WWW.SYSTRA.COM

BALANCING THE NEED FOR SECONDARY TRAIN DETECTION IN UTO PROJECTS, IN ORDER TO OPTIMIZE CBTC CAPITAL INVESTMENT AND OPERATING COST

by Sébastien LACROIX, CBTC expert, SYSTRA

SYSTRA

BALANCING THE NEED FOR SECONDARY TRAIN DETECTION IN UTO PROJECTS, IN ORDER TO OPTIMIZE CBTC CAPITAL INVESTMENT AND OPERATING COST

by Sébastien LACROIX, CBTC expert, SYSTRA

CBTC ARCHITECTURE AND SMART FUNCTIONS ARE CHALLENGING THE NEED OF SECONDARY TRAIN DETECTION, POTENTIALLY LEADING TO SUBSTANTIAL BENEFITS IN CAPEX AND OPEX. THERE ARE SOME ISSUES TO DESIGN THE RIGHT LEVEL AND NATURE OF SECONDARY TRAIN DETECTION IN A PROJECT, INCLUDING THE CBTC FITTING OF USUALLY UNEQUIPPED TRAINS SUCH AS WORK TRAINS.

Introduction

As claimed by its acronym, a CBTC system is a "communication based" train control by opposition to being based on trackside train detection devices, de facto raising the question about the purpose of a secondary detection in a CBTC system.

CBTC systems have been designed and deployed to provide the highest levels of safety, performance, and operational flexibility. In addition, CBTC systems employ redundant computer-based equipment to provide very high levels of reliability and availability. The CBTC concept design as defined in the standards (IEEE 1474 and IEC 62290) is driven towards operation without the use of secondary detection, which is only deemed as complementary, yet not complimentary as the "Secondary Train Detection" System, referred to as "STD" later in this article, drastically increases, with up to 50%, the capital expenditure for a CBTC.

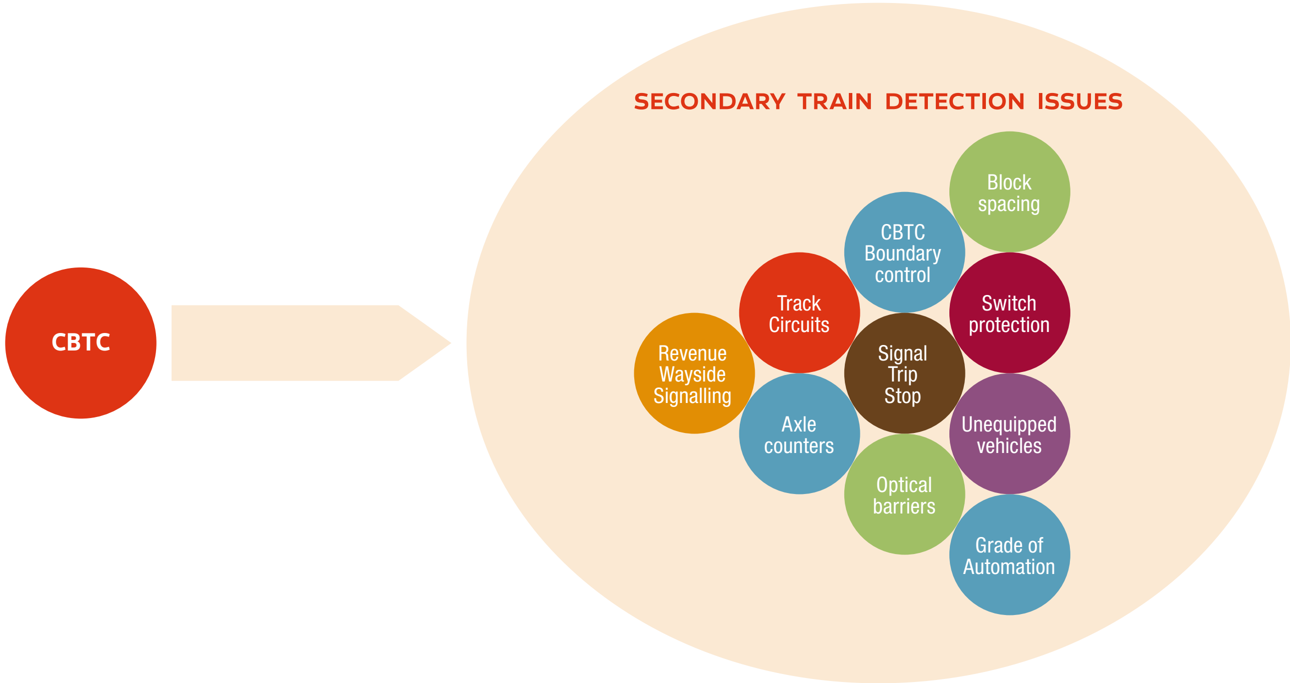
However, the CBTC concept is quite an evolution for the conservative railway industry for which train control safety has long been based on the track devices used as a "primary" mean of detection, mainly with the use of track circuits or axle counters. These existing devices were left incorporated in the CBTC design due to the CBTC concept that was undergoing trial as an overlay system in brownfield signaling upgrade projects: these track devices would ease migration and fallback issues to address the concerns of a by then unproven technology, and enable to protect unequipped vehicles operation. As confidence in CBTC has grown, the role assigned to STD devices reduces from a full signaling back-up option down to assisting the CBTC system in some failure scenarios (e.g. in system reinitialization functions or assisting the operation recovery).

