/PAS) or train modes. They were not included because they are well understood by operators who place a considerable effort to ensure these functions behave as per their requirements. The purpose of this paper was to focus on non-core functions usually missed or ignored.

Operators are switching to CBTC in increasing numbers and the primary motivation is the operational superiority (shorter headways) of a CBTC solution over a conventionally signalled system. However, to realize this advantage the Operators must understand their operational environment within in a CBTC context. Only then can Operators develop a CBTC specification that is tailored to their operational needs that the Suppliers can implement.

CBTC technologies are spreading across the industry as Operators demand more from their transit infrastructure. As a result, the industry has entered a brave new world and Operators need to familiarize themselves with the technology before informed decisions can be made.

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