In final, there are still some "strings attached" that may prevent the core CBTC concept, which is purely based on communication between intelligent systems, from blooming free of secondary detection. In this article we will review some of those attached strings that appear when developing UTO CBTC concept (Unattended Train Operation) in green field and brownfield applications, and focus on a few factors to be assessed in order to optimize the overall CBTC project cost.

Costing factors

On the financial aspects, experience can show that the secondary detection represents between from 20 to 50% of the investment cost of a CBTC system in a green field project, depending on the role assigned to the secondary detection, the STD track device resolution, the track topology/configuration... etc. This cost does not necessarily cover other indirect, potentially huge, costs generated by exported constraints to track and civil work, such as track electrical insulation required by certified track-circuits products, room for track equipment...etc

For brownfield project, assuming the inherited system uses secondary detection and the customer is willing to reuse it fully or partially to cover several aspects such as architecture migration, T&C, equipped and non-equipped train mixed operation or existing work train fleet, *[e.g. Paris Line 1, Santiago Line 1, New York NYCT merging existing track-circuits, Lyon removing existing wayside signals, Singapor NSEWL keeping existing track-circuits]*



the capital investment overcost will mainly result from the interfacing design issues between the CBTC and the track devices or associated interlocking logic, and the added complexity required to address the various operation scenarios to consider in the CBTC functions design.

The operating cost will mainly result from the maintenance resources required to manage the additional equipment carrying over the secondary detection function.

To assist in the estimation of this additional cost, analyzing the quantity of added equipment at the trackside and equipment rooms, associated with their reliability performances, will result in a globally averaged MTBF (Mean Time Between Failure) figure, covering service affecting and non-service affecting failures. This global MTBF figure is a structuring figure in the definition of the maintenance resources, and therefore operating cost implications of the overall signalling system.

With this global MTBF must also be taken into account the fact that some of the secondary track detection electronic equipment is located within the trackway and therefore can only undergo maintenance intervention off UTO passenger operation hours, i.e. during engineering hours, often at night man-hour rate and conditions. Obsolescence management of STD devices, often based on ageing electronic devices, is also a significant source of expenses to be addressed.

Role assigned to the secondary detection

The role assigned to the secondary train detection will likely determine the scope of supply and associated costs. In an optimally designed system for CBTC UTO projects with no or limited STD, there is no planned mix-mode revenue operation (mixed operation of UTO CBTC with unequipped trains), and the occurrence rate of CBTC unequipped or failed train circulation, (failed passenger trains, unequipped work trains or external train transit) is considered "exceptional".

The traditional signalling assignment for STD in existing systems usually consists in:

- Train spacing management
- Train shunting: track switch movement protection
- Wayside signaling
- ATP: train protection by an independent system

A tentative definition of STD levels that may characterize CBTC UTO project is given in Table 1. Other non-signalling assignment may be given to STD equipment such as broken rail detection, trackside hot box detection, stabling occupancy... depending on project system requirement.

STD levels	0	1	2	3	4	5	6
No secondary train detection devices	X						
CBTC territory boundary devices		X	X	X	X	X	X
CBTC zones boundary devices			X	X	X	X	X
Track switches protection				X	X	X	X
Block spacing					X	X	X
Trip stop						X	X
Revenue class wayside signalling							X

Table 1 - Tentative definition of secondary train detection levels

Depending on the project phasing and the migration strategy, STD may be used to support temporary mixed operation during line modernization with an upgrade to CBTC.

To reduce the overall investment and operating cost, the CBTC design goal is to reduce the scope of the STD to its minimum. This scope reduction can be allowed at least considering the following factors:

– CBTC availability
– Unequipped trains: Work trains management
– Degraded mode
– STD role in the overall signalling safety case
– Type of secondary track devices

In any case, the following concept must be integrated in the CBTC design:

– Train consist integrity is supervised by the CBTC
– In nominal UTO operation: the STD is not used, STD failures have no impact on CBTC operation
– Entry and exit of the CBTC territory is supervised through safe train identification and safe train follow-up

Degraded modes in the CBTC world

For a system with no or limited STD, the degraded modes must be carefully analyzed using a performance based approach, i.e. in the light of a high availability performance.

High availability can be addressed by qualitative measures: no single point of failures ("SPOF"), efficient failure diagnosis, easy failed unit replacement, fast recovery to nominal conditions… Of course, these qualitative measures are associated with fairly high quantitative RAM targets: high MTBF and failure identification rate, and low MTTR (mean time to repair), short software reinitialization durations…

CBTC architecture and concept, especially radio based, is particularly appropriate to full redundancy principle and eliminate single points of failures, unlike track devices for which redundancy benefit is dragged down by a poor efficiency due to common modes of trackside-related failures. For example, a wide array of events can trip track-circuits.

It is also critical that the CBTC nominal operation remain unaffected by STD failure or STD unavailability.

One undesirable effect of high availability is that the operator/maintainer may lose his hand on the maintenance and recovery procedures, and ends up mismanaging unfamiliar failure events. This effect should be addressed not only with proper training but by keeping designed operation and failure scenarios as simple as possible, and using high performance diagnostic tool to accurately pinpoint the failure, assist the operator in the most efficient way to manage the failure, and reduce down time.

Without secondary detection, the notion of CBTC territory gets it full meaning: the vehicles entries and exits must be vitally managed, with a guarantee that absolutely every vehicle is tracked by the CBTC primary localization system, and the central CBTC being aware of all the train consists, whether running or idle, within the CBTC territory. This allows the CBTC to reduce the impact of degraded modes and assist recovery by-passing the complex STD relying sieving process required by mixed traffic systems. (In this case: "mixed traffic" is of CBTC equipped and CBTC non equipped trains)

In a performance based design, one needs to determine the occurrence rate of the following scenarios and estimate their direct impact on operation, and the time necessary for nominal operation recovery:

1) Delocalisation of a non mute train
2) Loss of CBTC communication with a train
3) CBTC wayside controller failure
4) Car controller failure

For scenario 1, the occurrence rate is brought down by proper design, and the impact on service is kept to minimum with the assistance of remote control to help relocalize the train without resorting to manual driving intervention.

In case there is no remote control recovery options for scenario 1 or 2: evacuation of a failed train in manual driving by on-site staff dispatching or rescue train to the nearest pocket track or to the depot should be analyzed. In this case, the protection is ensured by track reservation for manual driving from OCC and the observance of rules and procedures.

Considering a fully redundant architecture, it must be noted that if common mode failures are properly eliminated by design, the occurrence rate of the scenarios 2, 3 and 4 becomes extremely low. Occurrence would be more likely in the case where an operator delays for any reason the necessary intervention following a single point of failure. Example: a train with a failed CC (Car Controller) is required to be taken out of main line as soon as feasible, to manage the risk of a second redundant CC failure.

In STD based signaling system, the above scenarios impact the service depending on the STD track resolution, as the signaling system would declare the whole STD track sections occupied. With CBTC with limited or no secondary detection, the CBTC automatically sets a protection area around the failed train, adapted to the plausible location of the emergency braked failed train, therefore limiting the impact on the rest of the line.

Based on the above scenarios analysis, the level and nature of STD contribution to CBTC can be assessed, keeping in target the minimization of wayside equipment.

Another factor to consider is the STD role in the overall signaling safety case.

As traditional secondary detection systems, such as track-circuits and axle counters, are widely relied upon when establishing safety cases, there is a risk that the safety assessment process leads to require some back-up STD.

One approach to the safety demonstration would be to consider the CBTC failure down time during which train movements rely essentially on rules and procedures, and introduce the human error rate (common figure is 1 wrong side error every 1000 hours) applied to the down time duration. The demonstration would consist in demonstrating that the CBTC down time duration is so short that the safety target is met.

This could apply to any of the 3 commonly used safety methodologies: ALARP, GAME, AREMA.

In this approach, the rule of thumb would be: the down time during which unequipped trains or non reporting failed trains are managed operating within CBTC territory must be:

– as low as reasonably practicable,
– Leading to a risk globally equivalent to systems using classic wayside signalling based on STD.

Work trains management by CBTC

The issue of equipping track engineering work trains with CBTC arises naturally along with the suppression of the secondary detection, and the underlying premise that anything that moves on wheels within the CBTC territory is talking (i.e. reporting its localization status) from the CBTC tracking system point of view.

Economically speaking, relying on the heavy duty CBTC infrastructure (i.e. CBTC radio, track mapping, and safe separation from passenger vehicles) is a sound choice, justifying the CBTC management of work trains as a highly advisable option.

The CBTC should at least provide a high grade ATP (Automatic Train Protection) to these work trains, that is a Grade of automation level 1 (GoA1), but other grades of automation can be foreseen depending on the vehicles maintenance task, and its inherent adequacy to CBTC automation: from GoA 0 if the vehicle is only reporting its CBTC location to the system to GoA2, 3 or even 4 for ATO semi-automated or fully automated assignments. Regardless of green or brown fields projects, some city networks (New York, Singapore...) rely anyway on CBTC equipped work trains in spite of the presence of wayside signaling in order to improve the traffic safety level, as well as operational performance and flexibility. Again, equipping 100% of a project fleet, provides independence from STD and facilitates the sieving process for train relocation by vitally polling the vehicles operating within the CBTC territory.

The CBTC may support the dispatching of Work trains which may then be safely inserted within the commercial service to get prepositioned near the track location undergoing maintenance, or be dispatched onto the work site at optimal speed (i.e. the line commercial speed): the goal is to meet the constraints of engineering hours windows by managing the work trains movement in the most efficient way.

Whether track engineering needs to deal with short night window time or 24 hours passenger service: equipping these vehicles makes sense, in the former case, this supports an efficient dispatching time of work vehicles, in the latter, the benefit comes with the flexibility of the CBTC traffic management to insert work trains within passenger trains traffic.

The CBTC may also assist by providing a vital supervision for the work trains operating within the possession zone by supervising the vehicle location and their distance to the work zone boundaries.

To minimize investment and operational costs, the work trains should be equipped with the same hardware product as for the passenger train CBTC hardware, and relying on subset of the passenger trains CBTC functions for the software. The main difference would be the use of the ATP driving mode (GOA1), which is usually already incorporated (by software indentation) within the CBTC suppliers products.

The main challenge to address when equipping work trains is the diversity of the engineering vehicles consists in terms of rolling stock characteristics but also in terms of varying configurations and lengths. Their mission should be carefully analyzed: for example dealing with train consists splitting while monitoring train integrity...

This challenge was already dealt with by railway signalling systems (ETCS - European Train Control System as part of ERTMS program - European Railway Train Management system) which have to face a very diverse fleet of rail vehicles, therefore paving the way for CBTC fitting of work vehicles.

This last issue of safely managing various work train length could be handled by one or a mix of the following solutions:

a) Taking the worst case configuration for the train length
b) Relying on the driver's input to the CBTC equipment when entering the CBTC territory (ETCS option)
c) Having a fixed hard wire consist identification
d) Relying on the couplers statuses
e) Relying on a track device to determine the consist length at the CBTC territory entrance.
f) Relying on wayside secondary detection in main line
g) Relying on CBTC reporting locomotive surrounding the consist

Here are some other of the technical input to study to equip engineering vehicles:

- Work train guaranteed emergency braking and acceleration performances (to ensure that they can smoothly mingle within passenger service trains). A particular attention is required to define failing modes on which is based the guaranteed emergency brake (failed: 1 brake unit, 1 axle unit, 1 bogie, 1 car...)
- Vehicles consist vital identification
- CBTC supervision of work trains on site (uncoupling, coupling...)
- Scope of the electric couplers
- Train integrity monitoring: by onboard devices (train lines, couplers statuses), double localization report by the CCs of locomotives surrounding the consist, by wayside devices (axle counting, track occupancy...), rule and procedures.

Type of secondary train detection: axle counters versus track circuits (T/C)

The main secondary train detection being track-circuit and axle counters, the pros and cons of these two technologies often come to discussion. This is a typical debate in signalling projects and the matter is unfortunately more often ruled by the institutional and historical framework surrounding projects rather than a rationale analysis. In the end, economic figures are neatly in favor of axle counters technology, especially considering Opex.

The main drawback of the axle counter is the track occupancy management after a STS reset, this drawback is now easily overcome by CBTC technology and an adapted design, i.e. by eliminating common mode failures, hence ensuring a technical independence between CBTC and axle counter system so that they can support each other's reinitialisation process. Note that eliminating common mode failures requires a high availability of the power supply chain.

An argument for the track-circuit technology is its contribution to the detection of broken rail. The end goal of this function is to address the risk of loss of train detection in the event of a second broken rail (the T/C would not detect a train between the 2 broken rail locations, causing a "detection hole") This specific risk of loss of train detection by track-circuit is now made obsolete by CBTC.

The broken rail detection function of the T/C is now pushed forward as a prevention to the risk of derailment: unfortunately, the poor efficiency records of T/C as a broken rail detector, which requires a clear loss of electrical continuity, is not sufficient to guarantee an acceptable risk level. Furthermore, the proactive approach of trying to avoid the broken rail event is preferable from having to deal with the consequences of this event, which will in any case bring severe disruption to the traffic.

Finally, the synergy between the CBTC intelligence and the axle counter output data can be put to profit in various ways: e.g. train movement detection between two occupied track zones, determination of train length based on counted axles, determination of the direction of travel by the counting head, speed measurement...

Conclusion

CBTC performance has now reached a level of maturity high enough to analytically challenge the necessity of secondary train detection in UTO projects, leading to substantial cost saving in capital and operational CBTC expenditures. However, the conservative approach in the railway world is still pushing for a traditional wayside detection layer. So in the digital era, where interconnectedness between live intelligent objects is setting the trend in engineering design, will CBTC find its way around secondary train detection? As Victor Hugo said: "nothing is as powerful as an idea whose time has come."